



“DRUMCORR” PROGRAM FOR SELECTING EARTHQUAKE MULTIPLETS BASED ON CROSS- CORRELATION ANALYSIS

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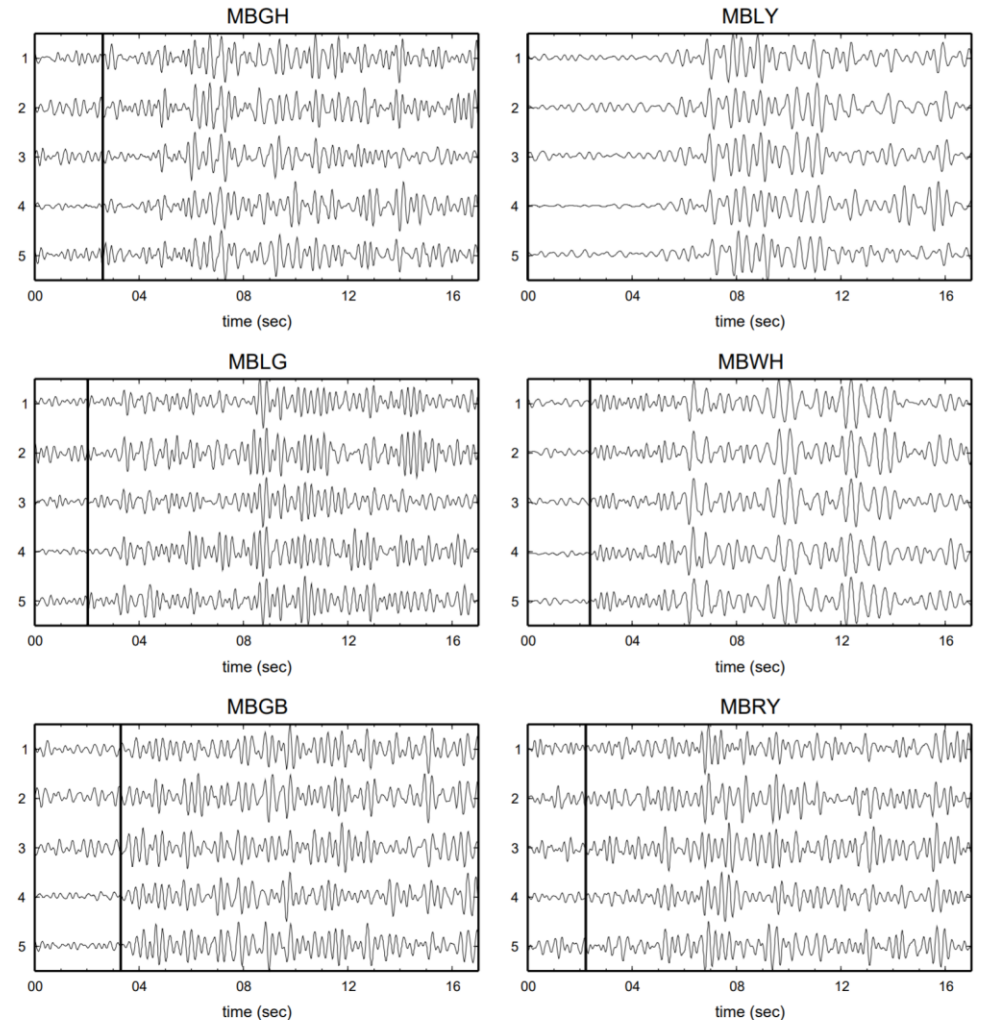
Introduction



Volcanic earthquakes recorded by one or several seismic stations can be characterized by fairly similar waveforms. This similarity arises when earthquakes have similar focal mechanisms and close hypocentral location.

The identification of multiplets (groups) of volcanic earthquakes is based on the mutual correlation of waveforms, which is very common in world practice [Ottemoller et al., 2008; Matoza et al; 2010].

FIGURE 1. Example of earthquakes multiplets that was registered at Soufriere Hills Volcano, Montserrat, 2003 [1].





Introduction



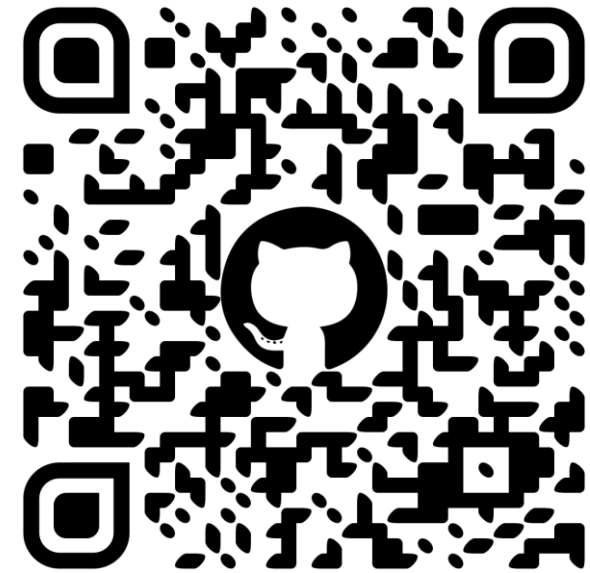
Purpose: to identify multiplets of earthquakes based on the similarity of waveforms.

