Coastal Storm Surge and Precipitation in Coastal Connecticut: a Preliminary Assessment

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Abstract

We examine observations of sea level and precipitation at Bridgeport, CT, to characterize the likelihood of flooding resulting from both precipitation and coastal storm surge. Data obtained from national archives show that anomalous sea level and precipitation levels are uncorrelated. High values (greater than the 10% per year return levels) of rainfall have not been observed to co-occur with his sea levels since the joint probability is low. However, likely sea level rise will substantially increase the frequency of high sea levels and, even without changes in the precipitation, substantially increase to probability of the joint probability of high sea level and high precipitation. A careful reassessment of the effectiveness of existing storm water management systems in coastal towns will be necessary, especially in areas that have recently been subject to flooding by rainfall..

1. Introduction

Climate change and sea level rise will lead to increases in the risk of flooding in all coastal areas. The designs of strategies and choices among plausible options, for flood risk reduction must be informed by statistics of sea level fluctuations and precipitation rates. The level, H_{100}, that has a likelihood of 1/100 of being exceeded in any year is frequently used for design and planning. At Bridgeport, CT, for example, NOAA (https://tidesandcurrents.noaa.gov/est/stickdiagram.shtml?stnid=8467150) estimate that $H_{100} = 9.08\ ft$, relative to the datum NAVD88. Similarly, a variety of rainfall statistics are published by the National Weather Service (NWS) at https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=ct for Connecticut and at Bridgeport the a daily rainfall total of 7 inches has a 1/100 probability of being exceeded.

The design of coastal flood defenses often include the construction of walls or berms around the coastline. However, that may reduce the rate of runoff of rainwater and resilience projects must then include storm water management. Whether retention ponds or pumps are required, and their design and capacity, will generally depends upon the joint probability of the exceedance of thresholds in both precipitation and sea level. There have been few studies of these statistics. This paper use observations from Bridgeport, CT, to develop a methodology to characterize the risk of coastal flooding. In the following section we describe the data sources and the character of the observations. We then present an analysis, summarize the results and discuss implications and priorities for further work.

2. Sea Level and Precipitation Data

Observations of sea level have been acquired at hourly intervals at Bridgeport harbor by the National Oceanic and Atmospheric Administration (NOAA), and predecessor agencies, since 1968 and are shared through a convenient interface at https://coastwatch.pfeg.noaa.gov/erddap/tabledap/. The observations were adjusted to the North American Vertical Datum of 1988 (NAVD88) and displayed in Figure 1. The highest value reached in each calendar day were identified and these are shown in by the red '+' symbols. The long-term trend associated with increasing global mean sea level was estimated by linear regression and is shown by the thin red line. The trend was then subtracted from the daily maxima for the return interval analyses. Note that the elevations should be adjusted for future mean sea levels when used to evaluate future risk.

The $M = 17965$ daily maxima, η_i, constitute 49.2 years of observations. These were indexed by increasing magnitude (i.e. $i = \{1, \dots M\}$) and then plotted in Figure 2 as $\eta_i(T_i)$, where $T_i = 49.2 \times (i + 1)/M$ in order to construct an empirical return interval diagram. The inverse of the return interval T_i represents the probability of that the sea level will exceed η_i in any year. NOAA's Mean High High Water (MHHW) is shown by the dashed red line and the 1 and 10 year return elevations are shown by the green triangle and the blue diamond. Since data at long return intervals are sparse, mathematical functions are generally used to smooth and extrapolate $\eta_i(T_i)$. Zervas (2013) explains this approach in great detail. The red square on the right of Figure 2 shows the NOAA, Zervas (2013), extrapolated estimate of $\eta(T = 100)$, i.e. the hundred year or 1% flood level. Note that a variety of choices for the smoothing and extrapolation function are in use and these lead to small differences between the levels adopted by the Federal Emergency Management Agency (FEMA) and NOAA. An alternative method was employed by O'Donnell and O'Donnell (2012). Since the uncertainty in large at the 100 year level, differences between these methods is not significant.

