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# 2015 State of U.S. "Nuisance" Tidal Flooding

William V. Sweet[1] and John J. Marra[2]
National Oceanic and Atmospheric Administration's Center for Operational Oceanographic Products and Services[1]
and National Centers for Environmental Information[2]

## Overview

High tide flooding, measured locally by National Oceanic and Atmospheric Administration (NOAA) tide gauges, is described as "nuisance", "sunny-day" and "recurrent". Such minor flooding is increasingly common with little or no storm effects (Sweet et al., 2014). Impacts include degraded storm water systems, infiltration into waste-water systems, contamination of fresh water supplies and salt-water flooding of roads, homes and businesses; tidal flooding is disrupting commerce and ways of life. During 2015, there was extensive reporting of tidal flooding impacting cites in New Jersey, Delaware, Maryland, Virginia, North and South Carolina, Georgia, Florida, Louisiana, Texas and California to name a few.

Tidal flooding is increasing in frequency within U.S. coastal communities due to sea level rise (SLR) from climate change and local land subsidence. Tidal flooding is further exacerbated by climate variability of the El Niño Southern Oscillation (ENSO). Decades ago powerful storms caused such impacts, but due to SLR, more common events are now more impactful. Event frequencies are increasing rapidly – two to three times or more frequent than just 20 years ago (Table 1). Annual tidal flood rates have entered a sustained acceleration phase at many locations (Sweet and Park, 2014) as the annual distribution of daily highest tides steadily surpasses "fixed" elevations. Thus, once flooding becomes problematic, impacts will become chronic rather quickly and communities should plan for this eventuality.

## 2015 Summary

This document updates the number of days during the May 2015 – April 2016 (2015) meteorological year with a nuisance tidal flood. Nuisance flooding is defined as a water level measured by NOAA tide gauges (tidesandcurrents.noaa.gov) above the local NOAA National Weather Service (NWS) threshold for minor impacts (water.weather.gov/ahps) established for emergency preparedness (Figure 1a). We highlight the 27 long-term gauges across the U.S. examined by Sweet and Park (2014) and an additional gauge in Virginia Key (Miami region) because of the extent of tidal flooding that occurred there in 2015.

<u>2015 Conditions.</u> During 2015, anomalously high (>0.1 m) coastal sea levels persisted (Figure 1b) along the U.S. Southeast and Gulf Coast and parts of the West Coast. This increased the reach of typical storm surges and high tides. In response, the frequency of nuisance tidal flooding in 2015 increased by more than 50% on average across all locations as compared to 2014 (Figure 1c). During 2015, several locations experienced all-time records (see Table 1), including Wilmington (90 days), Charleston (38 days), Port Isabel (36 days), Mayport (19 days), Virginia Key (Miami region) (18 days), Key West (14 days) and Fernandina Beach (7 days). Frequencies were at or above the 1950-2013 trend expected values for 2015 at most locations. It is important to note that the overall number of daily exceedances per year is correlated to the height of the local NWS threshold. Where the thresholds are low, more flooding occurs (e.g., Wilmington); where thresholds are highest such as in St. Petersburg and Galveston (reflecting hurricane flood mitigation structures), little to no exceedances were recorded.

