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Brief Communication: Bridging the data gap – enhancing the representation of global coastal flood protection

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Abstract. Understanding coastal flood protection is crucial for assessing risks from natural hazards and climate change. However, there is a significant lack of quantitative data on coastal flood protection and their standards. FLOPROS, currently the only global database of flood protection standards, relies on limited coastal observations and simplified assumptions. Despite these limitations, it is widely used by the research community, leading to potential uncertainties in impact estimates. We propose that a new community-driven effort is needed to develop a more complete dataset, and we present COASTPROS-EU, a dataset compiling coastal flood protection standards within Europe. This effort further highlights the urgent need for enhanced information. Establishing an accurate dataset requires using both bottom-up and top-down approaches and ensuring diverse societal representation.

1. Coastal flood protection

In Europe alone, damage from coastal flooding currently amounts to €1.4 billion annually, with around 100,000 people exposed (Feyen et al., 2020). The rise in global temperatures caused by anthropogenic greenhouse gas emissions means that the frequency and severity of coastal flood events is projected to increase over the next decades, for example due to sea level rise (Taherkhani et al., 2020). Concurrently, the degradation of foreshore vegetation and human-induced subsidence, due to land use and sediment retention by dams, contribute to heightened coastal flood hazards. This presents significant challenges for low-lying coastal communities and ecosystems, which are home to a large portion of the world's population, land area and assets (Bevacqua et al., 2020; Reguero et al., 2015).

The latest IPCC Synthesis Report warns of significant, irreversible damage to coastal areas from climate-induced flooding, with coastal flood hazard continuing to increase well beyond 2100 due to sea level rise (IPCC, 2023). Additionally, exposure to coastal flood events is expected to increase in the future due to factors such as increasing urbanisation in coastal areas (Darlington et al., 2023; Reimann et al. 2023; Neumann et al., 2015).

Addressing coastal flood risk and understanding the potential future impacts requires a comprehensive understanding of current coastal flood protection measures and standards, both in terms of infrastructure (e.g., levees) and nature-based solutions (e.g., mangroves) (Caretta et al. 2022; van Zelst et al., 2021; Toimil et al., 2020). However, the complexity and challenges involved in quantitatively assessing current flood protection levels hinder our understanding of flood protection on a global scale. Enhanced and detailed data on coastal flood

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protection is necessary to better prepare for and mitigate the risks associated with climate change and coastal flooding.

2. FLOPROS

In 2016, Scussolini et al. introduced the FLOPROS database, providing the first global collection of information on flood protection standards across different spatial scales. It consolidates information on protection standards (expressed as flood return periods) associated with protection measures and regulations. FLOPROS is structured into three layers: the design layer, which details engineered protection levels of existing river and coastal flood infrastructure derived from literature; the policy layer, which specifies legislative and normative standards for protection from river and coastal floods, also derived from literature; and the model layer, which infers river flood protection standards based on observed relationships with per capita wealth and flood risk.

The FLOPROS model layer assumes a maximum flood protection of a 1000-year return period and a minimum of a 2-year return period (no protection). An algorithm interpolates these values based on GDP per capita for different income regions. The model layer determines protection standards for sub-country units by calculating expected annual damage and interpolating additional units linearly. This approach overlooks the complexities of the determinants of flood protection standards between and within regions.

