2017 State of U.S. High Tide Flooding with a 2018 Outlook

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Author's Note

This report assesses the number of days with high tide flooding during 2017 and provides an outlook for 2018. It uses different flood elevation thresholds than in previous reports (Sweet and Marra, 2015; 2016; Sweet et al., 2017a), which in many locations, now describe deeper and more-severe flooding (e.g., Annapolis, MD, Charleston, SC and Miami, FL regions). The new coastal flood thresholds follow a nationally consistent pattern inherent to the limited number of NOAA's National Weather Service (NWS) minor coastal flood thresholds[1] as described in Sweet et al. (2018). The NWS coastal flood thresholds are used to issue local 'coastal flood advisories' for potentially disruptive coastal flooding, whereas the new thresholds are geared toward assessing national vulnerabilities to tidal flooding with similar impacts (often disruptive and sometimes damaging). As such, the annual number of days with high tide flooding (henceforth referred to as flood frequency) may be higher or lower than in previous reports since deeper (shallower) floods happen less (more) often. Computation of 2017 flood frequencies using the NWS minor flood thresholds can be readily estimated using verified data and analysis tools of NOAA's Center for Operational Oceanographic Products and Services[2].

Summary

In 2017, the nation-wide average annual frequency of high tide flooding as measured at 98 National Oceanic and Atmospheric Administration (NOAA) tide gauge locations along U.S. coastlines hit an all-time record of 6 flood days. More than a quarter (27) of the locations (Alaska sites were not included in this study) tied or broke their individual records for high tide flood days.

Regionally, high tide flooding in 2017 was most prevalent along the Northeast Atlantic and Western Gulf of Mexico Coasts in response to active nor'easter and hurricane seasons. Yearly records include 22 days in Boston, MA[3] and Atlantic City, NJ[4] and 23 days in Sabine Pass, TX and 18 days in Galveston, TX. Flood frequencies were also at record levels along parts of the Southeast Atlantic and Eastern Gulf, including 14 days at Bay Waveland, MS and 6 days each in Fort Myers, FL, Cedar Key, FL and Dauphin Island, AL. High tide flood frequencies were less in other U.S. regions, though San Diego, CA[5] experienced a record-breaking 13 days.

[1] https://water.weather.gov/ahps/
[2] https://tidesandcurrents.noaa.gov/inundation/
[3] https://www.boston.com/news/local-news/2017/12/05/the-king-tides-are-back-and-theyre-causing-some-flooding-in-boston-and-across-new-england
[4] http://www.pressofatlanticcity.com/pac/coastal-flood-alert-upgraded-road-closures-on-monday/article_9537c566-1567-5fdb-8ef9-130b27bca111.html
[5] http://fox5sandiego.com/2017/12/04/king-tides-flood-parts-of-national-city/

Mild El Niño conditions are predicted[6] during late 2018 and into 2019, which may result in higher than expected flood frequencies (e.g., above trend values) at about half (48) of the locations, primarily along the West and East Coasts. As a whole, high tide flood frequencies during 2018 are predicted to be about 60% higher (median value) across U.S. coastlines as compared to trend values at the start of this century (i.e., year 2000). Along the Northeast Atlantic and Northwest Pacific Coasts (where steeper topography often buffers the extent of impacts), 5-6 days (median values) are predicted or a 100% and 10% increase since 2000, respectively. Along the flatter and more-vulnerable Southeast Atlantic and Gulf Coasts, about 2-3 flood days are predicted in 2018 or a 160% and 50% increase since 2000, respectively. Along the Southwest Pacific Coast about 2 days of high tide flooding are predicted (70% increase). Little or no tidal flooding is expected (as in all cases, not considering wave or rainfall effects) within the Caribbean, Hawaii or U.S. Pacific Islands (Kwajalein Island being an exception).

If high tide flooding in 2018 follows historical patterns, flooding will be most common during the winter (Dec-Feb) along the West Coast and the northern section of Northeast Atlantic Coast in response to winter storms and more-predictable monthly highest astronomical tides (predicted tides). Along the Gulf and along much of the Atlantic Coasts, flood patterns are less predictable and occur usually in response to weather effects. Flooding is, however, most common during the fall (Sep-Nov) when the mean sea level cycle peaks, and more often during monthly highest predicted tides in some Southeast Atlantic locations.

Breaking of annual flood records is to be expected next year and for decades to come as sea levels rise, and likely at an accelerated rate (Sweet et al., 2017b). Already, high tide flooding that occurs from a combination of high astronomical tides, typical winter storms and episodic tropical storms has entered a sustained period of rapidly increasing trends within about 2/3 of the coastal U.S. locations (Sweet et al., 2018). Though year-to-year and regional variability exist, the underlying trend is quite clear: due to sea level rise, the national average frequency of high tide flooding is double what it was 30 years ago.

Background and Objectives

This report updates high tide flood frequencies during 2017 (meteorological year: May 2017 – April 2018) at 98 NOAA tide gauges examined by Sweet et al. (2018) and provides a statistical 'outlook' for 2018 (May 2018 - April 2019). It is the fourth in a series (Sweet and Marra, 2015; Sweet and Marra, 2016, Sweet et al., 2017a), but different in its expanded geographic coverage and that it does not necessarily assess the exact coastal elevation thresholds for 'minor flooding' set by NOAA's NWS for response preparedness (NOAA, 2017a). As a result, the flood frequencies in previous reports will not necessarily match. NWS flood thresholds are empirically calibrated from years of impact monitoring, but often for a particular part of a city within a region with variable topography, urbanization and storm-proofing. As such, when comparing NWS flood thresholds there exist large differences between 1) flood elevations (e.g., about a 0.6 m difference between Wilmington, NC and St. Petersburg, FL), 2) severity of impacts (e.g., primarily storm-water system infiltration in Wilmington, NC, Washington, D.C., Annapolis, MD to breaching of major hurricane seawalls in St. Petersburg, FL and Galveston, TX) and 3) flood frequencies (e.g., 84 days in Wilmington and 0 days in St. Petersburg during 2016).

