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Detecting the unbalanced distributions in the seismic signal, applications to the martian (and terrestrial) data

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Since February 2019, the InSight NASA mission and its seismometer (SEIS) allows us to study and analyse the motion of the martian ground. In order to investigate the reliability of all event detections made during this mission and so, the possible amount of available sources to be further inverted for structure, we develop a new approach to quantify the equirepartition of the seismic signal. This statistic method allows to point out low energy transient signals that are characterized by non-gaussian distributions of amplitudes in the raw signal. We are able to identify artifacts such as glitches (instrumental response to an external perturbation) and the seismic signatures of atmospheric pressure drops (vortices) that are travelling in the vicinity of the lander (also visible on the pressure sensor). Although this method can be used 1) to detect, 2) to classify the different kind of spurious signals, it is well-suited 3) to look for low-energy-long-period seismic signals (surface waves).

1 - Motivations

The seismic signal can be characterized by the following associated amplitude's histogram :

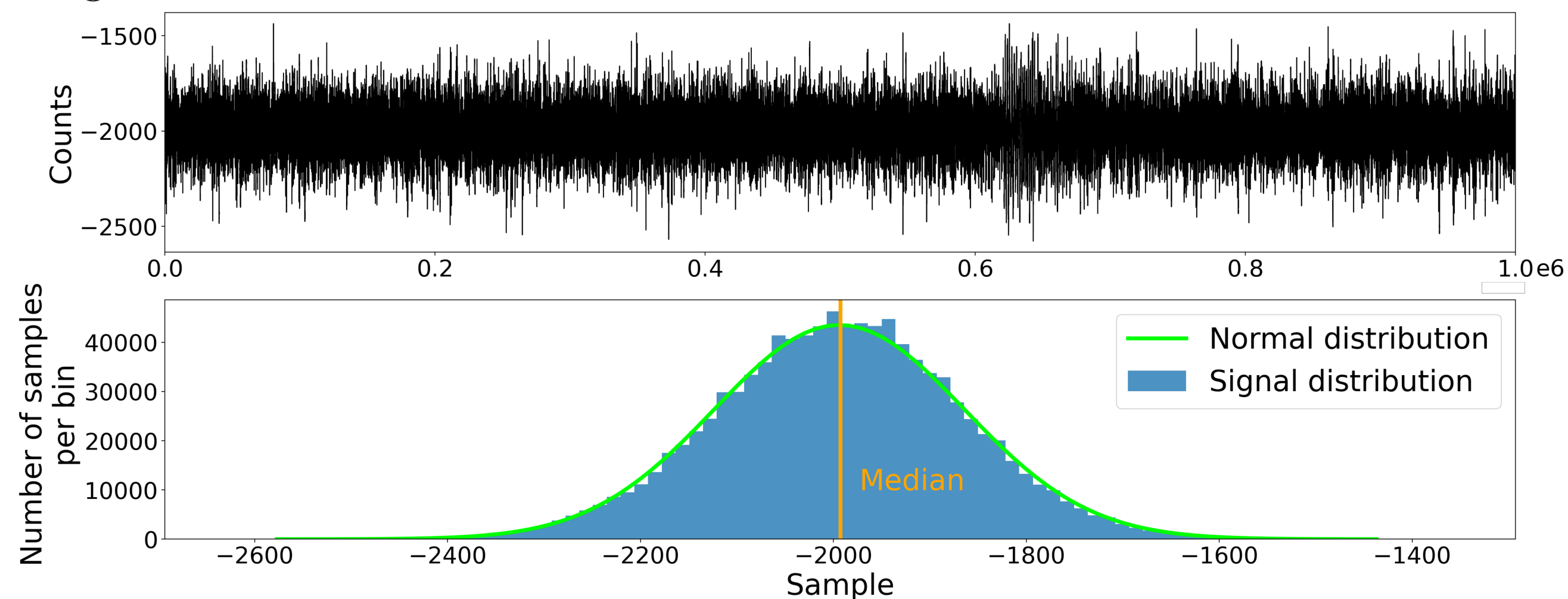


Fig. 1: Raw seismic signal (top) and its associated histogram amplitude distribution, bins=100 (bottom)

The histogram symmetry is inherent to a balanced signal.