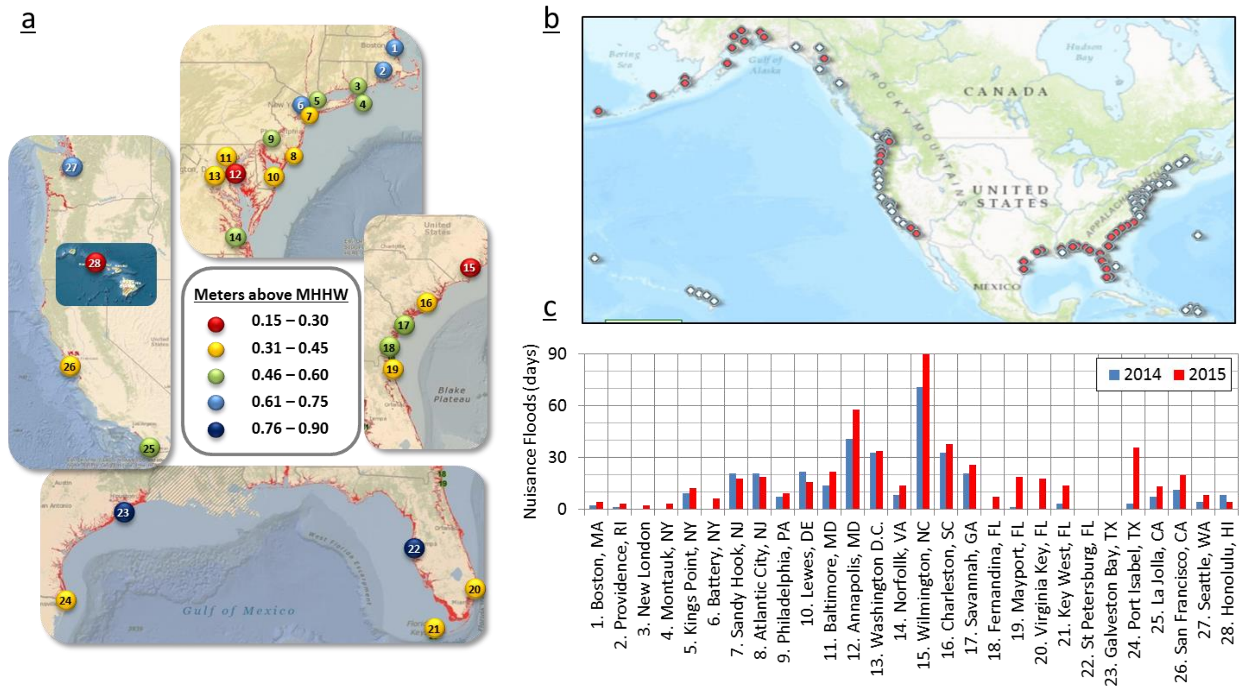


**Figure 1**. a) 28 NOAA tide gauges and nuisance elevation thresholds relative to mean higher high water (MHHW) with exposed topography (red) mapped by the NOAA SLR Viewer (https://coast.noaa.gov/slr), b) high sea level anomalies > 0.1 m (red star) over Oct 2015 – Feb 2016 (Zervas, 2009: http://tidesandcurrents.noaa.gov/sltrends) and c) days in 2014 and 2015 with nuisance tidal flooding.

2015 El Niño Effects. Tidal flood frequencies are typically higher along the mid-Atlantic and West Coasts during El Niño (Sweet and Park, 2014) from a combination of oceanic forcing along the West Coast and altered prevailing winds and storm tracks along the East Coast (Hamlington et al., 2015). During 2015 a strong El Niño dominated the global climate. The average Oceanic Niño Index (ONI) during 2016 was ~1.7 and close to the value predicted by a multi-model ensemble of Columbia University's International Research Institute (IRI: iri.columbia.edu). In response, regions along the mid-Atlantic and California coasts (e.g., Norfolk, Baltimore, La Jolla, and San Francisco) experienced greater tidal flooding consistent with the 33-125% predicted increase (Sweet and Marra, 2015; Table 1). Some flood frequencies (e.g., Atlantic City) were suppressed as compared to past El Niños. Examples of the bivariate statistical fits (SLR and ENSO-related trends) for San Francisco and Norfolk are shown in Figure 2a.

