Section A1: Tables and Figures

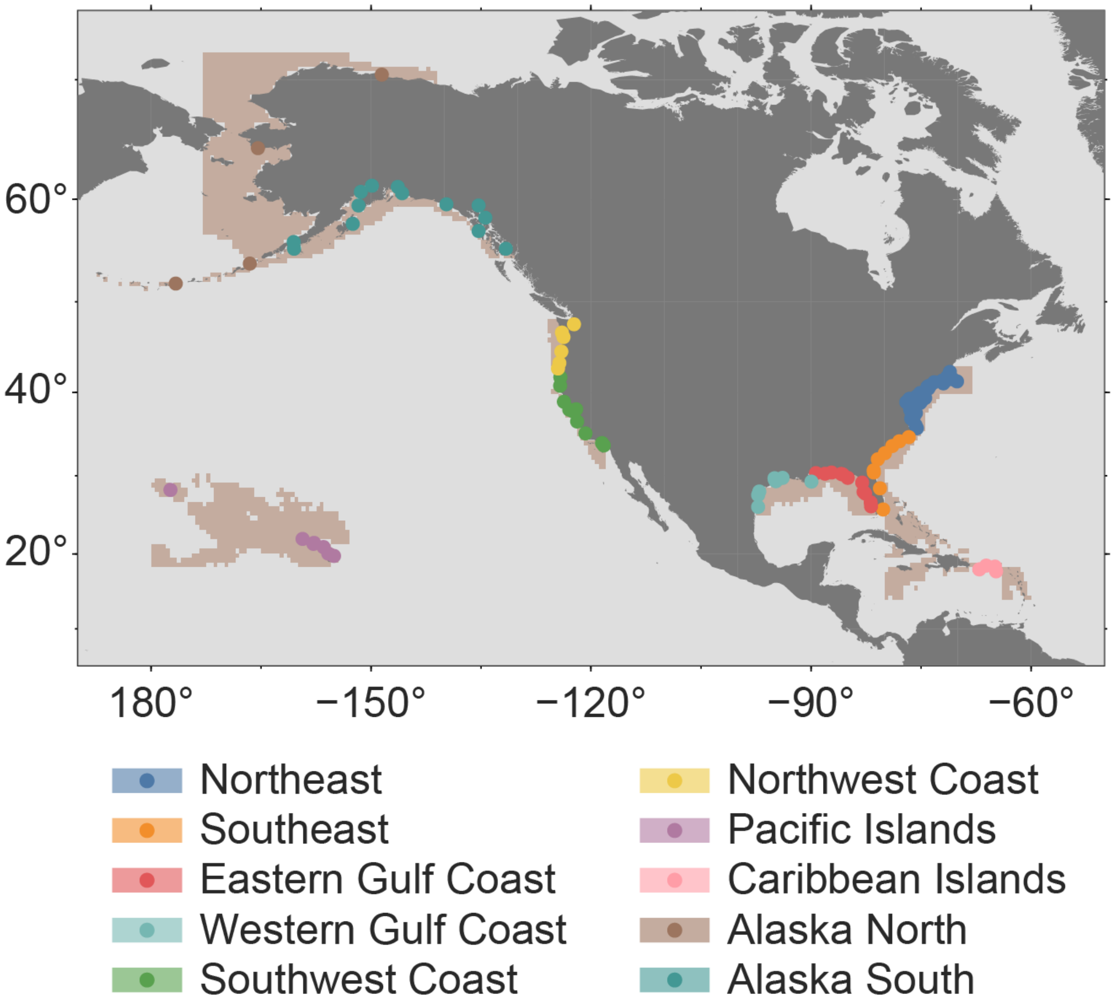

Figure A1.1: Region definitions for observation-based extrapolations and scenarios in Section 2. These regions are used both to group tide gauges and also to generate regional averages for the gridded scenarios. A bathymetry mask is used to define the regions for the gridded scenarios.

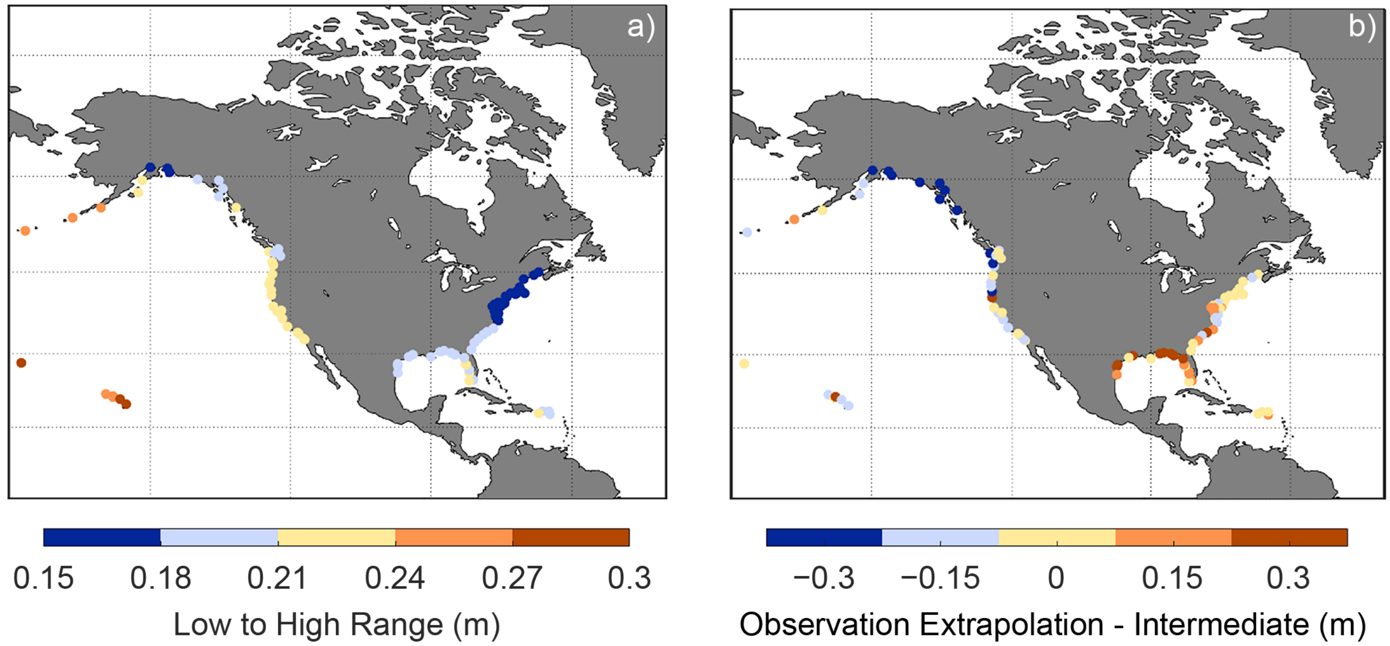

Figure A1.2. Shown for each tide gauge record with at least 30 years of record length between 1970 and 2020 are a) range, in meters, between median projection of Low and High Scenarios in 2050, and b) difference, in meters, between median observation-based extrapolation and Intermediate scenario in 2050.

Table A1.1: Projections methods employed.

Driver of GMSL or RSL change	Kopp et al. (2014) projection method (used in Sweet et al., 2017)	AR6 (Fox-Kemper et al., 2021) projection methods (used here)
Thermal expansion	CMIP5 ensemble drift-corrected zostoga	Two-layer model with climate sensitivity calibrated to the IPCC assessment and expansion coefficients calibrated to emulate CMIP6 models
Greenland ice sheet	*Likely* range from IPCC AR5, with shape of tails based on structured expert judgment (Bamber and Aspinall, 2013)	1. Emulated ISMIP6 simulations through 2100 (Edwards et al., 2021), extended after 2100 based on constant post-2100 rates 2. Structured expert judgment (Bamber et al., 2019)
Antarctic ice sheet	*Likely* range from IPCC AR5, with shape of tails based on structured expert judgment (Bamber and Aspinall, 2013)	1. Emulated ISMIP6 simulations through 2100 (Edwards et al., 2021), extended after 2100 with constant rates based on the IPCC AR5 parametric Antarctic Ice Sheet model (Church et al., 2013) 2. LARMIP-2 simulations (Levermann et al., 2020) augmented by AR5 surface mass balance model (Church et al., 2013), extended past 2100 based on constant rates 3. Single ice-sheet model incorporated marine ice cliff instability (DeConto et al., 2021) 4. Structured expert judgment (Bamber et al., 2019)
Glaciers	Distribution based on Marzeion et al. (2012) surface mass balance model	Emulated GlacierMIP (Marzeion et al., 2020; Edwards et al., 2021) extended after 2100 with IPCC AR5 parametric model refit to GlacierMIP (Marzeion et al., 2020)
Land water storage	Groundwater depletion: Population/groundwater depletion relationship calibrated based on Konikow (2011) and Wada et al. (2012) Water impoundment: Population/dam impoundment relationship calibrated based on Chao et al. (2008)	Groundwater depletion: Updated population/groundwater depletion relationship calibrated based on Konikow (2011) and Wada et al. (2012, 2016) Water impoundment: Population/dam impoundment relationship calibrated based on Chao et al. (2008), adjusted for new construction, following Hawley et al. (2020) for 2020 to 2040
Ocean dynamic sea level	Distribution derived from CMIP5 ensemble zos field	Distribution derived from CMIP6 ensemble zos field after linear drift removal
Gravitational, rotational, and deformational effects	Sea-level equation solver (Mitrovica et al., 2011) driven by projections of ice-sheet and glacier changes	Sea-level equation solver (Slangen et al., 2014) driven by projections of ice-sheet, glacier, and land water storage changes
GIA and other drivers of VLM	Spatiotemporal statistical model of tide-gauge data	Spatiotemporal statistical model of tide-gauge data (updated from Kopp et al., 2014)

Table A1.2: Offsets, in meters, for different time periods and for each region considered in Section 2. These offsets are assessed using the trajectory determined from the available tide-gauge data in each region.