2 - Instantaneous non-gaussianity measurement

The raw signal is sorted by increasing order (FIG 2, A2 and B2) which allows a comparison with a normal distribution. We define α as the area between the two curves. It represents the misfit to the Gaussian hypothesis.

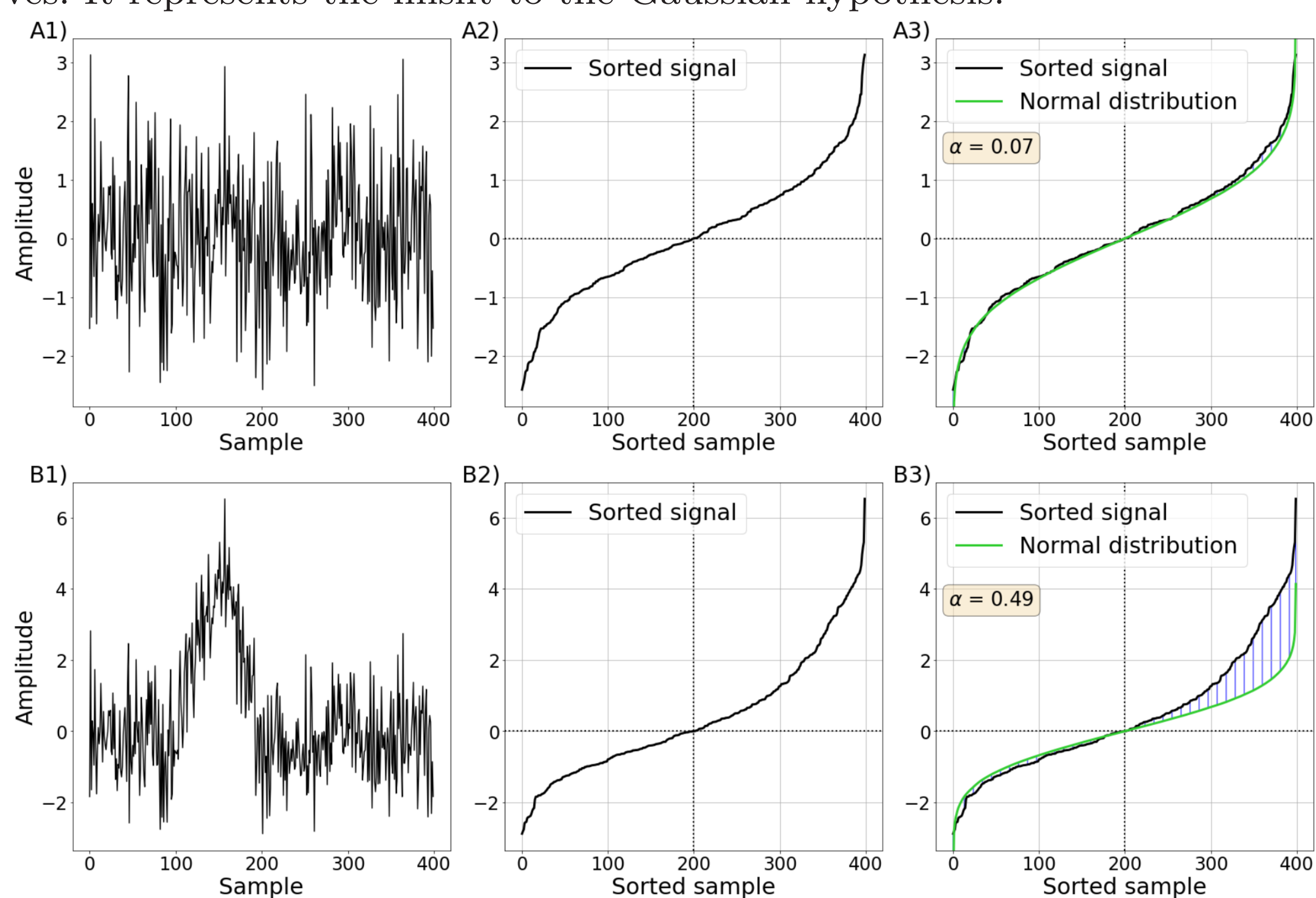


Fig. 2: Measurement examples of the amplitude's distribution for two given raw data. Balanced data (top), unbalanced data (bottom)