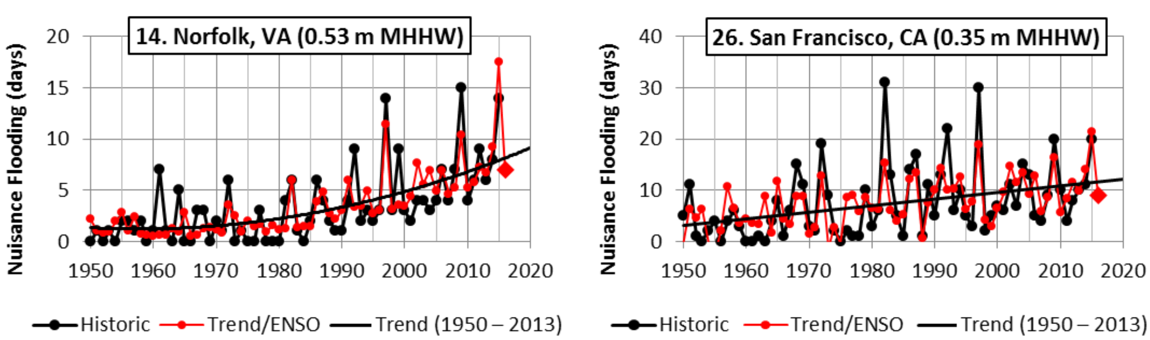


**Figure 2**. Annual flood frequencies (black circles) with 1950-2013 quadratic trends in Norfolk and a linear trend fit in San Francisco and bivariate regressions (red line-dot) including ENSO effects (ONI) and 2016 Outlooks (red star)

Historic Trends. Annual flood frequencies are increasing (Figure 3a) due to local SLR that includes the well-measured rise of the ocean (Merrifield et al., 2015) from thermal expansion and land-based ice melt and relative local changes from land subsidence (Zervas et al., 2013). Local relative SLR shifts annual water level distributions locally to higher elevations such that more-common tides and storm surges surpass the NWS flood thresholds (i.e., nuisance level). Comparing flood frequency estimates from trends (significant above the 90% level; p values < 0.1) of Sweet and Park (2014) fit over the 1950-2013 period (1994-2013 for Virginia Key gauge), we find that annual flood rates have increased locally by two to three times or more as compared to the rate experienced 20 years ago (since 1995, see Table 1).