	1992–2000	2000–2005	2005–2020
Contiguous U.S.	0.02	0.03	0.08
Northeast	0.03	0.02	0.09
Southeast	0.03	0.02	0.09
Eastern Gulf	0.03	0.02	0.1
Western Gulf	0.05	0.04	0.14
Southwest	0.01	0.01	0.05
Northwest	0.01	0.01	0.04
Hawaiian Islands	0.02	0.02	0.06
Caribbean	0.02	0.01	0.06

Table A1.3: Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
Pacific	39509	1611400	Nawiliwili, HI	21.95	−159.36	0.558	0.244	1.7	1983–2001	0.522	0.817	1.192
	39511	1612340	Honolulu, HI	21.31	−157.87	0.580	0.248	1.3	1983–2001	0.523	0.817	1.193
	39511	1612480	Mokuoloe, HI	21.43	−157.79	0.646	0.265	2.0	1983–2001	0.526	0.819	1.196
	39153	1615680	Kahului, HI	20.90	−156.48	0.686	0.252	2.1	1983–2001	0.527	0.821	1.197
	39154	1617433	Kawaihae, HI	20.04	−155.83	0.659	0.237	7.9	1983–2001	0.526	0.820	1.196
	38795	1617760	Hilo, HI	19.73	−155.06	0.731	0.272	3.1	1983–2001	0.529	0.822	1.199
	37704	1619000	Johnston Atoll	16.74	−169.53	0.674	0.295	2.2	1983–2001	0.527	0.820	1.197
	42004	1619910	Midway Islands	28.21	−177.36	0.381	0.303	1.9	1983–2001	0.515	0.811	1.185
	36941	1630000	Apra Harbor, Guam	13.44	144.65	0.715	0.249	4.2	1983–2001	0.529	0.821	1.199
	36941	1631428	Pago Bay, Guam	13.43	144.80	0.525	0.287	4.2	1983–2001	0.521	0.816	1.191
	26574	1770000	American Samoa	−14.28	189.32	0.848	0.338	3.8	1983–2001	0.497	0.788	1.167
	35169	1820000	Kwajalein	8.73	167.74	1.194	0.446	3.1	1983–2001	0.548	0.836	1.218
	39117	1890000	Wake Island	19.29	166.62	0.718	0.295	2.1	1983–2001	0.529	0.822	1.199
NE	47859	8410140	Eastport, ME	44.90	−66.98	5.874	0.930	2.1	1983–2001	0.735	0.976	1.405
	47858	8411250	Cutler Naval Base, ME	44.64	−67.30	4.133	0.716	2.4	1983–2001	0.665	0.924	1.335
	47857	8413320	Bar Harbor, ME	44.39	−68.21	3.465	0.657	2.1	1983–2001	0.639	0.904	1.309
	47496	8418150	Portland, ME	43.66	−70.25	3.019	0.605	1.9	1983–2001	0.621	0.891	1.291
	47496	8419317	Wells, ME	43.32	−70.56	2.914	0.667	3.5	1983–2001	0.617	0.887	1.287
	47496	8423898	Fort Point, NH	43.07	−70.71	2.864	0.662	3.5	1983–2001	0.615	0.886	1.285
	47136	8443970	Boston, MA	42.35	−71.05	3.131	0.634	2.8	1983–2001	0.625	0.894	1.295
	46777	8447386	Fall River, MA	41.70	−71.16	1.456	0.566	3.5	1983–2001	0.558	0.844	1.228
	46778	8447930	Woods Hole, MA	41.52	−70.67	0.672	0.446	3.2	1983–2001	0.527	0.820	1.197
	46778	8449130	Nantucket Island, MA	41.29	−70.10	1.089	0.418	3.8	1983–2001	0.544	0.833	1.214
	46777	8452660	Newport, RI	41.51	−71.33	1.174	0.478	2.8	1983–2001	0.547	0.835	1.217

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NE (cont.)	46777	8452944	Conimicut Light, RI	41.72	−71.34	1.398	0.560	3.5	1983–2001	0.556	0.842	1.226
	46777	8454000	Providence, RI	41.81	−71.40	1.476	0.549	2.3	1983–2001	0.559	0.844	1.229
	46777	8454049	Quonset Point, RI	41.59	−71.41	1.249	0.547	3.5	1983–2001	0.550	0.837	1.220
	46776	8461490	New London, CT	41.36	−72.09	0.930	0.468	2.6	1983–2001	0.537	0.828	1.207
	46776	8465705	New Haven, CT	41.28	−72.91	2.045	0.603	3.5	1983–2001	0.582	0.861	1.252
	46775	8467150	Bridgeport, CT	41.17	−73.18	2.231	0.555	3.0	1983–2001	0.589	0.867	1.259
	46777	8510560	Montauk, NY	41.05	−71.96	0.771	0.487	3.4	1983–2001	0.531	0.823	1.201
	46416	8514560	Port Jefferson, NY	40.95	−73.08	2.181	0.527	2.5	1983–2001	0.587	0.865	1.257
	46416	8516945	Kings Point, NY	40.81	−73.76	2.378	0.638	2.5	1983–2001	0.597	0.873	1.267
	46415	8518750	The Battery, NY	40.70	−74.01	1.542	0.546	3.1	1983–2001	0.562	0.846	1.232
	46415	8519483	Bergen Point, NY	40.64	−74.14	1.681	0.549	4.4	1983–2001	0.567	0.850	1.237
	46415	8531680	Sandy Hook, NJ	40.47	−74.01	1.593	0.552	2.7	1983–2001	0.564	0.848	1.234
	46056	8534720	Atlantic City, NJ	39.36	−74.42	1.403	0.534	4.1	1983–2001	0.556	0.842	1.226
	45697	8536110	Cape May, NJ	38.97	−74.96	1.659	0.486	4.7	1983–2001	0.566	0.850	1.236
	46055	8537121	Ship John Shoal, NJ	39.31	−75.38	1.894	0.578	3.5	1983–2001	0.576	0.857	1.246
	46055	8540433	Marcus Hook, PA	39.81	−75.41	1.871	0.563	3.5	1983–2001	0.575	0.856	1.245
	46055	8545240	Philadelphia, PA	39.93	−75.14	2.039	0.462	3.1	1983–2001	0.582	0.861	1.252
	46055	8551762	Delaware City, DE	39.58	−75.59	1.830	0.540	3.5	1983–2001	0.573	0.855	1.243
	46055	8551910	Reedy Point, DE	39.56	−75.57	1.779	0.423	4.1	1983–2001	0.571	0.853	1.241
	45696	8555889	Brandywine Shoal, DE	38.99	−75.11	1.676	0.616	3.5	1983–2001	0.567	0.850	1.237
	45696	8557380	Lewes, DE	38.78	−75.12	1.418	0.530	3.5	1983–2001	0.557	0.843	1.227
	45696	8570280	Ocean City, MD	38.33	−75.08	1.187	0.413	3.5	1983–2001	0.547	0.836	1.217
	45696	8570283	Ocean City Inlet, MD	38.33	−75.09	0.751	0.360	3.5	1983–2001	0.530	0.823	1.200
	45695	8571421	Bishops Head, MD	38.22	−76.04	0.624	0.503	3.5	1983–2001	0.525	0.819	1.195