To our knowledge, FLOPROS and its coastal update by Tiggeloven et al. (2020), is the only global dataset documenting existing structural flood protection measures at the sub-national level, making it a cornerstone in contemporary research endeavours assessing flood risk. Consequently, the database is frequently used in coastal flood assessments (e.g. Almar et al., 2021; Hermans et al., 2023; Vousdoukas et al., 2018; Yesudian & Dawson, 2021; Ward et al., 2017). FLOPROS was created to support research related to large-scale flood risk management and has been utilised in several high-level policy documents, including PESETA IV (Feyen et al., 2020), PBL (2023), UNEP (2023a, b). Initiatives such as the Intersectoral Model Intercomparison Project (ISIMIP), which integrates these findings into Integrated Assessment Models like REMIND (Sauer et al., 2021), and webtools such as Aqueduct Floods also rely on FLOPROS. Additionally, many academic studies assessing current and future flood risk in coastal areas depend on the FLOPROS database (e.g. Chen et al., 2023; Tiggeloven et al., 2020; Mortensen et al., 2024; Vousdoukas et al., 2020; Hermans et al., 2023; Devitt et al., 2023; Haasnoot et al., 2021). As a result, FLOPROS is fundamental to current flood protection assumptions for coastal flood risk and impact assessments.

However, due to the limitations in FLOPROS, especially the limited number of observations for coastal flood protection, we argue that caution should be exercised in utilising it in coastal contexts. Overreliance on the dataset may lead to an underestimation of future climate risks, implying protection where it does not exist, or overestimating adaptation efforts, thus undermining the urgency of climate mitigation.

Current and Future Efforts

Since the publication of FLOPROS, several initiatives have aimed to improve the representation of flood protection for coastal regions.

Originally, FLOPROS focused on river flood protection in its design and model layers. Tiggeloven et al. (2020) extended this by calculating global coastal flood protection using the same model-based approach but did not include new observations, leading to uncertainty in these estimates. Despite these advancements, there remains a lack of clear distinction between the use of the original FLOPROS by Scussolini et al. (2016) and its updated version by Tiggeloven et al. (2020). Frequently, both versions are cited without specifying whether coastal protection levels are used from the design, policy or model layer (Yesudian & Dawson, 2021). A notable relevant advancement is openDELve, which compiles an open database referencing the extent and design specifications of levees for 152 deltas, including levee height, crest width, and construction material, in a harmonized format (Nienhuis et al., 2022). However, there is a clear contrast in data availability between regions such as Africa, South-East Asia, and Southern and Central America in comparison to Australia, Europe, UK, USA (Nienhuis et al., 2022). Another significant research direction is the detection of flood defence infrastructure from high-resolution elevation data. Wing et al. (2019) applied a detection algorithm to map levees in the contiguous U.S., questioning the validity of the wealth-to-protection relationships used in FLOPROS. A similar method was subsequently applied by Sasaki et al. (2023).

Knowledge of river flood protection standards has been enhanced by studies such as Boulange et al. (2021), which reflect the protection provided downstream of global hydro dams. In China, river flood protection standards at higher resolution and confidence levels are available thanks to Wang et al. (2021). Advanced statistical approaches trained to infer flood protection standards from physical and socio-economic variables have been developed by Zhao et al. (2023). An indirect approach to infer flood protection standards for Europe, using new data on impacts and potential flood occurrences, was recently implemented by Paprotny et al. (2024).

3. COASTPROS-EU: a coastal flood protection standards database for Europe

Despite various advancements in recent years, a dataset with comprehensive global representation of coastal flood protection measures and their standards is still lacking. We present here, COASTPROS-EU, a new database on policy standards and defence structures along the European coast (Table S1). The database builds upon the approach followed by FLOPROS. As such, it compiles information on European coastal defences for each NUTS2 region, referencing three topologies of layers, namely geolocated coastal defences, regional coastal defence policies, and modeled defences based on Tiggeloven et al. (2020). Where applicable, flood protection standards are expressed in return periods. The "Summary Return Period" summarise the most accurate information layer type regarding flood protection collected. This column prioritizes the layers type in the following order: (a) geolocated coastal defences, (b) policy standards, and lastly, (c) modeled defence if no other information is applicable. The overview of the data availability summary is mapped in Figure 1. The database was produced through two key initiatives. First, an online survey was distributed within the network of the CoCliCo (Horizon 2020) project and the Institute for Environmental Studies (IVM) of Vrije Universiteit Amsterdam. Second, a data workshop was held at Vrije Universiteit Amsterdam in November 2023, where flood experts collected information on flood defense and protection standards in their respective language using academic and grey literature (policy reports and governmental data portals).