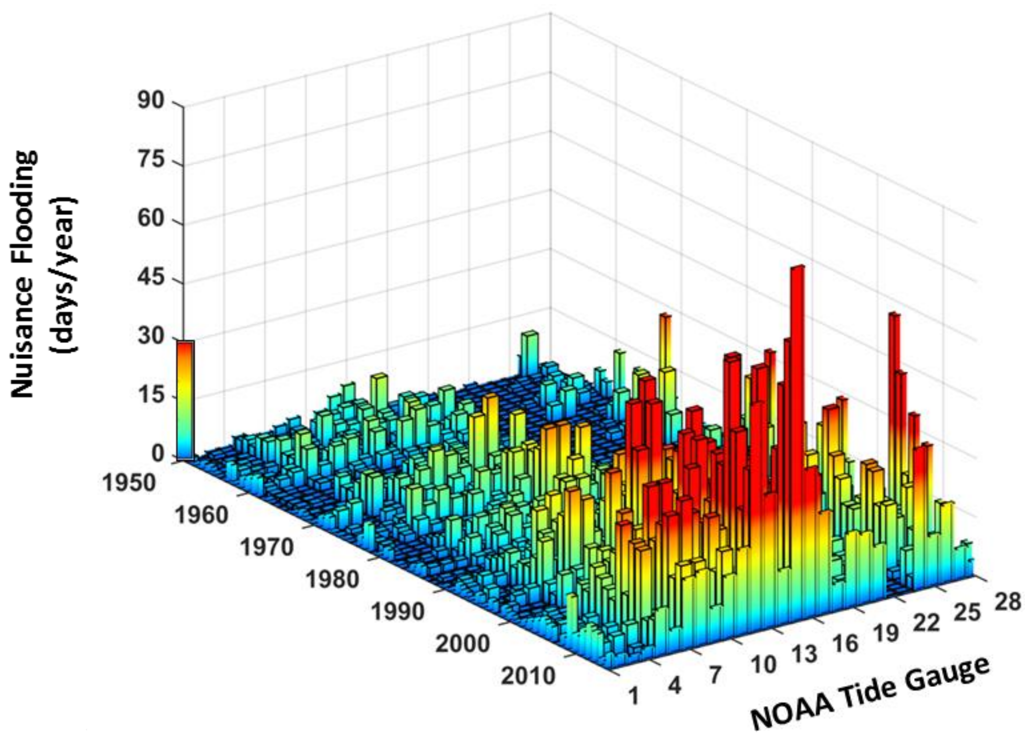


**Figure 3**. Annual tidal flood frequencies from 1950 – 2015 (meteorological year: May – April) above the local nuisance level for 28 NOAA tide gauges (location number listed in the Table 1)

**2016 Outlooks**

We provide near-term tidal flood-frequency "Outlooks" by projecting the 1950-2013 trends into 2016, and where applicable, consider the predicted ENSO phase strength (Table 1). La Niña is predicted to develop over 2016/2017 with an ONI annual-average value of -0.58 (IRI: May 19, 2016 prediction plume). La Niña conditions typically have less effect upon tidal flood frequencies as compared to El Niño. 2016 Outlooks are expected to remain near trend values. Highest Outlooks (based upon SLR and ENSO-related trends) in 2016 are for Annapolis (47 days), Wilmington (42 days), Washington D.C. (30 days), Charleston (27 days) and 26 days at Atlantic City and Sandy Hook. Along the California Coast, < 10 days are expected at La Jolla and San Francisco. The tidal flood Outlooks do not explicitly account for compounded flooding from local rainfall (Wahl et al., 2015) or waves, whose coastal erosion effects are the concern along the West Coast and Pacific Islands (Barnard et al., 2015). We note that tide gauges are capable of measuring waves and their dynamical effects (Sweet et al., 2015), but these high-frequency data have yet to be incorporated into total water level studies (Moritz et al., 2015).

Future Enhancements. As local mean sea levels continue to reach historic highs as they did during 2015 at locations 15-25 (https://tidesandcurrents.noaa.gov/sltrends), there will be an increasingly nonlinear response in flood frequencies that can result in significant under-estimation (>2 standard deviations, e.g., in Wilmington) in the Outlooks. This happens because the trends are currently based upon the 1950-2013 period and therefore are not able to fully recognize the geometric response (~exponential) from continued exceedance since 2013 of the cumulative distribution of daily highest water levels above the NWS thresholds (Sweet and Park, 2014). Periodic adjustments (e.g., every 5 years) to the trends will be made to incorporate more recent data and to extend the climatology basis of comparison. Future versions will also include Outlooks for additional locations and assessments above regionally consistent "planning" thresholds in addition to the NWS "emergency preparedness" thresholds analyzed here.

**Table 1.** Location number and name, NOAA-defined nuisance flood level, historic maximum number of annual nuisance tidal floods, the number of nuisance flood days estimated for 1995 and 2015 based upon 1950-2013 trends (± 1 standard deviation), the number of floods occurring in 2015 and Outlooks for (issued in early) 2015 and for 2016 based upon trend continuation and bivariate regression based upon inclusion of the 2016 ONI prediction. Only trend regressions significant above the 90% level (p values < 0.1) are provided.

