Manuscript Ref. No. se-2020-216: "*On the comparison of strain measurements from fibre optics with dense seismometer array at Etna volcano (Italy)*" by Gilda Currenti et al.

Anonymous Referee #1 (General Comments):

Distributed Acoustic Sensing (DAS) is a technique to measure strain (or strain rate) along a fiber optic cable at an unprecedented spatial resolution and is now used even in seismology. One concern of DAS is fidelity in the absolute amplitude of measured strain attributed to the coupling between the ground and the cable. In this study, based on a laborious seismic array observation at Etna volcano, the authors estimated strain by interpolating the seismic wave field with two different methods: the spatial interpolation methods and the seismo-geodetic method. Comparing these seismically estimated strain and DAS strain, the authors showed that both strains agreed well, which shows the fidelity in amplitude of DAS observation. This result made an essential contribution to validating seismological applications of DAS. And I highly evaluate the elaborate array observation by the authors in such a high mountain. The manuscript is clearly written. The subject of this manuscript is up-to-date and suitable for this journal. I would suggest this manuscript for a minor revision. The following comments should be addressed in the revised manuscript.

Authors: We are glad that the main message of the manuscript was well appreciated. We really thank the referee for the positive criticism and detailed questions which stimulate us in deepening the analysis and improving the manuscript.

Anonymous Referee #1 (Specific comments):

The two interpolation methods introduced different smoothing parameters. I am curious how these smoothing parameters are related to the gauge length of DAS. Can the authors comment on that?

Authors: The smoothing parameters cannot be easily related to the gauge length. We went again through the equations to try to find a quantitative mathematical relationship. Due to the adopted formulation, no a clear direct relationship was found. However, a few considerations can be drawn by examining their definition and effects on the solutions. For the SIM, the more sensitive smoothing parameter is the distance factor introduced to avoid singularities in the analytical solutions. The smaller it is, the sharper the solution. For the SGM, the smoothing parameter D weights the relative contribution of the station with distance in the weighted least square inversion. The smaller it is, the lesser the influence of the station at larger distance. So both of them locally average displacement/velocity to derive strain. Their performances change with the signal wavelength. Smaller distance smoothing parameters are adapted for shorter wavelengths, whereas larger ones may perform better for longer wavelengths It is worth of noting that the accuracy of the solution is dependent on the factor $\frac{\sin(\pi L/\lambda)}{\pi L/\lambda}$, that is the same multiplicative factor giving the DAS response to axial strain over a gauge length of L (Bakku, 2015). This multiplicative factor comes, however, from two independent analyses based on the estimate of strain under spatially uniform approximation (Spudich and Fletcher, 2008) and on the computation of averaging strain over a gauge length L (Bakku, 2015).

Anonymous Referee #1 (Specific comments):

The average inter-station distance of the seismic array observation is approximately 70m that is larger than the gauge length of 10m. Therefore, it seems reasonable that the seismically estimated strain's spatial distribution is smoother than that of the DAS strain. I wonder if the authors can increase the gauge length by taking the spatial average of DAS strain records and compare that with the seismically estimated strain. I am interested to know to what degree such a smoothing averages out the small-scale medium heterogeneities

Authors: Thanks for giving us this hint. The DAS measurements were acquired at a fixed gauge length of 10 m. In the iDAS interrogator the user cannot change it. With sampling resolution of 25 cm, the iDAS internally uses an advance de-noising algorithm to improve the signal-to-noise ratio prior to data decimation to 2 m spacing. To properly estimate the effect of the gauge length it would have been ideal to have the raw data and set the gauge length before data decimation. However, following the suggestion of the reviewer, we attempt to investigate how the gauge length may average out the effect of the small-scale heterogeneities by virtually increasing the gauge length with a spatial average of DAS data. Results are included in the Supplementary Figures (Figs. S3-S8). We report the analysis on the VE event, where the effect of increasing the gauge length from 10 to 30 and 100 m is more significant due to the higher frequency content. Indeed, as expected, at higher gauge lengths the shorter wavelengths are filtered out (Fig. S3, S6). We used two averaging approaches: (i) a simple average over channels (Figs. S4, S7); (ii) a moving average with a shift of 1 channel (Figs. S5, S8). Also with a gauge length of 30 m, the simple average degrades the signals and the main phases are already lost. On the other hand, the moving average preserves the main signal but smooths out local scattering and reflections which are no more visible. When computing the misfit with the array derived strain estimates, the localized anomalies (Fig. 3) in coincidence of the faults due to the small-scale heterogeneities are flattened and broaden. These findings confirm that the distortion of the strain field is very localized and difficult to be observed by traditional seismic array methods, which require deployment of a dense network along well-chosen active faults and a good amount of luck. It is also important to stress that the fault system in Piano delle Concazze comprises minor faults in a complex volcano-tectonic setting. They mainly represent the accommodation in response to the extension of the North-East Rift. Being limited in extension and shallow (Napoli et al., 2021), distortions are expected to be narrow and very localized as our findings seem to support.

