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2019 State of U.S. High Tide Flooding with a 2020 Outlook

Photo Credit: New York Sea Grant

Silver Spring, Maryland
July 2020

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services
National Ocean Service
National Oceanic and Atmospheric Administration
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2019 State of U.S. High Tide Flooding with a 2020 Outlook

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Sea level rise flooding of U.S. coastlines is happening now, and it is becoming more frequent each year. This flooding typically occurs when ocean waters reach 0.5 meter (m) to 0.65 m above the daily average high tide and starts spilling onto streets or bubbling up from storm drains. Evidence of a rapid increase in sea level rise related flooding started to emerge about two decades ago, and it is now very clear. This type of coastal flooding will continue to grow in extent, frequency, and depth as sea levels continue to rise over the coming years and decades.

Observations from NOAA's national tide gauge network calibrated to the national set of coastal flood thresholds used by local emergency managers are tracking this phenomenon. NOAA's National Ocean Service calls such flooding high tide flooding (HTF), and its cumulative toll is damaging to subsurface and ground-level infrastructure and is disrupting lives and livelihoods. As the frequency of HTF increases, NOAA's National Weather Service is issuing record numbers of watches/warnings for coastal flooding, often with no storm in sight. This will become the new normal unless coastal flood mitigation strategies are implemencted or enhanced. Communities are investing in coastal infrastructure upgrades and adaptation strategies to address current flooding issues, but concerns regarding property access and future valuation/exposure, business disruption, public health, and other such concerns are growing.

In 2019 (May 2019–April 2020), the national (outside of Alaska) median HTF frequency of 4 days tied its second highest value, and its decadal trend continues to accelerate. The U.S. annual HTF frequency now is more than twice that in the year 2000 due to rising relative sea levels (RSL), which in 2019 rose to a record-setting 0.34 m (1.1 ft) nationally relative to1920 levels. Individual RSL records were set along most (57 of 62) East and Gulf Coast locations, where annually HTF is now occurring at upwards of twice the national rate or more. Nineteen locations also broke or tied their all-time HTF records (median of 13 days) in 2019 along the East and Gulf Coasts including multiple locations along the Texas coastline, as well as at Miami, Savannah, Charleston and Annapolis. Annual HTF frequencies are accelerating (increasing nonlinearly) at 75% of East and Gulf Coast locations with nearly all others rising but not (yet) accelerating. For perspective, it was not until 1979 (more than 50 years of observations) that Charleston, S.C. experienced 13 total days of HTF; in 2019, 13 days of HTF occurred[1].

Next year (May 2020–April 2021), acceleration in HTF and its impacts are expected to continue under near-neutral conditions of the El Niño Southern Oscillation. Nationally, the HTF outlook is 2–6 days (likely range). The Northeast Atlantic and Western Gulf outlook is 6–11 days and 5–11 HTF days, respectively. The outlook for the Southeast Atlantic, the Eastern Gulf, and the Northwestern and Southwestern Pacific coastlines are less: 3–6 days, 2–5 days, 0–7 days and 0–3 days, respectively. No HTF flooding (relative to the threshold applied here) is projected for U.S. Island coastlines. This outlook does not consider wave and local rain effects.

Under current floodplain management practices, by 2030 the national HTF frequency trend is likely to further increase by about 2–3 fold (national median of 7–15 days). In 30 years (by 2050), it is likely to be 5–15 fold higher (national median of 25–75 days), which could, in some places, imply HTF flooding would become the new high tide (~180 days/year).

[1] For more information, please visit https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html.

1. INTRODUCTION

Tide gauges of the National Oceanic and Atmospheric Administration (NOAA) are sentinels along the U.S. coastline, supporting safe shipping operations and emergency responses during the fiercest of storms. For over a century, they also have been observing a rise in relative sea level (RSL) and the loss of coastal freeboard. Paired with coastal flood thresholds for local impacts used when issuing contemporary weather/water level warnings (NOAA, 2020; Sweet et al., 2018), NOAA tide gauges show that a rapid growth in coastal flood risk is now occurring within many U.S. coastal communities (Sweet and Park, 2014; Figure 1). Flooding that decades ago happened only during a severe storm can now occur during a full-moon tide or with a change in prevailing winds or currents. Such high tide flooding (HTF) is becoming common and is of growing concern within U.S. coastal communities.

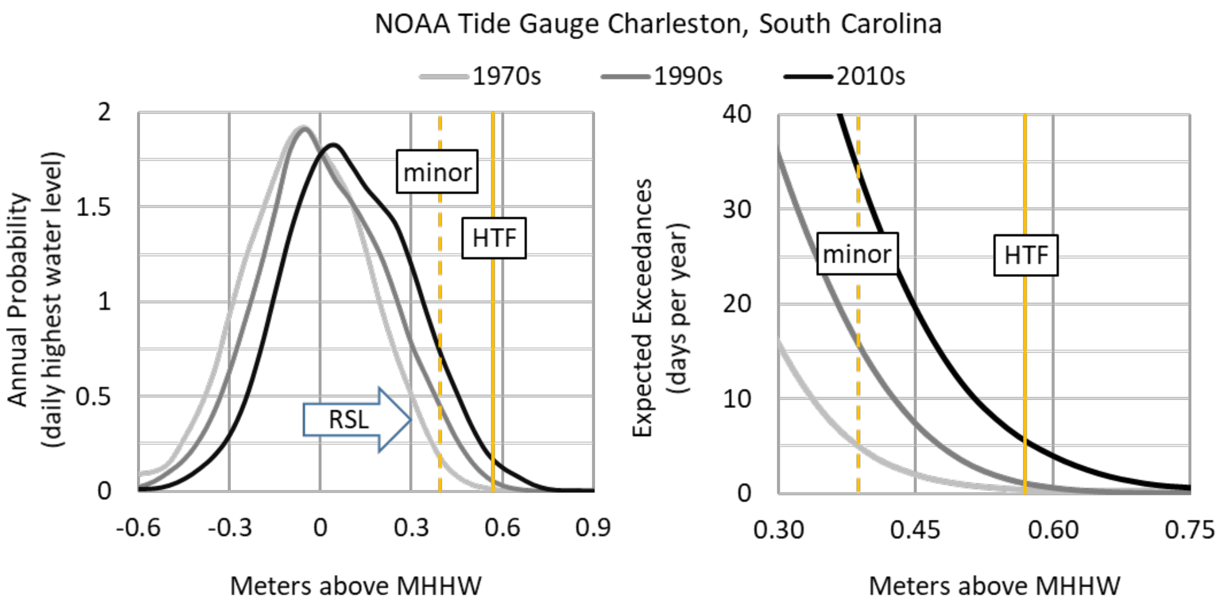

Figure 1. Decadal empirical probability distributions (left) and expected exceedances (right: 1-cumulative distribution) for daily highest water levels in Charleston, S.C. during the 1970s, 1990s, and 2010s changing due to relative sea level (RSL) rise. Shown are the NOAA National Ocean Service (NOS) HTF threshold (Sweet et al., 2018) and the local NOAA NWS Weather Forecasting Office (WFO) minor flood threshold (https://water.weather.gov/ahps2/hydrograph.php?wfo=chs&gage=chts1).

