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Dynamic flood modeling essential to assess the coastal impacts of climate change

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Coastal inundation due to sea level rise (SLR) is projected to displace hundreds of millions of people worldwide over the next century, creating significant economic, humanitarian, and national-security challenges. However, the majority of previous efforts to characterize potential coastal impacts of climate change have focused primarily on long-term SLR with a static tide level, and have not comprehensively accounted for dynamic physical drivers such as tidal non-linearity, storms, short-term climate variability, erosion response and consequent flooding responses. Here we present a dynamic modeling approach that estimates climate-driven changes in flood-hazard exposure by integrating the effects of SLR, tides, waves, storms, and coastal change (i.e. beach erosion and cliff retreat). We show that for California, USA, the world's 5th largest economy, over $150 billion of property equating to more than 6% of the state's GDP and 600,000 people could be impacted by dynamic flooding by 2100; a three-fold increase in exposed population than if only SLR and a static coastline are considered. The potential for underestimating societal exposure to coastal flooding is greater for smaller SLR scenarios, up to a seven-fold increase in exposed population and economic interests when considering storm conditions in addition to SLR. These results highlight the importance of including climate-change driven dynamic coastal processes and impacts in both short-term hazard mitigation and long-term adaptation planning.

Over 600 million people worldwide live in the coastal zone (<10 m elevation) and migration trends forecast an increase to more than 1 billion by 2050 (ref.[1]). SLR acceleration in recent decades[2] and median global SLR projections ranging from 0.5 (ref.[3]) to 1.8 m by 2100 (ref.[4]) indicate that growing coastal populations will be increasingly at risk of displacement due to permanent flooding (i.e. inundation), as well as annual flood damages and adaptation costs that could top $1 trillion by the end of the 21st century[5]. Further elevating coastal societal risk is the recent instability of the Antarctic ice sheets[6,7], indicating plausible SLR up to 3 m by 2100 (refs[4,8,9]).

In addition to long-term SLR, the exposure of the coastal zone population and infrastructure to flooding is amplified during episodic storms, when coastal water levels can increase by several meters or more due to locally-varying combinations of tides[10], storm surge[11], waves[12], river discharge[13], and seasonal water level fluctuations, as exemplified during El Niño events along the west coast of North America[14] (Fig. 1). In combination with SLR, these dynamic water level components can disproportionately increase the flood frequency[15] and volume in the coming decades[16]. To date, most climate-driven, hazard assessments exclude the short- and long-term effects of storms on coastal flooding, beach erosion, and cliff retreat, and instead only account for SLR[17,18], single components of storm-driven variability[19,20], or shoreline change due to SLR[21].

Here we describe a primarily physics-based numerical modeling approach, the Coastal Storm Modeling System (CoSMoS), which was designed to thoroughly assess future coastal flooding exposure by integrating SLR, dynamic water levels, and coastal change. We apply CoSMoS to one of the world's largest economies and most developed coastal environments worldwide, the urbanized portion of the state of California, USA, which accounts for 95% of the 26 million residents of California coastal counties (2010 U.S. Census Bureau estimate).

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