[6] May 18, 2018 plume: https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current

Following Sweet et al. (2018), high tide flooding is defined as a coastal water level reaching or exceeding a median height of 0.54 m (spread of 0.50 – 0.64 m) above the long-term average daily highest tide (MHHW; Figure 1a, Appendix 1). Locally, the flood thresholds are higher where tide ranges are higher, following a nationally consistent pattern inherent to the set of NWS coastal flood thresholds (Figure 1b). With this consistent definition of high tide flooding, a national assessment of flood risk and vulnerability to past flooding and planning for future-anticipated flooding is possible. High tide flooding (aka nuisance flooding) is typically disruptive and sometimes damaging (e.g., infiltration of storm- and waste-water systems, flooding of road ways and infrastructure). National patterns based upon tide range also exist when analyzing existing NWS flood thresholds for moderate/damaging and major/often-destructive flooding, which occur at median values of 0.85 m and 1.2 m above MHHW, respectively (Sweet et al., 2018). Together these thresholds broadly quantify flood-height vulnerabilities of U.S. coastal infrastructure in terms of the freeboard remaining above today's high tide.

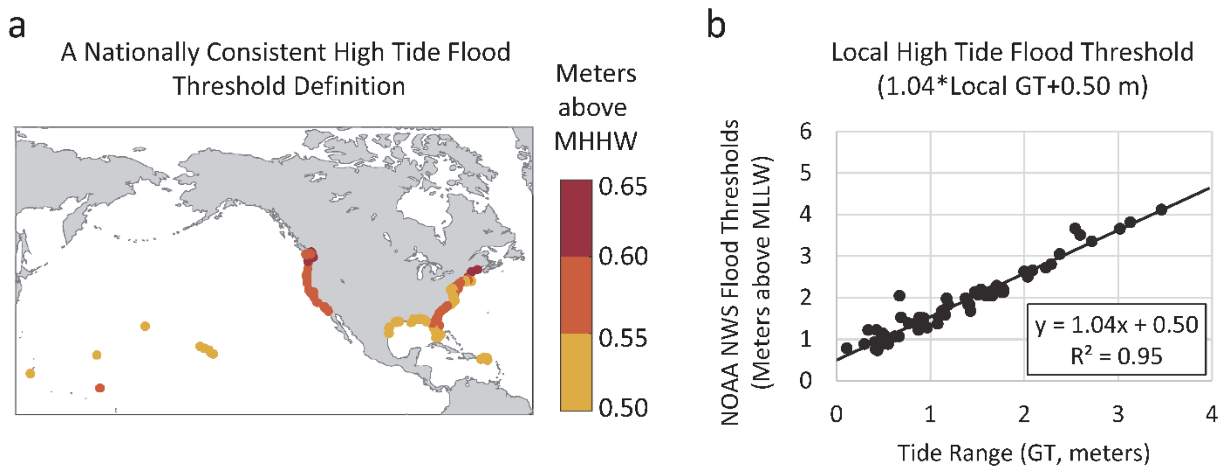

Figure 1: a) Elevation thresholds for high tide flooding at 98 NOAA tide gauges recently analyzed by Sweet et al. (2018) based upon the regression relationship shown in b) as a scatter plot of a national set (about 60 locations) of NOAA NWS flood thresholds for minor impacts (y-axis) shown relative to the mean lower low water (MLLW) tidal datum versus the local diurnal tide range (GT) on the x-axis. Adapted from Sweet et al. (2018).

To provide a high tide flood outlook, we project into 2018 the expected flood frequencies based upon: 1) a multi-decadal linear or quadratic regression model fit to the annual number of days with high tide flooding through time (Figure 2a) or 2) a bivariate regression model that also considers the strength of the El Niño Southern Oscillation (ENSO, Figure 2b) where applicable (Sweet and Park, 2014; Sweet et al., 2018). Multi-model ensemble predictions of ENSO strength for 2018/2019 were obtained from the International Research Institute for Climate and Society[7].

[7] May 18, 2018 plume: https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current

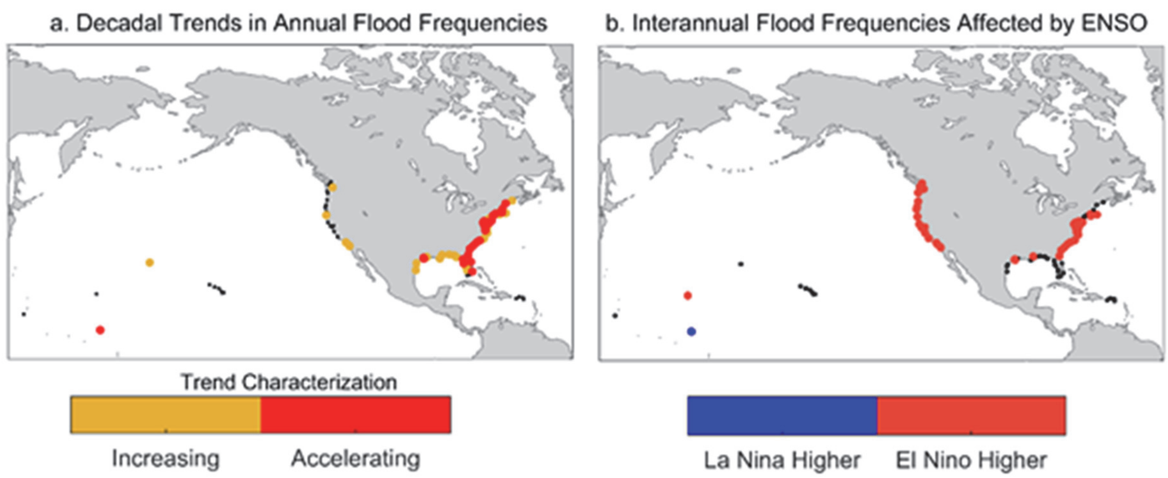

Figure 2: a) Characterization of increases in decadal annual high tide flood frequencies (significant above the 90% significance level): accelerating (quadratic), linear increasing or no trend (black dot) and b) locations whose high tide flood frequencies change on an inter-annual basis due to phases of ENSO. Adapted from Sweet et al. (2018).