HTF begins to occur when coastal water levels reach heights between 0.5 meter (m) and 0.65 m above the mean higher high water (MHHW) level (Figure 2a). HTF thresholds vary with tide range, as do the NOS-defined moderate and major flooding thresholds that begin to occur at about 0.8 m and 1.2 m above MHHW, respectively (Sweet et al., 2018). The HTF thresholds are based upon the coastal flood thresholds set by NOAA National Weather Service (NWS) Weather Forecasting Offices (WFOs) and on-the-ground local emergency managers who prepare for response to impending conditions (NOAA, 2020). WFOs will typically issue a *coastal flood advisory* when NWS minor flooding is expected. NWS flood thresholds are calibrated empirically from years of impact monitoring, but they are valid usually for only particular parts of a city or region that has variable topography, urbanization, and storm-proofing. As a best-fit solution to the NWS thresholds (Figure 2b: regressed with tide range), the NOS HTF thresholds provide a nationally consistent height that broadly defines infrastructure vulnerabilities to flooding that can be mapped along U.S. coastlines (Figure 2c). It is acknowledged that in some locations (e.g., Miami, Fla.; Charleston, S.C.; Honolulu, Hawaii), some obvious (but spatially more limited) flooding might occur before water levels reach the local HTF threshold used here. Conversely, in some locations (e.g., directly behind the seawalls of Galveston, Tex.; St. Petersburg, Fla.; and New York City), water levels reaching the HTF threshold may not cause obvious flooding (but still may affect subsurface infrastructure like storm-water infiltration).

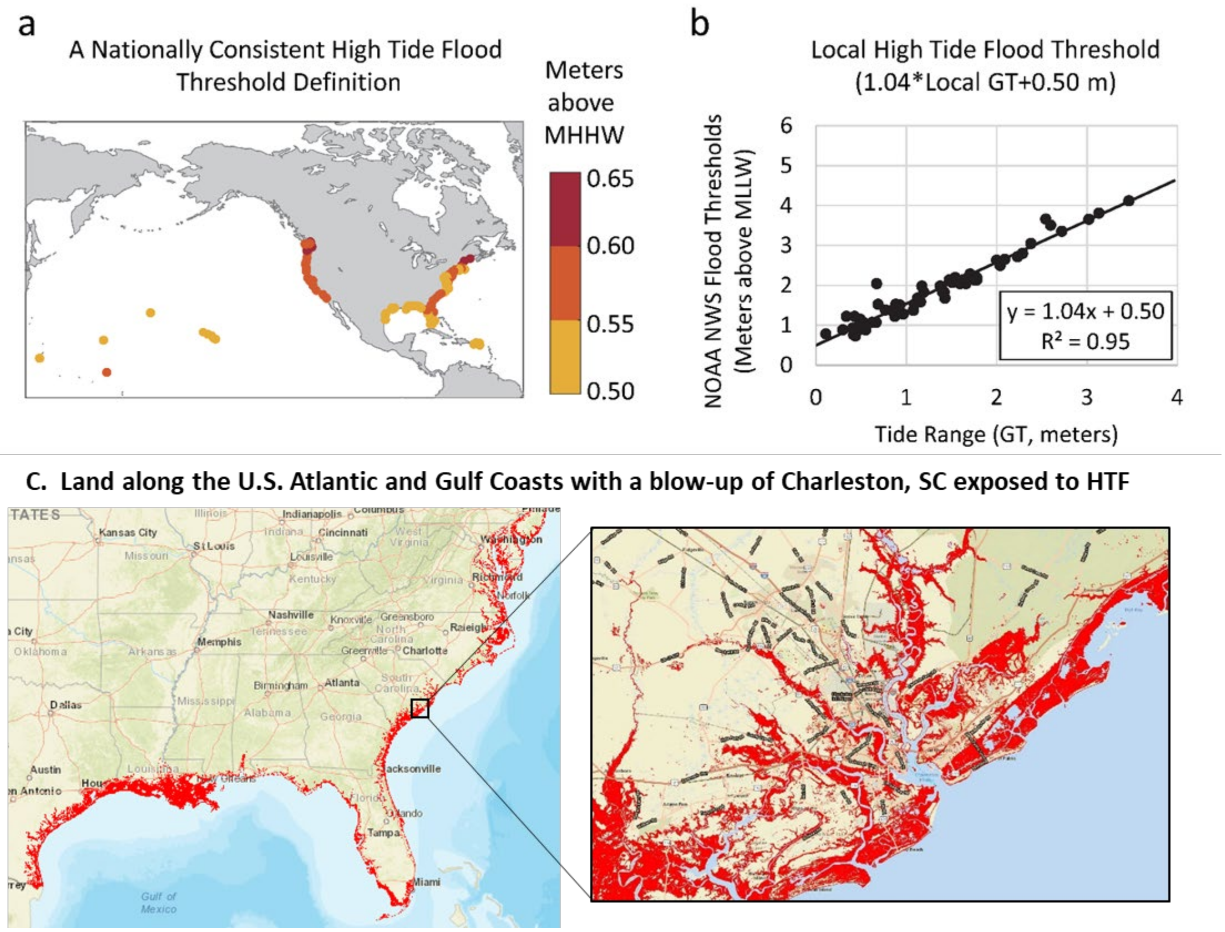

Figure 2. a) HTF height thresholds established at NOAA tide gauges based upon the regression relationship shown in b) as a scatter plot of a national set (about 60 locations) of NOAA NWS flood thresholds for minor impacts (y-axis) shown relative to the mean lower low water (MLLW) tidal datum versus the local great diurnal tide range (GT) on the x-axis. Adapted from Sweet et al. (2018). In c) is a map of the areas (red) at or below the HTF threshold interpolated between locations for the U.S. East and Gulf Coasts with a zoom-in of the Charleston, S.C. region. (Data accessible from NOAA's Sea Level Rise Viewer: https://coast.noaa.gov/slr/)

HTF is called by many names: sunny-day, nuisance, recurrent, king-tide, tidal, or sea level rise flooding. One thing they all have in common is that the cumulative toll of impacts are becoming disruptive and damaging within many coastal communities. HTF impacts are increasing in frequency and spatial extent and threaten a myriad of coastal infrastructure. In 2019, there were numerous media reports of ongoing impacts and related concerns of the future, including 1) access to homes and important transportation links due to flooding and erosion of roadways[2], 2) flooding of homes[3], as well as unforeseen consequences to recent mitigation efforts[4], 3) the cost of replacing antiquated combined storm and wastewater systems being impacted by rising seas and groundwater tables[5], 4) the health effects of such combined systems[6], and 5) the negative pressure on real estate values[7]. There was also reporting about efforts underway to help address the impacts, including 1) holding public 'Flood Stat' meetings[8] and 2) using social media technology to better discern where and when HTF is occurring[9].

This report is the sixth in an annual series to look back at HTF over the past year and to look forward to the years to come with annual and multi-decadal HTF projections building upon past studies (Sweet and Park, 2014; Sweet et al., 2018). The report provides 1) an assessment of HTF that occurred in 2019 relative to measured flood-frequency trends, 2) maps of areas potentially exposed to HTF, and 3) a 2020 outlook based upon temporal trends and predicted strength of the El Niño Southern Oscillation (ENSO). This report and accompanying NOAA website[10] also continue to provide projections of HTF by Sweet et al. (2018) based upon the range of RSL rise *likely* to occur by 2030 and 2050 using projections of the Fourth National Climate Assessment[11]. This information is intended to raise awareness of the growing impact of RSL rise through HTF and inform decision-making not only next year (e.g., budgeting and allocating for necessary coastal flood responses) but over the longer term (e.g., major infrastructure upgrades and land-use planning) to ensure resilience to sea level rise impacts.