Anonymous Referee #1 (Specific comments):

It is necessary to show the correspondence between the location and the number of DAS channels. I would suggest showing the channel number in Figure 1 with a step of 100. Or the authors will be able to indicate the channel numbers at the corners and bends of the cable in Figure 1.

Authors: We appreciate this suggestion. Since Figure 1 is already too full of information, we indicate the channel numbers at the corners and bend of the cable in Figure 3 and 4.

Anonymous Referee #1 (Specific comments):

In equation (1), the second term on the top equation's right-hand side should be w, not p. And q, p, and w may be better to be explicitly shown even in this manuscript.

Authors: The term in the equation (1) was corrected. As suggested by the referee we added the expression of the Green's functions q, p, q as reported in Sandwell and Wessel (2016).

Anonymous Referee #1 (Specific comments):

On page 5, line 113, the authors mentioned that the authors used the least-squares method to solve the system. However, since the number of data and the number of unknown parameters are the same, the authors will solve the system directly. It is not necessary to use the least-squares method.

Authors: Thanks for highlighting this mis-information. We completely agree and we solved directly the system of linear equations. We corrected the text accordingly.

Anonymous Referee #1 (Specific comments):

In equation (5), the authors can show T (transposition operator) on the right-hand side, not on the left-hand side.

Authors: done.

Anonymous Referee #1 (Specific comments):

Page 6, line 155, fmax is about 7Hz, not 6Hz.

Authors: done.

Anonymous Referee #1 (Specific comments):

In Figure 1, the authors need to mention the red circle at Bb04. Otherwise, I misunderstand that Bb04 malfunctioned.

Authors: To avoid misunderstanding, we changed the color of Bb04 like the other broadband seismometers. There is no particular reason to put Bb04 in evidence.

Anonymous Referee #1 (Specific comments):

At the end of the caption of Figure 2, an average scaling factor should be 1s/km, not 1000m/s.

Authors: We agree. In the text the scaling factor is reported as apparent slowness and not in apparent velocity. Accordingly, in the caption we report the scaling factor in apparent slowness, as suggested by the referee.

Anonymous Referee #1 (Specific comments):

In Figures 3 and 4, the authors just mentioned that the discrepancies are large around fault zones. However, it is necessary to mention clearly if the seismically estimated strain is overestimated or underestimated.

Authors: The array derived strain estimates are in general underestimated in proximity of the fault. Amplification is observed in the DAS records as expected in presence of a damaged zone with lower velocity (Cao and Mavroeidis, 2019; Jousset et al., 2018).

Anonymous Referee #1 (Specific comments):

I want to ask the authors to show Figures 7 and 8 on precisely the same scale as Figure 2.

Authors: The figures were redone to set precisely the same scale as Figure 2.

On the comparison of strain measurements from fibre optics with dense seismometer array at Etna volcano (Italy)