2017 Conditions

More than a quarter (27) of the 98 U.S. coastal locations examined tied or broke their individual records for high tide flooding in 2017 (Appendix 1). Annual frequencies (Figure 3a) were highest along the Northeast Atlantic and Western Gulf of Mexico (median values of 11 and 12 days, respectively). Record flood frequencies occurred along much of the coastline between Massachusetts to New Jersey and along Texas, including 22 days in Boston, MA and Atlantic City, NJ, 23 days in Sabine Pass, TX and 18 days in Galveston, TX. Records were also broken along the Southeast Atlantic and Eastern Gulf, including 14 days at Bay Waveland, MS, and 6 days each in Fort Myers, FL, Cedar Key, FL and Dauphin Island, AL and 3 days each in Virginia Key, FL and Naples, FL. High tide flood frequencies were less in other U.S. regions, though San Diego, CA experienced a record-breaking 13 days.

When high tide flood frequencies along the entire U.S. coastline are averaged (Figure 3b), the 2017 national average of 6 days (per Appendix 1) is record breaking. Rising ocean levels along the U.S. coastline (Figure 3b, blue line) of about 2 mm/year since 1920 are driving (along with local land subsidence) a rapid increase in U.S. high tide flood frequencies. The U.S. average high tide flood frequency is now 50% greater since 2000 and 100% greater than it was 30 years ago (based upon quadratic fit of data in Figure 3b, not shown).

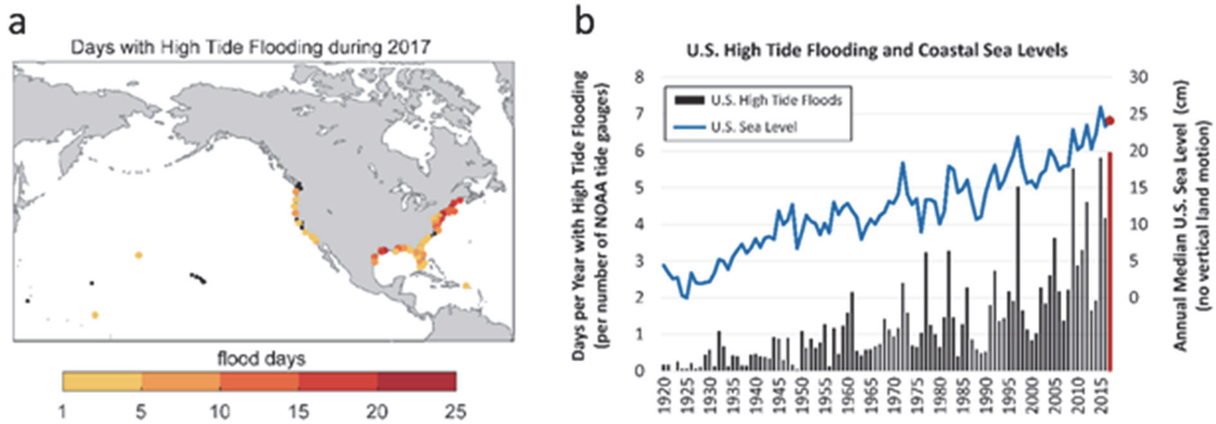

Figure 3: a) Number of days with high tide flooding using the nationally consistent flood severity thresholds (Figure 1a) at 98 NOAA tide gauges. Black dots are locations without a flood during 2017. b) Average high tide floods per year (black bars) through 2017 with 1920-2016 data from Sweet et al. (2018)[8] and the annual median coastal ocean level (blue line) through 2017 with local vertical land motion removed using estimates from Sweet et al. (2017b) for locations shown in a). 2017 sea level and flood frequency values in b) are shown in red. High (low) sea level and flood frequency years in b) such as during 1997 (1988) often correspond to El Niño (La Niña) conditions.

In many regions, 2017 high tide flood frequencies included flooding in response to several strong storms that produced deeper (and more widespread) flooding than would occur at the local high tide flood height. During 2017, there were numerous tropical storms or hurricanes that impacted the Caribbean, Gulf of Mexico, and Southeast Atlantic Coasts; extratropical storms or nor'easters also impacted Northeast Atlantic coastlines. For example, a strong nor'easter in early January 2018 during a period of seasonal highest astronomical tides pushed water levels in Boston, MA to a record-setting 1.49 m above MHHW[9], which is about 0.85 m above the local high tide threshold (Appendix 1). Similarly, water levels during Hurricane Irma broke 15 NOAA tide gauge records along the Caribbean and Southeast Atlantic coasts (NOAA, 2017b). Flood depths in Virginia Key, FL (record of 1.12 m above MHHW) during Hurricane Irma reached a height close to its nationally consistent level for major flooding (1.20 above MHHW; Sweet et al., 2018) with undoubtedly greater flood extent and severity within the Miami region than occurs at high tide flood threshold levels (0.53 above MHHW; Figure 4a)[10]. Near-record water levels were also experienced in Hawaii during August 2017 at peak high tide that occurred during westward propagating and long-lived high sea level anomalies[11]. Levels in Honolulu reached approximately 0.4 m above MHHW, and though some inland flooding and wave over wash did occur and was reported in media[12], the tide gauge-measured water level did not exceed the local high tide flood level (0.52 m for Honolulu: Figure 1a, Appendix 1).