The NOAA National Climatic Data Center archives precipitation observations are numerous stations in the United States. Menne et al. (2012) describes the data validation procedures and the database format. Figure 3 shows the measurements of the 24 hour precipitation totals available at the Sikorsky Memorial

Airport in Bridgeport, CT. A total of 24660 values, P_i, equivalent to 67.6 years, are shown. No precipitation was reported on 68% of these days. Using the same approach as discussed above, the return interval diagram for daily precipitation, $P_i(T_i)$ where $T_i = 67.6 \times (i+1)/M$, was constructed and is shown in Figure 4. The red square shows the NWS estimate of $P(T = 100)$ and the green triangle and blue diamond again show the P(T=1) and P(T=10) year 24 hour precipitation totals.

3. Joint Probability Analysis

To examine the co-occurrence of high precipitation at times of anomalously high water the overlapping interval of two series, shown in Figures 1 and 3, were identified and plotted in Figure 5. Note that the maximum sea level on days when the rainfall was zero are shown on the horizontal axis by red squares and the level of the Mean High High Water (MHHW) is shown by the green line. A total of 16805 days (46 year) are plotted. The data evidently cluster between daily maximum elevations of 2 and 6 feet and below 2 inches of daily precipitation. There is little evidence in Figure 5 that there is correlation between the occurrence of precipitation and high water levels.

Rainfall was recorded on only 22 days in which the sea level exceeded the 1 year return interval of 6.1 ft. These points are to the right of the dashed red vertical line in Figure 5. The data, therefore, suggest that the probability of rainfall on days when the sea level exceeds 6.2ft NAVD is approximately 0.1 % each year. The maximum value of the precipitation on those days was less than 2 inches. It is also clear in Figure 5 that on all the days during which the precipitation exceeded the 1 year return level (points above the dashed horizontal red line) the high water level was below the 1 year return level (i.e. to the left of the dashed red vertical line).

4. Discussion and Conclusions

This data analysis shows that there is no evidence in the observational record at Bridgeport, CT, a station that has long data records and is representative of coastal Connecticut, that the occurrence and extreme values of high sea level and 24 hour precipitation are correlated. All days with anomalously high precipitation occur when the maximum sea level is in the normal range (i.e. less than the annual return level). This suggests that the design for high rainfall events should not necessarily anticipate the need to accommodate a very high sea level as well. Further, this result suggest that the construction of an empirical joint probability distribution function, analogous to that developed in O'Donnell and O'Donnell (2012) would be useful. It must be noted that though the data records at Bridgeport, CT, are quite long relative to most other sites, they are inadequate to describe low probability events. It is also important to note that high precipitation rates do not lead to flooding everywhere. The local geomorphology and development patterns play important roles. Project plans should consider the potential consequences of extremely unlikely events.

There is strong scientific evidence that the global mean sea level is likely to rise in the future as the climate warms. O'Donnell (2018) studied data from the Connecticut shoreline and the results of global change models and recommended that coastal towns anticipate that the mean sea level in 2050 will be up to 20 inches above the mean of the interval 1983-2001 (the National Tidal Datum Epoch). Similarly, the Connecticut Physical Science Assessment Report (Seth et al., 2019) examined the predictions of a wide range of models for future precipitation and temperature changes in Connecticut. They found that the mean of the model projections for the annual precipitation in Connecticut in 2050 to be 4 inches per year above current levels. They also used downscaling approaches to project changes in the 24 hour precipitation level with a 10 year return interval and found that an increase of 2 inches per day.

If we assume that the statistics of the variability of sea level remain unchanged as the mean level increases, we can estimate the increase in the probability that the sea the level will exceed the current 10 year return level (7.4 ft) by simply adding 20 inches to the observed data and constructing a revised return interval diagram. The result is that the 7.4 ft level will be exceeded 2.5 times per year. Further, the probability that it will rain on days that the sea level exceeds 7.4 ft increases from 0.1% to 5.7%. Note that this factor of 50 increase in the probability occurs even without an increase in rainfall. This will require an assessment of the effectiveness of existing storm water management systems in the coastal zone.