Tasks:

1. Get acquainted with the existing techniques for the detector of groups of earthquakes.
2. Program development.
3. Testing the program using the example of the seismic mode "drumbeats"
4. Qualitative assessment of the program results.



Program implementation



<https://github.com/ZiCode0/DrumCorr>

FIGURE 2. Libraries for the “DrumCorr” implementation.



Algorithm of the program "DrumCorr"

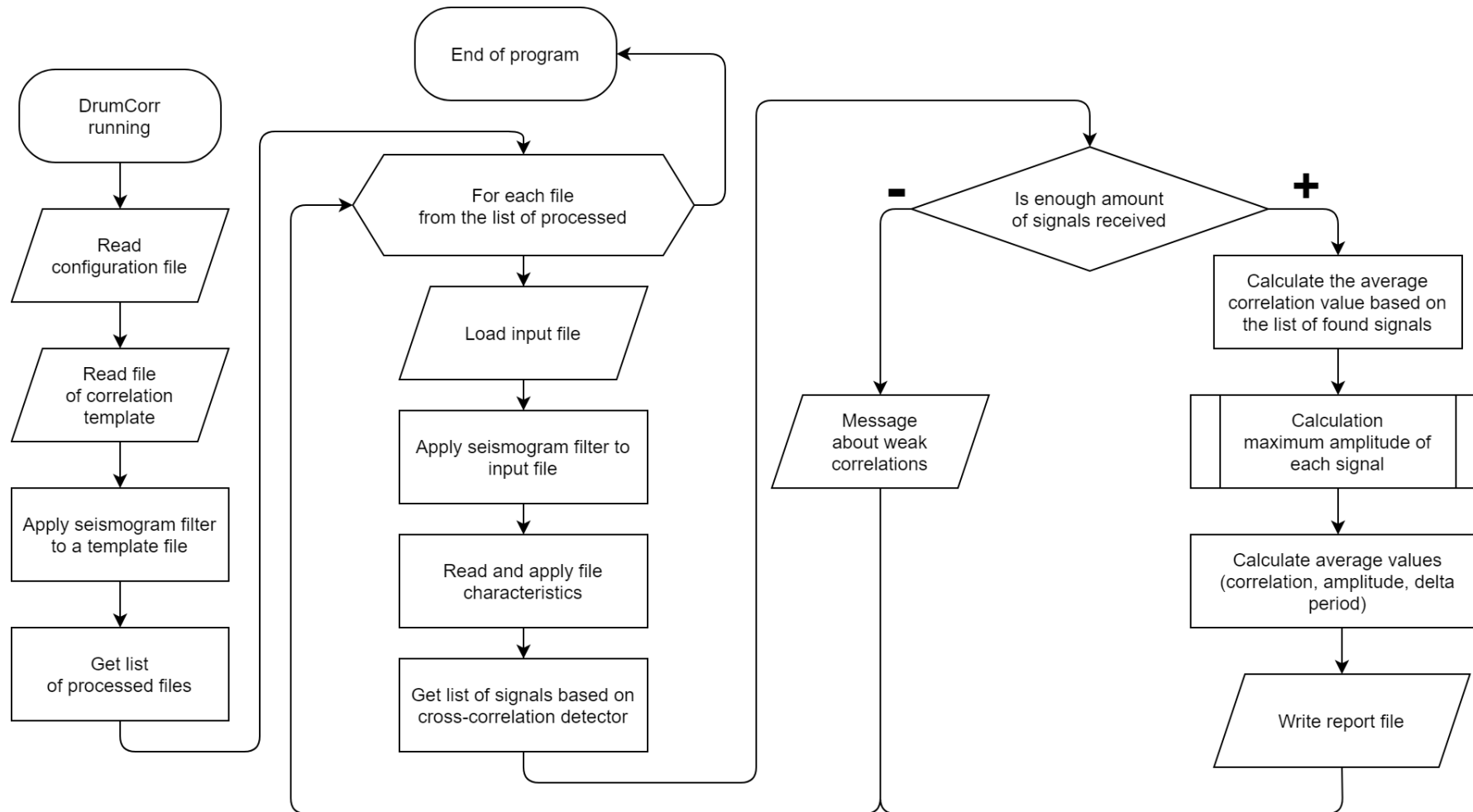


FIGURE 3. Flowchart of the "DrumCorr" program operation algorithm.