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[8] https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.csv
[9] https://www.bostonmagazine.com/news/2018/01/04/boston-flooding-bomb-cyclone-2018/
[10] http://www.miamiherald.com/news/weather/hurricane/article172495761.html
[11] https://uhslc.soest.hawaii.edu/pacific-sea-level-monitoring/
[12] https://www.theatlantic.com/science/archive/2017/05/the-ghost-of-climate-change-future/528471/

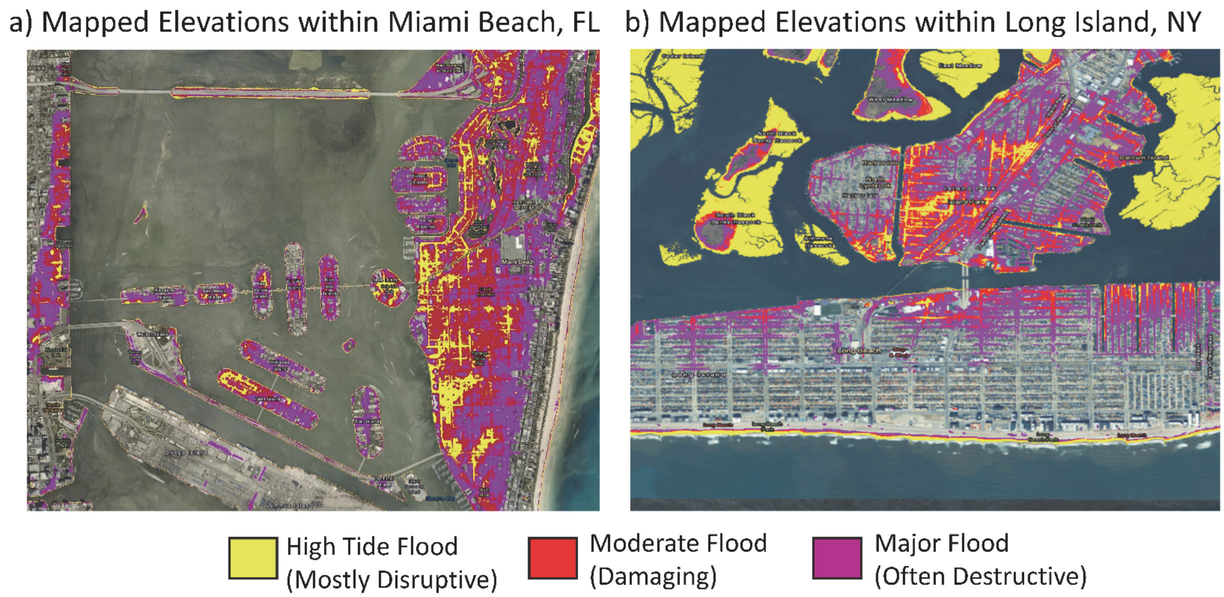

Figure 4: Mapping of elevations at or below the nationally consistent flood severity levels for high tide/disruptive flooding (0.53 and 0.56 m above MHHW shaded yellow), moderate/damaging levels (0.82 and 0.85 m above MHHW shaded in red) and major/often-destructive flooding (1.20 and 1.23 m above MHHW shaded in purple) of Sweet et al. (2018) for a) Miami Beach, FL and Long Island, NY. Elevations exposed to high tide flooding (and sea level rise in general) are more extensive within the urbanized sections of Miami Beach than Long Island due to its flatter and low-lying topography, which is typical of coastal zones within the Southeast Atlantic.

2018 High Tide Flood Outlook

Mild El Niño conditions are predicted to form during late 2018 and into 2019 (0.5° C average Oceanic Niño Index value)[13]. In response, higher than expected (e.g., above trend values) flood frequencies are predicted at 48 West and East Coast locations (Figure 2) as is illustrated in Figure 5 for San Diego, CA and Norfolk (Sewells Point), VA. In 2018 (Figure 6a), 5-6 days (median values) are predicted along the Northeast Atlantic and Northwest Pacific Coasts where steeper topography may help buffer the spatial extent of impacts (e.g., Figure 4b). Along the flatter and more-vulnerable Southeast Atlantic (e.g., Figure 4a) and Eastern and Western Gulf Coasts about 2-3 days are predicted. About 2 days are predicted along the Southwest Pacific Coast, with little or no flooding expected (not considering wave or rainfall effects) within the Caribbean, Hawaii or U.S. Pacific Islands; Kwajalein Island is an exception.

[13] May 18, 2018 plume: https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current