References

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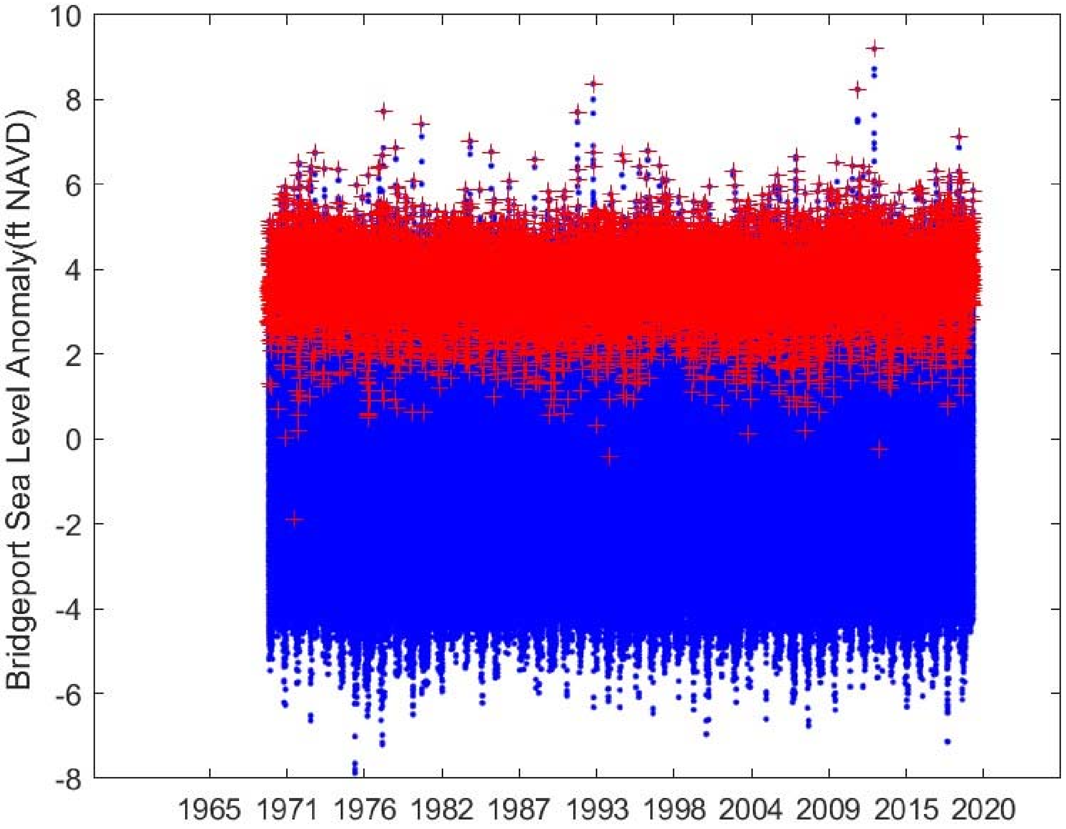

Figure 1. Observations of the sea level at the Bridgeport, CT, tide gage at hourly interval (blue) and referenced to NAVD 88 obtained from https://coastwatch.pfeg.noaa.gov/erddap/tabledap/. The daily maxima are shown by the red '+' symbols.