Algorithm of the program "DrumCorr"



Calculation maximum amplitude of each signal

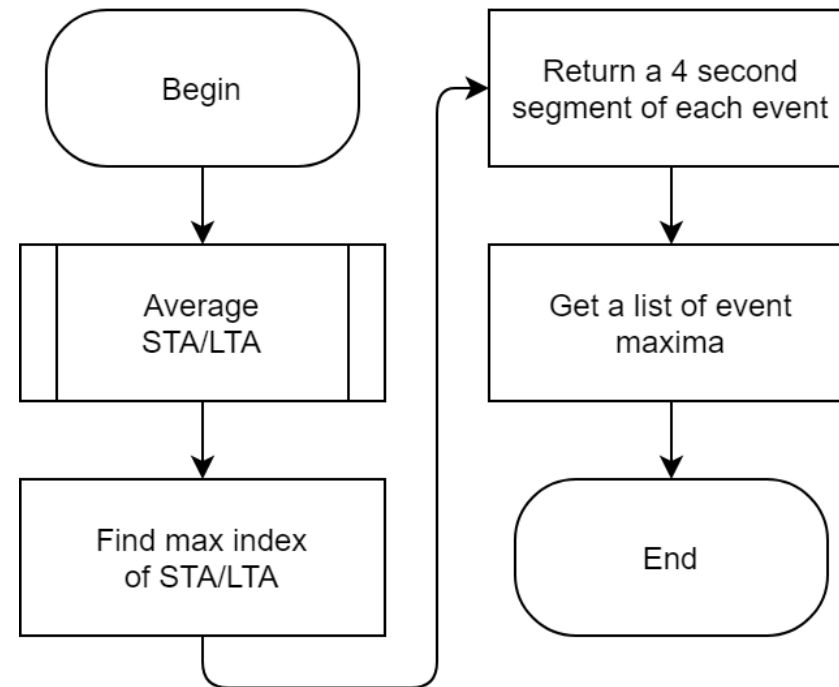


FIGURE 4. Flowchart of the algorithm for calculating the maximum amplitude of each signal.



