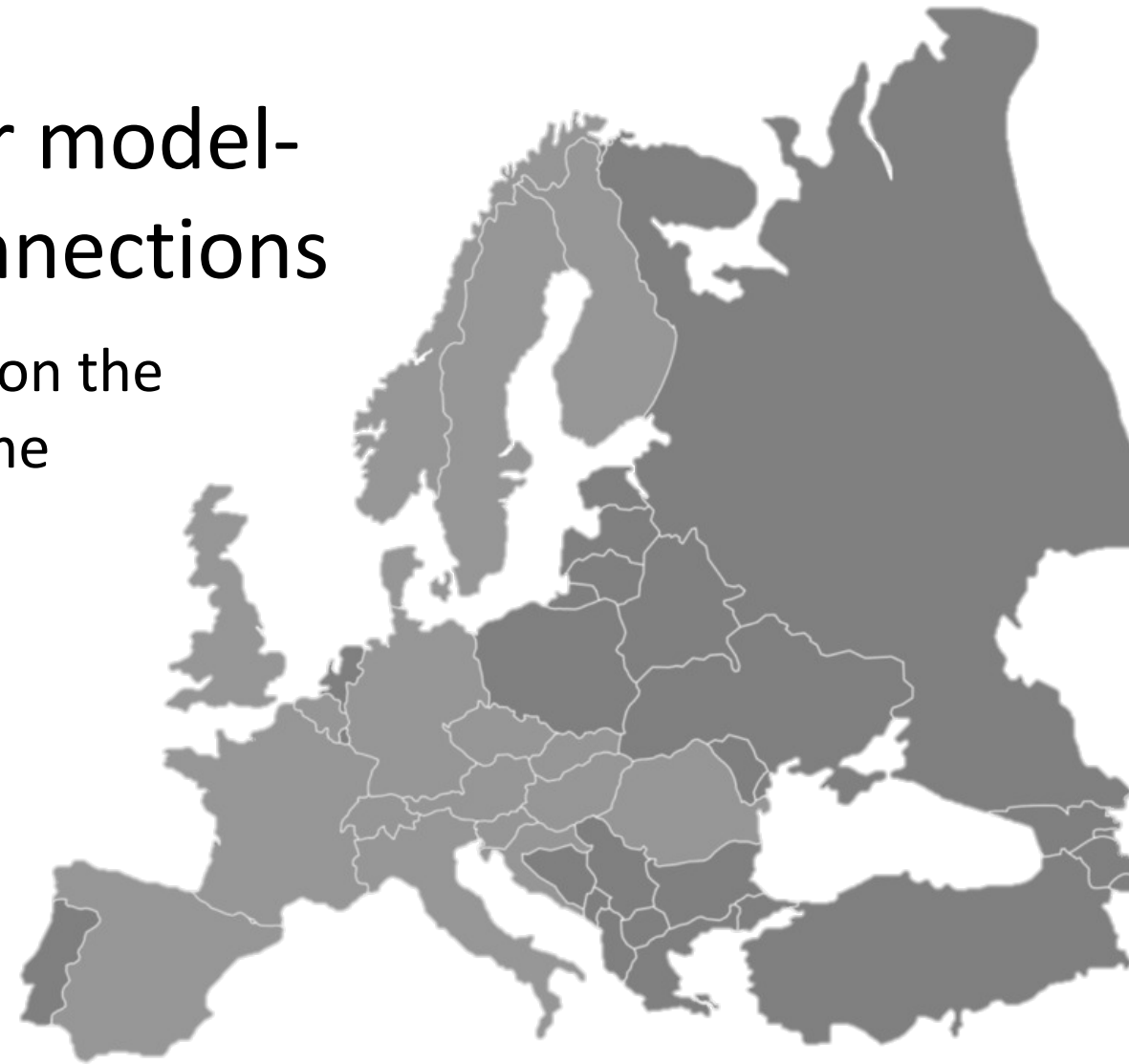


Towards tide gauges selection for model-based **hydrodynamic leveling** connections

with application to assess the potential impact on the quality of the European Vertical Reference Frame

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1. Background

- **Model-based hydrodynamic leveling** between tide gauges is an efficient and flexible technique to transfer heights over water bodies.
- Shift between the height datum of tide gauge A and tide gauge B, respectively (δHD) given by:

$$\delta HD = (H_{MWL}(B) - H_{MWL}(A)) - ((\zeta_{MWL}(B) - \zeta_{MWL}(A)))$$

where H_{MWL} is the observed mean water level (MWL) with respect to the local datum and ζ_{MWL} is the model-based MWL, at the location a tide gauge.

