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Likelihood of High Sea Levels in the Hawaiian Islands

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Besides being at risk from four natural phenomena—earthquake, volcanic eruptions, tsunamis, and hurricanes—Hawaii is also threatened by coastal erosion, sea-level rise, coastal stream flooding, and extreme seasonal high wave energy. Examples of some common coastal Hazards in Hawaii are presented in Figure 1. The occurrence of these dangerously high water levels and associated erosion and inundation is an extremely important issue, and there is a demand for such information on seasonal-to-longer time scales. This information is significant to decision analyses for coastal hazard management. The objective of this article is to provide an improved climatology of seasonal extremes of sea levels on long-term time scales for the Hawaiian Islands.

Research-quality, tide-gauze data were used (Source: University of Hawaii Sea Level Center; *http://ilikai.soest.hawaii.edu/uhslc/rqds.html*) and the varying likelihood of extremely high sea levels was examined using the hourly sea-level data. The Generalized Extreme Value (GEV) model is used to estimate the returns of expected extremes of high sea level. These results show that the extreme events in these islands vary both temporally and spatially. These seasonal increases are likely to cause tidal inundations followed by increased erosion, which may result in considerable damage to roads, harbors, unstable sandy beaches, and other major infrastructures. Finally, the results are compared and evaluated with respect to global sea-level rise. For this purpose, reports by the Intergovernmental Panel for Climate Change (IPCC) are discussed.

Synopsis of sea level extremes

Sea-level extremes for seasonal [January-February-March (JFM), April-May-June (AMJ), July-August-September (JAS), and October-November-December (OND)] scale on 1- to 100-year return periods were plotted for Honolulu, Kahului, Mokuoloe, Nawiliwili, and Hilo (see Fig. 2 for

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location), with both upper and lower bounds at the 90% confidence level. For simplicity, only the plot for high sea level in Honolulu is presented (Fig. 3). The upper and lower bounds of sea-level extremes for all other stations are presented in Table 1.

Figure 1: Common coastal hazards in Hawaii
(Source: *http://www.soest.hawaii.edu/coasts/presentations/*)

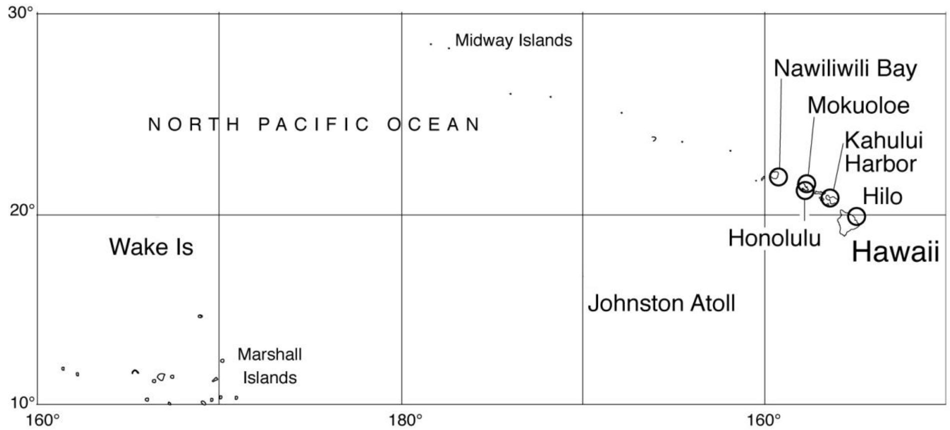

Figure 2: Geographical locations of Hawaiian Islands

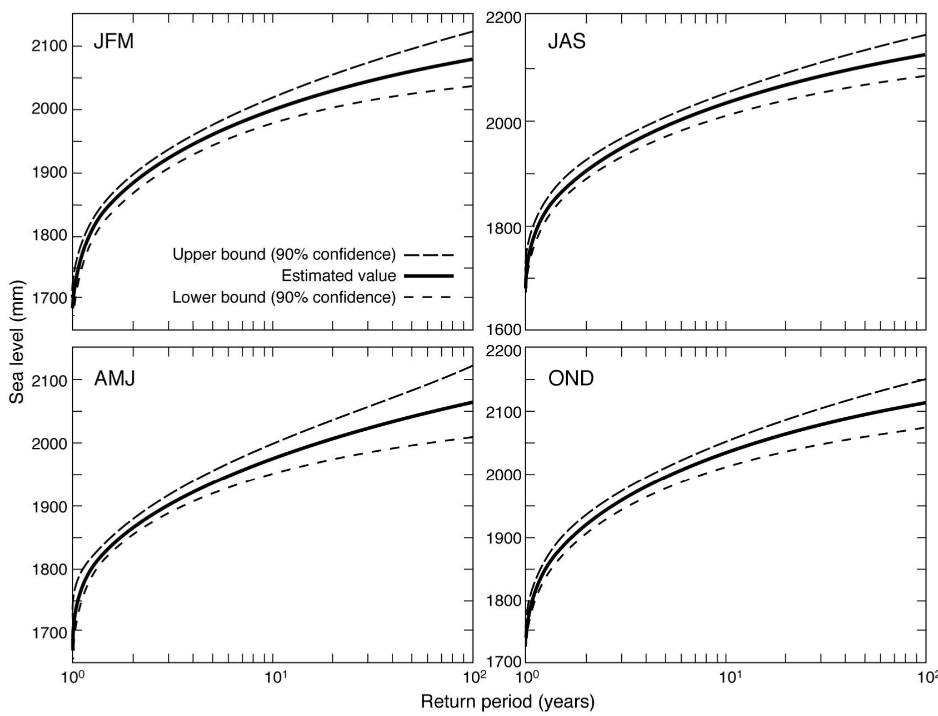

Figure 3. The highest (maximum) sea level values at station Honolulu on seasonal (JFM, AMJ, JAS, OND) scale (at 1- to 100-years return period). The solid line shows the estimated value by analyzing the true observations. The dashed and dotted lines are the upper and lower bounds at 90% confidence level.