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Supplementary Information

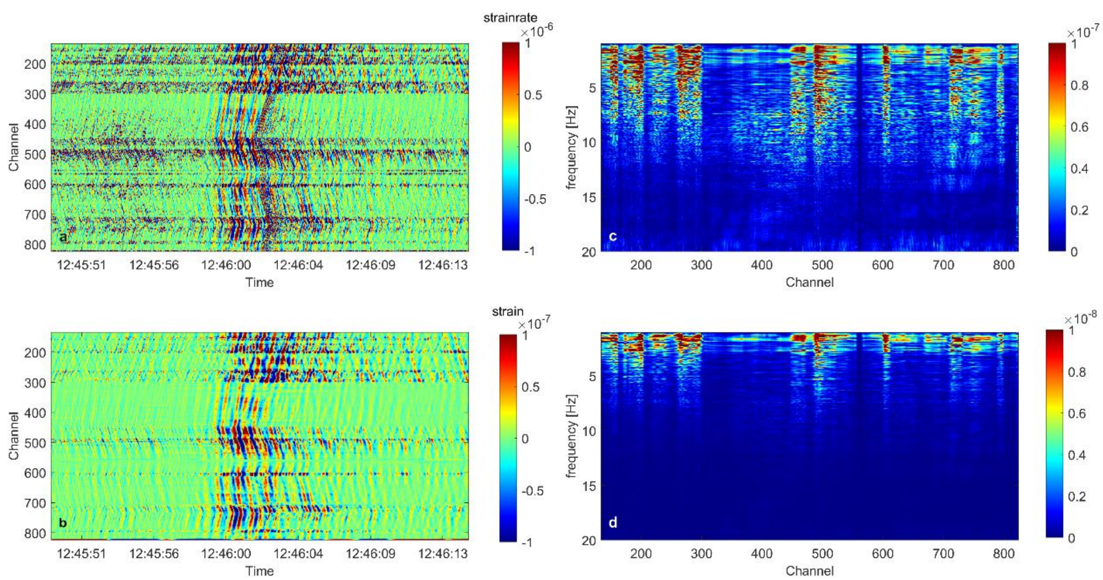

Figure S1: Time series (a, b) and spectra (c, d) during a small volcanic explosion (VE) at Etna on 6 July 2019. (a) Raw DAS strainrate; (b) strain computed by integrating over time the raw strainrate data; (c) spectra of the raw strainrate DAS records overall the channel; (d) spectra of strain records.

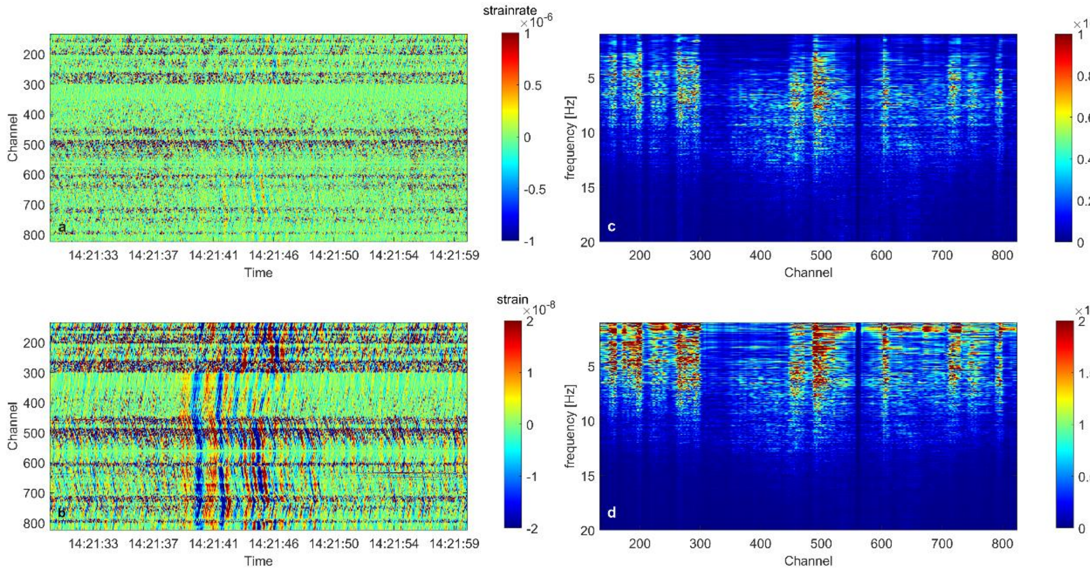

Figure S2: Time series (a, b) and spectra (c, d) during an LP event (LP) at Etna on 27 August 2019. (a) Raw DAS strainrate; (b) strain computed by integrating over time the raw strainrate data; (c) spectra of the raw strainrate DAS records overall the channel; (d) spectra of strain records.

