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Quantifying the Non-Gaussian Perturbations in the Continuous Seismic Signal

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InSight

Several methods classically exist for capturing perturbations (earthquake, explosion...) in the continuous seismic signal. Most of them, like the famous STA/LTA, detect seismic events by taking advantage of the impulsive nature of their waveform compared to the background noise. In contrast, very few are able to point out long period transient signals (typically greater to 5 s period). However, these long-period waveforms often exist in the continuous seismic signal due to technical problems (as the so called glitches) or to external forcings (e.g. pressure drops, acoustic waves). We present here a novel method that quantifies the strength of the Gaussianity of the seismic signal in a given time window. It relies on the basic assumption that the ground motion oscillations balance around an equilibrium position. After a sorting operation, the localisation of the expected Gaussian distribution enables us to extract the mean and the standard deviation of its background noise which allows, in turn, an analysis of the signal's statistical deviations through the Z-score parameter. We show that this method is able to quantify the Gaussianity of various types of smooth perturbations in a noisy background signal. Some examples using both terrestrial and martian seismic data are shown. Finally, based only on statistical thresholds we propose a new way to detect non-Gaussian perturbations.

1 - Motivations: Gaussianity of the seismic signal

The seismic signals can be characterised by the following associated amplitude's histograms :

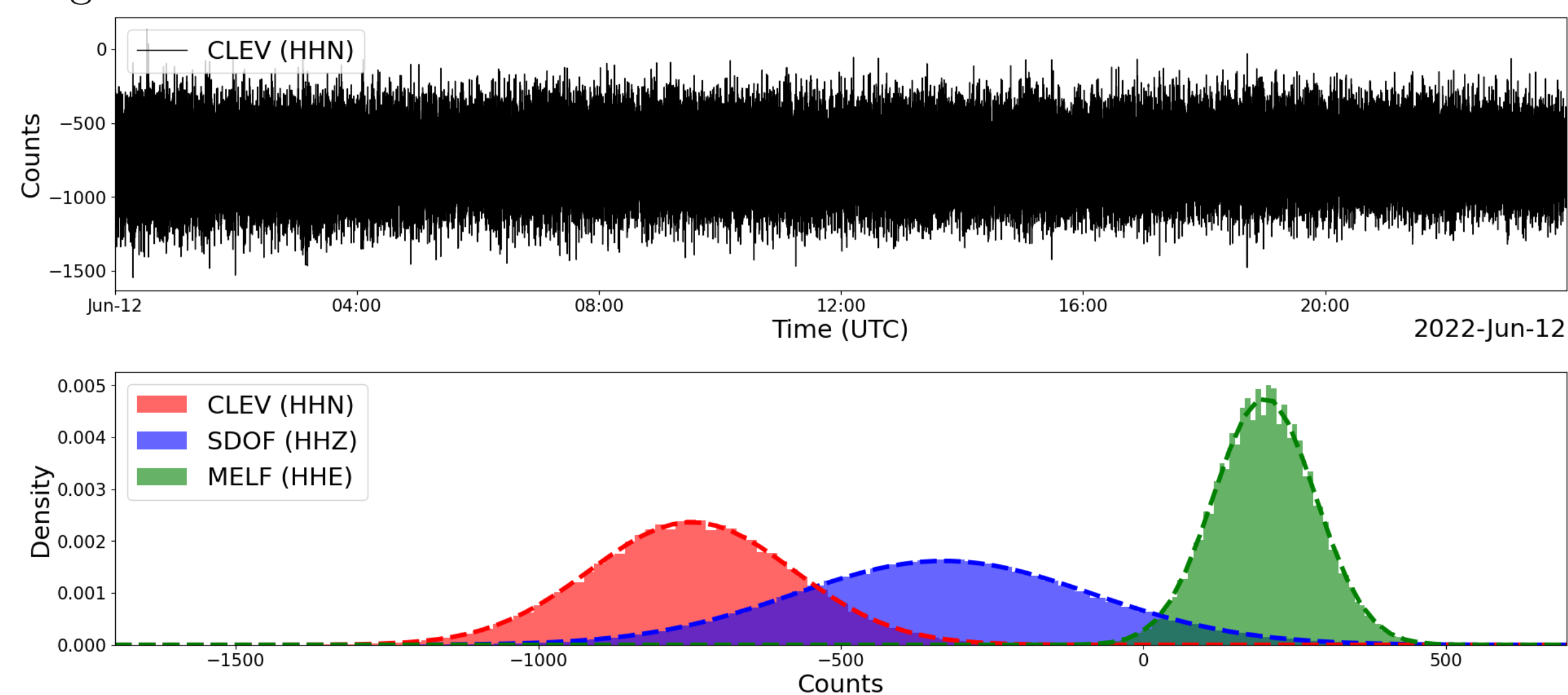


Fig. 1: Raw seismic signal (top) and its associated histogram amplitude distribution, bins=100 (bottom)

The good fit between a seismic signal's histograms and a Gaussian probability density function seems to be caused by the Gaussianity of the seismic signal.