Highlighting events with STA / LTA

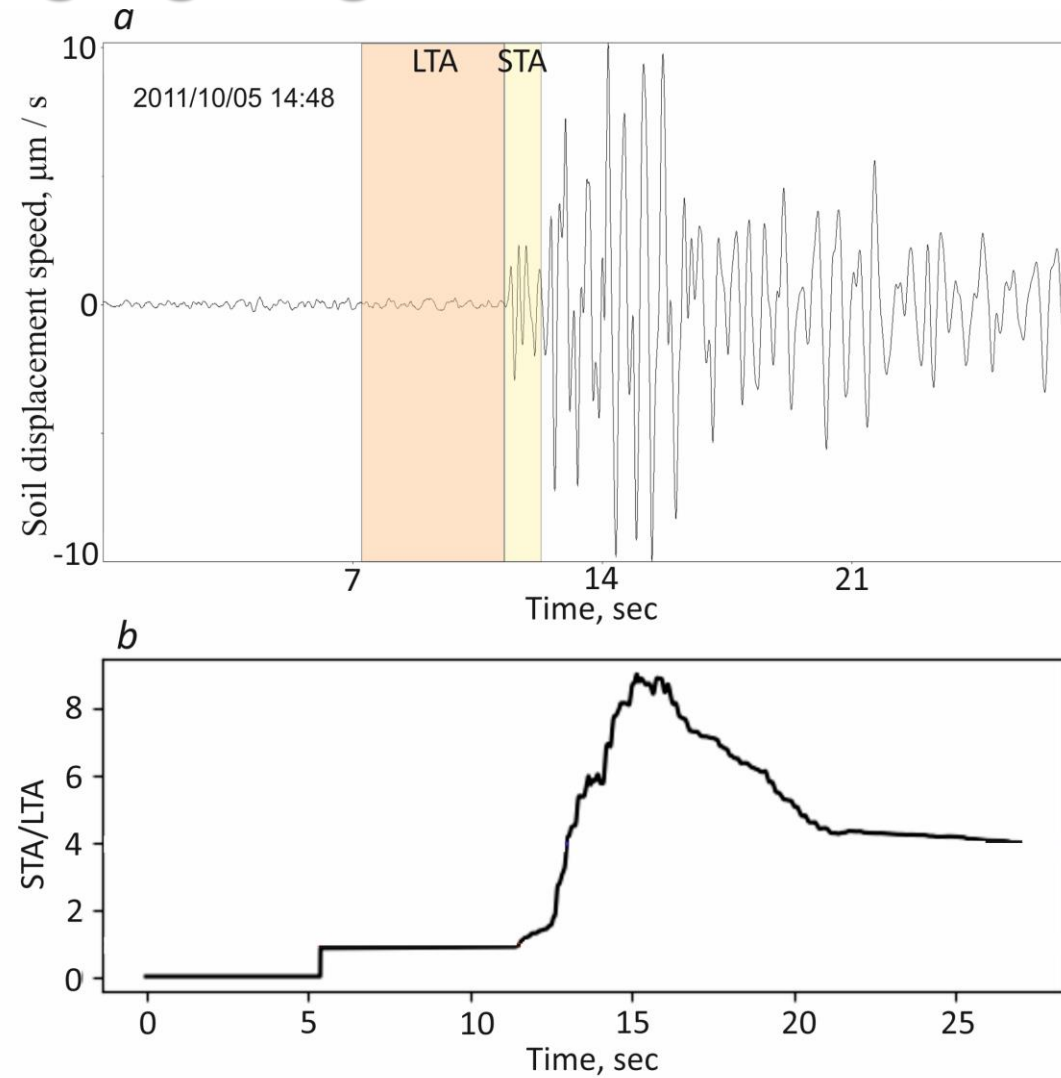


FIGURE 7. The 1: 4 ratio for STA / LTA when selecting the time series of each signal.



Algorithm of the program "DrumCorr"

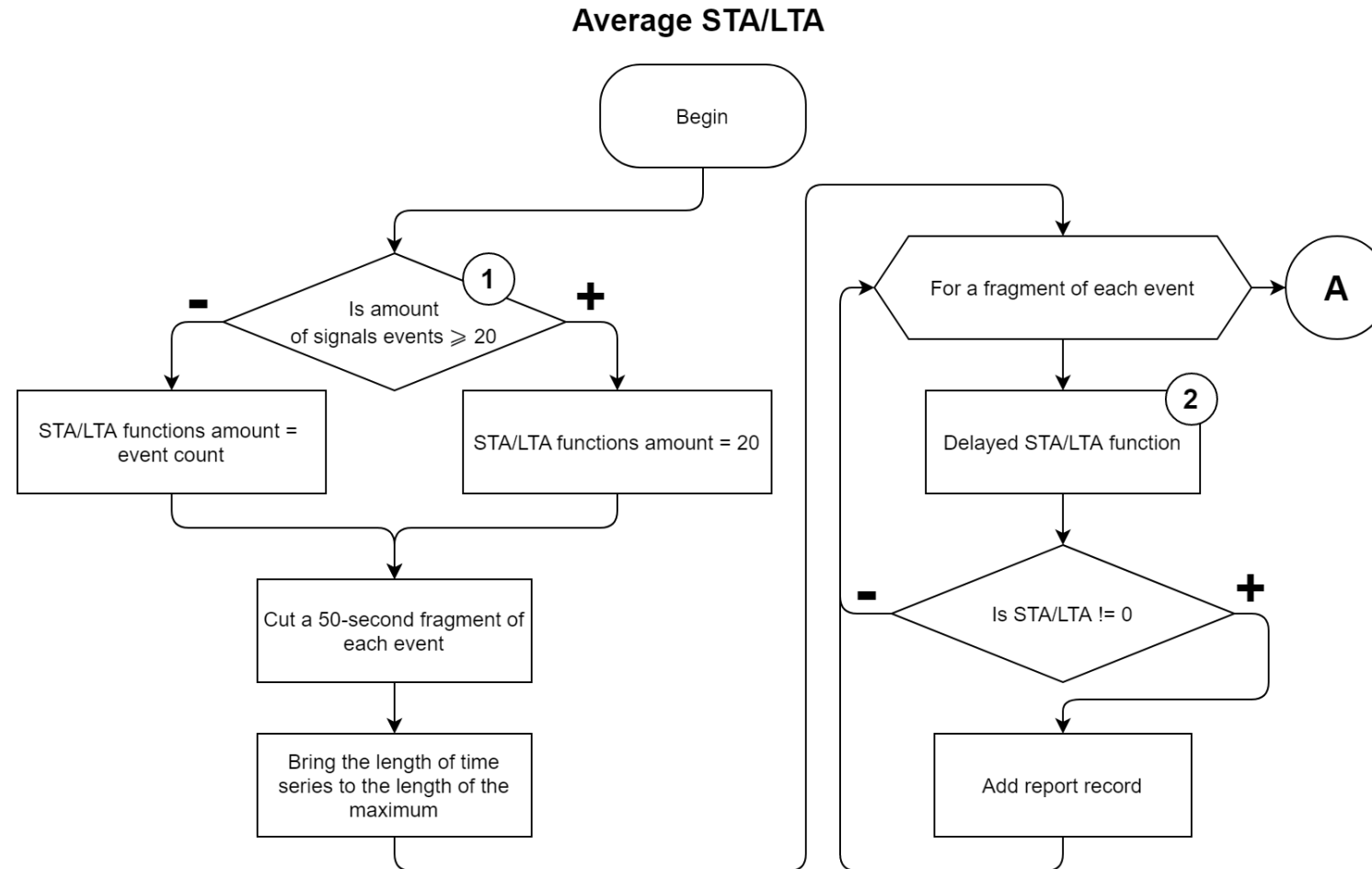


FIGURE 5. Flowchart of the algorithm for calculating the average STA/LTA 1/2.