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NE (cont.)	45695	8571892	Cambridge, MD	38.57	−76.07	0.622	0.414	4.9	1983–2001	0.525	0.819	1.195
	46054	8573364	Tolchester Beach, MD	39.21	−76.25	0.527	0.484	2.5	1983–2001	0.519	0.814	1.189
	46055	8573927	Chesapeake City, MD	39.53	−75.81	0.980	0.470	3.8	1983–2001	0.539	0.829	1.209
	46054	8574070	Havre De Grace, MD	39.54	−76.09	0.746	0.482	3.5	1983–2001	0.530	0.822	1.200
	46054	8574680	Baltimore, MD	39.27	−76.58	0.506	0.443	3.2	1983–2001	0.520	0.815	1.190
	45695	8575512	Annapolis, MD	38.98	−76.48	0.438	0.430	3.7	1983–2001	0.518	0.813	1.188
	45695	8577330	Solomons Island, MD	38.32	−76.45	0.449	0.398	6.0	1983–2001	0.518	0.813	1.188
	45694	8594900	Washington, DC	38.87	−77.02	0.965	0.461	3.3	1983–2001	0.539	0.829	1.209
	45337	8631044	Wachapreague, VA	37.61	−75.69	1.376	0.508	5.4	1983–2001	0.564	0.850	1.234
	45337	8632200	Kiptopeke, VA	37.17	−75.99	0.896	0.435	4.7	1983–2001	0.536	0.827	1.206
	45695	8635150	Colonial Beach, VA	38.25	−76.96	0.591	0.406	4.7	1983–2001	0.524	0.818	1.194
	45336	8635750	Lewisetta, VA	38.00	−76.46	0.458	0.420	5.6	1983–2001	0.518	0.814	1.188
	45336	8636580	Windmill Point, VA	37.62	−76.29	0.424	0.419	5.2	1983–2001	0.532	0.828	1.202
	45336	8637689	Yorktown, VA	37.23	−76.48	0.786	0.567	3.5	1983–2001	0.531	0.824	1.201
	44977	8638610	Sewells Point, VA	36.95	−76.33	0.841	0.502	4.6	1983–2001	0.534	0.825	1.204
	44977	8638863	CBBT, VA	36.97	−76.11	0.885	0.503	6.0	1983–2001	0.535	0.827	1.205
	44977	8639348	Money Point, VA	36.78	−76.30	0.977	0.528	5.6	1983–2001	0.539	0.829	1.209

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
SE	44978	8651370	Duck, NC	36.18	−75.75	1.124	0.494	4.6	1983–2001	0.545	0.834	1.215
	44619	8652587	Oregon Inlet, NC	35.80	−75.55	0.360	0.384	4.6	1983–2001	0.514	0.811	1.184
	44619	8654400	Cape Hatteras, NC	35.22	−75.64	1.056	0.412	3.2	1983–2001	0.542	0.832	1.212
	44619	8654467	USCG Hatteras, NC	35.21	−75.70	0.186	0.598	3.2	1983–2001	0.507	0.806	1.177
	44259	8656483	Beaufort, NC	34.72	−76.67	1.079	0.362	3.8	1983–2001	0.543	0.832	1.213
	44258	8658120	Wilmington, NC	34.23	−77.95	1.427	0.327	2.3	1983–2001	0.557	0.843	1.227
	44258	8658163	Wrightsville Beach, NC	34.21	−77.79	1.366	0.564	3.2	1983–2001	0.555	0.841	1.225
	43898	8661070	Springmaid Pier, SC	33.66	−78.92	1.707	0.493	2.9	1983–2001	0.568	0.851	1.238
	43897	8662245	Oyster Landing, SC	33.35	−79.19	1.561	0.496	3.2	1983–2001	0.562	0.847	1.232
	43538	8665530	Charleston, SC	32.78	−79.93	1.757	0.453	3.3	1983–2001	0.570	0.853	1.240
	43537	8670870	Fort Pulaski, GA	32.03	−80.90	2.287	0.500	3.3	1983–2001	0.591	0.869	1.261
	42818	8720030	Fernandina Beach, FL	30.67	−81.47	1.999	0.473	2.3	1983–2001	0.580	0.860	1.250
	42818	8720218	Mayport, FL	30.40	−81.43	1.508	0.378	2.6	1983–2001	0.557	0.842	1.227
	42818	8720357	St Johns River, FL	30.19	−81.69	0.312	0.333	3.2	1983–2001	0.512	0.809	1.182
	42459	8720587	St. Augustine Beach, FL	29.86	−81.26	1.569	0.531	3.2	1983–2001	0.563	0.847	1.233
	42101	8721604	Trident Pier, FL	28.42	−80.59	1.193	0.407	5.1	1983–2001	0.537	0.825	1.207
	41024	8723214	Virginia Key, FL	25.73	−80.16	0.667	0.317	5.1	1983–2001	0.518	0.811	1.188
	40664	8723970	Vaca Key, FL	24.71	−81.11	0.297	0.249	4.2	1983–2001	0.512	0.809	1.182
	40664	8724580	Key West, FL	24.56	−81.81	0.551	0.262	2.5	1983–2001	0.522	0.817	1.192

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
E. Gulf	41382	8725110	Naples, FL	26.13	−81.81	0.875	0.323	2.9	1983–2001	0.535	0.826	1.205
	41382	8725520	Fort Myers, FL	26.65	−81.87	0.401	0.325	3.1	1983–2001	0.516	0.812	1.186
	41740	8726384	Port Manatee, FL	27.64	−82.56	0.669	0.260	6.6	1983–2001	0.527	0.820	1.197
	41740	8726520	St Petersburg, FL	27.76	−82.63	0.688	0.337	2.8	1983–2001	0.528	0.821	1.198
	41740	8726607	Old Port Tampa, FL	27.86	−82.55	0.749	0.304	3.2	1983–2001	0.530	0.822	1.200
	41740	8726667	Mckay Bay Entrance, FL	27.91	−82.43	0.814	0.320	3.2	1983–2001	0.533	0.824	1.203
	41740	8726724	Clearwater Beach, FL	27.98	−82.83	0.841	0.294	7.1	1983–2001	0.540	0.831	1.210
	42457	8727520	Cedar Key, FL	29.14	−83.03	1.157	0.415	2.2	1983–2001	0.546	0.835	1.216
	42456	8728690	Apalachicola, FL	29.73	−84.98	0.492	0.390	3.0	1983–2001	0.520	0.815	1.190
	42814	8729108	Panama City, FL	30.15	−85.67	0.409	0.368	2.5	1983–2001	0.516	0.812	1.186
	42814	8729210	Panama City Beach, FL	30.21	−85.88	0.420	0.348	4.3	1983–2001	0.517	0.813	1.187
	42812	8729840	Pensacola, FL	30.40	−87.21	0.383	0.345	2.4	1983–2001	0.515	0.811	1.185
	42812	8732828	Mobile Bay, AL	30.42	−87.83	0.490	0.519	4.3	1983–2001	0.520	0.815	1.190
	42811	8735180	Dauphin Island, AL	30.25	−88.08	0.367	0.354	4.3	1983–2001	0.512	0.808	1.182
	42811	8736897	Mobile, AL	30.65	−88.06	0.517	0.535	4.3	1983–2001	0.521	0.816	1.191
	42811	8737048	Mobile State Docks, AL	30.71	−88.04	0.501	0.439	4.3	1983–2001	0.520	0.815	1.190
	42811	8741533	Pascagoula NOAA Lab, MS	30.37	−88.56	0.466	0.494	4.3	1983–2001	0.519	0.814	1.189
	42810	8747437	Bay Waveland Yacht Club, MS	30.33	−89.33	0.529	0.498	4.6	1983–2001	0.522	0.816	1.192

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
W. Gulf	42092	8760922	Pilots Station East, SW Pass, LA	28.93	−89.41	0.356	0.399	4.3	2012–2016	0.514	0.811	1.184
	42451	8761724	Grand Isle, LA	29.26	−89.96	0.323	0.309	7.8	2012–2016	0.428	0.725	1.098
	42809	8761927	New Canal Station, LA	30.03	−90.11	0.164	0.485	5.6	1983–2001	0.507	0.805	1.177
	42450	8762075	Port Fourchon, LA	29.11	−90.20	0.368	0.298	4.3	2012–2016	0.515	0.811	1.185
	42449	8764227	Amerada Pass, LA	29.45	−91.34	0.487	0.535	4.3	1983–2001	0.519	0.815	1.189
	42449	8765251	Cypremort Point, LA	29.71	−91.88	0.518	0.458	4.3	1983–2001	0.521	0.816	1.191
	42448	8766072	Freshwater Canal Locks, LA	29.56	−92.31	0.657	0.696	4.3	1983–2001	0.526	0.820	1.196
	42806	8767816	Lake Charles, LA	30.22	−93.22	0.427	0.494	4.3	1983–2001	0.517	0.813	1.187
	42447	8768094	Calcasieu Pass, LA	29.77	−93.34	0.589	0.465	6.1	1983–2001	0.524	0.818	1.194
	42447	8770570	Sabine Pass North, TX	29.73	−93.87	0.488	0.368	6.1	1983–2001	0.520	0.815	1.190
	42446	8770613	Morgans Point, TX	29.68	−94.99	0.398	0.488	3.1	1983–2001	0.535	0.831	1.205
	42446	8771013	Eagle Point, TX	29.48	−94.92	0.338	0.331	13.8	1983–2001	0.494	0.790	1.164
	42446	8771341	Galveston Bay Entrance, TX	29.36	−94.72	0.510	0.499	6.1	1983–2001	0.520	0.815	1.190
	42446	8771450	Galveston Pier 21, TX	29.31	−94.79	0.429	0.366	6.5	1983–2001	0.517	0.813	1.187
	42446	8771510	Galveston Pleasure Pier, TX	29.29	−94.79	0.622	0.425	6.5	1983–2001	0.525	0.819	1.195
	42086	8772440	Freeport, TX	28.95	−95.31	0.536	0.391	9.0	1983–2001	0.521	0.816	1.191
	42086	8772447	USCG Freeport, TX	28.94	−95.30	0.549	0.460	6.1	1983–2001	0.522	0.816	1.192
	42084	8774770	Rockport, TX	28.02	−97.05	0.111	0.336	5.7	2002–2006	0.504	0.803	1.174
	41725	8775870	Corpus Christi, TX	27.58	−97.22	0.497	0.391	4.8	1983–2001	0.529	0.824	1.199
	41366	8779770	Port Isabel, TX	26.06	−97.22	0.418	0.337	4.0	1983–2001	0.517	0.813	1.187

