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A Preliminary Analysis of High Water Events in Venice Based on Multi-Decadal Observations and Clustering

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High water events in Venice are a recurrent phenomenon, as the city is located only slightly above mean sea level and is directly influenced by water-level variations within the lagoon. Flooding occurs when several physical processes act in combination. The astronomical tide determines the baseline water level, which is subsequently modulated by seiche oscillations in the Adriatic Sea, meteorological forcing (e.g. wind stress and atmospheric pressure), and slower, low-frequency geophysical processes and sea level rise. When these factors co-occur, even if individually moderate, large portions of the city may experience flooding.

Repeated flooding has significant economic and social impacts, limits pedestrian and naval traffic and contributes to the degradation of buildings and cultural heritage. To mitigate these effects, a range of protective measures is implemented and coordinated by an early warning system. The effectiveness of these measures depends on their timely activation. However, mitigation actions are associated with substantial economic costs and may themselves generate negative impacts if deployed unnecessarily. For instance, interruptions to public transport services affect daily activities, while the operation of the MOSE barrier entails considerable financial costs. Accurate and reliable forecasts are therefore essential to balance flood protection with the economic and social costs of mitigation measures.

Current forecasting systems primarily estimate water levels and peak values, and these are typically estimated at a limited number of locations. These systems are based on sophisticated statistical and hydrodynamic models. Although they perform well in most situations, their accuracy can be affected by uncertainties in atmospheric forcing and by limitations in representing the full variability of high water events. This work explores the potential of complementary approaches based on the analysis of observational data rather than explicit physical modelling.

Data-driven approaches, in particular Machine Learning (ML) methods, analyze historical data without relying on predefined, human-designed model structures. ML models are able to capture recurring patterns and complex feature interactions that are difficult to incorporate into traditional numerical models. Among these approaches, clustering techniques aim to identify recurrent types of events based on similarities in their temporal evolution and associated meteorological conditions. This enables events characterized by similar water levels to be differentiated according to the combinations of underlying meteorological drivers, thereby providing additional information to support forecasting and response planning.

In this work, we present a preliminary analysis based on several clustering approaches, including k-means, DBSCAN, and deep learning–based methods, applied to a multi-decadal atmospheric dataset and to the longest available reconstructed hourly sea-level records for the northern Adriatic Sea, specifically developed for this study. We compare the resulting event classifications and discuss how cluster-derived information may complement existing forecasting systems in support of flood-mitigation strategies for the city of Venice.