Algorithm of the program "DrumCorr"

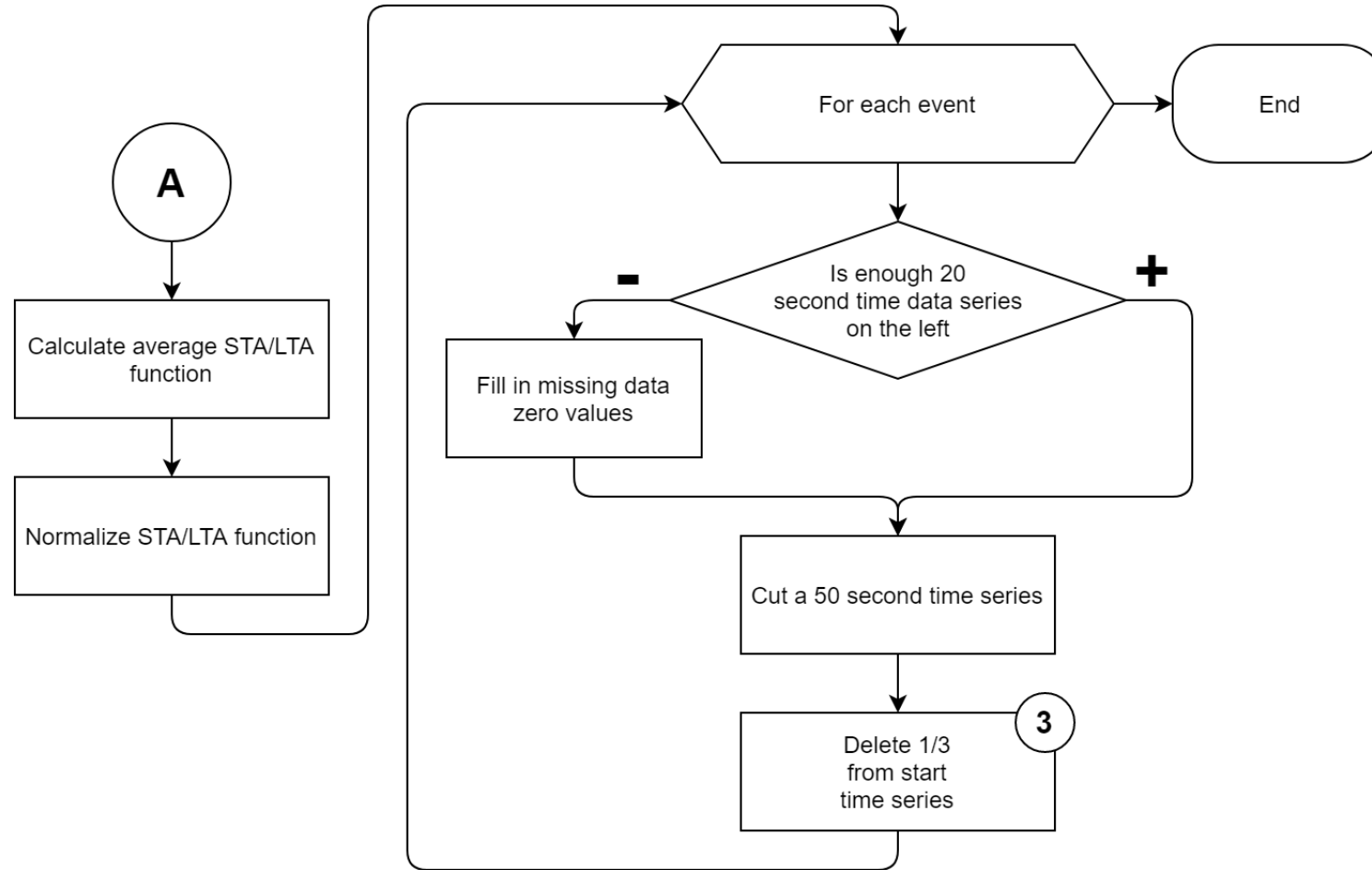


FIGURE 6. Flowchart of the algorithm for calculating the average STA/LTA 2/2.



Preparation before starting the program



```
config_example.json ×
1  {
2    "config": {
3      "filter": {
4        "filter_name": "bandpass",
5        "filter_params": [
6          0.2,
7          10
8        ]
9      },
10     "xcorr_detection_value": 0.6,
11     "xcorr_minimum_count": 0.0,
12     "template_filename_format": "+{file_name}",
13     "exclude_filename_formats": ["-{file_name}", ".{file_name}"],
14     "report_format": "{file_name}-report.txt",
15     "notify": ["gmail"],
16     "experimental": 1
17   }
18 }
```

FIGURE 8. Configuration file for running the program in Json format.