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
SW	43500	9410170	San Diego, CA	32.71	−117.17	1.745	0.490	2.2	1983–2001	0.570	0.852	1.240
	43500	9410230	La Jolla, CA	32.87	−117.26	1.624	0.468	2.1	1983–2001	0.565	0.849	1.235
	43858	9410660	Los Angeles, CA	33.72	−118.27	1.674	0.472	1.0	1983–2001	0.567	0.850	1.237
	44217	9410840	Santa Monica, CA	34.01	−118.50	1.654	0.489	1.8	1983–2001	0.566	0.850	1.236
	44216	9411340	Santa Barbara, CA	34.41	−119.69	1.645	0.485	0.6	1983–2001	0.566	0.849	1.236
	44574	9412110	Port San Luis, CA	35.18	−120.76	1.623	0.449	1.0	1983–2001	0.565	0.849	1.235
	44932	9413450	Monterey, CA	36.61	−121.89	1.627	0.431	1.6	1983–2001	0.565	0.849	1.235
	45290	9414290	San Francisco, CA	37.81	−122.47	1.780	0.375	1.9	1983–2001	0.571	0.853	1.241
	45290	9414523	Redwood City, CA	37.51	−122.21	2.501	0.400	2.7	1983–2001	0.600	0.875	1.270
	45290	9414750	Alameda, CA	37.77	−122.30	2.010	0.411	0.4	1983–2001	0.580	0.860	1.250
	45290	9414863	Richmond, CA	37.93	−122.40	1.846	0.359	3.1	1983–2001	0.574	0.855	1.244
	45290	9415020	Point Reyes, CA	38.00	−122.98	1.758	0.447	2.1	1983–2001	0.570	0.853	1.240
	45649	9415144	Port Chicago, CA	38.06	−122.04	1.498	0.388	1.4	1983–2001	0.560	0.845	1.230
	45648	9416841	Arena Cove, CA	38.91	−123.71	1.787	0.500	0.6	1983–2001	0.573	0.856	1.243
	46365	9418767	North Spit, CA	40.77	−124.22	2.090	0.491	4.8	1983–2001	0.584	0.863	1.254
	46724	9419750	Crescent City, CA	41.75	−124.18	2.095	0.548	-0.8	1983–2001	0.584	0.863	1.254
	47083	9431647	Port Orford, OR	42.74	−124.50	2.220	0.594	0.2	1983–2001	0.572	0.850	1.242
	47442	9432780	Charleston, OR	43.35	−124.32	2.323	0.586	1.1	1983–2001	0.593	0.870	1.263
	47801	9435380	South Beach, OR	44.63	−124.04	2.543	0.579	1.7	1983–2001	0.602	0.876	1.272
	48161	9437540	Garibaldi, OR	45.55	−123.92	2.536	0.597	2.4	1983–2001	0.601	0.876	1.271
	48520	9439040	Astoria, OR	46.21	−123.77	2.624	0.629	−0.2	1983–2001	0.605	0.879	1.275

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
NW	48520	9440910	Toke Point, WA	46.71	−123.97	2.720	0.807	0.6	1983–2001	0.609	0.882	1.279
	48519	9441102	Westport, WA	46.90	−124.11	2.786	0.670	1.9	1983–2001	0.611	0.884	1.281
	48878	9442396	La Push, WA	47.91	−124.64	2.577	0.766	1.9	1983–2001	0.603	0.877	1.273
	49237	9443090	Neah Bay, WA	48.37	−124.61	2.425	0.688	−1.7	1983–2001	0.597	0.873	1.267
	49238	9444090	Port Angeles, WA	48.13	−123.44	2.153	0.562	0.2	1983–2001	0.586	0.865	1.256
	49239	9444900	Port Townsend, WA	48.11	−122.76	2.597	0.538	1.7	1983–2001	0.604	0.878	1.274
	48880	9446484	Tacoma, WA	47.27	−122.41	3.595	0.517	3.4	1983–2001	0.644	0.908	1.314
	48880	9447130	Seattle, WA	47.60	−122.34	3.462	0.541	2.1	1983–2001	0.639	0.904	1.309
	49239	9449424	Cherry Point, WA	48.86	−122.76	2.788	0.585	0.4	1983–2001	0.612	0.884	1.282
	49238	9449880	Friday Harbor, WA	48.55	−123.01	2.364	0.554	1.2	1983–2001	0.595	0.871	1.265
Alaska	51743	9450460	Ketchikan, AK	55.33	−131.63	4.708	1.086	−0.4	1983–2001	2.059	2.359	2.759
	52099	9451054	Port Alexander, AK	56.25	−134.65	3.329	0.738	−5.8	1983–2001	1.031	1.331	1.731
	52457	9451600	Sitka, AK	57.05	−135.34	3.029	0.768	−2.4	1983–2001	0.883	1.183	1.583
	52817	9452210	Juneau, AK	58.30	−134.41	4.970	1.152	−15.1	2012–2016	2.319	2.619	3.019
	53175	9452400	Skagway, AK	59.45	−135.33	5.100	1.218	−19.9	2012–2016	2.456	2.756	3.156
	52815	9452634	Elfin Cove, AK	58.19	−136.35	3.360	1.149	−5.8	1983–2001	1.048	1.348	1.748
	53171	9453220	Yakutat, Yakutat Bay, AK	59.55	−139.73	3.070	0.891	−10.7	2012–2016	0.902	1.202	1.602
	53524	9454050	Cordova, AK	60.56	−145.75	3.838	0.937	0.8	1983–2001	1.344	1.644	2.044
	53882	9454240	Valdez, AK	61.13	−146.36	3.702	0.878	−5.8	1983–2001	1.253	1.553	1.953
	53520	9455090	Seward, AK	60.12	−149.43	3.238	0.884	−4.0	1983–2001	0.983	1.283	1.683
	53159	9455500	Seldovia, AK	59.44	−151.72	5.499	1.350	−9.8	2012–2016	2.906	3.206	3.606
	53518	9455760	Nikiski, AK	60.68	−151.40	6.262	1.254	−9.9	2012–2016	NaN	NaN	NaN
	53879	9455920	Anchorage, AK	61.24	−149.89	8.889	1.269	−2.7	1983–2001	NaN	NaN	NaN
	52440	9457292	Kodiak Island, AK	57.73	−152.51	2.675	0.715	−9.2	2012–2016	0.743	1.043	1.443

Table A1.3 (cont.): Regional designation, tide gauge information, extreme water level metadata, and high tide flood heights.

US Region	EWL Grid No.	NOAA ID	Location	Latitude	Longitude	Tide Range (m)	Flood Index u (m, MHHW)	u Trend (mm/yr)	Epoch of u	Minor Flood (m, MHHW)	Moderate Flood (m)	Major Flood (m)
Alaska (cont.)	52079	9457804	Alitak, AK	56.90	−154.25	3.578	0.908	−5.8	2012–2016	1.174	1.474	1.874
	51714	9459450	Sand Point, AK	55.34	−160.50	2.204	0.737	1.4	1983–2001	0.615	0.915	1.315
	51712	9459881	King Cove, AK	55.06	−162.33	2.082	0.753	−5.8	1983–2001	0.592	0.892	1.292
	50262	9461380	Adak Island, AK	51.86	−176.63	1.131	NaN	NaN	NaN	0.572	0.872	1.272
	50623	9461710	Atka, AK	52.23	−174.17	1.041	0.424	−5.8	1983–2001	0.584	0.884	1.284
	50629	9462450	Nikolski, AK	52.94	−168.87	1.213	0.537	−5.8	1983–2001	0.563	0.863	1.263
	50990	9462620	Unalaska, AK	53.88	−166.54	1.098	NaN	NaN	NaN	0.576	0.876	1.276
	51714	9463502	Port Moller, AK	55.99	−160.57	3.175	0.697	−5.8	1983–2001	0.952	1.252	1.652
	52422	9464212	Village Cove, AK	57.13	−170.29	1.005	NaN	NaN	NaN	0.589	0.889	1.289
	54940	9468756	Nome, AK	64.50	−165.43	0.464	NaN	NaN	NaN	0.719	1.019	1.419
	56018	9491094	Red Dog Dock, AK	67.58	−164.07	0.269	NaN	NaN	NaN	0.787	1.087	1.487
	57111	9497645	Prudhoe Bay, AK	70.40	−148.53	0.214	NaN	NaN	NaN	0.808	1.108	1.508
Carib	38168	9751364	St. Croix, VI	17.75	−64.71	0.226	0.205	2.4	1983–2001	0.509	0.807	1.179
	38527	9751381	St. John, VI	18.32	−64.72	0.252	0.210	2.4	1983–2001	0.510	0.808	1.180
	38168	9751401	Lime Tree Bay, VI	17.69	−64.75	0.216	0.154	3.0	1983–2001	0.509	0.806	1.179
	38527	9751639	Charlotte Amalie, VI	18.34	−64.92	0.240	0.172	2.3	1983–2001	0.510	0.807	1.180
	38526	9752695	Vieques Island, PR	18.09	−65.47	0.225	0.190	2.4	1983–2001	0.509	0.807	1.179
	38525	9755371	San Juan, PR	18.46	−66.12	0.481	0.191	2.4	1983–2001	0.519	0.814	1.189
	38165	9759110	Magueyes Island, PR	17.97	−67.05	0.204	0.157	1.9	1983–2001	0.508	0.806	1.178
	38524	9759938	Mona Island, PR	18.09	−67.94	0.247	0.257	2.4	1983–2001	0.510	0.807	1.180