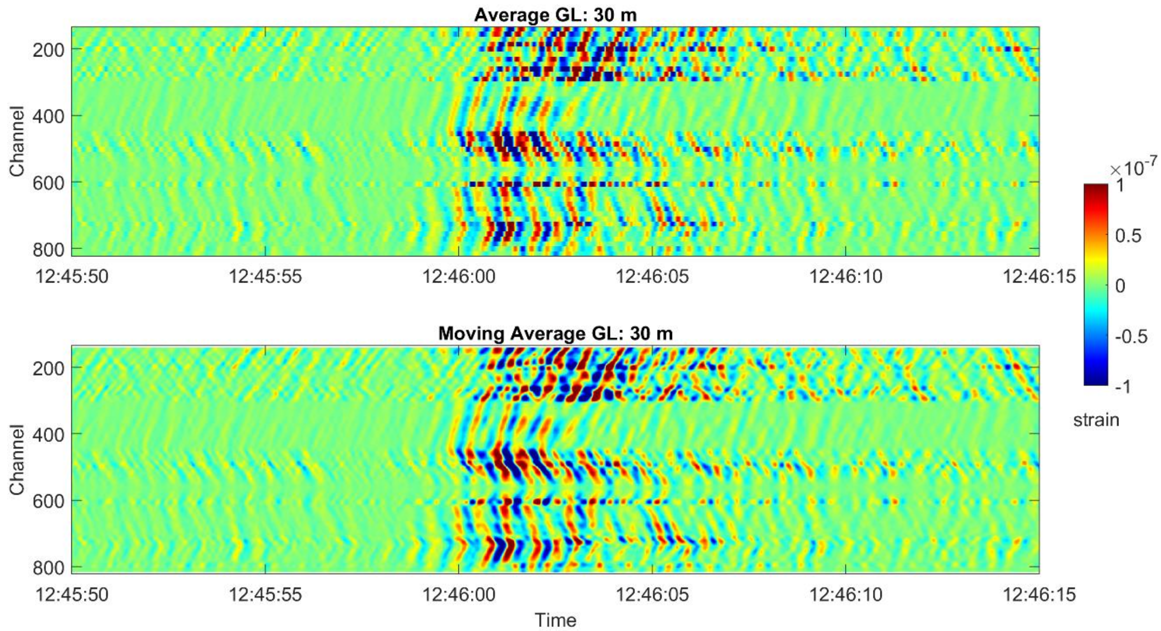

Figure S3: Strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 30 m. Two methods were used: (top) averaging the data every 15 channels (30 m); (bottom) averaging the data with a mobile mean over 15 channels with a shift of 1 channel.