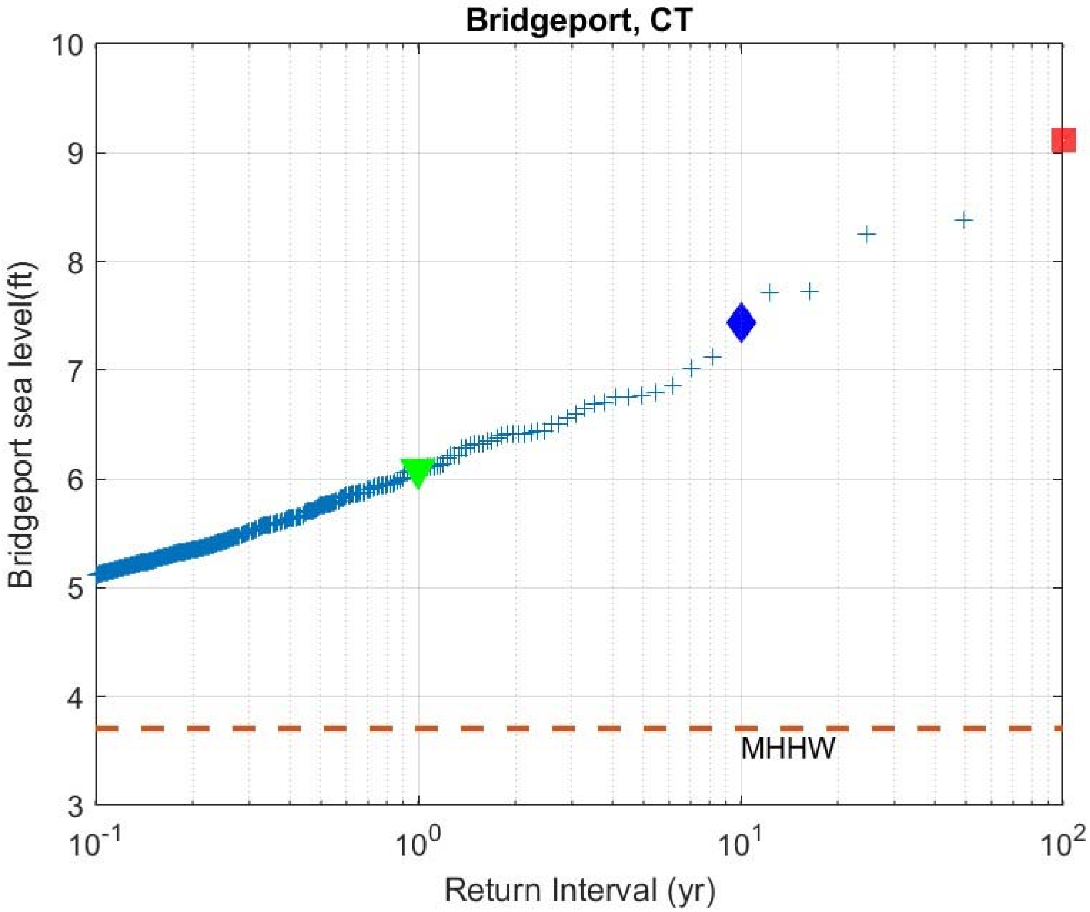

Figure 2. A "return interval diagram" for the daily high water elevation relative to NAVD 88 measured at Bridgeport, CT. The green triangle and blue diamond show the 1 and 10 year return levels (6.1 ft, and 7.4 ft) obtained by interpolation of the data. The red square at 100 years is the elevation with a 1% risk of exceedance reported by NOAA at https://tidesandcurrents.noaa.gov/est/stickdiagram.shtml?stnid=8467150.