| | Location Name | Nuisance Level | Historic Record | 1995 Flood Days | ---------- 2015 Flood Days ---------- | | | ----- 2016 Outlook ----- | |
|---|---|---|---|---|---|---|---|---|---|
| | | (above MHHW) | Yearly Floods (Days) | Trend[1] | Trend[1] | w/ El Nino[1,2] | Observed | Trend[1] | w/ La Nina[1,2] |
| 1 | Boston, MA | 0.68 | 14 | 2 | 7±2 | --- | 4 | 7 | --- |
| 2 | Providence, RI | 0.66 | 5 | 1 | 2±1 | --- | 3 | 2 | --- |
| 3 | New London, CT | 0.60 | 6 | --- | --- | --- | 2 | --- | --- |
| 4 | Montauk, NY | 0.60 | 7 | 1 | 3±1 | 6±1 | 3 | 3 | 2 |
| 5 | Kings Point, NY | 0.52 | 29 | 8 | 18±4 | --- | 12 | 18 | --- |
| 6 | Battery (NYC), NY | 0.65 | 9 | 2 | 5±2 | --- | 6 | 5 | --- |
| 7 | Sandy Hook, NJ | 0.45 | 37 | 11 | 27±5 | 40±5 | 18 | 28 | 26 |
| 8 | Atlantic City, NJ | 0.43 | 37 | 11 | 27±5 | 36±5 | 19 | 28 | 26 |
| 9 | Philadelphia, PA | 0.49 | 30 | 6 | 13±4 | --- | 9 | 14 | --- |
| 10 | Lewes, DE | 0.41 | 39 | 10 | 24±5 | 41±5 | 16 | 25 | 23 |
| 11 | Baltimore, MD | 0.41 | 24 | 6 | 15±3 | 22±3 | 22 | 15 | 14 |
| 12 | Annapolis, MD | 0.29 | 66 | 20 | 45±8 | --- | 58 | 47 | --- |
| 13 | Washington D.C. | 0.31 | 48 | 18 | 32±9 | 53±8 | 34 | 33 | 30 |
| 14 | Norfolk, VA | 0.53 | 15 | 4 | 8±3 | 18±2 | 14 | 8 | 7 |
| 15 | Wilmington, NC | 0.25 | 90 | 17 | 43±8 | 62±7 | **90** | 44 | 42 |
| 16 | Charleston, SC | 0.38 | 38 | 14 | 26±5 | --- | **38** | 27 | --- |
| 17 | Savannah, GA | 0.46 | 34 | 9 | 18±5 | --- | 26 | 18 | --- |
| 18 | Fernandina Beach, FL | 0.59 | 7 | 1 | 2±1 | --- | **7** | 2 | --- |
| 19 | Mayport, FL | 0.44 | 19 | 2 | 6±2 | --- | **19** | 6 | --- |
| 20 | Virginia Key (Miami), FL | 0.40 | 18 | *0 | *4±2 | | **18** | 4* | --- |
| 21 | Key West, FL | 0.33 | 14 | 1 | 3±1 | --- | **14** | 3 | --- |
| 22 | St. Petersburg, FL | 0.84 | 1 | --- | --- | --- | 0 | --- | --- |
| 23 | Galveston (Bay), TX | 0.79 | 4 | --- | --- | --- | 0 | --- | --- |
| 24 | Port Isabel, TX | 0.34 | 36 | 6 | 16±5 | --- | **36** | 17 | --- |
| 25 | La Jolla, CA | 0.51 | 14 | 4 | 6±3 | 10±3 | 13 | 6 | 5 |
| 26 | San Francisco, CA | 0.35 | 31 | 9 | 12±6 | 21±5 | 20 | 12 | 9 |
| 27 | Seattle, WA | 0.65 | 10 | --- | --- | --- | 8 | --- | --- |
| 28 | Honolulu, HI | 0.22 | 57 | 12 | 17±11 | --- | 4 | 17 | --- |

(1) based upon 1950-2013 linear/quadratic and ENSO-bivariate regressions where significant > 90% level (Sweet and Park, 2014)

(2) El Nino (ONI = 1.68) during 2015 (iri.columbia.edu: August 20, 2015 plume) and La Nina (ONI = -0.58) during 2016 (May 19, 2016 plume)

* based upon 1994-2013 linear fit

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