2. 2019 CONDITIONS

In 2019[12] the national (median) HTF occurrence along U.S. coastlines as a whole was 4 days. This is 1 day less than the record reached in 2018 as measured by 98 NOAA tide gauges[13] (Figure 3a). Assessed over several decades, the national trend in HTF frequency is accelerating, and HTF is more than twice as likely now as it was in 2000. The rapid growth is in response to RSL rise, which is occurring along most U.S. coastlines. (Our study does not include Alaska, where land-based ice melt is contributing to land rebound[14]). In 2019, RSL along U.S. coastlines (median value) reached an all-time record of 0.34 m since 1920 (last 100 years), which is about 4

[2] https://www.hawaiinewsnow.com/2020/01/08/collapse-highway-hauula-latest-example-sea-level-rise-impacts/; https://www.nytimes.com/2019/12/04/climate/florida-keys-climate-change.html
[3] https://www.nj.com/news/2020/01/our-homes-flood-monthly-and-we-need-help-jersey-shore-residents-say.html
[4] https://www.miamiherald.com/news/local/environment/article239486308.html
[5] https://www.miamiherald.com/news/local/environment/article239005633.html
[6] https://www.sun-sentinel.com/local/broward/fort-lauderdale/fl-ne-sewage-spills-health-risks-20200102-5hgi2hjsffea7cbjaoyhw3il3q-story.html
[7] https://www.miamiherald.com/news/local/environment/article239285848.html; https://www.nytimes.com/2020/06/19/climate/climate-seas-30-year-mortgage.html
[8] https://www.postandcourier.com/news/charleston-and-the-south-carolina-coast-flooded-record-times-in/article_7c18ee5e-2e3b-11ea-8784-23ddbc8d4e0c.html
[9] https://www.cnn.com/2020/02/05/us/sea-level-rise-flooding-twitter-study/index.html
[10] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html
[11] https://scenarios.globalchange.gov/sea-level-rise
[12] Unless otherwise noted, a year in this report is defined as a meteorological year spanning May-April.
[13] Following the reasoning of Sweet et al. (2018), Alaska and locations with tide ranges greater than 4 meters and where RSL trends are decreasing are not included in this report.
[14] https://tidesandcurrents.noaa.gov/sltrends/

centimeters (1.5 inches) higher than it was in 2018. The national RSL (linear) trend along U.S. coastlines examined here is 2.8 millimeters/year over this period (not shown). Inherent to the RSL measurement in Figure 3a is the effect of land subsidence, which nationally (median plus or minus standard deviation value of the 98 tide gauges monitored) is occurring at a rate of 0.7 ±1.4 mm/year, but can be as high as 7 mm/year along the coastline of Louisiana (Zervas et al., 2013; Sweet et al., 2017). Annual mean RSLs at most East and Gulf Coast tide gauges (57 of the 62) broke their historical records (Figure 3b) in 2019 by (median value) 2.6 cm (about 1 inch).

Locally, these record RSLs (and the underlying RSL trends) are a primary factor of HTF occurrence rates in 2019 as shown for Charleston, S.C. (Figure 3c). For example, the combination of predicted (astronomic) tide and the monthly nontidal residual (sea level anomaly) in Charleston together account for about 75% of the record-breaking HTF days in 2019. Although water level variance (e.g., typical frequency of and response magnitude to windstorms) is a factor in annual HTF frequencies locally in any given year (Figure 3c) and helps explain regional HTF patterns, it exhibits few long-term trends around U.S. coastlines (Sweet and Park, 2014). HTF flooding is occurring more often now than in the past because of RSL rise and not changes in ‘storminess.’

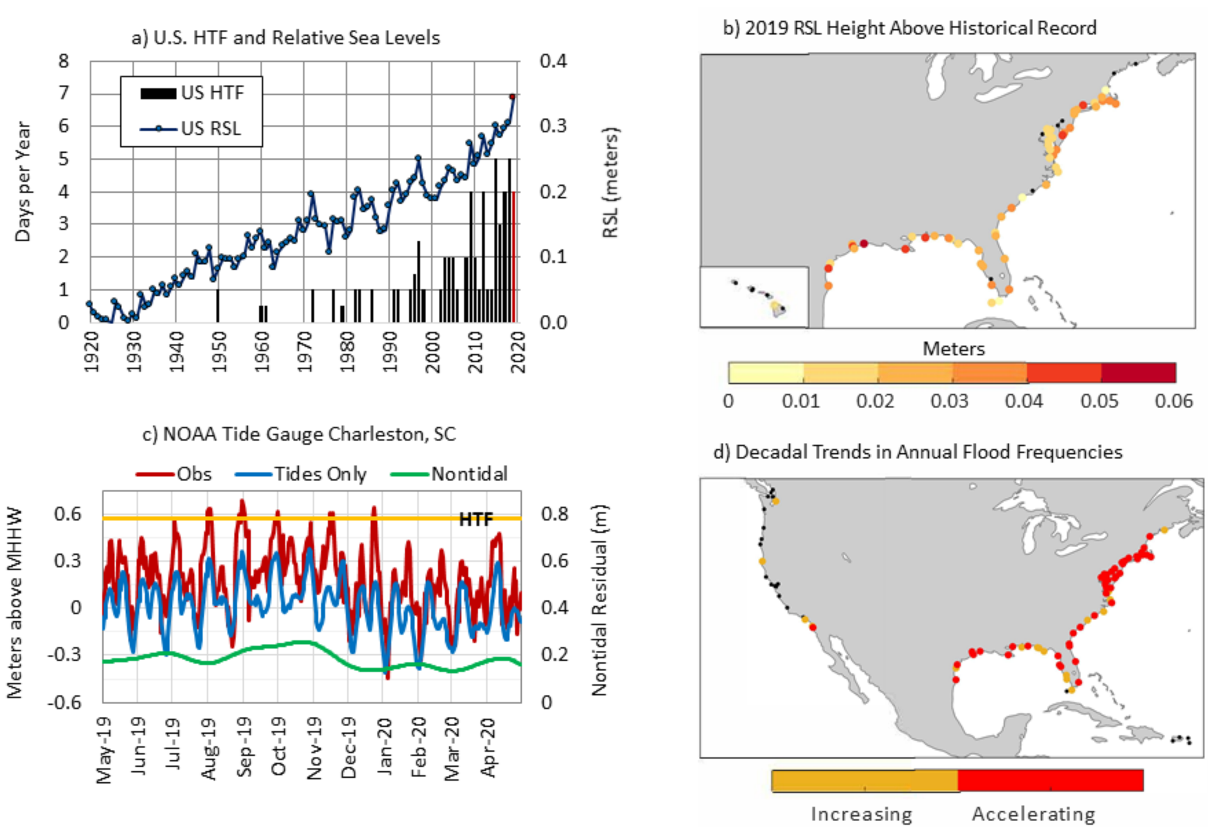

Figure 3. a) Median HTFs per year (black bars) from 1920–2019 with the annual-median rise in RSL (blue line). 2019 sea level and flood frequency values are shown in red. In b) are the individual tide gauge locations that broke historical RSL records in 2019. In c) is a time series of 2019 daily highest water level observation (red line) and its tide component only (blue line) with monthly average nontidal residual levels (green line: observations – tide only) at the NOAA tide gauge in Charleston, S.C. In d) is the characterization of the trends in annual HTF frequencies, with 49 locations now accelerating and 19 increasing linearly. Trends are significant at the 90% level (p value <0.1) or higher.

The acceleration in the national HTF frequency (Figure 3a) is a reflection of the acceleration occurring at most (48 of 68) U.S. East and Gulf Coast tide gauges (Figure 3d) with the remainder (except Key West, Fla.) increasing linearly. Nationally, there are 49 locations where HTF frequencies are accelerating and 19 that are linearly increasing. HTF acceleration is to be expected as RSL rises and flood-management or mitigation efforts are limited or insufficient (Sweet and Park, 2014; Sweet et al., 2018). Tide gauges will continue to measure higher sea levels and tide heights, but more flooding and impacts will not necessarily occur if flood management (mitigation, adaptation, etc.) efforts keep pace.