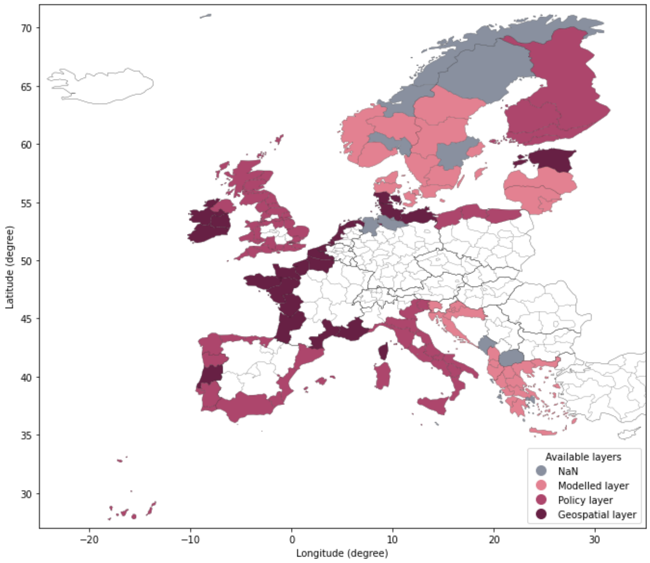

Figure 1: Data availability overview of COASTPROS-EU, representing the best available coastal protection standards in Europe per NUTS2 region for three typologies of layers: geolocated coastal defences, policy standards, and modeled defence standards.

Through these combined efforts, we aim to provide a more accurate and comprehensive understanding of coastal flood protection measures. By incorporating diverse data sources and methodologies, this new database addresses the critical need for detailed, reliable information to better prepare for and mitigate the risks associated with climate change and coastal flooding.

4. Embracing Diversity and Multi-Methods

Our new dataset only covers Europe and therefore does not satisfy the need for a global assessment. We argue that a global effort is essential to consolidate local information on coastal flood protection, ensuring representation from diverse social groups and geographical regions. This necessitates a multi-method approach, encompassing top-down methods like Earth Observation, as well as bottom-up approaches such as stakeholder interviews, surveys, and potentially crowdsourcing.

Further, it has emerged that hybrid approaches to flood protection, that integrate structural and nature-based measures, may offer the most effective and economically viable solutions (Du et al., 2020). As colleagues are gradually investigating and assessing the effectiveness and resilience of nature-based solutions, such as mangroves and salt marshes, for coastal flood protection (Inácio et al., 2022; Luo et al., 2023; Mortensen et al., 2024; Tiggeloven et al. 2022), we argue that it is also crucial to incorporate the flood protection standards provided by these measures.

To achieve this, there is a pressing need to ascertain where coastal flood protection is presently available and effective, and where it is not. We call on the flood protection community to join these efforts, working together to build a comprehensive, global understanding of coastal flood protection measures. Only through such a comprehensive approach can a reliable resource be established, enabling the analysis of both current and future

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coastal flood risk. Until then, we recommend using FLOPROS in applications that are commensurate with the nature of the data and with its methodology, emphasizing and clearly communicating the limitations of the dataset accordingly.

Data availability

The excel file and GIS shapefile of COASTPROS-EU are available on the following repository: De Plaen, J. J.-F. G., Colmenares, M., Koks, E., Scussolini, P., Lena, R., Lincke, D., Kiesel, J., Wolff, C., Tiggeloven, T., Peregrina Gonzalez, E. D., & Le Cozannet, G. (2024). COASTPROS-EU (v0.1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.12784278

Competing interests

At least one of the (co-)authors is a member of the editorial board of Natural Hazards and Earth System Sciences.

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