3 - Continuous non-gaussianity measurement

Iterating the local method presented in the last section with several windows on a large time signal, we are able to display α as a function of time (sliding step of one sample). The parameter λ defines the length (seconds) of the sliding window.

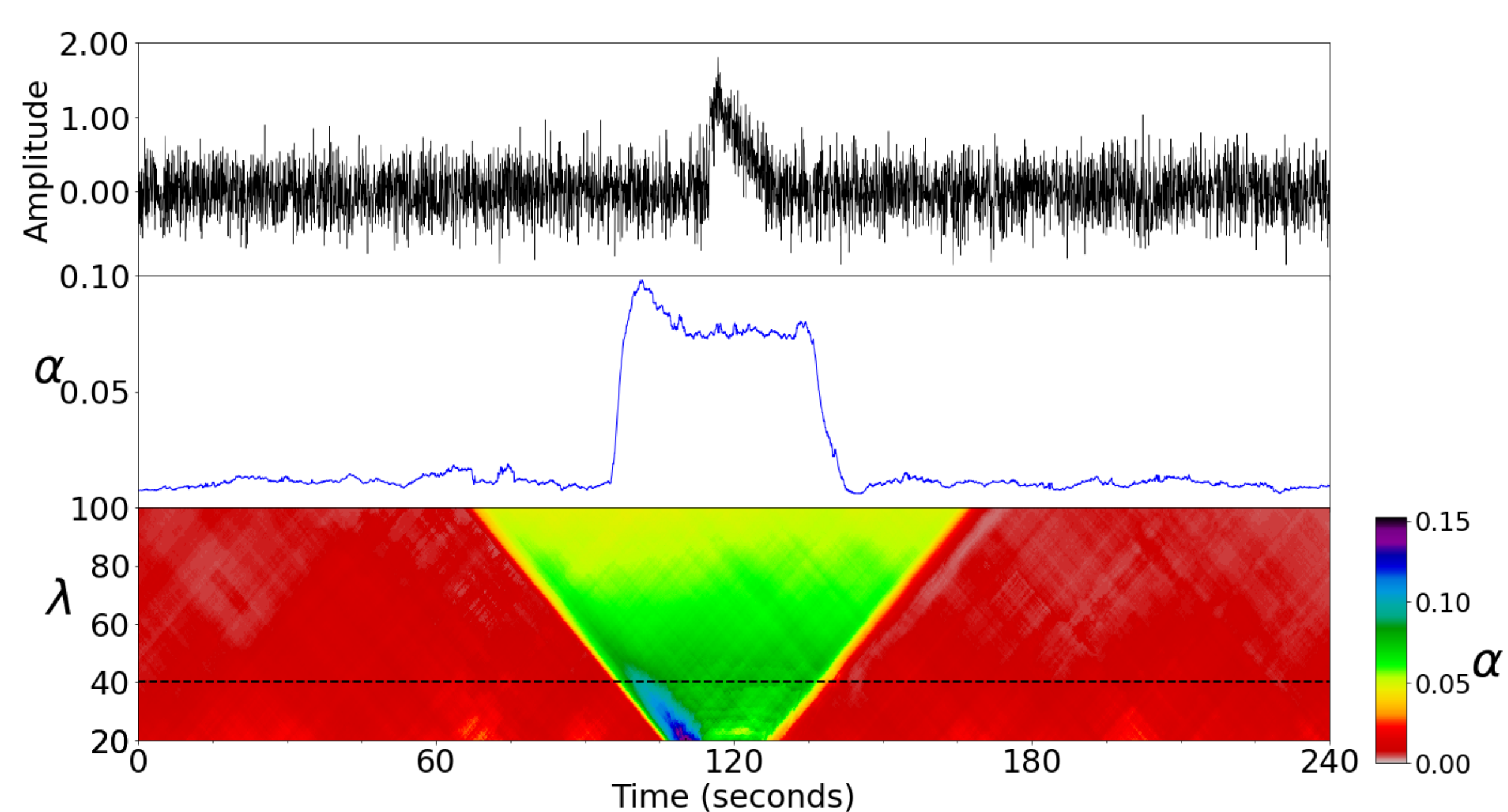


Fig. 3: Raw signal (up), misfit to a gaussian distribution for $\lambda = 40$ s (middle) and $20 \text{ s} \leq \lambda \leq 100 \text{ s}$ (bottom)

4 - Applications - Martian data

In the following applications, α is set to zero if the signal's distribution is close to a Gaussian (see FIG 4). We now apply the method presented in section 3 on martian signals. The different perturbations have been located well by our method even for the pressure drop which occurs during the noisy part of the martian day (see FIG 5).