The result of the program



```
20110906-00-00-00.asc-report.txt
1 DrumCorr File <20110906-00-00-00.asc> result:
2
3 Beats count:          3770
4 Detection value:      0.6
5 Average correlation:  0.8238013083301586
6 Max corr:
7   Value:              0.9719608293515986
8   Amplitude:          11.7908
9   Amp time:           2011-09-06 16:14:13
10
11 2011-09-05 23:59:14 0.863 22.4452
12 2011-09-06 00:00:40 0.843 13.6092
13 2011-09-06 00:01:00 0.786 6.0517
14 2011-09-06 00:01:27 0.824 10.3134
15 2011-09-06 00:02:01 0.856 26.1671
16 2011-09-06 00:02:18 0.668 7.2734
17 2011-09-06 00:02:51 0.817 9.0065
18 2011-09-06 00:03:08 0.890 6.421
19 2011-09-06 00:03:33 0.715 11.6488
20 2011-09-06 00:03:45 0.674 6.3074
21 2011-09-06 00:04:06 0.841 6.2506
22 2011-09-06 00:04:32 0.916 17.9561
23 2011-09-06 00:05:08 0.651 12.1318
24 2011-09-06 00:05:33 0.851 6.762
25 2011-09-06 00:06:01 0.929 9.9725
26 2011-09-06 00:06:24 0.899 8.211
27 2011-09-06 00:06:36 0.730 5.7676
28 2011-09-06 00:07:08 0.814 5.1425
29 2011-09-06 00:07:27 0.840 24.9738
30 2011-09-06 00:07:50 0.756 7.9268
31 2011-09-06 00:08:18 0.923 14.2626
32 2011-09-06 00:08:30 0.656 5.796
33 2011-09-06 00:08:50 0.909 6.2506
34 2011-09-06 00:09:03 0.723 3.8924
```

```
20110908-00-00-00.asc-report.txt
1 DrumCorr File <20110908-00-00-00.asc> result:
2
3 Beats count:          3514
4 Detection value:      0.6
5 Average correlation:  0.8129146383204265
6 Max corr:
7   Value:              0.9634770769163326
8   Amplitude:          12.5863
9   Amp time:           2011-09-08 21:49:43
10
11 2011-09-07 23:59:10 0.888 7.8984
12 2011-09-07 23:59:31 0.935 9.5747
13 2011-09-07 23:59:52 0.907 10.1998
14 2011-09-08 00:00:14 0.867 7.87
15 2011-09-08 00:00:31 0.865 23.4112
16 2011-09-08 00:01:06 0.883 15.115
17 2011-09-08 00:01:21 0.672 6.8188
18 2011-09-08 00:01:46 0.929 16.5071
19 2011-09-08 00:02:03 0.684 7.387
20 2011-09-08 00:02:21 0.832 5.5118
21 2011-09-08 00:02:41 0.913 14.5751
22 2011-09-08 00:02:58 0.807 6.9324
23 2011-09-08 00:03:19 0.849 9.5747
24 2011-09-08 00:03:37 0.834 6.421
25 2011-09-08 00:03:54 0.744 22.7577
26 2011-09-08 00:04:28 0.904 10.768
27 2011-09-08 00:04:42 0.666 5.6255
28 2011-09-08 00:05:03 0.912 10.0009
29 2011-09-08 00:05:20 0.725 4.489
30 2011-09-08 00:05:36 0.895 18.9789
31 2011-09-08 00:05:51 0.727 5.796
32 2011-09-08 00:06:23 0.904 26.6785
33 2011-09-08 00:06:56 0.900 10.5975
34 2011-09-08 00:07:22 0.917 14.4331
```

```
20110908-00-00-00.asc-report.txt
1 DrumCorr File <20110908-00-00-00.asc> result:
2
3 Beats count:          3514
4 Detection value:      0.6
5 Average correlation:  0.8129146383204265
6 Max corr:
7   Value:              0.9634770769163326
8   Amplitude:          12.5863
9   Amp time:           2011-09-08 21:49:43
10
11 2011-09-07 23:59:10 0.888 7.8984
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33 2011-09-08 00:06:56 0.900 10.5975
34 2011-09-08 00:07:22 0.917 14.4331
```