2 - Quantifying the deviation to the Gaussianity

- After sorting the data by increasing order of amplitude, the localisation of the **expected Gaussian distribution** enables us to extract the mean μ and standard deviation σ of the background noise
- An analysis of the signal's statistical deviations through the Z-score parameter allows to locate each point altered by a perturbation.

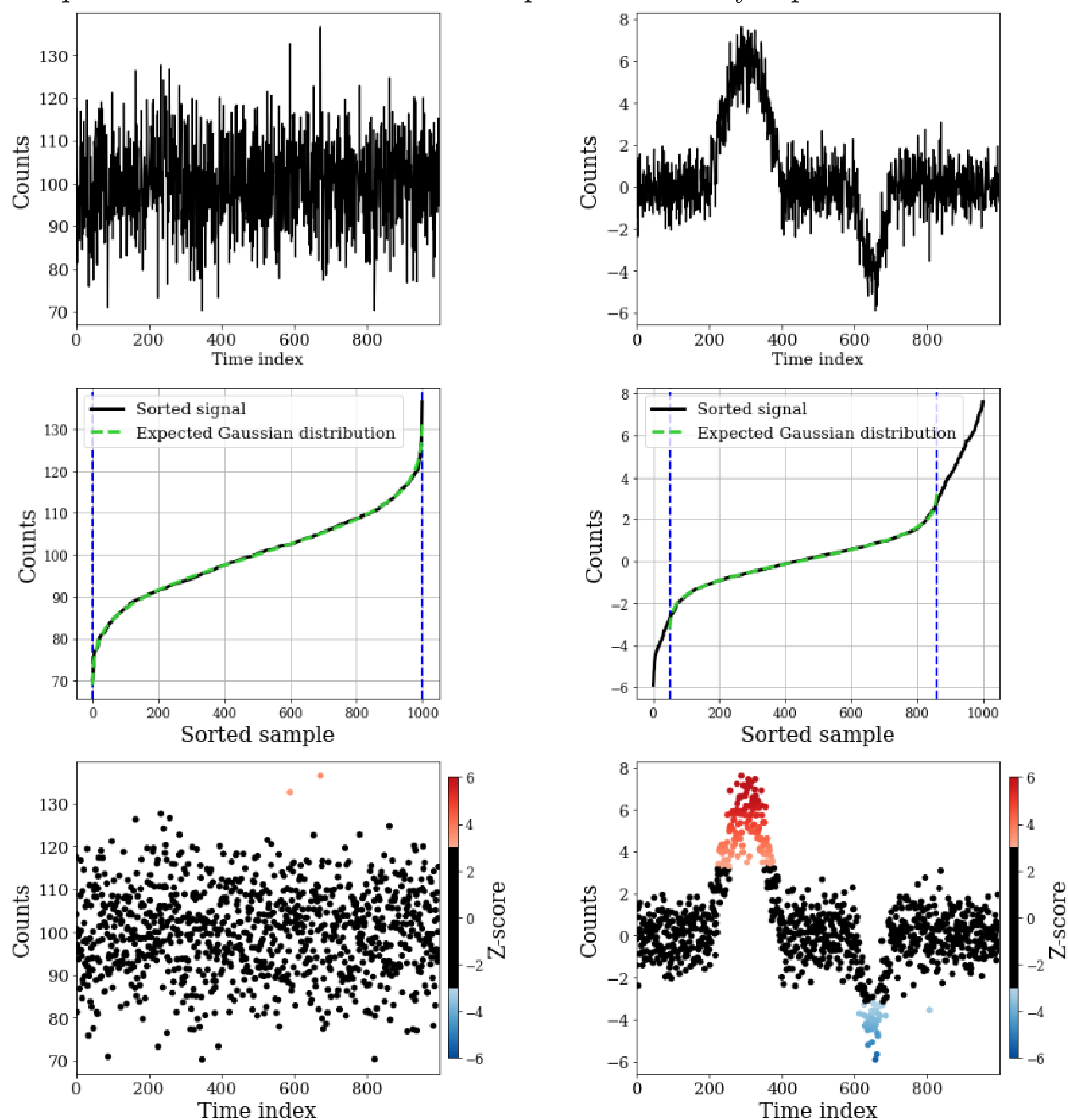


Fig. 2: Quantifying the points which have deviated from the Gaussianity on two examples. Balanced data (left), unbalanced data (right)

The Z-score is defined by $\frac{X - \mu}{\sigma}$. In the special case of a Gaussian signal, 99.7% of the points have a Z-score value between -3 and 3 (black points in FIG 2, bottom).

