Robust, an Earthquake Early Warning System in the Lower Rhine Embayment, Germany

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Abstract

The Lower Rhine Embayment in western Germany is one of the most important areas of earthquake recurrence north of the Alps, facing a moderate level of seismic hazard in the European context but a significant level of risk due to a large number of important industrial infrastructures.

In this context, an early warning system, meaning an early detection of an event whose unfolding may result in damage and loss is of high importance. In the ROBUST project a user-oriented hybrid earthquake early warning and rapid response system is designed. The approach to find the optimal station configuration is presented here.

Area of study and earthquake scenarios

The earthquake scenarios are selected from the seismicity models developed by Grünthal et al., 2018 to produce a new probabilistic hazard maps of Germany. The branch C of the logic tree has been implemented in OpenQuake and a stochastic catalogue of earthquakes has been produced fully consistent with the PSHA seismicity model (Bindi et al., 2017; Boore et al., 2014). Simulation Database is built using finite-fault stochastic method EXSIM, and tailored for Earthquake Early Warning purposes (with additional P-wave).

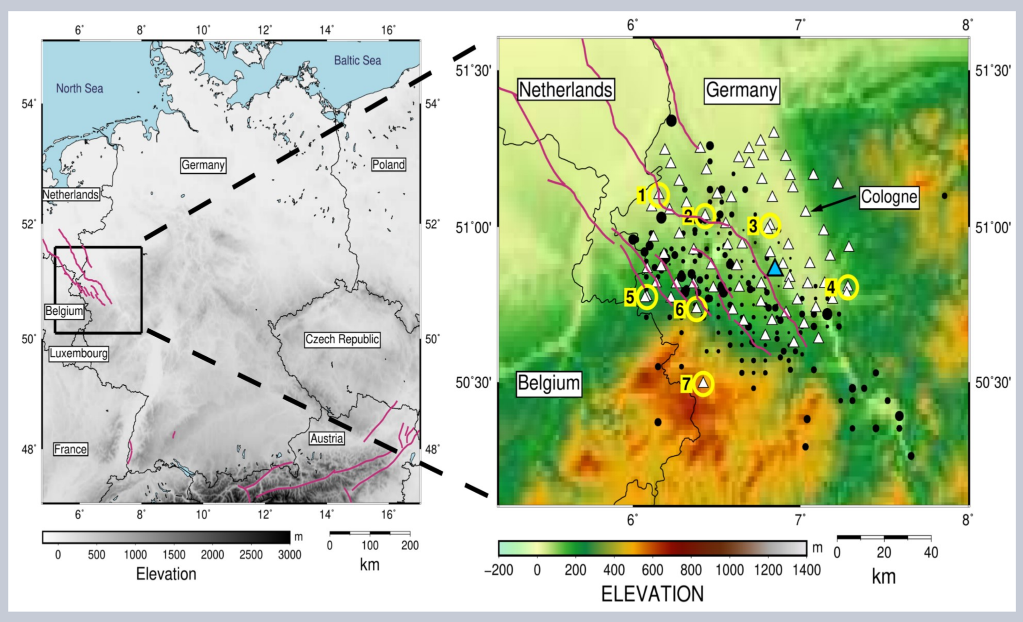

Figure 1. Left: The Lower Rhine Embayment, Germany. The area of study is enclosed in the black box. Right: Candidate stations (blue triangles) and permanent stations (enclosed with yellow circles) and the stochastic catalog (black circles).

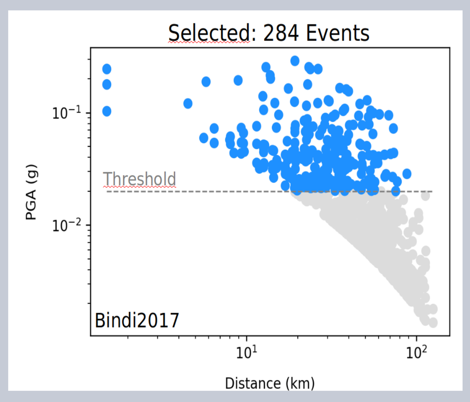

Figure 2. PGA levels of the stochastically simulated earthquakes. The Scenarios from OpenQuake are preselected using the empirical GMM of Bindi et al., 2017. Events with PGA above the thresholds 0.02g are selected.