Section A2: Methods Appendix: Extreme Water Levels and Alaska Coastal Flood Height

A2.1: Data and Regional Frequency Analysis

A regional frequency analysis (RFA) of NOAA tide gauges is used to estimate extreme water levels (EWLs) along U.S. coastlines at and away from tide gauges. The RFA method (Hosking and Wallis, 1997) is based on the assumption that similar physical forcing across a region will produce a similar frequency of events and a probability density up to a local index (u), which is a local scaling factor that captures response peculiarities (Dalrymple, 1960). An RFA uses regional sets of data that have been locally normalized by their respective local index with a statistical heterogeneity test (H value) to assess the extent that the data are sufficiently similar. Using statistical L-moments, heterogeneity is a measure of the variation between sites of a location's summary distribution statistics and the amount of dispersion expected if the locations were indeed a homogeneous region (Hosking and Wallis, 1997). If $H < 1$, the region is considered acceptably homogeneous. If $1 \leq H < 2$, the region is considered possibly heterogeneous but acceptable for our study. If $H \geq 2$, then the tide-gauge group is definitely heterogeneous and not suitable for analysis. Once the regional bounds are established whose data are acceptably homogeneous, the aggregated data are fit with an extreme value distribution.

This study uses hourly and "top ten" data from all NOAA tide gauges[46] with at least 10 years of record (Figure A2.1). Water levels are put onto the mean higher high water (MHHW) tidal datum and detrended (the trend value is retained and shown in Table A1.3) relative to the midpoint of the current national datum tidal epoch (1983–2001), which is similar for NOAA EWL procedures using a single-gauge analysis (Zervas, 2013; Extreme Water Levels[47]). From the datasets, daily highest water levels are picked and declustered at each tide gauge using a 4-day storm window to ensure event independence. The 98th percentile of the

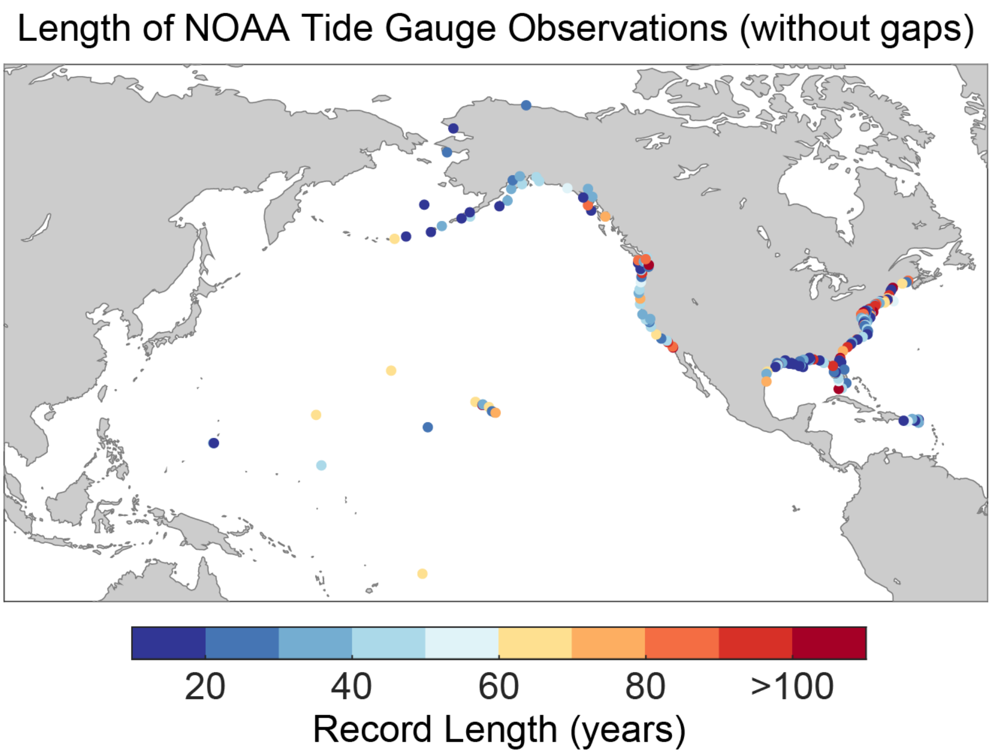

Figure A2.1: NOAA tide gauges used in the regional frequency analysis to generate extreme water level probabilities for U.S. coastlines.

[46] https://tidesandcurrents.noaa.gov/
[47] https://tidesandcurrents.noaa.gov/est/

declustered daily highest levels at each tide gauge is used as the local index (u) to normalize the data for the RFA process.

To form regions, the tide-gauge data is aggregated across a 400 km radius, similar to methods of Hall et al. (2016) but from the midpoint of a continuous set of coastline-intersecting 1-degree grids instead of site-specific installations. A maximum of 10 and a minimum of 3 tide gauges are included for each grid. Next, the regional data are spatially declustered with an additional 4-day event (i.e., storm) window to ensure that only the maximum water level within a region is retained (keep only the highest peak water levels for a particular event). Then, the statistical heterogeneity measure is estimated to ensure that the grouped tide-gauge data are sufficiently homogeneous (H < 2). In some instances, when a region surrounding a grid centroid

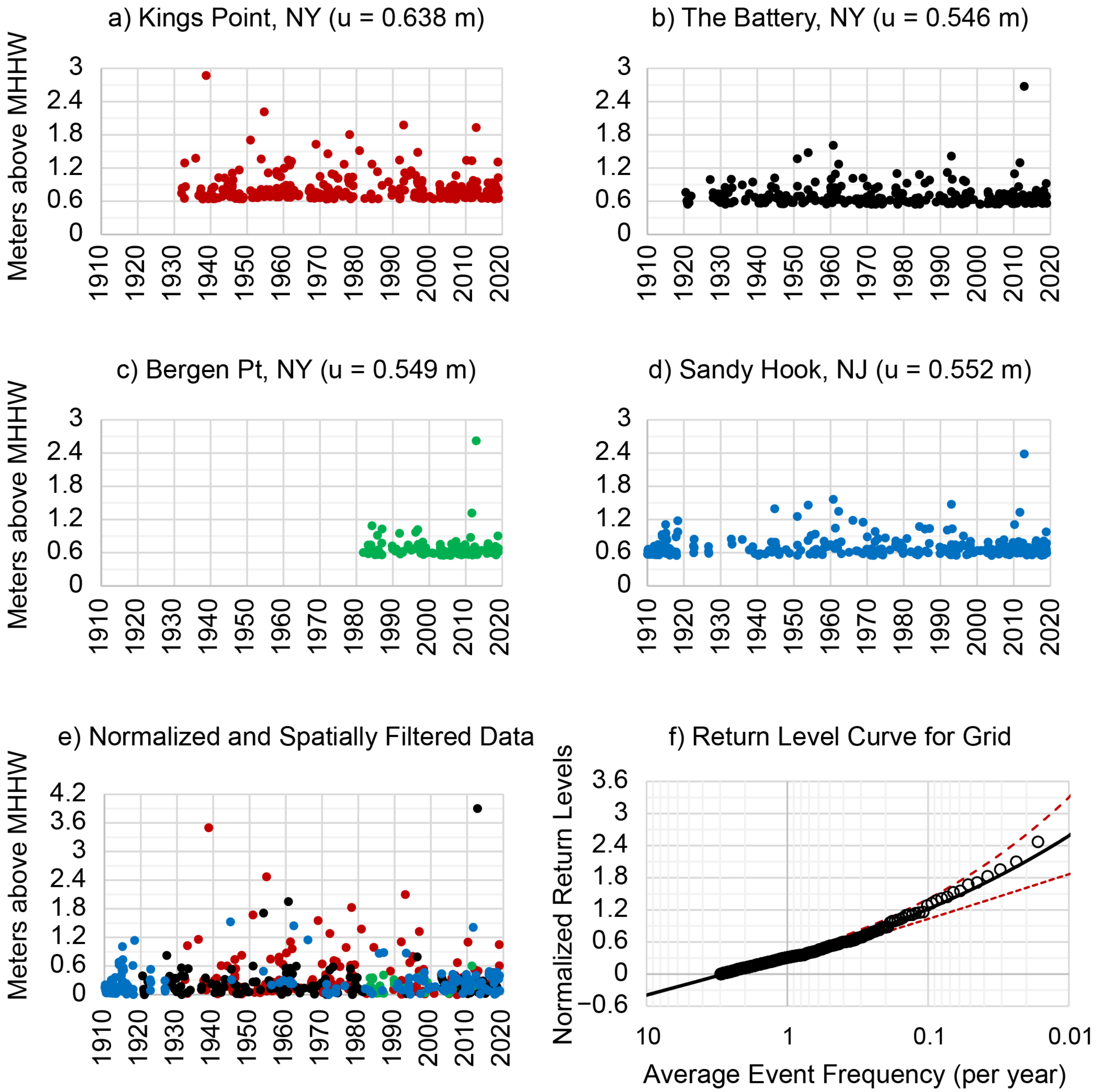

Figure A2.2: Example of data from grid number 46415 showing exceedances above each local index (u) relative to the 1983–2001 mean higher high water (MHHW) tidal datum at a) Kings Point, New York; b) The Battery, New York; c) Bergen Point, New York; and d) Sandy Hook, New Jersey, which are e) aggregated into a single dataset and f) fit by a Generalized Pareto Distribution to form a return level interval curve for the grid.