- We aim to exploit the model-based hydrodynamic leveling to enlarge the extent of European Vertical Reference System (EVRS) and improve the quality of the European Vertical Reference Frame (EVRF).

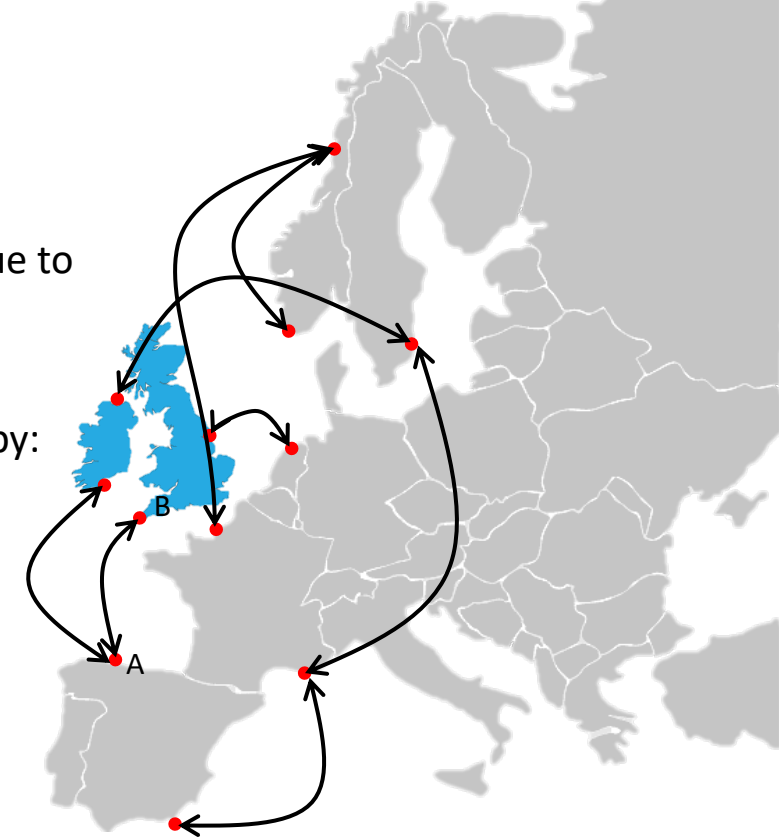


Fig 1: Hydrodynamic leveling connects height datums across water bodies.

? How much is the potential improvement? Which tide gauges are the most profitable ones?

2. Method and data

- We aim to combine **spirit leveling** data used to realize the [EVRF2019](#) with **hydrodynamic leveling** data and assess the impact on the precision of the network.
- For spirit leveling data (Unified European Leveling Network (UELN))
 - Location of height benchmarks and variance of observations provided by [BKG](#).
- For hydrodynamic leveling data
 - Location of tide gauges are taken from the [PSMSL](#) database.
 - We assume to have access to hydrodynamic models each covers a specific basin of European seas (Fig.3).

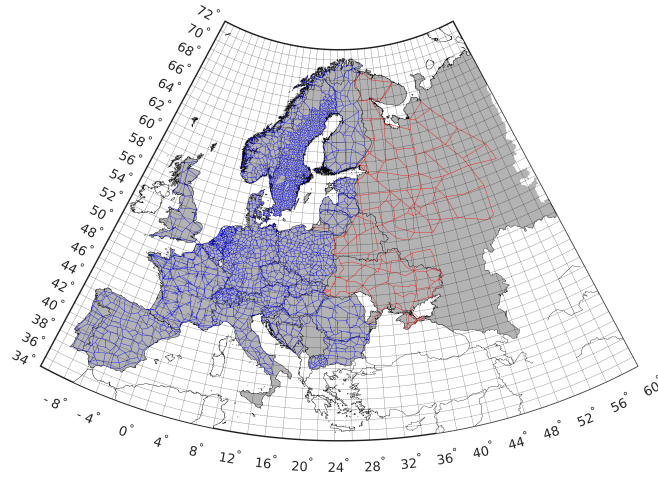


Fig 2: UELN connections. For Belarus, Ukraine and Russia BKG was not allowed to share the data, so we reconstructed the network from [EVRF2019 report](#) (red lines).