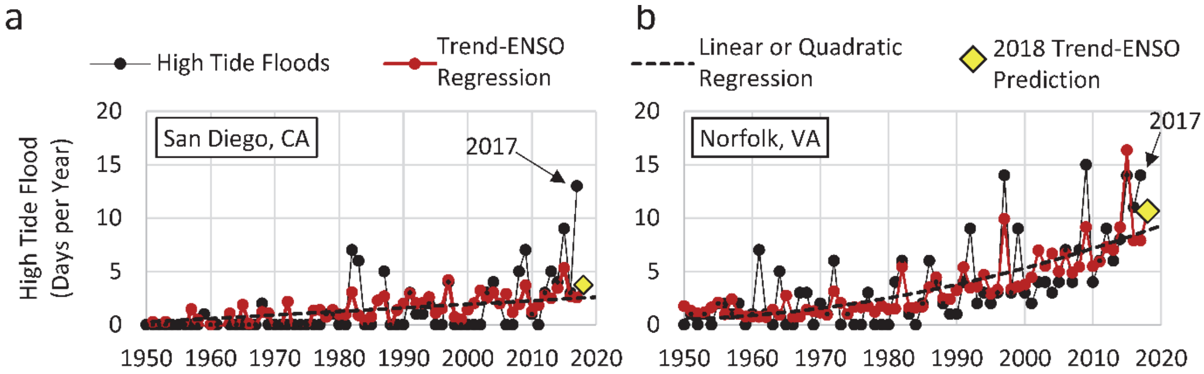

Figure 5: Annual high tide flood frequencies from 1950 to 2017 (black dots) with regression-based fits over 1950-2016 and projected through 2018 in a) San Diego, CA as a linear trend and as a quadratic trend in b) Norfolk, VA. Also shown are bivariate regressions (red line-dot) that include ENSO effects (ONI) in addition to the temporal changes with 2018 Outlooks (yellow diamond) based on an 2018 ONI predicted value of 0.5° C (May 18, 2018: https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current). Update to Sweet et al. (2018).

High tide flood frequencies continue to rapidly increase (Figure 2a); in 2018, they are predicted to be about 60% higher (median value) across U.S. coastlines as compared to frequencies typical in 2000 under ENSO neutral conditions (Figure 6b, Appendix 1). Flood frequencies are rising the fastest along the Southeast Atlantic Coast (median value of 160%). Rapid increases are also occurring along the Northeast Atlantic (100%), the Eastern and Western Gulf Coasts (about 50%). The marked increase in high tide flooding along the Southeast Atlantic versus the Northeast Atlantic Coast, for example, is problematic as topography along the Southeast Atlantic is flatter and more low lying, which exposes more infrastructure and populations to flooding (i.e., Figure 4). Along the Southwestern Pacific Coast, flood frequencies are predicted to be about 70% higher in 2018 than in 2000 due to the predicted mild El Niño.

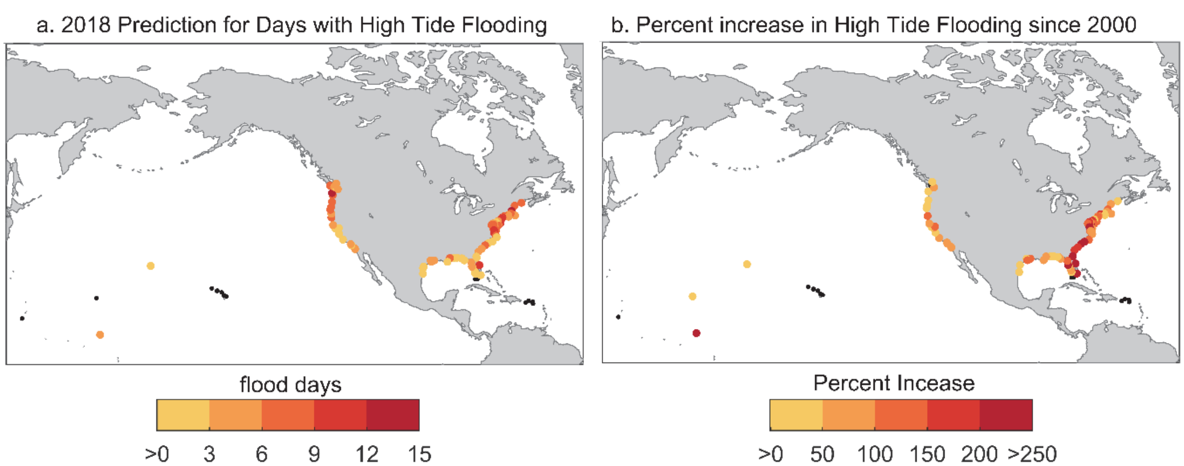

Figure 6: a) Number of high tide flood days predicted for 2018 (May 2018 – April 2019) based upon the combination of statistical models highlighted in Figure 2. In b) is the percent change since 2000 based upon similar trend fits but for ENSO neutral conditions. Black dots denote locations where high tide flooding still occurs less than once a year or in some cases has yet to occur.

Seasonality of 2018 High Tide Flooding

Intra-annual patterns of high tide flooding and the underlying drivers over the last couple of decades (as in Sweet et al., 2018) are used to identify peak-flood seasons during 2018. Accordingly, flooding is expected to be most prevalent during the 2018 winter season (Dec-Feb) along the West Coast and the northern section of Northeast Atlantic Coast (Figure 7a). High water levels (that may or may not cause flooding) in these regions routinely occur during monthly highest predicted tides (Figure 7b). Tide heights peak during both the winter and summer solstices due to the position of the sun relative to the earth's equator. Winter storms, which are less predictable, are also an important factor, especially when occurring during the days surrounding the highest tides.

Along most of the Northeast and Southeast Atlantic and the Gulf Coasts, high tide flooding is expected to be most frequent during the fall (Sep-Nov; Figure 7a) with predicted tides more of a factor along the Southeast Atlantic (Figure 7b, light blue region) and weather (less predictable) more important elsewhere (especially regions like the Chesapeake Bay shown as dark red in Figure 7b). Flooding is most common during the fall from a combination of an annual peak in mean sea level (included in NOAA tide predictions) and increased wind forcing. Changes in regional winds also influence the transport of coastal boundary currents like the Gulf Stream, and thus coastal sea levels (Ezer et al., 2017).