has H ≥ 2, tide gauges farthest away are sequentially dropped until homogeneity is achieved. In the end, all 1-degree grids along the contiguous United States (CONUS) had H < 2 (considered acceptably homogeneous) except a grid (number 48519) along the Northwest Pacific coastline, which, along with the Hawaiian and other U.S. Pacific Islands, uses the much larger physical-process regions identified and quantified in Sweet et al. (2020b). Grids along the Alaska coastline are fairly well resolved by the RFA except along the western and northern coasts.

An example is shown for grid number 46415, which is where the NOAA tide gauge at The Battery in New York City (NYC) is located (Figure A2.2). Four tide gauges are included in this grid (Kings Point, New York; The Battery, New York; Bergen Point, New York; and Sandy Hook, New Jersey [Figure A2.2a–d]), and their data are considered homogeneous (H value of 0.32). After the 4-day spatial filtering for events, each of the tide-gauge datasets is normalized by (divided by) its respective local index (u) value and aggregated as shown in Figure A2e.

A2.2: Gridded (Regional) Extreme Water Level Probabilities

With the tide gauges identified for each 1-degree grid, the aggregated and normalized datasets are fit with a Generalized Pareto Distribution (GPD; Coles, 2001). Using the penalized maximum likelihood method (Coles and Dixon, 1999; Frau et al., 2018; Sweet et al., 2020b), expected and 95% confidence interval (2.5th% and 97.5th% levels) values are estimated for the gridded EWL probabilities and defined as:

1) $$G\,(Z;\, u, \alpha, \xi) \;=\; \lambda\left[1 + \xi\left(\frac{z-u}{\alpha}\right)\right]^{-1/\xi}$$

where G is the exceedance probability (P[Z > z]), λ is the probability of an individual (normalized) observation exceeding the local index (u), α is the scale parameter, and ξ is the shape parameter. It is assumed that the distribution of the number of exceedances per year follows a Poisson distribution and that the return level for an EWL of height (Z) is given by:

2) $$Z_N = u + \frac{\alpha}{\xi}\left[\left(N n_y \lambda\right)^{\xi} - 1\right]$$

where N is the average recurrence interval (referred to in this study as the average event frequency, which is the reciprocal value), n_y is number of days per year (365.25), and λ is the average number of event exceedances per year (about 3 on average across all tide gauges in the study). To estimate EWLs with return levels with a 10 events/year frequency, we extrapolate the gridded GPD model with a logarithmic fit for return levels between the 0.5–3 events/year frequencies. A return level interval curve fit to the aggregated data (Figure A2.2e) for the grid where NYC is located is shown in Figure A2.2f.

A2.3: Localized Extreme Water Level Probabilities

When fitting a GPD to the RFA of aggregated tide-gauge data, the local EWL (EWL_{local}) probabilities including the model of expected values and their 95% confidence interval at a particular location are given as

3) $$EWL_{local} = EWL_{gridded} * u_{local} + u_{local}$$

where $EWL_{gridded}$ is the gridded return level for a particular coastal 1-degree grid and u_{local} is the local index used in both the RFA and GPD processes. The value of u is a height (98th percentile of 4-day event filtered daily highest water level) above the local MHHW tidal datum for the current (1983–2001) national tidal datum epoch (NTDE) or for a modified 5-year epoch. The associated uncertainty of the $EWL_{gridded}$ estimated during the RFA is expressed as $\sigma_{gridded.}$ When localized at a tide gauge used in the formulation of the grids (see Figure A1), u is assumed to have no uncertainty. However, just as the location parameters in generalized extreme value (GEV) have time-dependent characteristics (Menéndez and Woodworth, 2010), it is recognized that u would experience similar behavior, but that is not quantified in this study.

In this RFA framework, it is possible to estimate EWL_{local} from the $EWL_{gridded}$ probabilities (expected values and 95% confidence interval) through the use of other sources of data. Specifically, the local indices needed to localize the $EWL_{gridded}$ values can either be 1) obtained from short-term tide-gauge data (or by targeted deployments) within a particular grid that is not included in the RFA formulation (<10 years; Figure A2.3) or 2) based on an underlying relationship between regional sets of local index (u) values and tide range available from, for example, NOAA VDatum.[48] In both cases, we establish large U.S. coastal regions (note: these are slightly different than the regions discussed in Sections 2 and 3 of the report and shown in Figure A1.1) that encompass several 1-degree grids to quantify information needed to obtain local indices and/or estimate variance/uncertainties (e.g., RMSE). These alternative methods, which are discussed below, may be of interest to coastal communities that are not co-located to a tide gauge used in this study but have predictions of tide range or have access to or are planning temporary tide-gauge installations to establish tidal datums and/or EWLs.

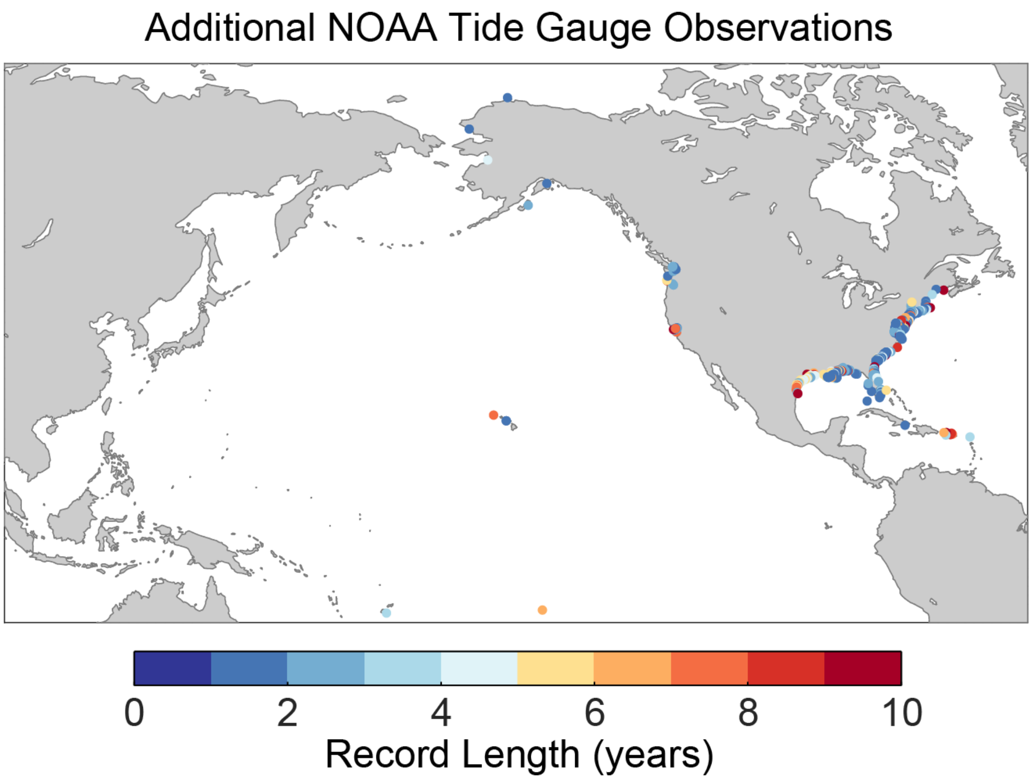

Figure A2.3: Additional tide-gauge data available from NOAA that can be used to localize the 1-degree gridded set of regional frequency analysis-based extreme water level probabilities. See https://tidesandcurrents.noaa.gov/.