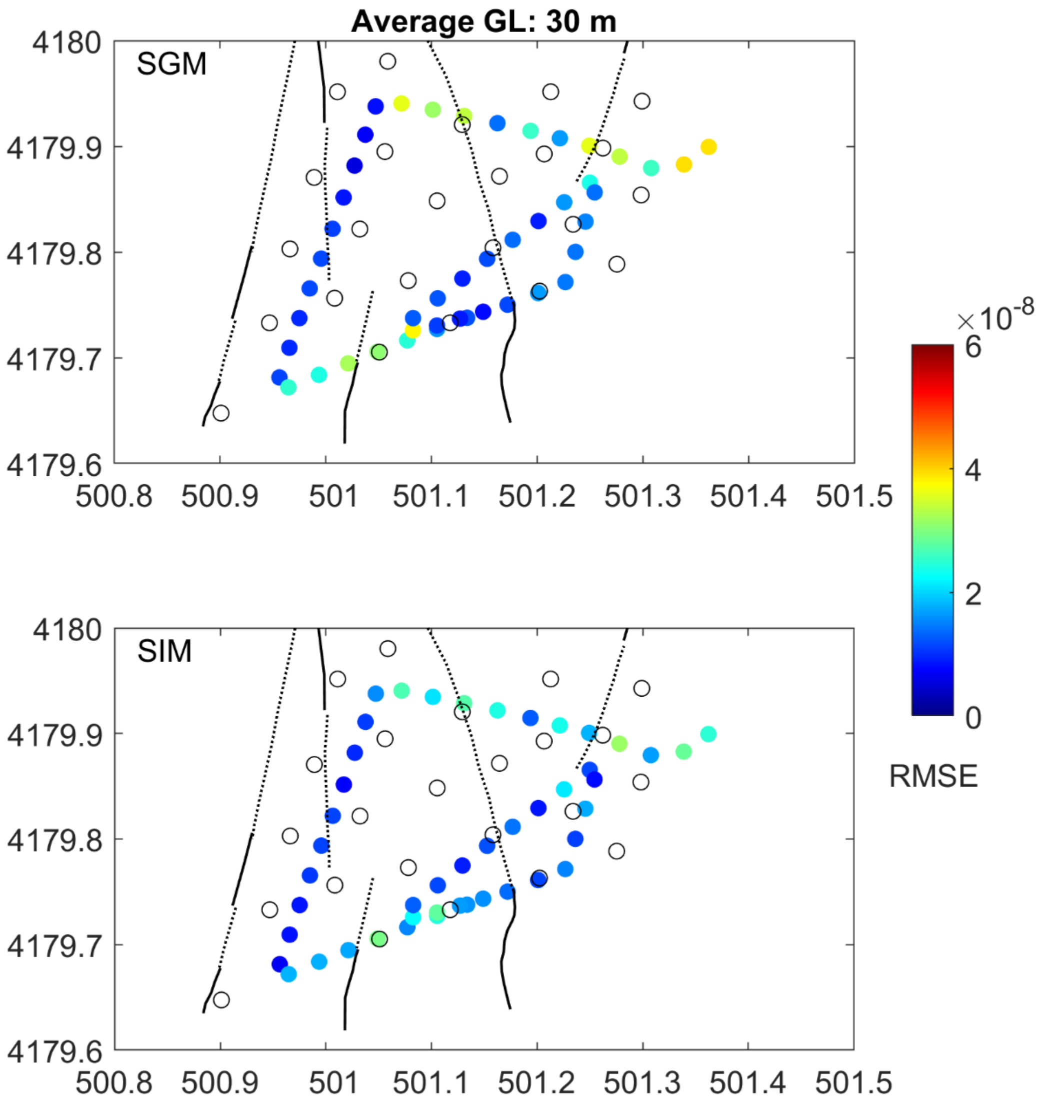

Figure S4: Misfits between the array derived strain and the DAS strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 30 m using a simple average.