3 - Applications - Earth data

In FIG 3, we apply the method presented in section 2 on a seismic data set altered by two perturbations: one quarry blast around 9h59:30s and one other minor perturbation at 9h58.

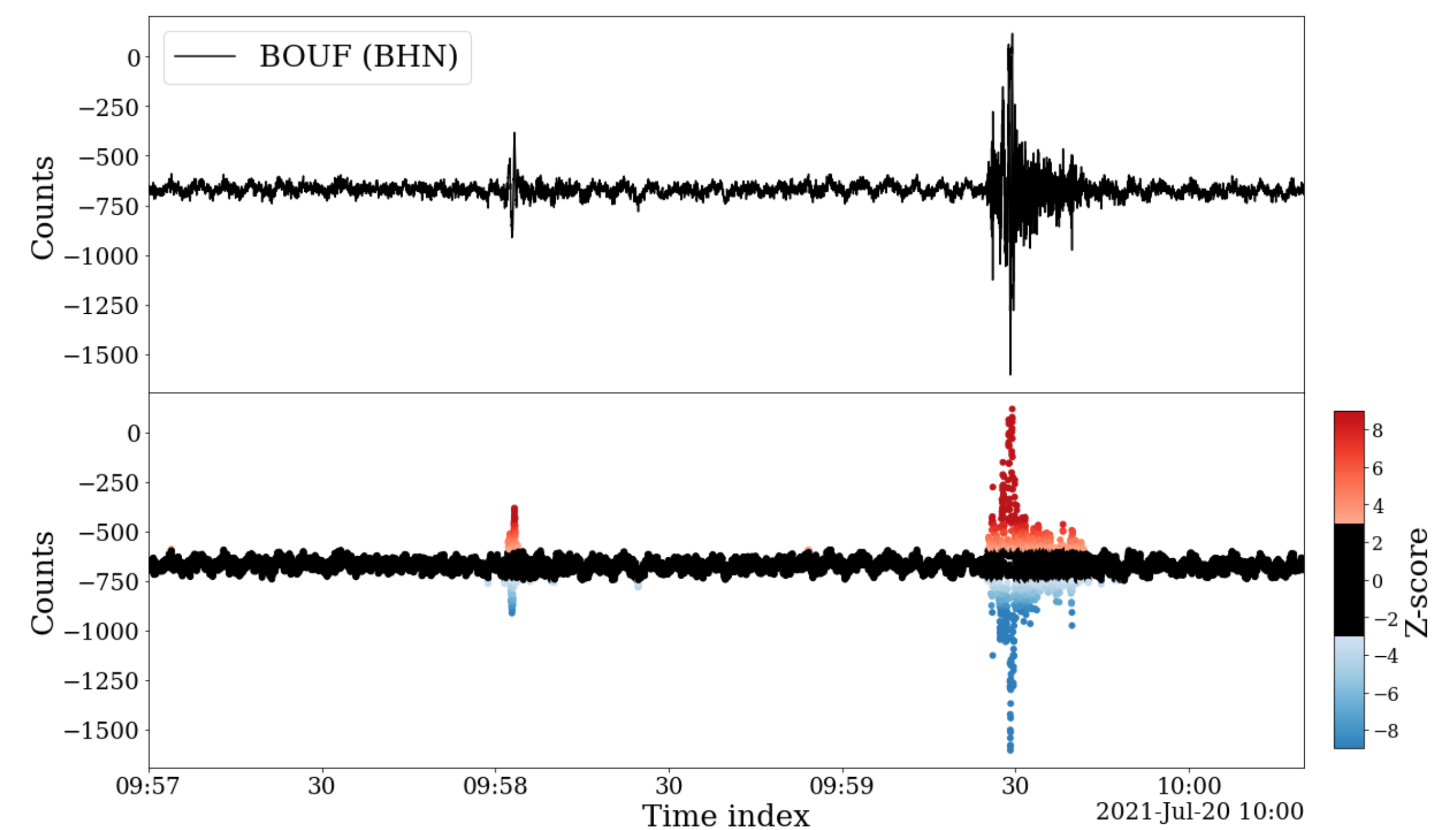


Fig. 3: Extracting the perturbed points from the Gaussian noise using the Z-score. Perturbed data set from the BOUF station (top), Z-score of each points of the data set (below).