HTF in 2019 occurred the most along the Western Gulf of Mexico coastline with 18 ±19 (median ±1 standard deviation or 0–37 days at 1 standard deviation) days, with the Northeast (9 ±5 days) and the Southeast (7 ±4 days) Atlantic coastlines also experiencing relatively high number of HTF days (Figure 4). The Eastern Gulf experienced several (3 ±4 or 0–7 days at 1 standard deviation) HTF days with the remainder of the U.S. experiencing relatively few, if any, HTF days. Thus, HTF occurred more often along the Southeast Atlantic and Gulf Coasts in 2019 where record-breaking RSL also occurred (Figure 3b).

The frequency of HTF in 2019 was within the range predicted by the NOAA 2019 HTF outlook (Sweet et al., 2019) at about 60% of locations, and it was above and below prediction at about 25% and 15% of locations, respectively. The U.S. West Coast was largely over-predicted due in part to a weakened El Niño (Oceanic Niño Index [ONI] of about 0.4 °C[15] and as compared to what was predicted and used in the 2019 outlook (ONI value of 0.75 °C, Sweet et al., 2019).

[15] https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php

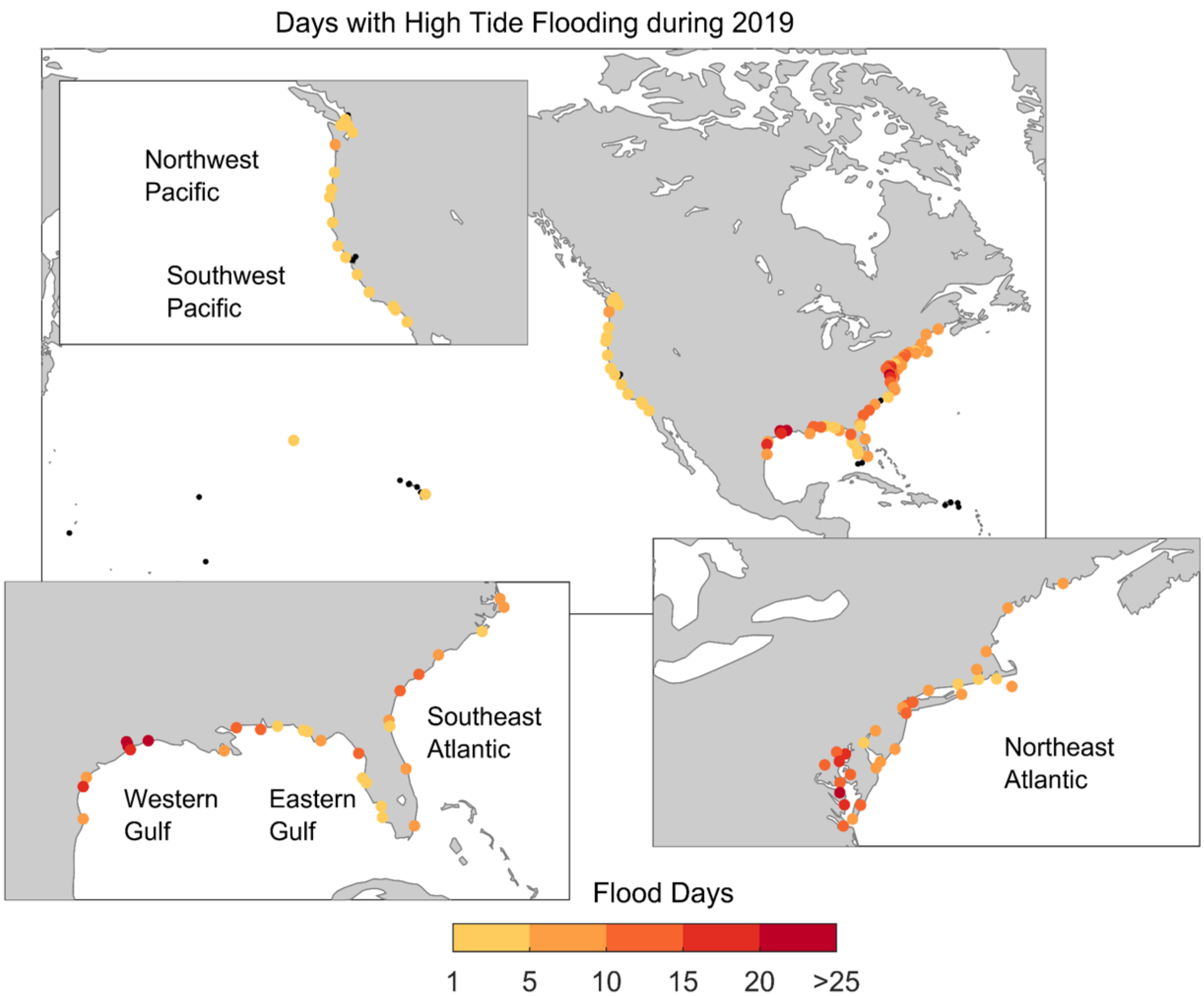

Figure 4. Number of days with HTF in 2019 at 98 NOAA tide gauge locations with values listed in Appendix 1. Black dots identify locations where HTF did not occur during 2019.

Of the 25 locations where HTF in 2019 was above the predicted range, 19 broke their all-time records. Records were set throughout the Chesapeake Bay region and along the Southeast Atlantic coastlines, as well as both the Eastern and Western Gulf of Mexico coastlines. HTF occurred most frequently (64 days) at Eagle Point, Tex., which is within Galveston Bay. This location has been an anomaly over the last two decades[16] presumably in response to localized land subsidence with RSL rise rates of 1.4 cm/year over the last 26 years (>1 ft)[17]. It is unclear whether any localized impacts associated with HTF are apparent or disruptive within this community. Other notable locations setting records include (see Appendix 1 for complete list) Annapolis, Md. (18 days) where HTF often causes parking and transportation disruption in the downtown area (Hino et al., 2019), Charleston, S.C. and Savannah, Ga. (13 days each), Virginia Key in the Miami region (9 days), Dauphin Island, Ala. (10 days) and Galveston, Tex. (18 days).

[16]https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.csv
[17]See monthly sea level data at https://tidesandcurrents.noaa.gov/waterlevels.html?id=8771013.

Compared to HTF frequencies typical in 2000 assessed with an accelerating or linearly increasing significant trend (e.g., Figure 3d), HTF in 2019 was extraordinary. Flood days occurred 100–150% more frequently than in 2000 along the Northeast Atlantic and Eastern Gulf coastlines (e.g., 14 HTF days in 2019 at Norfolk, Va. is >150% higher than the trend value of about 5 days in 2000). Even higher percentage increases (>300%) occurred along the Southeast Atlantic (e.g., >500% increase in Charleston with 13 HTF days in 2019 compared to about 2 days in 2000). Percentage increases compared to 2000 were the greatest in the Western Gulf (>500%). For example, Sabine Pass and Corpus Christi, Tex. had 21 and 18 HTF days in 2019, and in 2000 the trend values were about 1 and 3 days (>1000% and 500% increase), respectively. This increase is in part driven by about a 0.15 m (0.5 ft) rise in RSL[18]. Five out of Texas's seven NOAA tide gauges broke records last year, and it is likely that both the rise in RSL and HTF are affecting groundwater levels and contributing to poor coastal water quality along many Texas coastlines, which have showed elevated bacteria counts over the last year[19] (personal communication with Jason Pinchback, Manager of the Texas Coastal Resources/Water Resources Program).