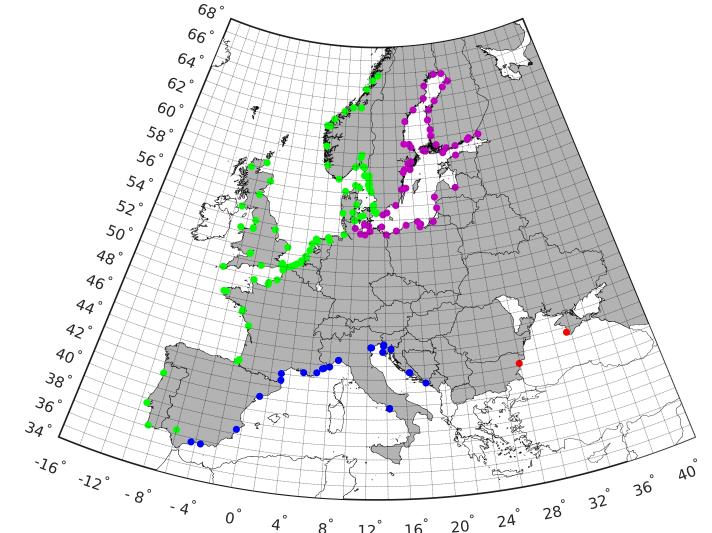


Fig 3: Location of tide gauges used in this study. Different colors refer to the four water basins defined in this study.

- To establish the hydrodynamic leveling connections
 - All tide gauges must be connected to the UELN.
 - The hydrodynamic models should be capable of resolving the local MWL at the tide gauge's locations.
- So, we connect all tide gauges artificially to the closest UELN benchmark. For simplicity, we assume that each hydrodynamic model provides the MWLs with uniform accuracy.
- Using a heuristic search method, we identify the best set of hydrodynamic leveling connections that makes the average standard deviation of the network as lowest as possible.

3. Experimental setup

- In total 186 tide gauges were used.
- We only allow for connection between tide gauges located in the same basin, total number of independent connections is 182.
- Noise level for hydrodynamic leveling connections range from 1 to 5cm.

4. Results

- Adding maximum possible hydrodynamic leveling connections results in a reduction of the standard deviation of the network between **19% to 34%**, depending on the noise level.
- By adding a limited number of connections, we get a significant improvement.
- By increasing the noise level, more connections are needed to achieve a certain amount of improvement.
- Tide gauges located in the countries with the highest number of height benchmarks are favored. Also, our results show that the improvement does not depend on the exact geographical location of the tide gauges.
- Model-based hydrodynamic leveling method is quite flexible in selecting the tide gauges involved in the connections. This relaxes the need for a hydrodynamic model that can resolve the local processes to the MWL at all tide gauges.

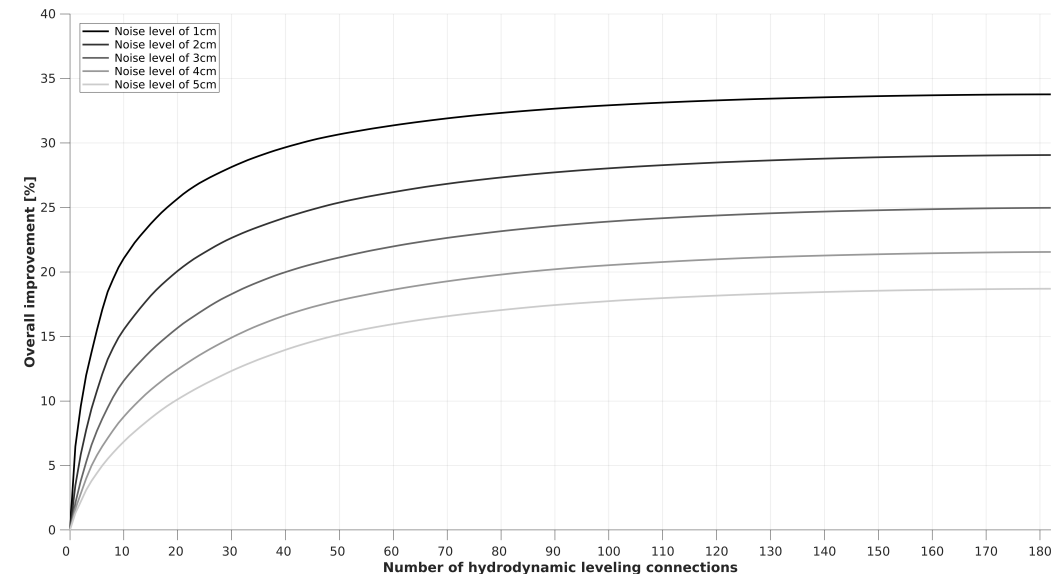


Fig 4: Amount of improvement for different noise level for hydrodynamic leveling connections