Mars Seismic Catalogue, InSight Mission; V4 2020-10-01.

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Overview

This is the description of V4 of the Marsquake Catalogue for InSight, and includes the Martian seismic events as recorded by InSight up to June 30, 2020 / Sol 567 for the InSight mission. The catalogue is provided by InSight's Marsquake Service (MQS). The catalogue files are available at IPGP and IRIS. New versions of the Marsquake Catalogue are released in synch with new waveform data releases.

The citation for the catalogue is:

InSight Marsquake Service (2020). Mars Seismic Catalogue, InSight Mission; V4 2020-10-01. ETHZ, IPGP, JPL, ICL, MPS, Univ. Bristol. https://doi.org/10.12686/a9

This catalogue is an update of V1-3 (*InSight Marsquake Service, 2020a*, *InSight Marsquake Service, 2020b, InSight Marsquake Service, 2020c*).

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 of the Mars-specific extension is also provided in the catalogue package. Documentation of this will be provided in a subsequent release.

A detailed description of this V4 version of the catalogue, as well as key event presentations and MQS procedures, is provided at *Clinton et al (2020)* – this is a pre-print of an article submitted to PEPI, and documents V3. All MQS conventions for this version, V4, are detailed in this publication. Key details are also repeated here.

An overview of the major changes between V3 and V4 (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 2.4Hz 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 filter is 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 attibuted to P or S, they are labelled x1, 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.

B/ Aligned Phase Picks
In V4, aligned phase picks based on *Giardini et al. (2020)* are available.

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, 2020.*** 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 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 provided in the catalogue since V3, and new LF/BB events in V4 have been 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*.

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 V4 catalogue (unchanged from V3).

Magnitude
V4 uses the relations as described in ***Clinton et al (2020)*** 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.

V4 Catalogue Overview

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

	Total	A	B	C	D
Total	465 (+16)	2	85 (+3)	183 (+5)	195 (+8)
LF	29 (+1)	1	6	11	11 (+1)
BB	14 (+1)	1	2 (+1)	9	2
HF	54 (+2)	-	32 (+1)	18	4 (+1)
2.4Hz	359 (+10)	-	38	141 (+4)	180 (+6)
VF	25 (+2)	-	10 (+1)	9 (+1)	6

Super high frequency events

	Total	A	B	C	D
SF	788 (+76)	-	-	165 (+36)	623 (+40)

Overview of Major Changes from V3 to V4

- The DOI of publications associated with key events are now indicated in comment elements. These elements are direct child elements of event. Each associated publication requires an own comment element. The comment text includes two keywords: rm:related_resource_id (required) and rm:related_resource_desc (optional). The latter can be used to give a description of the associated resource in free text. An XML example is

```
<event>
 ...
 <comment>
  <text>rm:related_resource_id=doi:10.1029/2020JE006382
        rm:related_resource_desc=impact search</text>
 </comment>
 <comment>
  <text>rm:related_resource_id=doi:10.1029/2020JE006376</text>
 </comment>
 ...
</event>
```

The DOI is specified with the doi: prefix only, not the https://doi.org/ prefix. If both parameters are specified, there has to be white space (preferably a single blank character) between both. There has to be a "=" character between parameter name and value without any whitespace characters in between.

- SNR values, as defined and provided in *Clinton et al (2020)* for V3, are now provided in an XML element (mars:snr) in the Mars extension of the QuakeML BED package with the namespace prefix mars:. The three different SNR values are represented as XML attributes (snrMQS, snrPressure, snrWind). Here is an XML example.

```
<event>
 ...
 <mars:snr  snrMQS=1.4 snrPressure=2.83 snrWind=1.83 />
 ...
</event>
```

- Aligned distances for LF family events following *Giardini et al (2020)* that were added to the catalogue now also include P and S picks.
- Origin times for non-located events have been homogenized. Depending on event type, they are a fixed time before the 'start' pick:
    o LF family: OT = (start pick time -180s)
    o HF family: OT = (start pick time -300s)
    o SF events: OT = (start pick time -20s)
- Changelogs now include any changes to time or uncertainty of existing picks

References

Clinton, J. et al., 2020. The Marsquake Catalogue from InSight, Sols 0-478. https://doi.org/10.31219/osf.io/ws967

Dahmen, N. et al., submitted. Super high frequency events: a new class of events recorded by the InSight seismometers on Mars. JGR Planets

van Driel, M. et al., submitted. High frequency seismic events on Mars observed by Insight. JGR Planets

Giardini, D. et al., 2020. The seismicity of Mars, Nature Geoscience. doi:10.1038/s41561-020-0539-8

InSight Marsquake Service, 2020a. Mars Seismic Catalogue, InSight Mission; V1 2/1/2020. ETHZ, IPGP, JPL, ICL, ISAE-Supaero, MPS, Univ. Bristol. https://doi.org/10.12686/a6

InSight Marsquake Service, 2020b. Mars Seismic Catalogue, InSight Mission; V2 2020-04-01. ETHZ, IPGP, JPL, ICL, ISAE-Supaero, MPS, Univ. Bristol. https://doi.org/10.12686/a7

InSight Marsquake Service, 2020c. Mars Seismic Catalogue, InSight Mission; V3 2020-07-01. ETHZ, IPGP, JPL, ICL, ISAE-Supaero, MPS, Univ. Bristol. https://doi.org/10.12686/a8