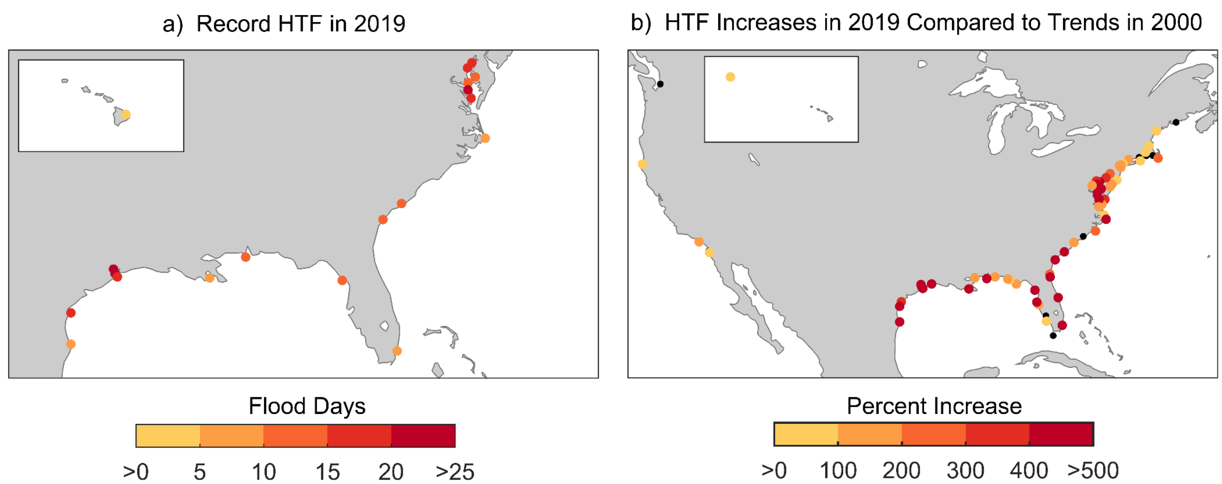

Figure 5. a) Locations where HTF either tied or broke all-time records and b) the percent increase in 2019 HTF days as compared to trend values for year 2000 for locations shown in Figure 3d.

In terms of public communication of possible coastal (HTF) flooding, NOAA NWS WFOs issue *coastal flood advisories* if minor coastal flooding is expected; if moderate or major coastal flooding is imminent, *coastal flood warnings* are issued (NOAA, 2020)[20]. HTF flood threshold by design (best-fit regression, Sweet et al., 2018) align closely with NWS minor flood thresholds, but counts of HTF also include less-frequent moderate and major flooding when they occur. Not surprisingly, as frequencies of HTF increase, the frequency of WFOs coastal flood advisory/warning issuances increase as well (Sweet et al., 2019). This upward trend in WFO

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[18] https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8770570, https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8775870

[19] https://cgis.glo.texas.gov/Beachwatch/index.html

[20] The NOAA NOS definition of moderate and major flooding uses similar regression analysis as with NWS minor coastal flooding (Figure 2b). Moderate and major flooding equate to heights of about 0.8–0.9 m and 1.15–1.3 m above MHHW (Sweet et al., 2018).

coastal flood guidance continued into 2019 (May 2019–April 2020). Half of the 22 coastal WFOs along the East and Gulf Coasts[21] issue more coastal advisories and warnings every year (significant positive trend from 2008–2019, not shown). In 2019, about a third (7 of 22) of the coastal WFOs issued a combined number of coastal flood advisories and warnings that tied (two WFOs) or exceeded (five WFOs) previous records. The NWS WFOs (map of the WFOs[22]) that set records include three East Coast WFOs (Wakefield, Charleston, and Jacksonville) and four Gulf Coast WFOs (Mobile, Lake Charles, Corpus Christi, and Brownsville). Similarly, about a third of the NOAA tide gauges along the East and Gulf Coast (19 of 62) set/tied their HTF records in 2019 (Figure 5a).

Histories of annual HTF at four NOAA tide gauges along the U.S. Atlantic and Gulf Coasts and the coastal flood advisories and warning from their surrounding WFOs are shown in Figure 6 to illustrate this relationship. All tied/broke their records in 2019, except for the count of HTF days at Norfolk (Sewells Point), Va. and Sabine Pass, Tex., which were both second highest on record. HTF flooding and coastal flood advisories/warnings at these four locations are correlated (r-value of 0.75–0.8) and accelerating through time. These results demonstrate the direct effects of RSL rise affecting coastal flood risk and weather/water level forecasting that is guiding day-to-day decision making.

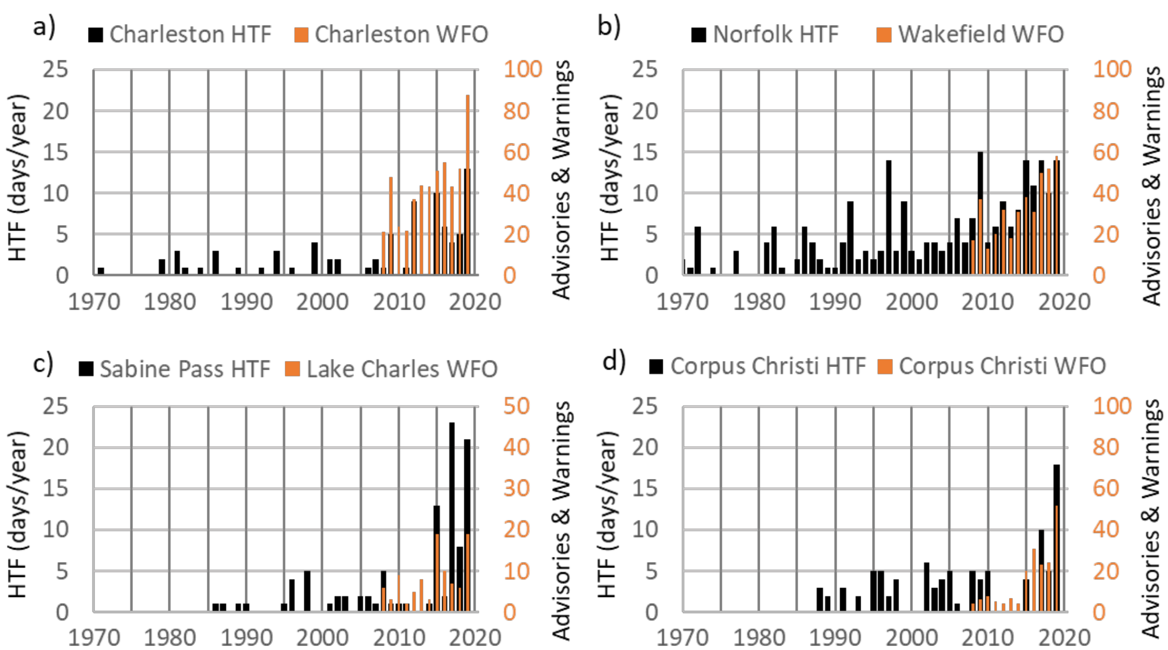

Figure 6. Annual (meteorological year: May–April) HTF frequencies measured at NOAA tide gauges at a) Charleston, S.C., b) Norfolk, Va. (Sewells Point), c) Sabine Pass, Tex. and d) Corpus Christi, Tex. with the number of annual coastal flood advisories and warnings from the encompassing coastal WFO[23] since 2008. Note: coastal flood advisories/warnings were issued prior to 2008, but only those with a valid time event code starting about 2008 are readily obtainable via archives by the University of Iowa.

[21] https://mesonet.agron.iastate.edu/archive/
[22] https://www.weather.gov/srh/nwsoffices
[23] https://www.weather.gov/srh/nwsoffices

3. 2020 HIGH TIDE FLOOD OUTLOOK

The 2020 outlook is a projected range of likely HTF days (expected value ±1 standard deviation) based upon the underlying statistical model. The projections are based on either: 1) a 19-year (2001–2019) climatological average where no trends exist, 2) an extrapolated linear or quadratic temporal regression trend fit, and/or 3) an extrapolated statistical fit that also uses the strength of ENSO quantified by the Oceanic Niño Index[24] in a bivariate regression. Statistical fits use data from 1950 (or the start of hourly observations) through 2019. All trend fits are significant above the 90% level (p value <0.1). Multi-model ensemble predictions of ENSO strength for 2020 and 2021 are obtained from the International Research Institute for Climate and Society in May 2020[25].

