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Probabilistic modelling of sea surges in coastal urban areas

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Urban floods are a major issue for coastal cities with severe impacts on economy, society and environment. A main cause for floods are sea surges stemming from extreme weather conditions. In the context of urban flooding, certain standards have to be met by critical infrastructures in order to protect them from floods. These standards can be so strict that no empirical data is available. For instance, protection plans for sub-surface railways against floods are established with 10,000 years return levels. Furthermore, the long technical lifetime of such infrastructures is a critical issue that should be considered, along with the associated climate change effects in this lifetime.

We present a case study of Copenhagen where the metro system is being expanded at present with several stations close to the sea. The current critical sea levels for the metro have never been exceeded and Copenhagen has only been severely flooded from pluvial events in the time where measurements have been conducted. However, due to the very high return period that the metro has to be able to withstand and due to the expectations to sea-level rise due to climate change, reliable estimates of the occurrence rate and magnitude of sea surges have to be established as the current protection is expected to be insufficient at some point within the technical lifetime of the metro.

The objective of this study is to probabilistically model sea level in Copenhagen as opposed to extrapolating the extreme statistics as is the practice often used. A better understanding and more realistic description of the phenomena leading to sea surges can then be given. The application of hidden Markov models to high-resolution data of sea level for different meteorological stations in and around Copenhagen is an effective tool to address uncertainty. For sea surge studies, the hidden states of the model may reflect the hydrological processes that contribute to coastal floods. Also, the states of the hidden Markov model can very well be related to the thresholds that apply in the physical urban context: i.e. the level at which water flows over the harbor crest and the level at which a given metro station is flooded. In addition, the underlying stochastic process can vary in time, and climate change can be integrated in the model. The important characteristics within the hidden Markov framework are the number of hidden states, the estimation of parameters and the state frequency.