In a few locations situated along major river systems (e.g., Washington D.C.) high tide flooding is predicted to be most frequent during the spring season when river discharge peaks[14]. For Hawaii and the U.S. Pacific Islands, and for the U.S. Caribbean Islands, high water levels typically occur during periods of highest predicted tides, similar to the West and Southeast Atlantic coasts respectively. However, as the high tide flood thresholds are still above the reach of most historical tide gauge-measured water levels, high tide flooding is not predicted to occur in these regions unless directly impacted by storms or large waves.

Relatively few locations along U.S. coastlines will experience high tide flooding from predicted tides alone under current sea levels, though in the coming decades predicted tides will routinely flood many more locations if flood defenses are not enhanced (Sweet et al., 2018). In regions like the U.S. West Coast and the U.S. Pacific Islands where predicted tides typically dictate the occurrence of high water levels, seasonal outlooks of mean sea level (e.g., Widlansky et al., 2017)[15] and predicted tides[16] can help identify dates with potential high tide flood impacts.

[14] https://www.washingtonpost.com/news/capital-weather-gang/wp/2018/05/21/raging-water-at-great-falls-flooding-at-the-tidal-basin-after-last-weeks-deluge/?utm_term=.6b749f4f3daa
[15] https://uhslc.soest.hawaii.edu/sea-level-forecasts/
[16] https://oceanservice.noaa.gov/news/high-tide-bulletin/

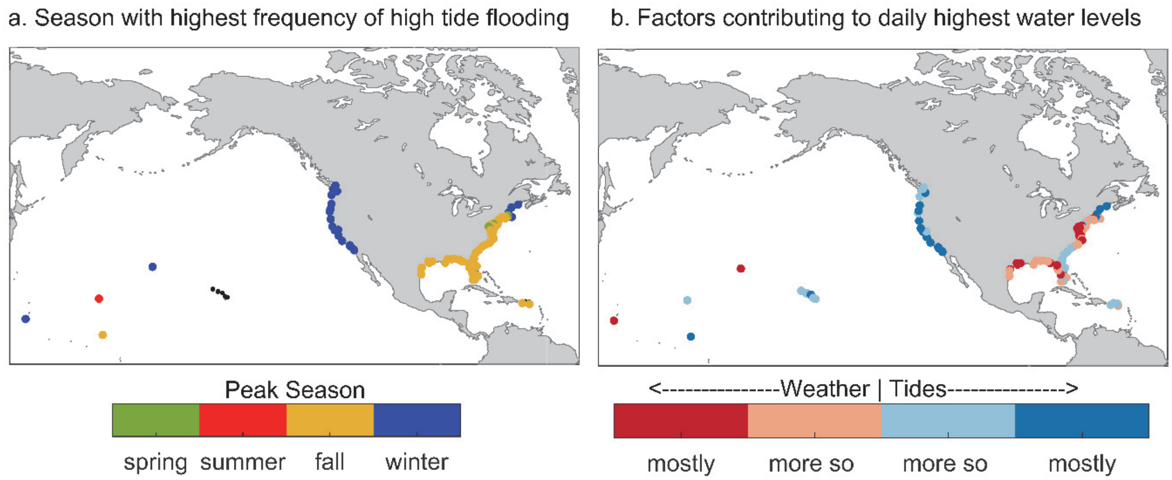

Figure 7: a) Season (spring: Mar-May; summer: Jun-Aug; fall: Sep-Nov; winter: Dec-Feb) with highest percentage of high tide flood days experienced over 1998–2016 with b) four categories based upon the ratio between variances of daily highest predicted tidal component of water level to observed water levels for 1998–2016 daily highest water levels. Adapted from Sweet et al. (2018).

Acknowledgements

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Appendix 1: U.S. Regions, tide gauge location information and NOAA ID, high tide flood threshold (meters above MHHW) based upon the national pattern of Sweet et al. (2018), annual high tide flood frequency record through 2016, high tide flood frequency typical of year 2000 based upon trend fits, high tide flood frequencies measured in 2017 (May 2017 – April 2018), the 2018 predicted outlook ± 1 standard deviation, the season when flooding has historically peaked and main factors producing high water levels