ENSO neutral conditions (ONI value of 0.07 °C) are predicted into 2021. As such, the 39 locations whose HTF frequency reveal significant dependence upon influence of El Niño (Figure 7a) are not projected to deviate much (i.e., above long-term average or temporal trend projected values). The annual HTF frequency history, quadratic trend characterization and the additional dependence upon ENSO is illustrated for San Diego, Calif. and Norfolk, Va. in Figure 7b. The 2020 outlook is also shown as the red shade, with 9–13 HTF days for Norfolk and 4–7 days for San Diego.

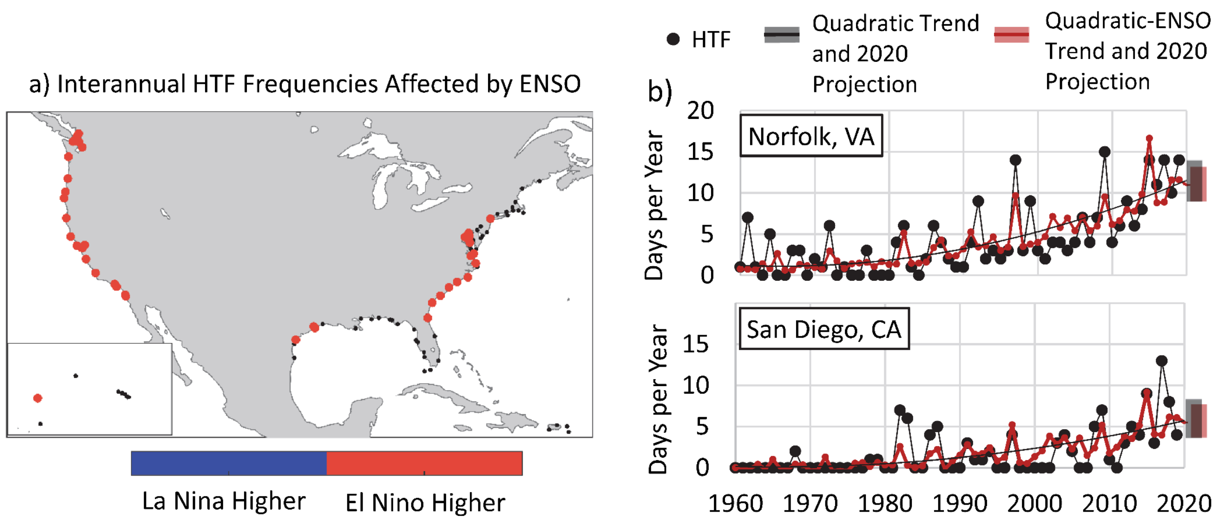

Figure 7. a) Locations where annual HTF frequencies from 1950 (or data start)–2019 are influenced by phases of the ENSO and b) annual HTF occurrence (black dots) with quadratic regression fits (black line) projected through 2020 (grey shading) in Norfolk, Va. and San Diego and bivariate regressions (red line-dot) that include ENSO effects (ONI) in addition to the temporal changes. The 2020 ENSO-based outlooks (red shading) include the 2020 ONI predicted value of about 0.07 °C.

The 2020 HTF outlook is shown in Figure 8, listed in Appendix 1, and displayed on a NOAA website[26]. The Northeast Atlantic and Western Gulf coastlines are projected to experience the most HTF in 2020 (median range values of 6–11 days and 5–11 HTF days, respectively), e.g., 9–

[24]ONI: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php
[25]Dynamical and statistical El Niño average of 0.07 predicted for the rest of 2020 meteorological year https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/?enso_tab=enso-sst_table.
[26] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

14 days in the New York City region and about the same (9–13 days) in Norfolk, Va., 9–17 days at Sabine Pass, Tex. and 7–12 days in Galveston, Tex. The Southeast Atlantic, Eastern Gulf, and Northwestern Pacific coastlines are projected to experience fewer overall HTF days (median range values of 3–6 days, 2–5 days, and 0–7 days, respectively), e.g., 3–6 days at Virginia Key (Miami, Fla. region), 2–5 days projected at Pensacola, Fla., and 1–5 days in Seattle, Wash. The Southwestern Pacific coastline is projected to experience 0–3 days of HTF, e.g., with 0–2 days at San Francisco and locally higher projections (4–7 days) for San Diego, Calif., which is unique for this region in that its HTF frequencies have begun to accelerate (Figures 3b, 7b). HTF flooding is not projected to occur along the Hawaiian Islands or the U.S. Caribbean or U.S. Pacific Island territories; the exceptions are Midway Island (0–2 days) and Kwajalein Atoll (0–1 days). This outlook does not consider wave and local rain effects. It should be noted that the predicted active (i.e., above average) Atlantic hurricane season[27] has the potential to affect some East and Gulf Coast locations with major (HTF) flooding.

[27] https://www.noaa.gov/media-release/busy-atlantic-hurricane-season-predicted-for-2020

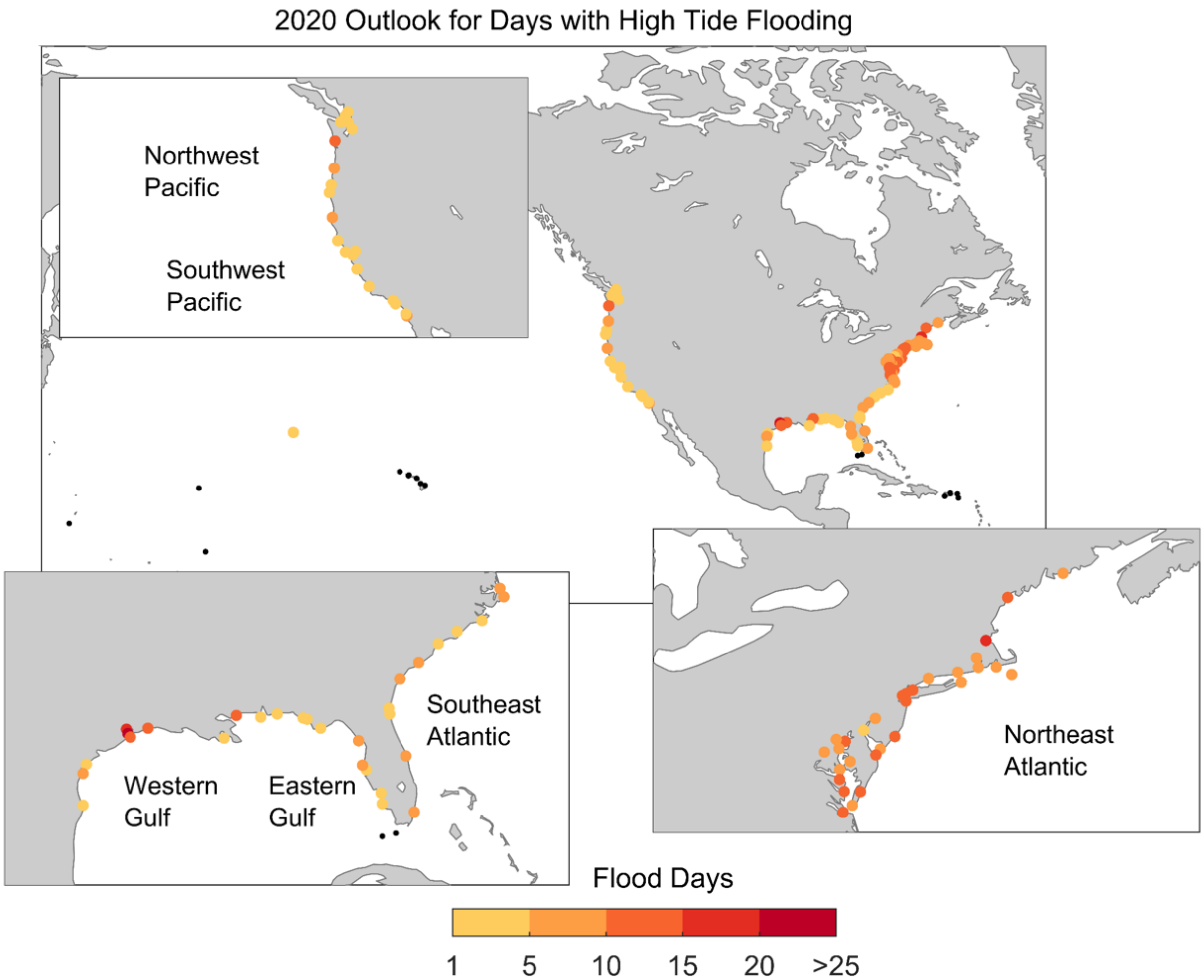

Figure 8. Outlook for number of HTF days projected to occur in 2020 (May 2020–April 2021) with color-codes associated with the 'expected' value, whereas the actual outlooks are given as a likely range (expected value ±1 standard deviation).