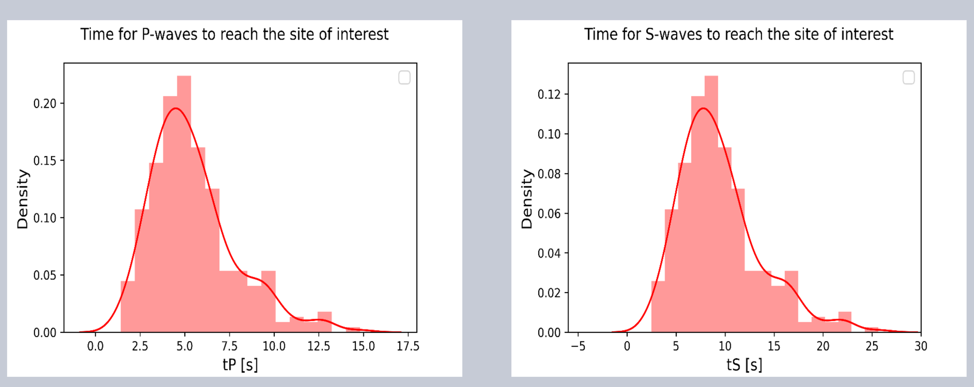

Figure 3. Distribution of the arrival times of P-waves (left) and S-waves (right) for the set of scenarios reaching the target site. The arrival times are overall shorter than previous studies performed in Turkey (Oth et al., 2010) and Kazakhstan (Stankiewicz et al., 2013).

Methodology

- Network evaluation using cost functions is done to have the longest possible lead times against the false alarms.
- Optimization (minimizing the cost function) with microgenetic algorithms is used to compare the performance of different EEW system variants.

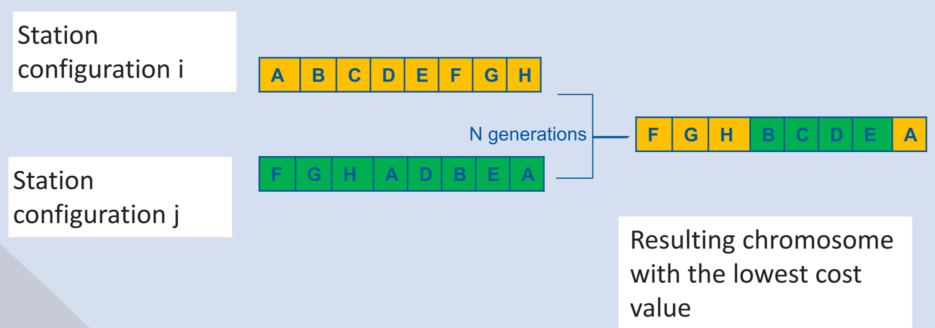

Figure 4. Microgenetic algorithm: each station configuration represents a chromosome, made of n stations plus 3 threshold genes. For each chromosome, the cost function is calculated according to equation 1.

Weighting of events

$$\text{cost} = \sum_{i=1}^{N_{evt}} W_i \left[L \cdot (1-K) \cdot sigmoid(t_{warn,i}, t_{center}, S) + K\right]$$

with

$$sigmoid(t_{warn,i}, t_{center}, S) = 1 - \frac{1}{1+\exp\left[-S(t_{warn,i} - t_{center})\right]}$$

Available warning time

Fixed center time of the sigmoid function

Equation 1. Cost function used to find the optimum arrangement of stations.