The perturbed points are localised, as testified by the large values of the Z-score.

4 - Applications - Martian data

In FIG 4, the application of our method on the martian seismic signal recorded from the SEIS instrument of the InSight mission allows the detection of the "glitches", which are perturbations characterised by long period transients signals.

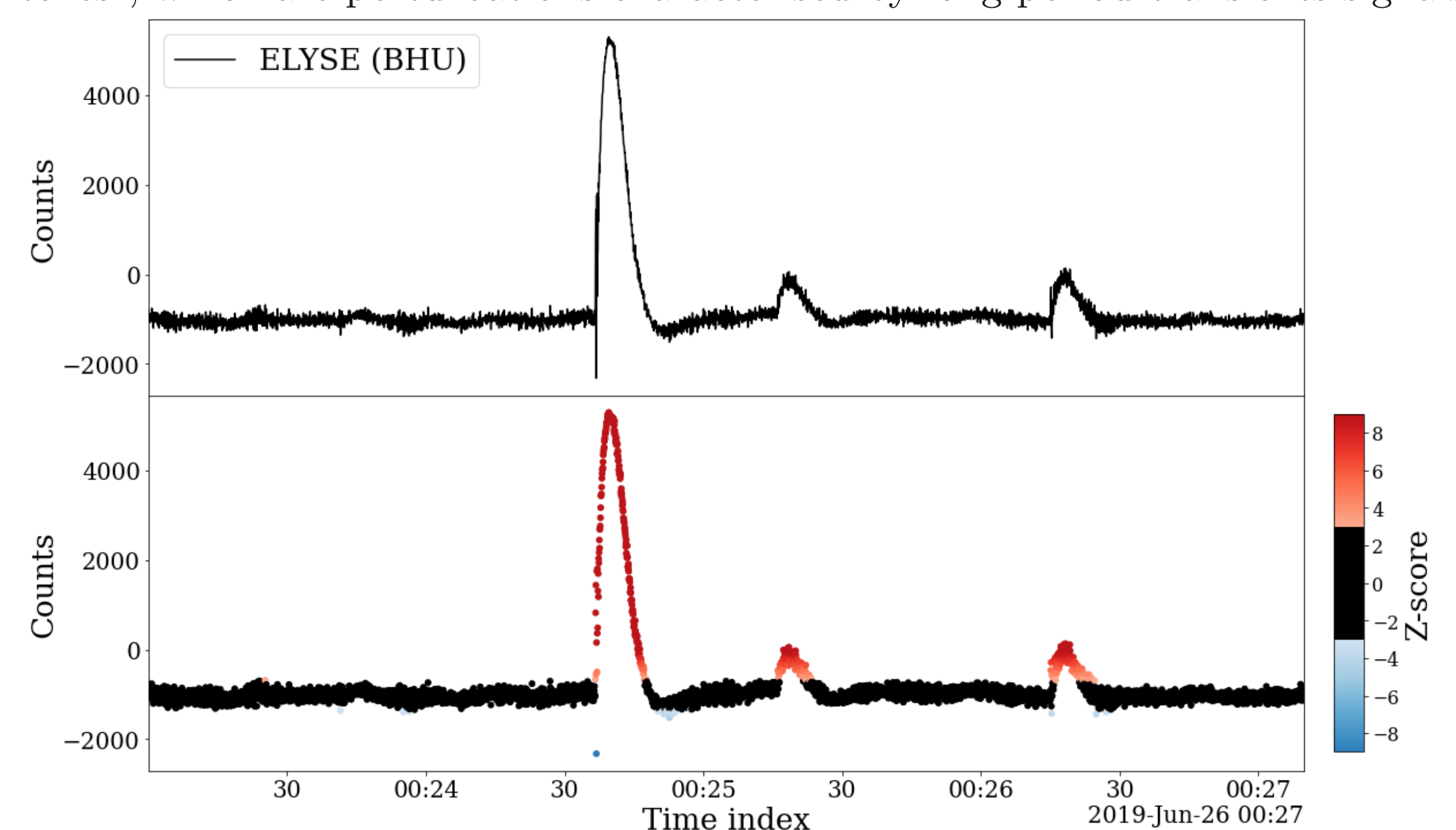


Fig. 4: Extracting the perturbed points from the Gaussian noise using the Z-score. Perturbed data set from the SEIS station of the InSight mission (top), Z-score of each points of the data set (below).

Conclusion and perspectives

- We developed a new approach to detect any non-Gaussian perturbations
- This method can find applications on any signal with Gaussian noise
- Finally, the next step will be to perform a statistical study of all the perturbations detected during the whole InSight mission (4 years of data).

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