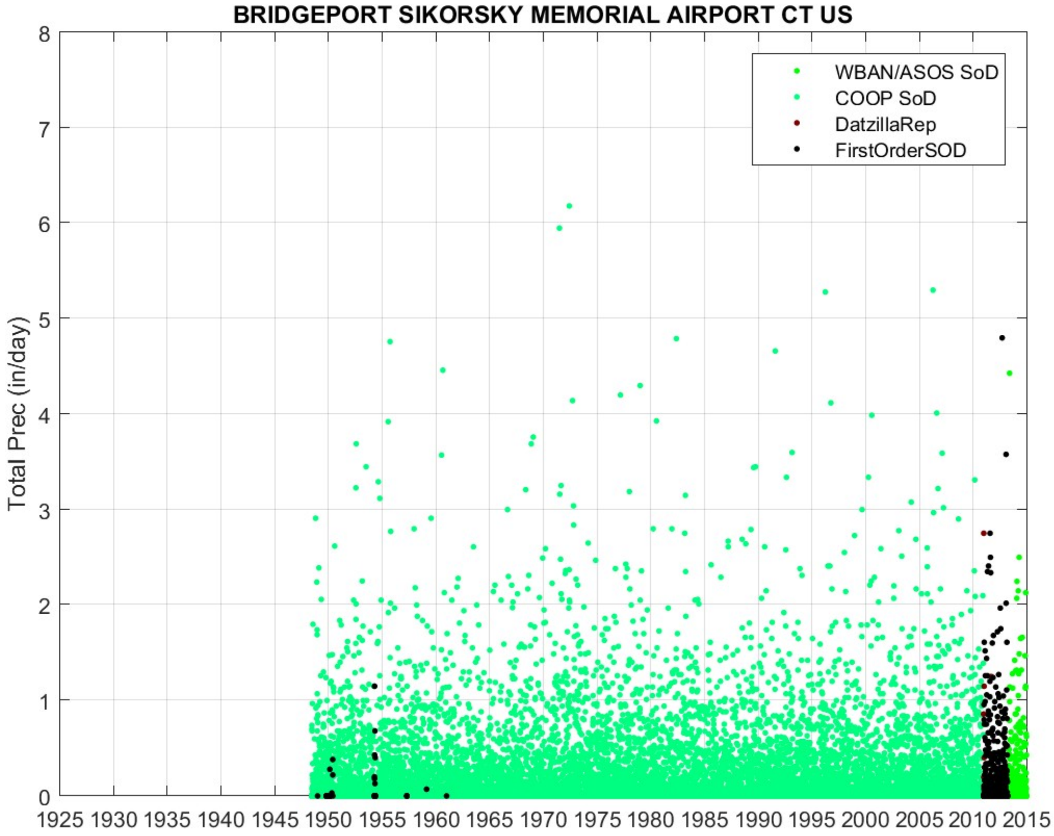

Figure 3. Observations of the daily total precipitation at the Bridgeport (Sikorsky Memorial Airport) gage obtained from the (green) the NOAA National Climatic Data Center (see Menne et al. 2012).

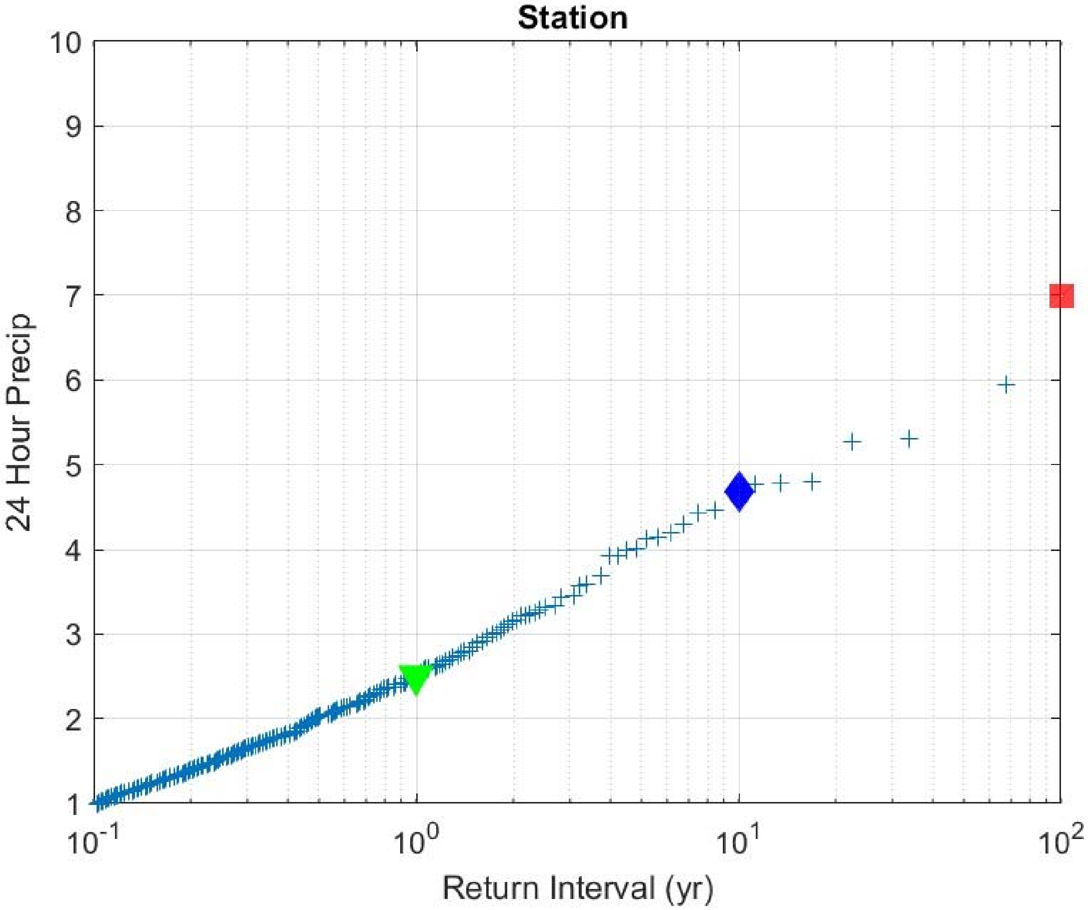

Figure 4. The "return interval diagram for the daily total precipitation at the Bridgeport, CT, precipitation gage at Sikorsky airport. The green triangle and blue diamond show the 1 and 10 year return levels (2.5 in, and 4.7 in) obtained by interpolation of the data. Data were obtained from the NOAA National Climate Data Center.