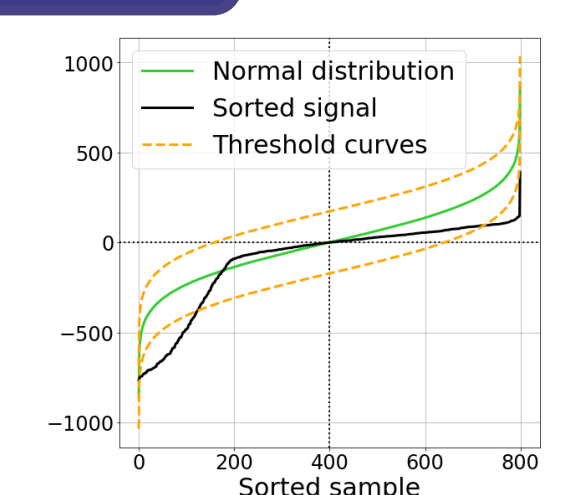


Fig. 4: Non-gaussian distribution

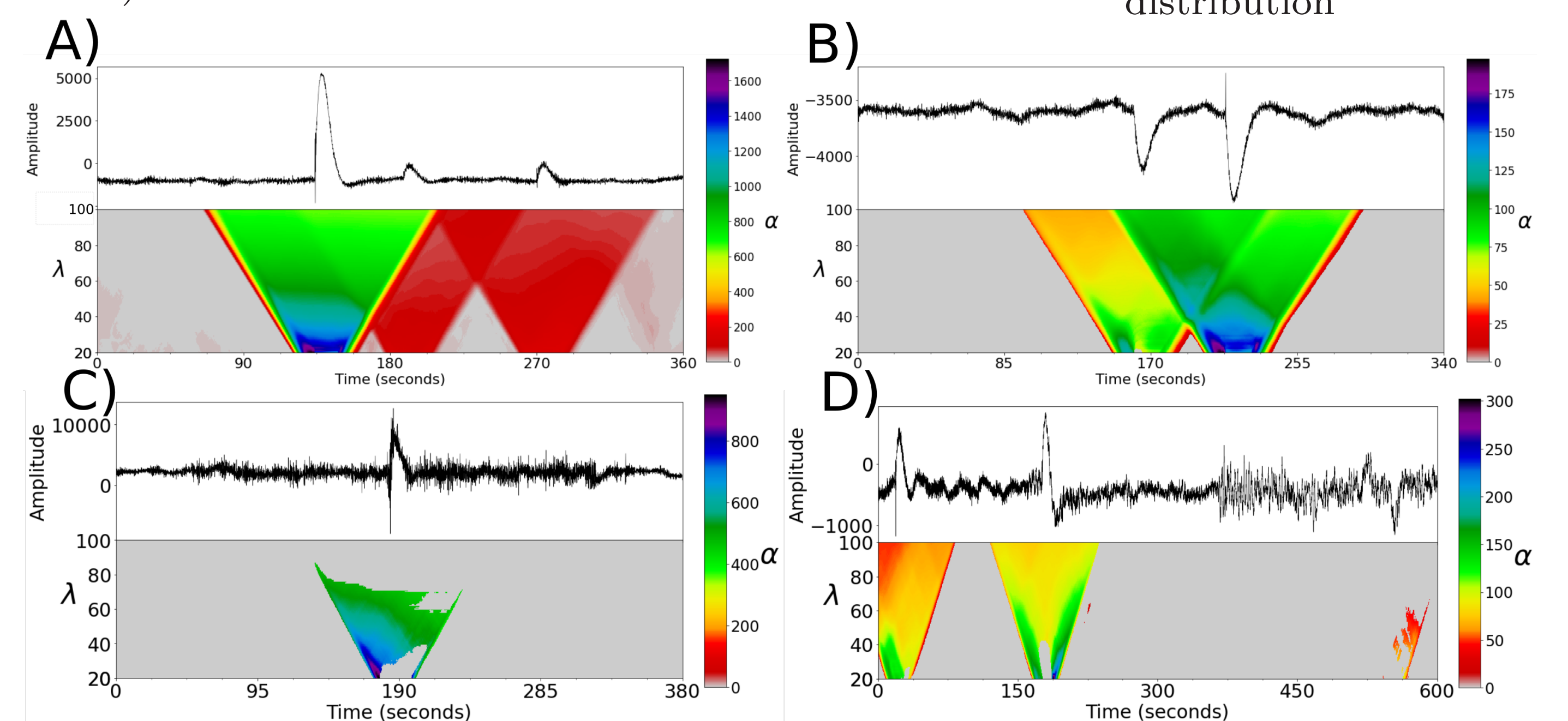


Fig. 5: Different glitches (A and B), pressure drop (C) and a marsquake (D)

By counting the number of areas which are non-gaussian on each sol (martian day), we are able to estimate the signal's quality of the SEIS seismometer during the InSight mission :

