Optimal Network Design for Microseismic Monitoring in Urban Areas - A Case Study in Munich, Germany

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We would like to thank the editor and the reviewer for the critical assessment of our work and the helpful comments. Changes in the manuscript are highlighted in red.

Response to reviewer's comments:

Secondary issues:

1. **Line 48: "Several approaches have been proposed to solve this problem…" - for background and completeness I would suggest adding a very concise review / list of some of the many published methods for network optimization, along with justification for your choice of methodology for this study.**

   A short overview of some existing methods was added in lines 48 – 55 in the introduction.

   We chose to use the method of Kraft et al. (2013), which is based on simulated annealing, since this approach allows the optimization of seismic networks in complex settings, taking into account user-specified velocity models and heterogeneous noise conditions, as well as already existing monitoring stations. In addition, expected location uncertainties and detection thresholds of the resulting network are returned. The simulated annealing implementation solves this optimization problem computationally efficient.

2. **Line 96: "following the approach of Aki (1976)" – A sentence or so describing this procedure in more detail seems appropriate here, and seems necessary for understanding the importance of signal band-width in the following sentence.**

   We utilize the estimated SNR of a seismic phase at a station to calculate the expected uncertainty of the phase's onset time following the approach of Aki (1976) based on information theory (Shannon, 1948). According to Shannon (1948) a simple relation for the estimation of the information content of a signal exists:

   W T $\log 2 \frac{S2+N2}{N2}$

where S2 and N 2 represents the power of signal and noise, respectively, and T is the duration of the time series. The signal bandwidth W is approximated by max(fc, fmax). Here fc represents the Brune corner frequency of the event, and fmax corresponds to the high-frequency band limitation of the radiated field, as estimated from the attenuation model of Edwards et al. (2011) for Switzerland.

This explanation was added in lines 105 – 112 in the Methodology section.

3. **Line 235: "The NetOpt3D program performs the simulated annealing and returns the optimal locations for these 5 new stations (Figure 7 b)." Is this "the" optimal locations or "an" optimal location set? Since simulated annealing is a stochastic method, it seems likely that re-running the optimization with different random seeds or slightly different parameters would give different sets of "optimal" stations. Or can you confirm that the effective misfit landscape smooth enough that a global optimal solution can be found, in general, independent of the initialization of the network optimization procedure?**

The reviewer is correct, re-running the optimization with different parameters could lead to different results. However, we fine-tuned the simulated annealing parameters such as starting temperature, cooling schedule, maximum number of temperature steps, temperature reduction by step, minimum temperature, trials per step, … in order to achieve a slow and smooth convergence of the solution to the global minimum. Even varying these parameters in a reasonable range does not change the final results. This suggests that in our case the misfit landscape of the optimization problem is smooth enough to find a global optimal solution.

A sentence concerning the fine-tuning of the simulated annealing parameters was added in lines 90-93.

Minor suggestions:

1. **Line 29, 283: "a save" → "safe"**

Thank you for highlighting this mistake, it was corrected in both lines.

2. **Line 39: "Hereby" → "Consequently"**

This suggestion was adopted.

3. **Line 55: might be useful to cite Figure 1 here**

We agree with the reviewer. The reference to Figure 1 was added.

4. **Line 63: "raising" → "growing"**

The expression was changed to growing.

5. **Figure 1b: The colors for some of the stations (e.g. MNH, EGA) may not be distinct for some forms of color blindness (I check with https://michelf.ca/projects/sim-daltonism/). Similar issue for Figures 2b, 6.**

   We agree with the reviewer. The colors were changed in Figures 1, 2b and 6 to make it more color blind friendly. We found the same issue for Figures 3 and 8, therefore the colors were adjusted accordingly.

6. **Line 136, Figure 2 caption: For completeness, maybe specify hour defining day and nighttime. Specify which 5 days were monitored and which of these may be noisy days (e.g. Mon-Fri) or quiet days (Sun?).**

   For the estimation only noisy days (Mo-Fr) were used. We defined daytime from 6am to 10pm and nighttime from 10pm to 6am. These specifications were added in the caption of Figure 2.

7. **Line 219: "without optimization option" → "without optimization"**

   The expression was corrected.

8. **Line 225: "The location uncertainties are calibrated using recorded events at the geothermal plants in the southern part of the study area (Megies and Wassermann, 2014)." - Not clear what this calibration involves, some more explanation here would be useful.**

   The originally calculated uncertainties were too high to be realistic, which is most likely due to the implementation of the source model, which is based on scaling relations found for Switzerland. Therefore, we compared the computed uncertainties to actually measured uncertainties for specific events and found that a scaling factor of 3 results in reasonable values.

   This explanation was added in lines 238-241.

9. **Figures 7, 9 10: The epicentral and vertical uncertainty maps might be easier to read and more informative if the color scale included a break at the corresponding the FKPE-recommended location accuracy. Then the areas greater and less than this accuracy and the limit between these cases are clearly distinguished.**

   For the vertical uncertainty plots the color scale clearly shows the break at the FKPE-recommended location uncertainty: all dark green areas are above the threshold. We chose the same color scale for the epicentral uncertainty plots in order to make comparison with the vertical uncertainties easier. Therefore, the red contour line that marks the FKPE-recommended threshold of 500 m was added to the epicentral uncertainty plots. From our point of view this highlights the areas greater and less than this accuracy sufficiently well.

10. **Line 271: To be consistent with the terminology in the preceding paragraph, perhaps change "scaling factor" → "borehole noise level factor" or similar.**

    We agree with the reviewer. The terminology was changed to "borehole noise level factor".

11. **Line 272: "Fig. 9 b" → "Fig. 10 b"**

    Thank you for highlighting this mistake. The reference was corrected to Fig. 10 b.

12. **Fig 10: It would be more informative and avoid ambiguity to specify the borehole depths for each panel. The borehole and surface station symbols appear to change color – explain in caption (perhaps the same issue for other evaluation map figures?).**

    We agree with the reviewer that the borehole depths should be specified. This was added in the caption of Fig. 10.
    We disagree that the surface and borehole station colors change in the evaluation maps (Figures 7, 9 and 10). Existing surface stations are always marked in orange, existing borehole stations in light blue, new surface stations in pink and new borehole stations in dark blue. Only in Figure 8 the color of the existing surface stations was changed due to conflicts with the background color map.

13. **Line 275: "Even though, borehole stations": remove comma.**

    The comma was removed.

14. **Line 287: "We showed, that": remove comma.**

    The comma was removed.

15. **Line 290: "are indispensable" → "may be indispensable" – in other cases it may be found that surface stations are sufficient. But if you can show that Munich is generally quieter than other urban areas, you may strengthen this conclusion to something like "are likely indispensable".**

    We agree with the reviewer that the conclusion should be formulated in a more general way. Therefore, we changed the expression to "may be indispensable".

16. **Line 292: "results indicate solutions for improving" → "study presents procedures and shows solutions for improving"**

    We thank the reviewer for this suggestion. The sentence was reformulated.

17. **Line 309: Link does not work: http://doi.org/10.5281/zenodo.763885**

    The repository was not open to the public yet and there was a mistake in the link. This one should work:
    https://doi.org/10.5281/zenodo.7638856

Summary:

The suggestions of the reviewer were added to the manuscript and marked in red. No mayor changes were made to the manuscript. The largest changes include the change of the colors in Figures 1, 2b, 3, 6 and 8 to make it more color blind friendly.