A2.3.1: Local Index Estimates from Short-Term Installations

When other sets of tide/water level data are available, a local index can be directly estimated to obtain EWL_{local} probabilities from the $EWL_{gridded}$ probabilities. The first step for using data that are not from NOAA would be to estimate a local MHHW tidal datum using, for example, NOAA's online datum tool.[49] Following Equation 3 above, there will be some uncertainty in the local index value that is dependent on record length (e.g., 1–10 years). To account for short-record uncertainty in the local indices (u), RMSE (1 standard error) is estimated for regional estimates of u for the tide gauges used in the RFA (see Figure A2.1). Root mean square error is estimated using a logarithmic fit over a 19-year record length (Figure A4). To compute the RMSE, the maximum absolute differences are computed between u derived over the entire record and for progressively longer consecutive record lengths between 2001 and 2019 at each tide gauge (e.g., 19 discrete 1-year

[48] https://vdatum.noaa.gov/
[49] https://access.co-ops.nos.noaa.gov/datumcalc/

records; 18 consecutive 2-year records). The maximum (absolute) difference is used to account for interannual variability that can be significant (e.g., during phases of El Niño–Southern Oscillation [ENSO]). This difference is considered the error in estimating u for shorter records, and the average of the absolute differences across the regional set of tide gauges is considered the bias. The standard deviation of the absolute differences is also computed across all tide gauges, and an estimate of the RMSE is then computed as the square

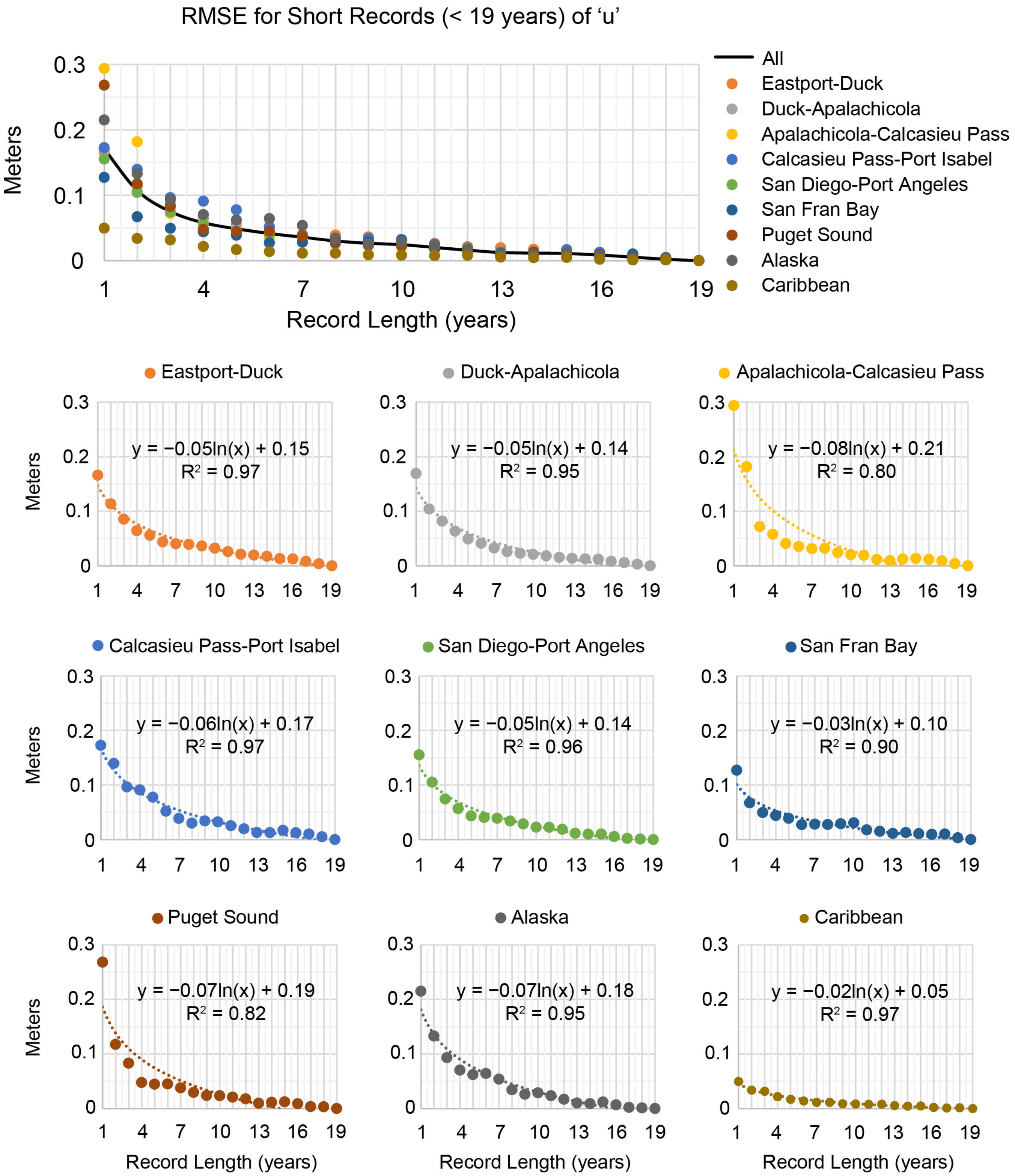

Figure A2.4: Root mean square error for regional estimates of flood indices (u) based on 1–19 years of consecutive data over the 2001–2019 period, based on regional sets of tide gauges used in this study. Note: these regions are not the same as those shown in Figure A1.1 and used to describe results in Sections 2 and 3 of the report.

root of the sum of the square of the bias and the standard deviation (variance). The estimates for Hawaiian and U.S. Pacific Islands follow estimates of Sweet et al. (2020b).

A2.3.2: Obtaining a Local Index from Tide Range Information

Another method to obtain an estimate of a local index (u) and its uncertainty is based on a dependency (correlation) that exists with tide range (great diurnal [GT]) along most coastal regions similar to findings of Merrifield et al. (2013). In essence, tide range (GT), which represents the spread between MHHW and mean lower low water (MLLW), partially quantifies the variance of the daily highest water level distribution and the height of the local index u. Figure A2.5 illustrates the regression-based relationships between tide range and u along U.S. coastal regions (these are the same regions used in Figure A2.4). All regressions are significant above the 90% significance level (p values < 0.1) and applicable for the 1983–2001 tidal epoch. For the Hawaiian and U.S. Pacific Islands, the Pacific-wide regression of Sweet et al. (2020b) is used.

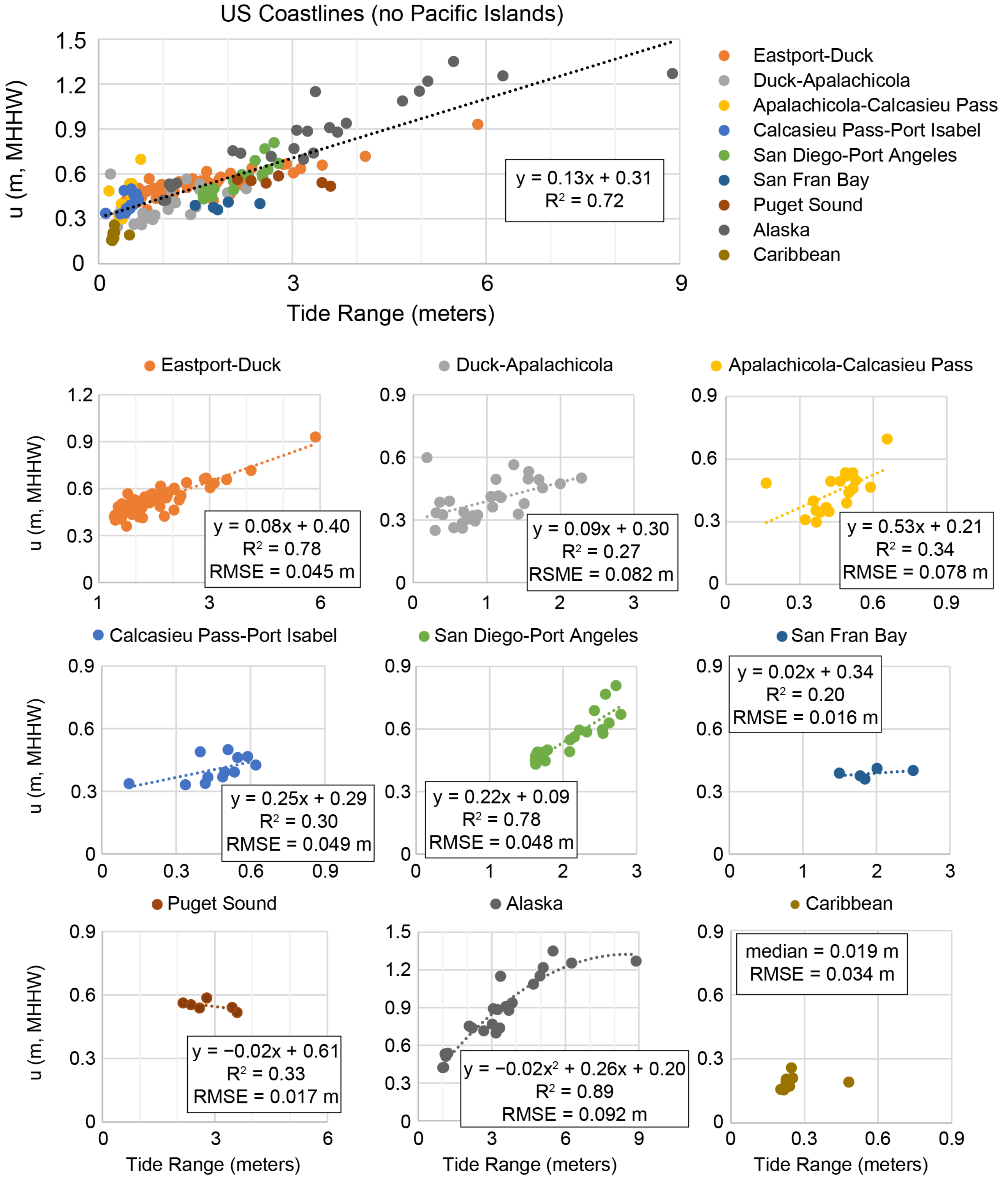

Figure A2.5: Tide range to local index (u) regressions with equations, goodness of fit (R^2), and root mean squared error (RMSE) shown by regions. Note: all local indices (u) are relative to the 1983–2001 tidal datum epoch. In the equations, y represents the local index (u) and x represents tide range.