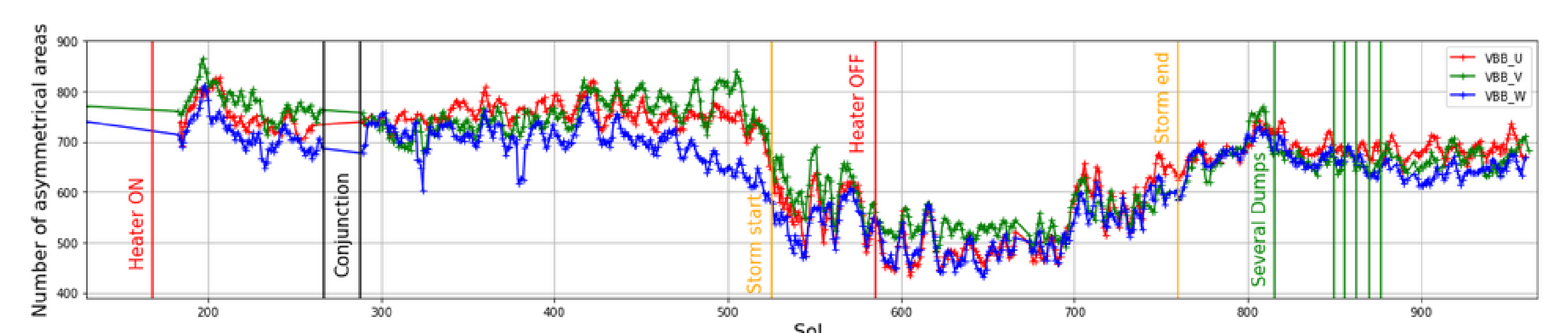


Fig. 5: Detected perturbations on the InSight mission, component U, V and W

5 - Preliminary applications - Terrestrial data

Several examples of signal quality check using our method on various terrestrial data over long and short periods of time :