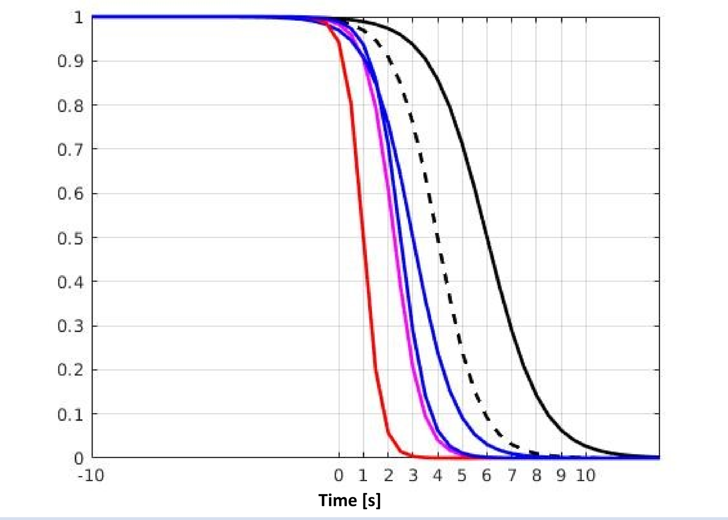

Figure 5. Sigmoid functions as defined in equation 1 and tested in this study. Sigmoid functions plotted with dashed and solid black lines correspond to the other studies performed in Turkey (Oth et al., 2010) and Kazakhstan (Stankiewicz et al., 2013), which are also tested here.

Optimal design of the seismic network

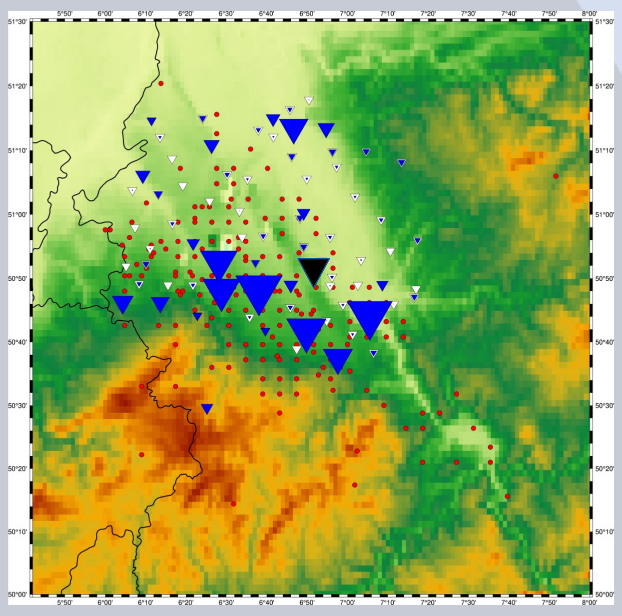

Figure 6. Stations appearing most frequently in the 500 runs for a ten-station networks with the lowest cost values. Stations are enlarged according to how frequently they appear in the best solutions. The sigmoid functions in blue in figure 5 are used.

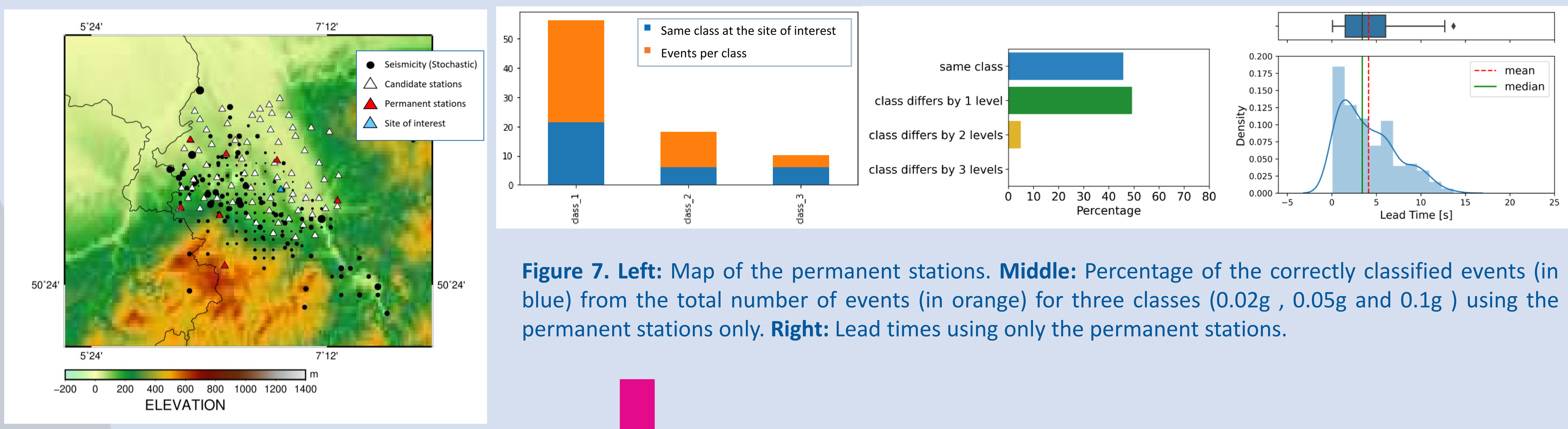

Figure 7. Left: Map of the permanent stations. **Middle:** Percentage of the correctly classified events (in blue) from the total number of events (in orange) for three classes (0.02g , 0.05g and 0.1g) using the permanent stations only. **Right:** Lead times using only the permanent stations.