4. SUMMARY

NOAA tide gauges are measuring rapid changes in coastal flooding along U.S. coastlines due to RSL rise. The most noticeable impact of RSL rise is the increasing frequency of HTF, whose cumulative impacts are damaging to infrastructure and cause other economic impacts (transportation delays, businesses closed, tourism impacts, etc.) in coastal communities. Thus, HTF is of a growing concern to coastal residents, emergency managers, community planners and resource managers. In response, NOAA will continue to provide not only projections for the coming decades (e.g., Sweet et al., 2018) but also for the coming year to support planning and preparedness.

The national median HTF occurrence was 4 days in 2019, and the trend continues to accelerate (a nonlinear rise). The median number of HTF along U.S. coastlines was more than twice what it was in 2000 due to rising RSL, which nationally reached an all-time high of 0.34 m (1.1 ft) as measured since 1920 (last 100 years). Currently HTF is affecting mostly U.S. East and Gulf coastlines where annual HTF frequencies are upwards of twice the national rate. This is due to relatively high rates of RSL rise (57 of 62 locations broke records in 2019), propensity for storm surge/set up and flat and low-lying coastal elevations (Sweet and Park, 2014). Nineteen locations broke or tied their all-time HTF records (median of 13 days) in 2019, including most locations along the Texas coastline and at Miami, Savannah, Charleston and Annapolis to name a few. The trend in annual frequencies of HTF is accelerating (increasing nonlinearly) in 75% of East and Gulf Coast locations with most of the others linearly increasing. To put these records in perspective, as an example, it took the first 58 years of operation (since 1921) of the NOAA tide gauge in Charleston to record 13 HTFs; in 2019, it had that many alone.

Next year (May 2020–April 2021), acceleration in HTF and its impacts are expected to continue. Near-neutral ENSO conditions are not likely to substantially affect the number of flood days. Nationally, the median HTF outlook is 2–6 days (likely range). Regionally, the 2020 HTF outlook is:

- 6–11 days along the Northeast Atlantic
- 5–11 days along the Western Gulf
- 3–6 days along the Southeast Atlantic
- 2–5 days along the Eastern Gulf
- 0–7 days along the Northwestern Pacific
- 0–3 days along the Southwestern Pacific

By 2030, the national HTF frequency is likely to increase about 2–3 fold (national median of 7–15 days) compared to today without additional flood-management efforts (Sweet et al., 2018; Appendix 1). By 2050, HTF is likely to be 5- to 15-fold higher (national median of 25–75 days), and potentially in some locations reaching nearly 180 days per year, effectively becoming the new high tide.

5. ACKNOWLEDGEMENTS

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APPENDIX 1

Location-specific high tide flooding occurrences and projections. U.S. Regions, NOAA tide gauges, NOAA NOS high tide flood (HTF) threshold (meters above MHHW), annual HTF record through 2019, HTF frequency typical of year 2000 based upon trend fits, HTF measured in 2019 (May 2019–April 2020), the 2020 Outlook, peak HTF season and HTF range considered likely by 2030 and 2050 (Sweet et al., 2018).

Region	Tide Gauge Location	NOAA ID	HTF Height (m, MHHW)	Record HTF (days/year)	Year of Record	Typical HTF days in 2000	HTF days in 2019	2020 HTF Outlook	Peak HTF Season	2030 HTF Projection	2050 HTF Projection
Pacific Islands	Nawiliwili, HI	1611400	0.52	1	1992	0	0	0	---	0-0	1-30
	Honolulu, HI	1612340	0.52	0	---	0	0	0	---	0-0	2-30
	Mokuoloe, HI	1612480	0.53	0	---	0	0	0	---	0-0	3-30
	Kahului, HI	1615680	0.53	1	1963	0	0	0	---	0-0	4-55
	Kawaihae, HI	1617433	0.53	0	---	0	0	0	---	0-0	0-15
	Hilo, HI	1617760	0.53	1	1963, 2019	0	1	0	---	0-1	10-65
	Midway Island	1619910	0.52	6	2004	1	1	0-2	winter	3-4	7-55
	Apra Harbor, Guam	1630000	0.53	1	1992	0	0	0	winter	0-0	2-45
	Pago Pago, Am. Samoa	1770000	0.53	0	---	0	0	0	---	0-0	0-2
	Kwajalein Island	1820000	0.55	2	2017	0	0	0-1	winter	7-15	35-90
	Wake Island	1890000	0.53	2	2004	0	0	0	summer	0-2	6-55
Northeast Atlantic	Bar Harbor, ME	8413320	0.64	30	1977	6	6	3-14	winter	20-35	45-90
	Portland, ME	8418150	0.62	21	2009	5	5	7-13	winter	15-30	35-80
	Boston, MA	8443970	0.63	22	2017	6	7	11-18	winter	20-35	45-95
	Woods Hole, MA	8447930	0.53	10	2017	2	2	3-6	winter	8-20	35-135
	Nantucket Island, MA	8449130	0.54	11	2017	2	6	3-7	winter	7-15	30-125
	Newport, RI	8452660	0.55	11	2017	2	1	3-7	fall	10-25	40-120
	Providence, RI	8454000	0.56	15	2017	3	6	5-10	spring	15-30	40-105
	New London, CT	8461490	0.54	10	2017	2	2	3-7	fall	8-15	25-120
	Bridgeport, CT	8467150	0.59	11	2017	3	6	6-11	fall	15-30	35-105
	Montauk, NY	8510560	0.53	11	2017	3	5	3-7	fall	10-25	40-150
	Kings Point, NY	8516945	0.60	15	2012	5	10	8-14	fall	20-35	40-110
	The Battery, NY	8518750	0.56	15	2017	5	10	9-14	fall	20-40	50-135
	Bergen Point, NY	8519483	0.57	13	2017	3	8	8-13	fall	15-35	45-130
	Sandy Hook, NJ	8531680	0.56	20	2017	5	11	10-15	fall	25-45	70-160
	Atlantic City, NJ	8534720	0.56	22	2017	5	9	8-14	fall	20-35	65-155
	Cape May, NJ	8536110	0.57	14	2009	3	7	6-11	fall	15-30	55-135
	Philadelphia, PA	8545240	0.58	12	2011	3	9	4-8	fall	10-20	30-105
	Reedy Point, DE	8551910	0.57	5	2012	1	3	2-4	spring	6-15	25-100
	Lewes, DE	8557380	0.56	15	2017	4	9	7-12	fall	15-30	50-135
	Cambridge, MD	8571892	0.53	11	2019	1	11	5-8	fall	9-20	40-150
	Tolchester Beach, MD	8573364	0.52	17	2019	2	17	7-12	fall	15-25	50-160
	Baltimore, MD	8574680	0.52	12	2018	3	11	5-9	fall	15-25	50-155
	Annapolis, MD	8575512	0.52	18	2019	2	18	6-10	fall	15-25	55-170
	Solomons Island, MD	8577330	0.52	11	2019	1	11	6-9	fall	10-20	45-165
	Washington, DC	8594900	0.54	22	2018	3	10	6-11	spring	10-20	35-120
	Wachapreague, VA	8631044	0.56	17	2017	3	13	8-15	fall	15-25	40-120
	Kiptopeke, VA	8632200	0.54	11	1997	3	9	4-8	fall	10-20	40-120
	Lewisetta, VA	8635750	0.52	20	2019	2	20	9-14	fall	15-25	50-170
	Windmill Point, VA	8636580	0.53	17	2019	2	17	10-16	fall	15-25	45-160
	Sewells Point, VA	8638610	0.53	15	2009	5	14	9-13	fall	20-25	65-170
Southeast Atlantic	Duck, NC	8651370	0.55	18	2009	5	9	6-11	fall	20-30	55-135
	Oregon Inlet, NC	8652587	0.51	8	2009, 2019	1	8	4-7	fall	7-15	35-165
	Beaufort, NC	8656483	0.54	10	2015	1	4	1-3	fall	6-15	25-100
	Wilmington, NC	8658120	0.56	14	2018	1	0	2-5	fall	4-9	15-65
	Springmaid Pier, SC	8661070	0.57	11	2015	3	6	2-6	fall	10-20	30-75
	Charleston, SC	8665530	0.57	13	2019	2	13	4-7	fall	10-20	35-90
	Fort Pulaski, GA	8670870	0.59	13	2019	2	13	4-8	fall	15-25	40-95
	Fernandina Beach, FL	8720030	0.58	9	2015	3	7	3-6	fall	9-15	25-70
	Mayport, FL	8720218	0.56	6	2015	1	4	1-3	fall	5-10	20-65
	Trident Pier, FL	8721604	0.54	12	2015	0	8	7-12	fall	7-15	20-65
	Virginia Key, FL	8723214	0.52	9	2019	0	9	3-6	fall	2-5	10-55
	Vaca Key, FL	8723970	0.51	1	2017	0	0	0	fall	1-3	9-65
	Key West, FL	8724580	0.52	2	1944	0	0	0	fall	0-2	8-60