Visual representation of the program results

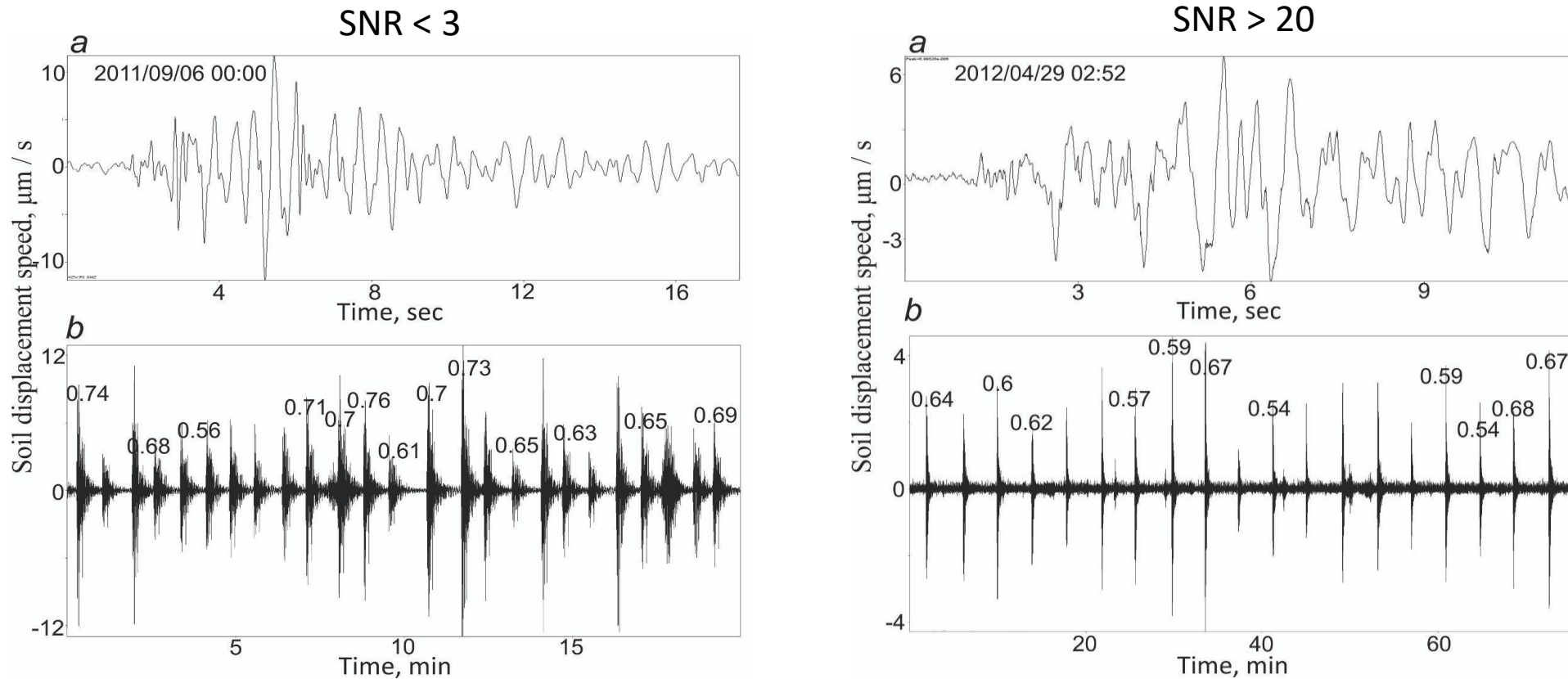


FIGURE 9. A template earthquake of the “drumbeats” regime, KZV, channel SHZ (a); a fragment of the seismic record, KZV, channel SHZ, 2011/09/27 with the corresponding correlation coefficients relative to the template earthquake (b).



Estimation of the standard deviation of the correlation coefficient

$$\hat{\delta}(r_i) = \frac{\hat{\delta}}{\sqrt{\sum_{i=1}^n x_i^2}}$$

- r_i - correlation coefficient
- n - number of samples
- x_i - amplitude

$$\hat{\delta}_z = \sqrt{\frac{1}{(1-m)} \sum_{i=1}^m x_i^2}$$

- $\hat{\delta}_z$ - estimate of the standard deviation of the noise z
- m - number of samples
- x_i - amplitude.