Region	Tide Gauge Location	Lat	Long	NOAA ID	Flood Height (m above MHHW)	Record as of 2016 (days/year)	Typical Flood Frequency (circa 2000)	2017 High Tide Floods (observed[1])	2018 Outlook (trend, El Nino[2])	Peak Season[3] (1998-2016)	Main Factor[4] (tides or weather)
Northeast Atlantic	Bar Harbor, ME	44.4	-68.2	8413320	0.64	30	7	18	9 ± 5	winter	tides
	Portland, ME	43.7	-70.2	8418150	0.62	21	5	16	9 ± 3	winter	tides
	Boston, MA	42.4	-71.1	8443970	0.63	22	6	22	13 ± 3	winter	tides
	Woods Hole, MA	41.5	-70.7	8447930	0.53	7	2	10	2 ± 2	winter	more so weather
	Nantucket Island, MA	41.3	-70.1	8449130	0.54	9	2	11	3 ± 2	winter	more so weather
	Newport, RI	41.5	-71.3	8452660	0.55	8	2	11	4 ± 2	fall	more so tides
	Providence, RI	41.8	-71.4	8454000	0.56	12	3	13	6 ± 2	spring	tides
	New London, CT	41.4	-72.1	8461490	0.54	9	2	10	3 ± 2	fall	weather
	Bridgeport, CT	41.2	-73.2	8467150	0.59	11	3	11	7 ± 2	fall	more so weather
	Montauk, NY	41.0	-72.0	8510560	0.53	8	2	11	3 ± 2	fall	more so weather
	Kings Point, NY	40.8	-73.8	8516945	0.60	15	5	13	10 ± 3	fall	more so weather
	The Battery, NY	40.7	-74.0	8518750	0.56	15	4	15	9 ± 3	fall	more so weather
	Bergen Point, NY	40.6	-74.1	8519483	0.57	12	4	13	7 ± 3	fall	more so weather
	Sandy Hook, NJ	40.5	-74.0	8531680	0.56	14	5	20	10 ± 3	fall	more so weather
	Atlantic City, NJ	39.4	-74.4	8534720	0.56	18	5	22	11 ± 3	fall	more so weather
	Cape May, NJ	39.0	-75.0	8536110	0.57	14	3	12	6 ± 2	fall	more so weather
	Philadelphia, PA	39.9	-75.1	8545240	0.58	12	3	5	4 ± 2	fall	more so weather
	Reedy Point, DE	39.6	-75.6	8551910	0.57	5	1	3	2 ± 1	spring	weather
	Lewes, DE	38.8	-75.1	8557380	0.56	14	4	15	9 ± 2	fall	more so weather
	Cambridge, MD	38.6	-76.1	8571892	0.52	7	1	3	5 ± 1	fall	weather
	Tolchester Beach, MD	39.2	-76.2	8573364	0.52	9	3	5	5 ± 2	fall	weather
	Baltimore, MD	39.3	-76.6	8574680	0.52	9	2	4	6 ± 2	fall	weather
	Annapolis, MD	39.0	-76.5	8575512	0.52	10	2	7	6 ± 2	fall	weather
	Solomons Island, MD	38.3	-76.5	8577330	0.52	9	1	6	6 ± 1	fall	weather
	Washington, DC	38.9	-77.0	8594900	0.54	10	3	3	6 ± 2	spring	weather
	Wachapreague, VA	37.6	-75.7	8631044	0.56	14	4	17	8 ± 3	fall	more so weather
	Kiptopeke, VA	37.2	-76.0	8632200	0.54	11	3	7	6 ± 2	fall	weather
	Lewisetta, VA	38.0	-76.5	8635750	0.52	9	2	8	8 ± 2	fall	weather
	Windmill Point, VA	37.6	-76.3	8636580	0.52	10	3	7	10 ± 3	fall	weather
	Sewells Point, VA	36.9	-76.3	8638610	0.53	15	5	14	11 ± 2	fall	weather
	Chesapeake Bay Br., VA	37.0	-76.1	8638863	0.54	19	6	---	11 ± 3	fall	weather
Southeast Atlantic	Duck, NC	36.2	-75.7	8651370	0.54	18	5	12	9 ± 3	fall	more so weather
	Oregon Inlet, NC	35.8	-75.5	8652587	0.51	8	2	6	2 ± 2	fall	weather
	Beaufort, NC	34.7	-76.7	8656483	0.54	10	1	0	2 ± 2	fall	more so weather
	Wilmington, NC	34.2	-78.0	8658120	0.56	9	1	0	3 ± 1	fall	more so weather
	Springmaid Pier, SC	33.7	-78.9	8661070	0.57	11	2	3	8 ± 2	fall	more so tides
	Charleston, SC	32.8	-79.9	8665530	0.57	9	2	4	4 ± 2	fall	more so weather
	Fort Pulaski, GA	32.0	-80.9	8670870	0.59	12	2	4	5 ± 2	fall	more so tides
	Fernandina Beach, FL	30.7	-81.5	8720030	0.58	9	2	6	2 ± 3	fall	more so tides
	Mayport, FL	30.4	-81.4	8720218	0.56	6	0	4	2 ± 1	fall	more so weather
	Trident Pier, FL	28.4	-80.6	8721604	0.55	12	0	9	10 ± 3	fall	more so tides
	Virginia Key, FL	25.7	-80.2	8723214	0.53	3	0	3	3 ± 1	fall	more so weather
	Vaca Key, FL	24.7	-81.1	8723970	0.51	1	0	1	0 ± 0	fall	more so tides
	Key West, FL	24.6	-81.8	8724580	0.52	2	0	1	0 ± 0	fall	more so weather
Caribbean	Lime Tree Bay, VI	17.7	-64.8	9751401	0.51	1	0	---	0 ± 0	fall	more so weather
	Charlotte Amalie, VI	18.3	-64.9	9751639	0.51	1	0	---	0 ± 0	---	more so tides
	San Juan, PR	18.5	-66.1	9755371	0.52	1	0	1	0 ± 0	---	more so tides
	Magueyes Island, PR	18.0	-67.0	9759110	0.51	1	0	---	0 ± 0	fall	more so tides