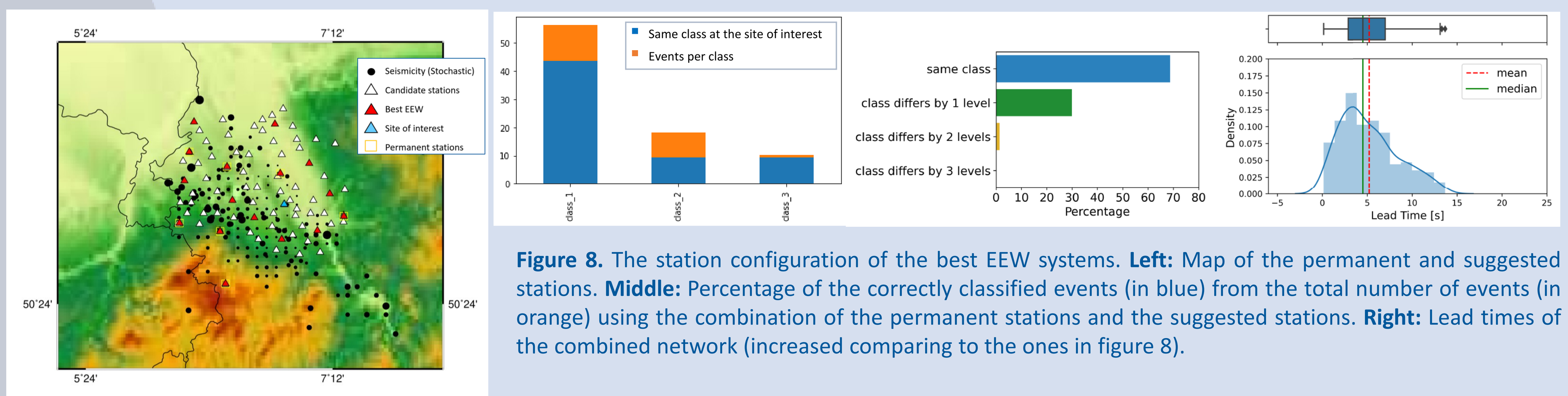

Figure 8. The station configuration of the best EEW systems. **Left:** Map of the permanent and suggested stations. **Middle:** Percentage of the correctly classified events (in blue) from the total number of events (in orange) using the combination of the permanent stations and the suggested stations. **Right:** Lead times of the combined network (increased comparing to the ones in figure 8).

