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Key Points:
- Nuisance coastal flooding is increasing along U.S. coastlines
- Event rates accelerate as water level distributions exceed elevation thresholds
- Tipping points for coastal inundation are surpassed in the coming decades

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From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise

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Abstract Relative sea level rise (RSLR) has driven large increases in annual water level exceedances (duration and frequency) above minor (nuisance level) coastal flooding elevation thresholds established by the National Weather Service (NWS) at U.S. tide gauges over the last half-century. For threshold levels below 0.5 m above high tide, the rates of annual exceedances are accelerating along the U.S. East and Gulf Coasts, primarily from evolution of tidal water level distributions to higher elevations impinging on the flood threshold. These accelerations are quantified in terms of the local RSLR rate and tidal range through multiple regression analysis. Along the U.S. West Coast, annual exceedance rates are linearly increasing, complicated by sharp punctuations in RSLR anomalies during El Niño Southern Oscillation (ENSO) phases, and we account for annual exceedance variability along the U.S. West and East Coasts from ENSO forcing. Projections of annual exceedances above local NWS nuisance levels at U.S. tide gauges are estimated by shifting probability estimates of daily maximum water levels over a contemporary 5-year period following probabilistic RSLR projections of Kopp *et al.* (2014) for representative concentration pathways (RCP) 2.6, 4.5, and 8.5. We suggest a tipping point for coastal inundation (30 days/per year with a threshold exceedance) based on the evolution of exceedance probabilities. Under forcing associated with the local-median projections of RSLR, the majority of locations surpass the tipping point over the next several decades regardless of specific RCP.

1. Introduction

Sea level has been rising for well over 10,000 years, although the last 4000 years have been remarkably stable with changes less than a few meters and on the order of half a meter over the last 2000 years [Fleming *et al.*, 1998, Milne *et al.*, 2005, Kemp *et al.*, 2011]. Human population, on the other hand, has experienced exponential growth over the last 2000 years with the establishment of expansive coastal population centers [U.S. Department of Commerce (USDOC), 2013]. Given the nearly imperceptible change in mean sea level (MSL) on generational timescales, it is natural that humans associate sea level change with tides and storms rather than climate. Nonetheless, the current scientific consensus is that anthropogenically forced climate change is warming the planet and contributing to sea level rise [Cazenave and Le Cozannet, 2013].

This climate warming has contributed to a global mean sea level rise (SLR) rate of 1.7 mm/year over the last century with higher rates of 3.2 mm/year over the last couple of decades [Church and White, 2011; Merrifield *et al.*, 2013]. Superimposed upon this global rise are regional sea level dynamics driven by ocean–atmosphere interactions with intra-annual, annual, interannual, and decadal timescales. This includes storm surge events that are influenced by changes to seasonal storm track tendencies [Hirsch *et al.*, 2001; Sweet and Zervas, 2011; Thompson *et al.*, 2013], and longer term sea level anomalies coherent with modes of ENSO, the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO). Dependent upon their state, these climate patterns can regionally exacerbate or suppress storm surge frequencies and SLR rates [Park *et al.*, 2010; Bromirski *et al.*, 2011; Merrifield *et al.*, 2012].

From the perspective of a specific location on land, such as a human dwelling, intertidal habitat, or water level (tide) gauge, vertical land motion also contributes to changes in sea level [Zervas *et al.*, 2013], and it is this relative sea level rise (RSLR) that is of interest to coastal infrastructure and its inhabitants. Relative sea level is normally specified with respect to the tidal datum of MSL, whereas coastal inundation and flooding are best described relative to Mean Higher High Water (MHHW; http://tidesandcurrents.noaa.gov/datum_options.html). The National Tidal Datum Epoch (NTDE) used in