Region	Tide Gauge Location	NOAA ID	HTF Height (m, MHHW)	Record HTF (days/year)	Year of Record	Typical HTF days in 2000	HTF days in 2019	2020 HTF Outlook	Peak HTF Season	2030 HTF Projection	2050 HTF Projection
Eastern Gulf	Naples, FL	8725110	0.54	3	2017	1	1	0-2	fall	2-4	9-55
	Fort Myers, FL	8725520	0.52	6	2017	1	1	1-4	fall	3-6	15-80
	St. Petersburg, FL	8726520	0.53	4	2016, 2018	1	3	2-3	fall	3-7	15-85
	Clearwater, FL	8726724	0.54	5	2018	0	4	4-6	fall	2-4	10-55
	Cedar Key, FL	8727520	0.55	11	2019	2	11	4-7	fall	5-10	20-70
	Apalachicola, FL	8728690	0.52	10	2018	2	5	2-6	fall	4-8	10-50
	Panama City, FL	8729108	0.52	7	2005	1	2	1-4	fall	4-7	10-65
	Panama City Beach, FL	8729210	0.52	8	2005	1	3	1-5	fall	4-6	10-50
	Pensacola, FL	8729840	0.52	10	2005	1	3	2-5	fall	4-8	15-70
	Dauphin Island, AL	8735180	0.52	10	2019	2	10	2-6	fall	5-10	30-95
	Bay Waveland, MS	8747437	0.52	14	2017	3	10	7-13	fall	25-40	110-205
Western Gulf	Grand Isle, LA	8761724	0.43	6	2008, 2019	1	6	2-5	fall	9-20	145-270
	Sabine Pass, TX	8770570	0.52	23	2017	0	21	9-17	fall	8-15	60-160
	Morgans Point, TX	8770613	0.52	22	2019	3	22	11-19	fall	30-45	110-215
	Eagle Point, TX	8771013	0.51	64	2019	0	64	32-48	fall	---	---
	Galveston Pier 21, TX	8771450	0.52	18	2017, 2019	3	18	7-12	fall	15-30	100-215
	Rockport, TX	8774770	0.50	7	2010, 2018	1	5	1-4	fall	7-15	60-160
	Corpus Christi, TX	8775870	0.52	18	2019	2	18	2-9	fall	10-20	55-150
	Port Isabel, TX	8779770	0.52	9	2019	1	9	1-4	fall	7-15	40-135
Southwest Pacific	San Diego, CA	9410170	0.57	13	2017	2	4	4-7	winter	10-15	30-60
	La Jolla, CA	9410230	0.57	8	2015	2	0	1-4	winter	10-15	25-55
	Los Angeles, CA	9410660	0.57	6	2015	1	3	1-3	winter	6-10	15-40
	Santa Monica, CA	9410840	0.57	7	2015	2	2	0-3	winter	7-15	20-50
	Port San Luis, CA	9412110	0.57	6	1982	1	1	0-2	winter	3-5	8-25
	Monterey, CA	9413450	0.57	7	1982	1	1	0-2	winter	3-5	10-30
	San Francisco, CA	9414290	0.57	6	1982	0	0	0-1	winter	2-3	6-25
	Alameda, CA	9414750	0.58	10	1982	1	0	0-2	winter	1-2	3-15
	Point Reyes, CA	9415020	0.57	8	2016	2	1	0-3	winter	4-7	15-40
	Port Chicago, CA	9415144	0.56	15	1982	1	0	0-3	winter	2-2	4-15
	Arena Cove, CA	9416841	0.57	14	1997	2	1	0-4	winter	5-7	10-30
Northwest Pacific	Humboldt Bay, CA	9418767	0.58	15	2016	4	4	4-10	winter	15-20	45-80
	Port Orford, CA	9431647	0.59	23	1997	5	1	0-8	winter	9-15	15-40
	Charleston, OR	9432780	0.59	27	1997	6	2	0-8	winter	9-15	15-35
	South Beach, OR	9435380	0.60	25	1997	7	1	1-10	winter	15-20	30-50
	Toke Point, WA	9440910	0.61	33	1997	12	7	4-17	winter	15-20	20-35
	Port Angeles, WA	9444090	0.59	12	1982	4	1	0-5	winter	5-7	8-15
	Port Townsend, WA	9444900	0.60	13	1982	3	1	0-4	winter	5-6	9-20
	Seattle, WA	9447130	0.64	11	1997	2	1	1-5	winter	4-6	9-20
	Cherry Point, WA	9449424	0.61	15	1982	3	0	0-5	winter	4-5	5-10
	Friday Harbor, WA	9449880	0.60	17	1982	4	1	0-6	winter	6-7	9-20
Caribbean	Lime Tree Bay, VI	9751401	0.51	1	1999	0	0	0	fall	0-0	0-3
	Charlotte Amalie, VI	9751639	0.51	1	1995	0	0	0	fall	0-0	0-7
	San Juan, PR	9755371	0.52	1	2017	0	0	0	fall	0-0	0-9
	Magueyes Island, PR	9759110	0.51	1	1998	0	0	0	fall	0-0	0-3

ACRONYMS

cm	Centimeter
°C	degree Celsius
ENSO	El Niño Southern Oscillation
GT	Great Diurnal Range
HTF	high tide flooding
m	meter
mm	millimeter
MHHW	mean higher high water
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWS	National Weather Service
ONI	Oceanic Niño Index
RSL	relative sea level
WFO	Weather Forecasting Offices