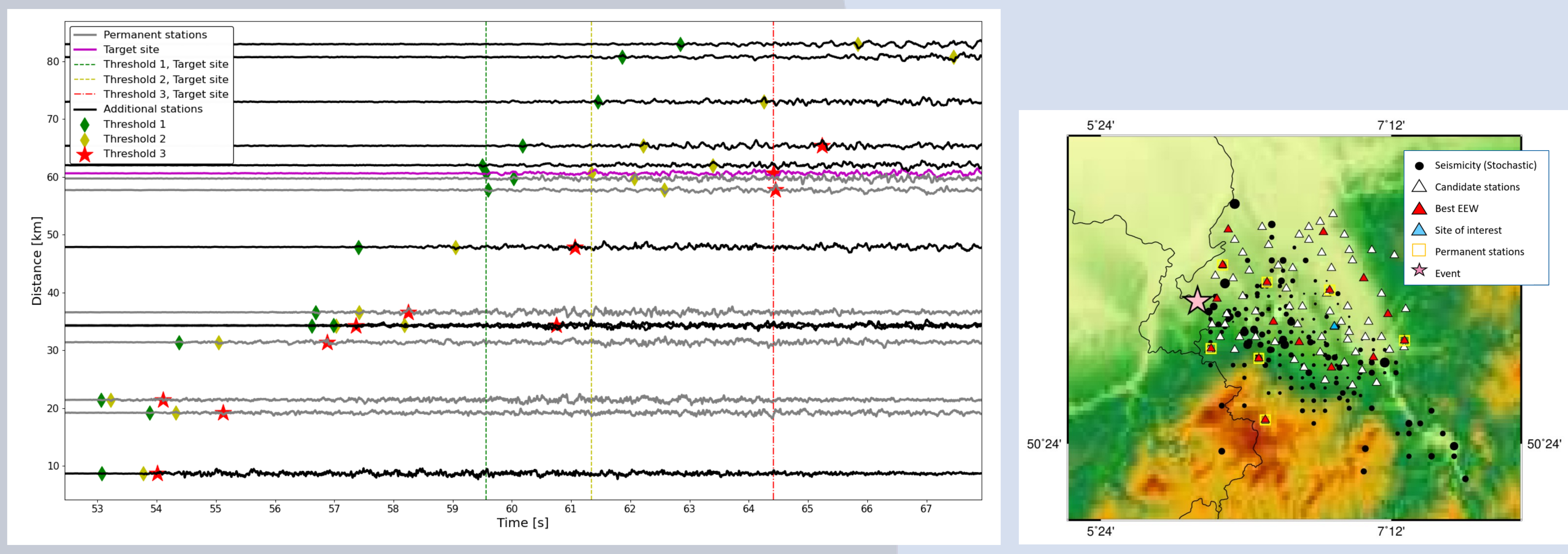

Figure 9. Left: Waveforms recorded by the example of best EEW system. The time of exceedance of thresholds in waveforms of permanent stations, suggested stations and the target site is illustrated. Note the extra warning time gained using the suggested station for each threshold. **Right:** Map of the network and the location of the suggested and permanent stations. The event is shown with the pink star.

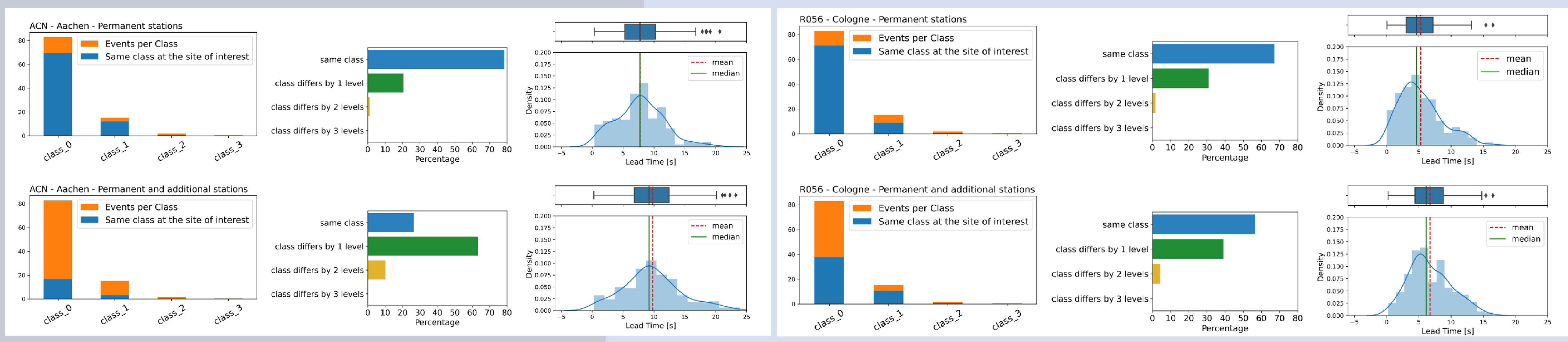

Figure 10. Left: Performance of the same EEW (designed for the site of interest) for city of Aachen. The upper panel shows the performance of the permanent stations only and the lower panel shows the performance of the permanent stations and the additional stations together **Right:** Performance of the EEW for Cologne.

Summary and Conclusion

- A user-oriented hybrid earthquake early warning and rapid response system is designed.
- Regional seismic monitoring is combined with smart, on-site sensors, resulting in the implementation of decentralized early warning procedures.
- A genetic optimization approach is used in order to densify the existing sparse network. The importance of the approach is shown.
- The approach is user-oriented and the thresholds can be designed against what is exactly needed by the (end) users.
- With the optimally compacted network, ground movements can be detected with higher accuracy for different classes of events. Adding additional stations will improve the EEW of the area.

References

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