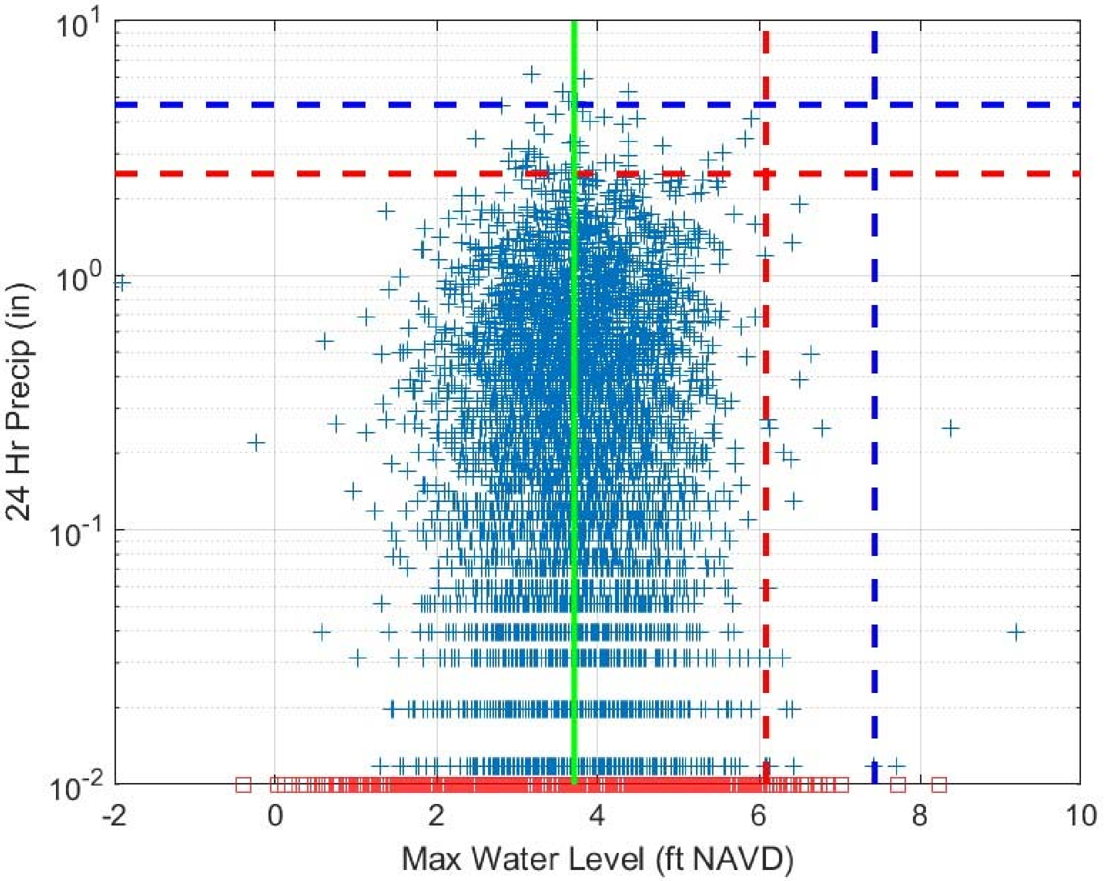

Figure 5. The variation of 24-hour precipitation rates are Bridgeport, CT, with sea level. The red squares show the range of sea level maxima on days when the precipitation was zero .The red and blue vertical dashed lines show the annual and decadal exceedance values for sea level and the horizontal dashed lines show he same thresholds but for 24-hour precipitation. These levels were estimated using Figures 2 and 4.