Estimation of the standard deviation of the correlation coefficient

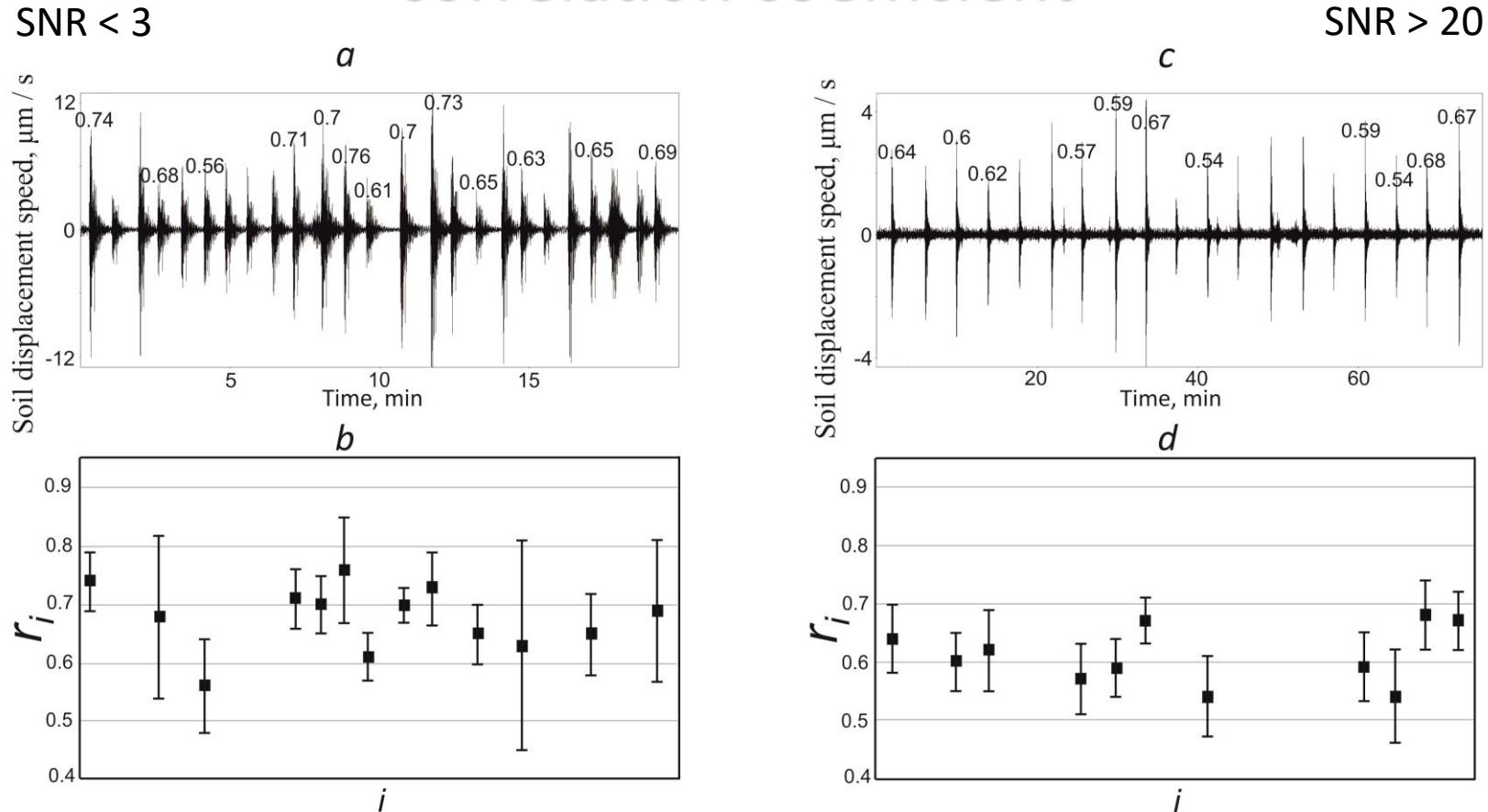


FIGURE 10. The calculated correlation coefficients of the sequence of the “drumbeats” regime earthquakes, shown in Fig. 7 and 8, and their standard deviation.

Thank you for your attention!

Photo by Sergey Gorshkov



**KIZIMEN
VOLCANO
ERUPTION**

Photo from the camera of the KF
FRC EGS RAS, installed 10 km
from the volcano



Photo by Nikolay Ushakov

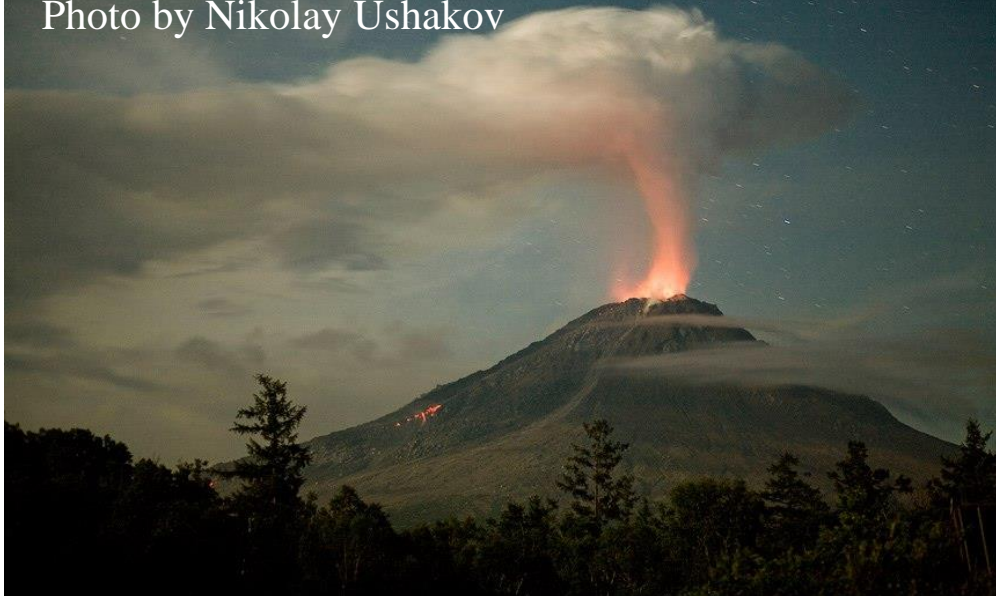


Photo by Alexander Bichenko