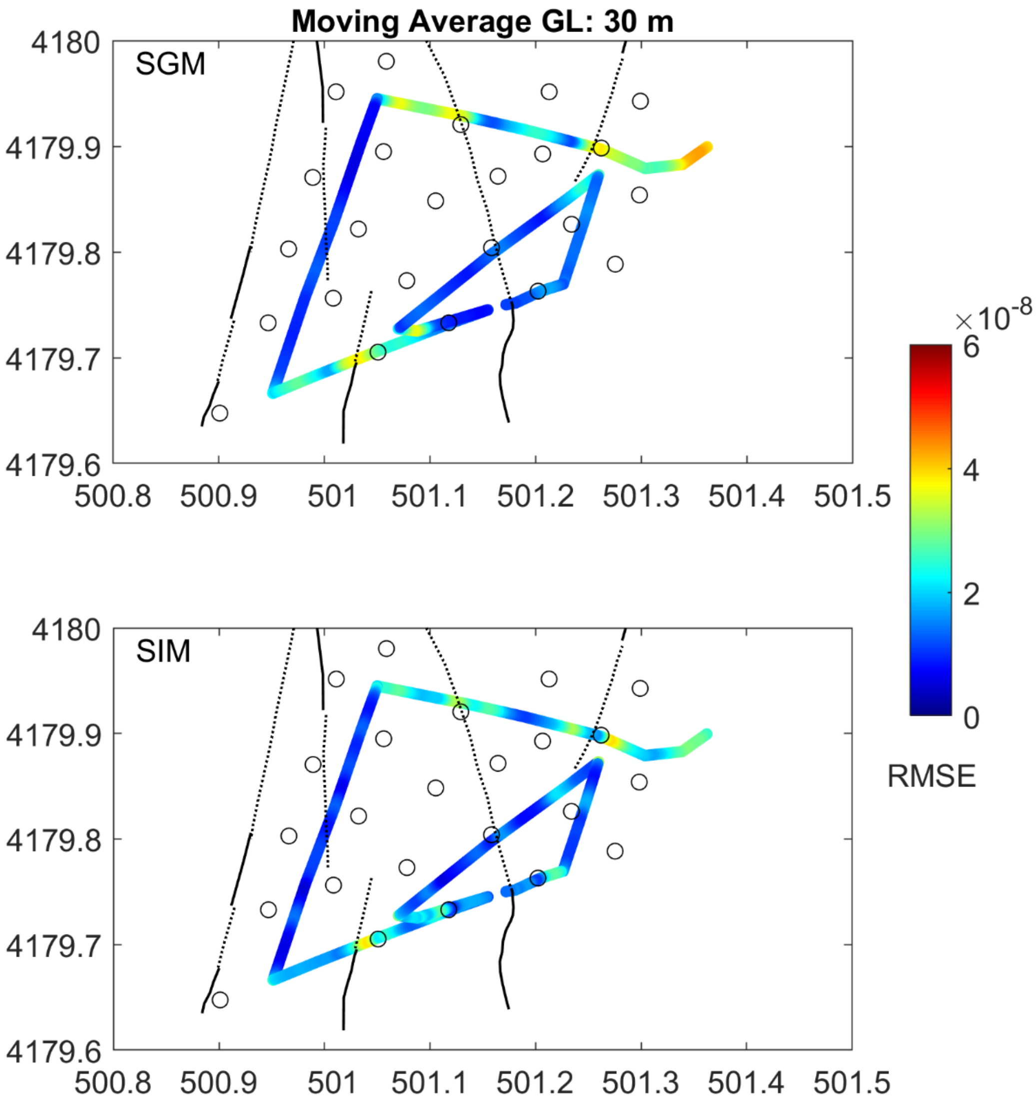

Figure S5: Misfits between the array derived strain and the DAS strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 30 m using a moving average.

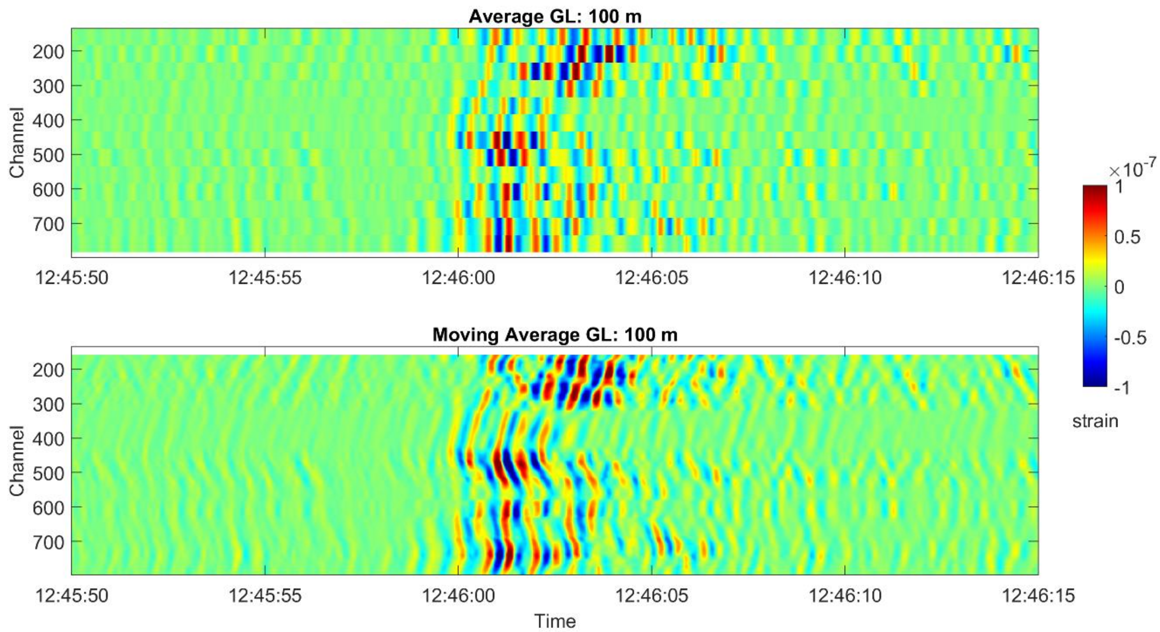

Figure S6: Strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 100 m. Two methods were used: (top) averaging the data every 50 channels (100 m); (bottom) averaging with a mobile mean over 50 channels with a shift of 1 channel.