Region	Tide Gauge Location	Lat	Long	NOAA ID	Flood Height (m above MHHW)	Record as of 2016 (days/year)	Typical Flood Frequency (circa 2000)	2017 High Tide Floods (observed[1])	2018 Outlook (trend, El Nino[2])	Peak Season[3] (1998-2016)	Main Factor[4] (tides or weather)
Eastern Gulf	Naples, FL	26.1	-81.8	8725110	0.53	2	1	**3**	1 ± 1	fall	more so weather
	Fort Myers, FL	26.6	-81.9	8725520	0.52	6	1	**6**	2 ± 1	fall	weather
	St. Petersburg, FL	27.8	-82.6	8726520	0.53	4	1	2	1 ± 1	fall	more so weather
	Clearwater, FL	28.0	-82.8	8726724	0.53	4	1	3	4 ± 1	fall	more so weather
	Cedar Key, FL	29.1	-83.0	8727520	0.55	5	1	**6**	3 ± 1	fall	weather
	Apalachicola, FL	29.7	-85.0	8728690	0.52	8	2	4	3 ± 2	fall	weather
	Panama City, FL	30.2	-85.7	8729108	0.52	7	1	2	2 ± 2	fall	more so weather
	Panama City Beach, FL	30.2	-85.9	8729210	0.52	8	2	3	2 ± 2	fall	more so weather
	Pensacola, FL	30.4	-87.2	8729840	0.52	10	1	6	2 ± 2	fall	more so weather
	Dauphin Island, AL	30.3	-88.1	8735180	0.51	6	2	**6**	2 ± 2	fall	more so weather
	Bay Waveland, MS	30.3	-89.3	8747437	0.52	12	5	**14**	8 ± 3	fall	more so weather
Western Gulf	Grand Isle, LA	29.3	-90.0	8761724	0.51	5	1	2	1 ± 1	fall	more so weather
	Sabine Pass, TX	29.7	-93.9	8770570	0.52	13	1	**23**	3 ± 2	fall	weather
	Morgans Point, TX	29.7	-95.0	8770613	0.52	16	5	14	5 ± 5	fall	weather
	Galveston Pier 21, TX	29.3	-94.8	8771450	0.52	15	2	**18**	6 ± 2	fall	weather
	Rockport, TX	28.0	-97.0	8774770	0.50	7	1	---	1 ± 2	fall	weather
	Corpus Christi, TX	27.6	-97.2	8775870	0.52	6	2	**10**	2 ± 1	fall	more so weather
	Port Isabel, TX	26.1	-97.2	8779770	0.52	3	1	**6**	1 ± 1	fall	more so weather
Southwest Pacific	San Diego, CA	32.7	-117.2	9410170	0.57	9	2	**13**	4 ± 2	winter	tides
	La Jolla, CA	32.9	-117.3	9410230	0.56	8	2	1	3 ± 2	winter	tides
	Los Angeles, CA	33.7	-118.3	9410660	0.57	6	1	1	2 ± 1	winter	tides
	Santa Monica, CA	34.0	-118.5	9410840	0.57	7	2	1	3 ± 2	winter	tides
	Port San Luis, CA	35.2	-120.8	9412110	0.56	6	1	1	1 ± 1	winter	tides
	Monterey, CA	36.6	-121.9	9413450	0.57	7	1	0	1 ± 1	winter	tides
	San Francisco, CA	37.8	-122.5	9414290	0.57	6	1	0	1 ± 1	winter	tides
	Alameda, CA	37.8	-122.3	9414750	0.58	10	1	0	1 ± 2	winter	tides
	Point Reyes, CA	38.0	-123.0	9415020	0.57	8	1	1	2 ± 2	winter	tides
	Port Chicago, CA	38.1	-122.0	9415144	0.56	15	1	0	2 ± 3	winter	more so tides
	Arena Cove, CA	38.9	-123.7	9416841	0.57	14	2	0	3 ± 3	winter	tides
Northwest Pacific	Humboldt Bay, CA	40.8	-124.2	9418767	0.58	15	4	7	8 ± 3	winter	tides
	Port Orford, CA	42.7	-124.5	9431647	0.59	23	5	2	6 ± 5	winter	more so tides
	Charleston, OR	43.3	-124.3	9432780	0.59	27	6	0	6 ± 4	winter	tides
	South Beach, OR	44.6	-124.0	9435380	0.60	25	7	2	8 ± 4	winter	tides
	Toke Point,WA	46.7	-124.0	9440910	0.61	33	13	7	14 ± 6	winter	more so tides
	Port Angeles, WA	48.1	-123.4	9444090	0.59	12	4	0	4 ± 2	winter	more so tides
	Port Townsend, WA	48.1	-122.8	9444900	0.60	13	3	0	3 ± 3	winter	more so tides
	Seattle, WA	47.6	-122.3	9447130	0.64	11	2	0	4 ± 2	winter	tides
	Cherry Point, WA	48.9	-122.8	9449424	0.61	15	3	0	4 ± 3	winter	more so tides
	Friday Harbor, WA	48.5	-123.0	9449880	0.59	17	4	0	3 ± 3	winter	more so tides
Pacific Islands	Nawiliwili, HI	22.0	-159.4	1611400	0.52	1	0	0	0 ± 0	---	more so tides
	Honolulu, HI	21.3	-157.9	1612340	0.52	0	0	0	0 ± 0	---	more so tides
	Mokuoloe, HI	21.4	-157.8	1612480	0.53	0	0	0	0 ± 0	---	more so tides
	Kahului, HI	20.9	-156.5	1615680	0.53	0	0	0	0 ± 0	---	tides
	Kawaihae, HI	20.0	-155.8	1617433	0.53	0	0	0	0 ± 0	---	more so tides
	Hilo, HI	19.7	-155.1	1617760	0.53	1	0	0	0 ± 0	---	more so tides
	Midway Island	28.2	-177.4	1619910	0.52	6	1	2	1 ± 1	winter	weather
	Apra Harbor, Guam	13.4	144.7	1630000	0.53	1	0	0	0 ± 0	winter	weather
	Pago Pago, Am. Samoa	-14.3	-170.7	1770000	0.53	0	0	0	0 ± 0	---	more so tides
	Kwajalein Island	8.7	167.7	1820000	0.55	8	1	2	4 ± 1	fall	tides
	Wake Island	19.3	166.6	1890000	0.53	2	0	0	0 ± 0	summer	more so tides

1) Red highlights denote that 2017 high tide flood frequencies tied or exceeded the station's historical record

2) A mild El Nino of 0.5° C as classified by ONI is predicted over 2018-2019 by the IRI international model ensemble (May 18, 2018 prediction plume) https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/)

3) Based on 1998-2016 high tide floods shown in Sweet et al., 2018 (their Figure 13d) occurring in winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug) and fall (Sep-Nov)

4) Based upon ratios of Sweet et al., 2018 (their Figure 9b) categorizing as weather (0.15-0.35), more so weather (0.35-0.55), more so tides (0.55-0.75) and tides (0.75-0.95)