Impact of sea level rise on hydrodynamics of estuaries with restricted entrances

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Worldwide, over 60% of the most populated cities are located near estuaries due to their invaluable economic, cultural, and ecological benefits. Coastal communities in and around estuaries are vulnerable to increases in sea level, which are projected to increase by 0.26-0.82 m (depending on the greenhouse gas forcing) by 2081-2100 relative to 1986-2005 mean sea levels. Potentially, SLR will lead to more frequent oceanic inundations, landward recession of shorelines, and failures of stormwater infrastructure and drainage systems. Therefore, sustainable management of estuaries and the social-ecological systems that they support requires thorough understanding of the implications of sea level rise (SLR) on estuarine hydrodynamics (e.g., tidal amplitude, tidal prism, and flow velocities), which is currently limited.

Estuarine hydrodynamics depend on the boundary conditions such as the geometry of the estuary and entrance conditions at the estuary mouth, as well as the forces directly influencing water movements including tides, wind, waves, and river flow. Among these factors, the estuarine entrance conditions can be trained and restricted to protect people and assets against flooding by maintaining an efficient flow through the estuarine system. However, the effects of managing the estuarine entrance on estuarine hydrodynamics under SLR are poorly understood and quantified. Further, most available estuarine studies have applied either static (also known as GIS-based or bathtub methods) or analytical approaches to capture the estuarine hydrodynamic response. The first approach fails to consider the full estuarine energy dynamics as it assumes the same horizontal water level from the open ocean boundary throughout the estuary. Therefore, a water level is applied over a land area without considering if the assumed inundated areas are hydraulically connected to the waterway which leads to meaningless results for low-lying areas that are protected from inundation by levees along the waterways. Analytical methods are particularly developed for prismatic and converging channels and cannot be applied in estuaries with complex geometry and bathymetry (i.e. constricted entrance), which are the general characteristics of many real-world estuaries. Even if a detailed hydrodynamic modelling approach is taken, sufficient resources are often not available to assess each individual estuary with restricted entrance at the scale required (e.g. over 1000 estuaries in Australia alone). Thus, the aim of this study is to predict hydrodynamic responses of estuaries with restricted entrances to SLR, by simulating a large ensemble of idealized estuary models of varying scale, geometry and level of entrance constriction. The idealised ensemble model approach permits a wide range of estuary restrictions to be assessed and highlights the most important ramifications resulting from different types of restrictions, such as changes to the tidal range, tidal current velocity distribution, and tidal asymmetry.

The results indicate that the tidal range at the open ocean boundary, estuary length, and level of entrance restriction significantly affect tidal propagation within all models of the ensemble. SLR tends to exacerbate flooding issues as tidal ranges are amplified by approximatively 10% per meter rise in sea level and engineered estuarine entrance restrictions are a possible solution to counteract this amplification. Further, SLR shifts the flow velocity distribution and the tidal asymmetry by increasing medium velocities and decreasing flood domination for the majority of ensemble runs (i.e. idealized estuaries). Our study highlights the benefits of utilizing an ensemble of idealized estuarine models and data analysis techniques to infer some of the key changes in the hydrodynamic regime that restricted estuaries are likely facing under increasing SLR. This approach is able to identify and prioritize the most dominant risks resulting from SLR in simple estuaries, even in the absence of high-quality field data. It provides an initial understanding of dominant hydrodynamic responses to SLR that can assist coastal managers to better predict SLR impacts in estuaries around the world, and specifically for regions with limited data on estuarine geometry and bathymetry.