Table 1: Lower and upper bounds of the sea level extremes (in mm) at 20- and 100-year return periods

Stations	*Sea level extremes (mm)* (100 mm = 3.94 inch)							
	20-year return period				**100-year return period**			
	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND
Honolulu	76~126	65~126	60~109	53~103	111~198	98~211	107~186	89~172
Kahului	99~165	93~158	77~110	96~167	106~220	120~233	89~144	133~262
Mokuoloe	89~120	84~172	75~126	87~146	90~135	128~284	92~174	113~203
Nawiliwili	90~142	85~122	80~332	73~107	109~209	116~184	98~770	94~143
Hilo	142~265	121~199	134~183	116~157	181~440	157~287	158~242	140~202

Note that JFM, AMJ, JAS, and OND stand for January-February-March, April-May-June, July-August-September, and October-November-December.

The deviations of sea-level extremes, which are derived by subtracting the average values from the estimated sea level extremes, are presented in Table 2. Positive deviations indicate a rise from the climatological mean value, while negative deviations indicate a fall. Findings revealed that all the Hawaiian stations are likely to experience positive deviations (extremes) in all the successive seasons on 20- to 100-year return periods. The deviations for most of the Hawaiian Islands (except Nawiliwili and Hilo) are found to be moderately elevated (close to 200 mm). From a historical perspective, observations reveal that any rise of 100-200 mm may cause slight local inundations; a rise greater than 300 mm can cause tidal inundations followed by increased erosion and damage to roads, harbors, and unstable sandy beaches.

Table 2: Deviations of sea-level extremes (in mm) at 20- and 100-year return periods

Stations	*Sea level deviations (mm)** (100 mm = 3.94 inch)							
	20-year return period				**100-year return period**			
	JFM	AMJ	JAS	OND	JFM	AMJ	JAS	OND
Honolulu	102	96	86	80	152	152	145	130
Kahului	131	130	94	136	148	181	114	198
Mokuoloe	102	134	103	121	103	219	133	159
Nawiliwili	118	108	194	95	153	150	<u>329</u>	121
Hilo	201	162	161	139	288	221	196	172

*Note that positive deviations indicate a rise from the climatologically mean value.

On a 100-year return period, an extreme of 329 mm is visible in the JAS season for Nawiliwili (Table 2). The reason for these high values is that some of these stations have recorded large and significant increases in their tidal range as a result of storms. Hurricane *Iniki* hit Nawiliwili in 1992. Formed during the strong El Niño of 1991–1994, *Iniki* was one of eleven Central Pacific tropical cyclones during the 1992 season. The eye of Hurricane *Iniki* passed directly over the island of Kaua'i on September 11, 1992, as a Category 4 hurricane on the Saffir-Simpson Hurricane Scale. As a result, these two stations recorded large sea-level increase in JAS. The probable reason for an abrupt rise at a specific station is that typhoons are mesoscale systems and only affect a narrow swath under the storm path. Despite increases at these two stations, other neighboring stations recorded no considerable variations caused by the same storm event. However, it is also true that other stations might experience the same storm surges in the future. Therefore, for planning purposes, the extreme events of Nawiliwili should be seen as a problem for the whole region.

Global Sea-level Rise and Potential Implications in Hawaiian Islands

The recent IPCC report on climate change illustrates that global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year from 1961 to 2003 (IPCC, 2007a). The rate was faster from 1993 to 2003: about 3.1 [2.4 to 3.8] mm per year. The IPCC report has already projected that coasts will be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas. By the 2080s, many millions more people are projected to be flooded every year due to sea-level rise. Densely populated and low-lying areas where adaptive capacity is relatively low, which already face other challenges such as tropical storms or local coastal subsidence, are especially at risk. The numbers affected will be largest in the mega-deltas of Asia and Africa, and small islands (Hawaii and others) are equally vulnerable. For the Hawaiian Islands, such impacts include increased coastal and beach erosion, higher and more frequent storm-surge flooding with more extensive coastal inundation, changes in surface-water quality and groundwater availability, increased loss of property and coastal habitats, increased flood risk and potential loss of life, loss of cultural resources and values, impacts on agriculture and aquaculture through decline in soil and water quality, and loss of tourism, recreation, and transportation functions. Many of these impacts will be severely detrimental to coastal communities in Hawaii.

In the future, Arctic warming and the melting of polar glaciers will be considerable. There are recent reports that if the dynamic effect of this ice-melt contribution is considered to project the global sea level rise, the rise would be approximately three times as much as projected currently by the IPCC-AR4 assessment. This is an alarming sign and may aggravate the problem of inundation in Hawaii further. Therefore, coastal hazards will necessitate a new planning initiative in Hawaii to manage these risks.

N. B. For a full version of this article, see "Chowdhury M R., Chu P-S, Schroeder T, and Xin Z (2008): Variability and predictability of sea-level extremes in the Hawaiian and U.S.-Trust Islands—A knowledge base for coastal hazards management, ***Journal of Coastal Conservation,*** *12:93-104****,*** *Springer".*

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