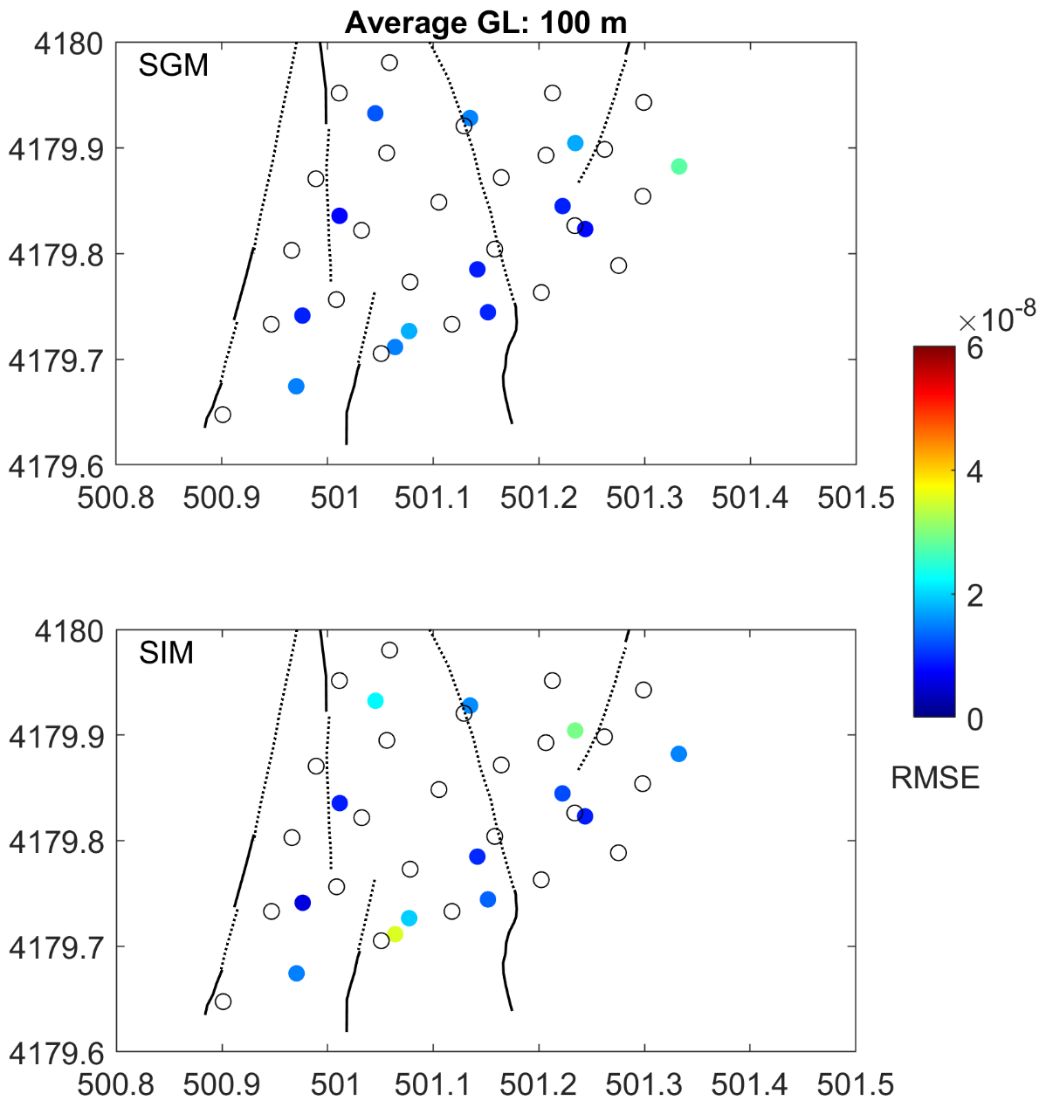

Figure S7: Misfits between the array derived strain and the DAS strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 100 m using a simple average.