A2.3.3: Uncertainties Using Alternative Methods to Estimate EWL_{local} Probabilities

When using either alternative method (tide range or short-record estimates) to obtain a local index (u), the uncertainty estimates of EWL_{local} probabilities will include additional uncertainty in u (σ_u). Following methods of Sweet et al. (2020b), it can be shown that

4) $$\sigma_{EWL(local)} = [(1 + \mu_{EWLgridded})^2 + \sigma^2_{EWLgridded}]\sigma_u^2 + \mu_u^2\sigma^2_{EWLgridded}$$

where $\mu_{EWLgridded}$ and μ_u are the expected values of the gridded return levels and the expected value of u, for example, estimated by the tide-range and u dependency (see Figure A2.5), respectively, σ_u^2 is the uncertainty inherent to any u-prediction relationship (e.g., RMSE). Thus, there is an additive uncertainty in u as estimated from this relationship, which would introduce additional uncertainty in estimates of EWL_{local}.

A2.3.4: Adjusting Local Extreme Water Level Probabilities to Time Periods

To adjust the EWL_{local} probabilities to a different sea level other than the current tidal epoch (e.g., from 1992 to 2000 or 2005 so as to apply the sea level rise scenarios), RSL estimates using the trends inherent to the hourly data used to compute the local index (u) should be applied (Table A1.3) to the epoch-specific EWL_{local} probabilities themselves. For tide gauges used in the RFA analysis and with more than 20 years of data, the local u trend can be used; otherwise, a median regional trend as defined in Figures A2.4 and A2.5 can be used. Alternatively, the RSL offsets derived from the regional observational RSL data (Table A1.2) could be used with differences between methods considered insignificant. For example, to estimate probabilities for the year 2000, the EWL_{local} probabilities values would be increased by an amount equal to the trend in u (or the median u trend value for the region) multiplied by 8 years (since 1992, which is the midpoint of the 1983–2001 epoch). The same procedure should be followed to adjust EWL_{local} probabilities for a given location estimated via the tide range regression (see Figure A5). In the case of a short-term estimate of u, similar procedures should be followed if local tidal datums have been computed and adjusted to the national tidal datum epoch (e.g., using the CO-OPS Tidal Analysis Datum Calculator[50]); in the case where no epoch can be established (see the CO-OPS Tidal Analysis Datum Calculator for guidance), then the measurements will be assumed to be referenced to the period of collection, and trend adjustment may be less straightforward.

A2.4: Alaska Coastal Flood Heights

To assess flood exposure, the coastal high tide flooding (HTF) heights of Sweet et al. (2018) are used for all U.S. coastlines outside of Alaska. Used in NOAA annual outlooks (e.g., Sweet et al., 2021; The State of High Tide Flooding and Annual Outlook[51]), these heights are a best-fit solution (regression) to the dozens of National Weather Service (NWS) emergency response warning thresholds established at many (but not all) NOAA tide gauges along the country's coastline. The NWS thresholds are used to communicate expected or ongoing coastal flood hazards to the public (NOAA, 2020), but often their depth-severity thresholds vary according to specific features near the tide gauge that affect both the associated flood frequency and the degree of broader vulnerabilities. Along the Alaska coastline, we follow the methodologies of Sweet et al. (2020b), who used a slight modification to assess "damaging flood heights" for the Pacific Basin coastlines. Here, the Alaska flood heights are based on a quadratic regression model using only Pacific Coast NWS minor flood heights and considered for only tide ranges below 6 meters (Figure A2.6a). To obtain moderate and major flood heights for Alaska, 0.3 m and 0.7 m are added to the regression, which is approximately the median difference between these heights and those for minor flooding along CONUS (Sweet et al., 2018). With flood heights defined nationally, minor, moderate, and major HTF are defined as occurring when water levels reach or exceed heights of about (median values) 0.55 m, 0.85 m, and 1.2 m above MHHW, respectively, and linearly vary with tide range (Figures A2.6b–d).

[50] https://access.co-ops.nos.noaa.gov/datumcalc/index.jsp
[51] https://tidesandcurrents.noaa.gov/HighTideFlooding_AnnualOutlook.html

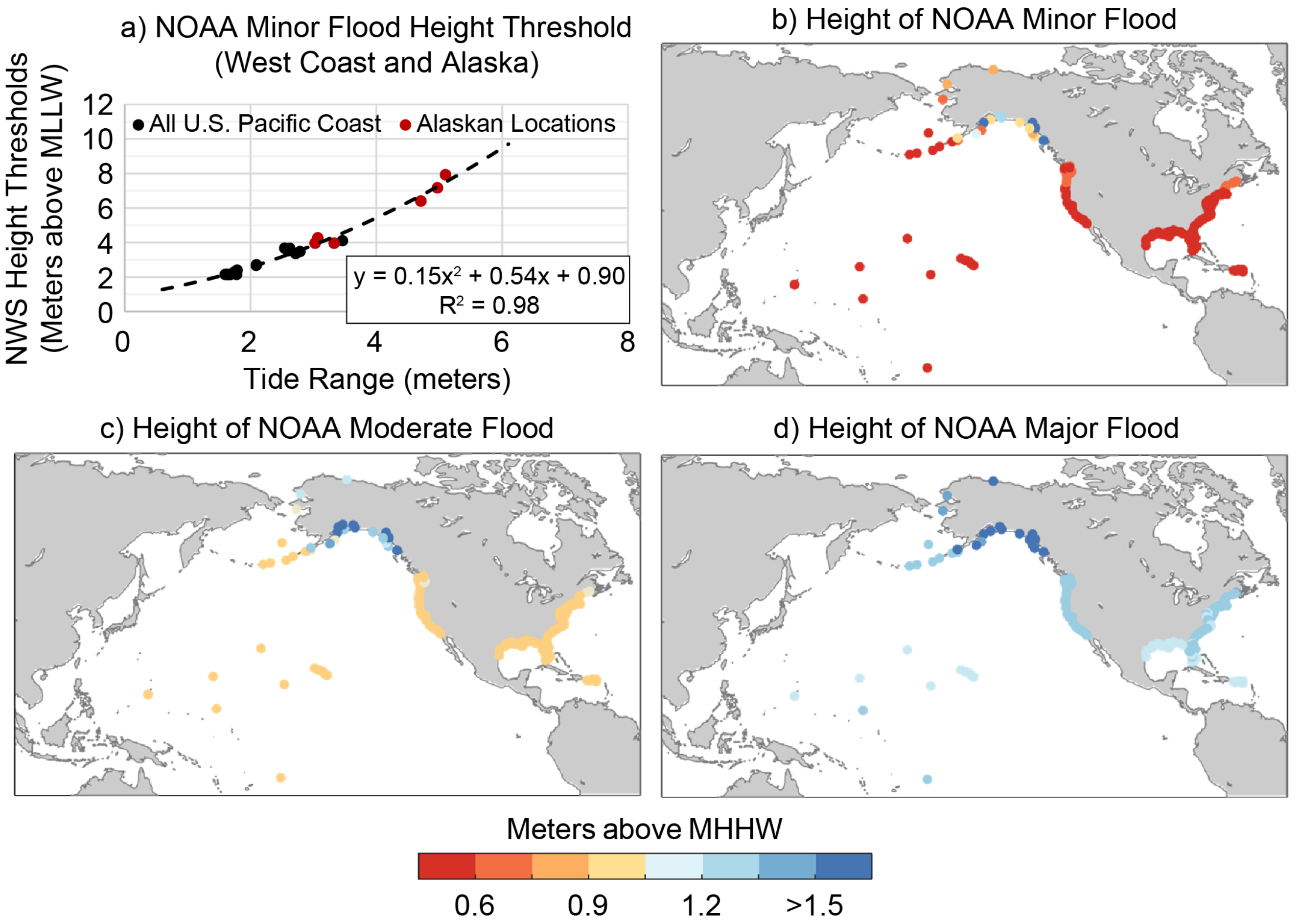

Figure A2.6: a) Quadratic regression of U.S. West Coast minor flood heights of NOAA's National Weather Service, following methods of Sweet et al. (2020b), to obtain a minor HTF definition for Alaska's coastline. The NOAA flood heights for b) minor, c) moderate, and d) major HTF are shown relative to mean higher high water.