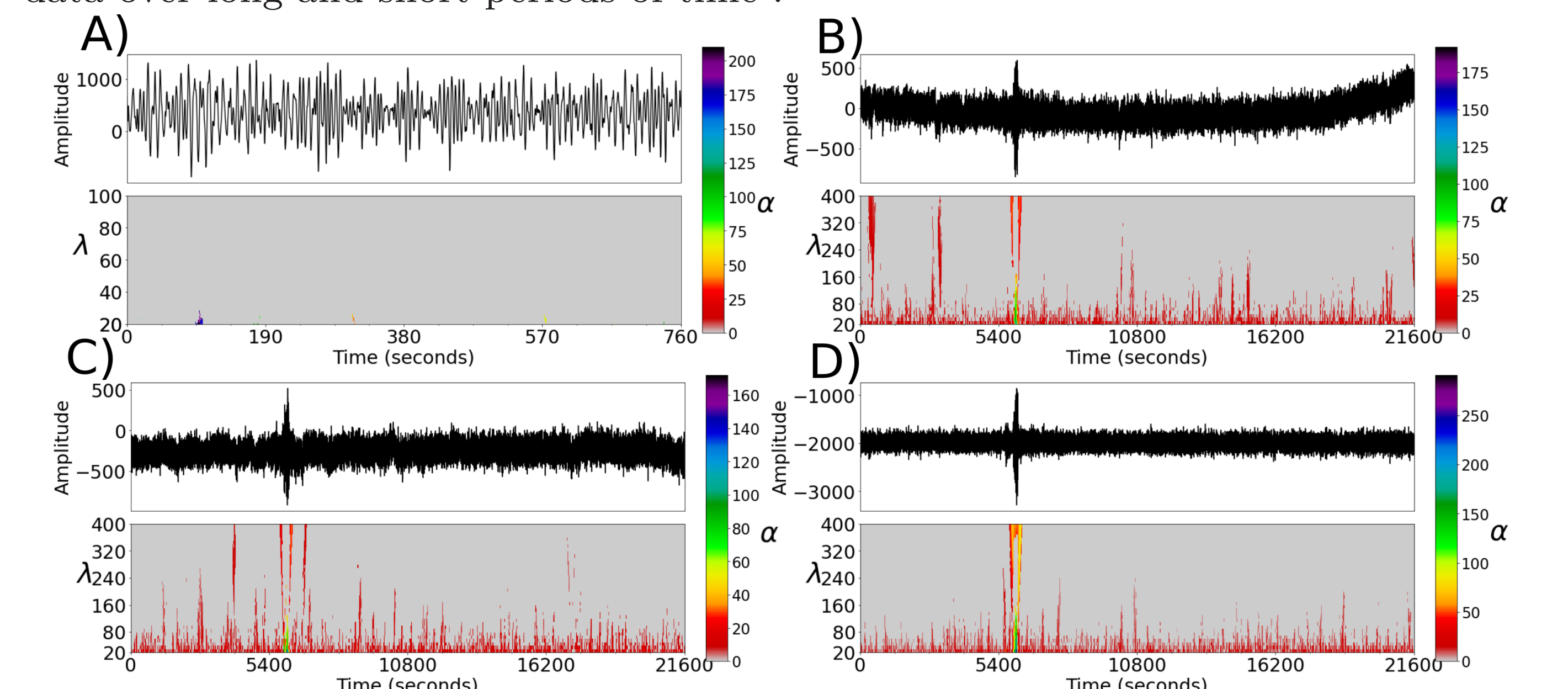


Fig. 6: Continuous seismic signal (A) and estimation of signal quality (CAMF station, North : B, East : C, Vertical : D)

Conclusion and perspectives

- The method locates and quantifies well the perturbations in a seismic signal
- This proceed can also be useful to estimate the quality of a signal
- Finally, the next step will be to study the pattern in the spectrums which could allow us to sort these events (Clustering method, deep learning,...)