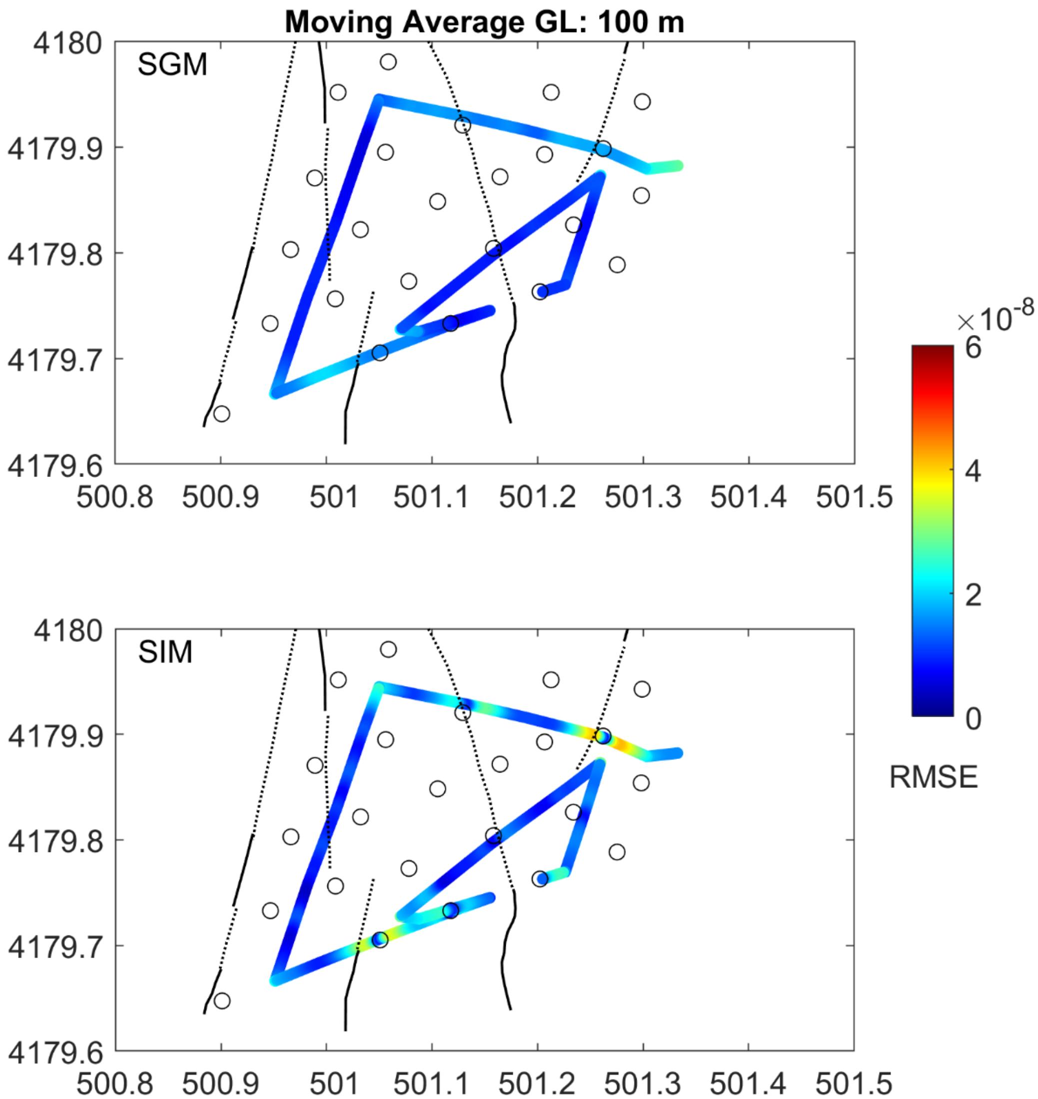

Figure S8: Misfits between the array derived strain and the DAS strain data (volcanic explosion on 6 July 2019) after increasing the gauge length to 100 m using a moving average.