

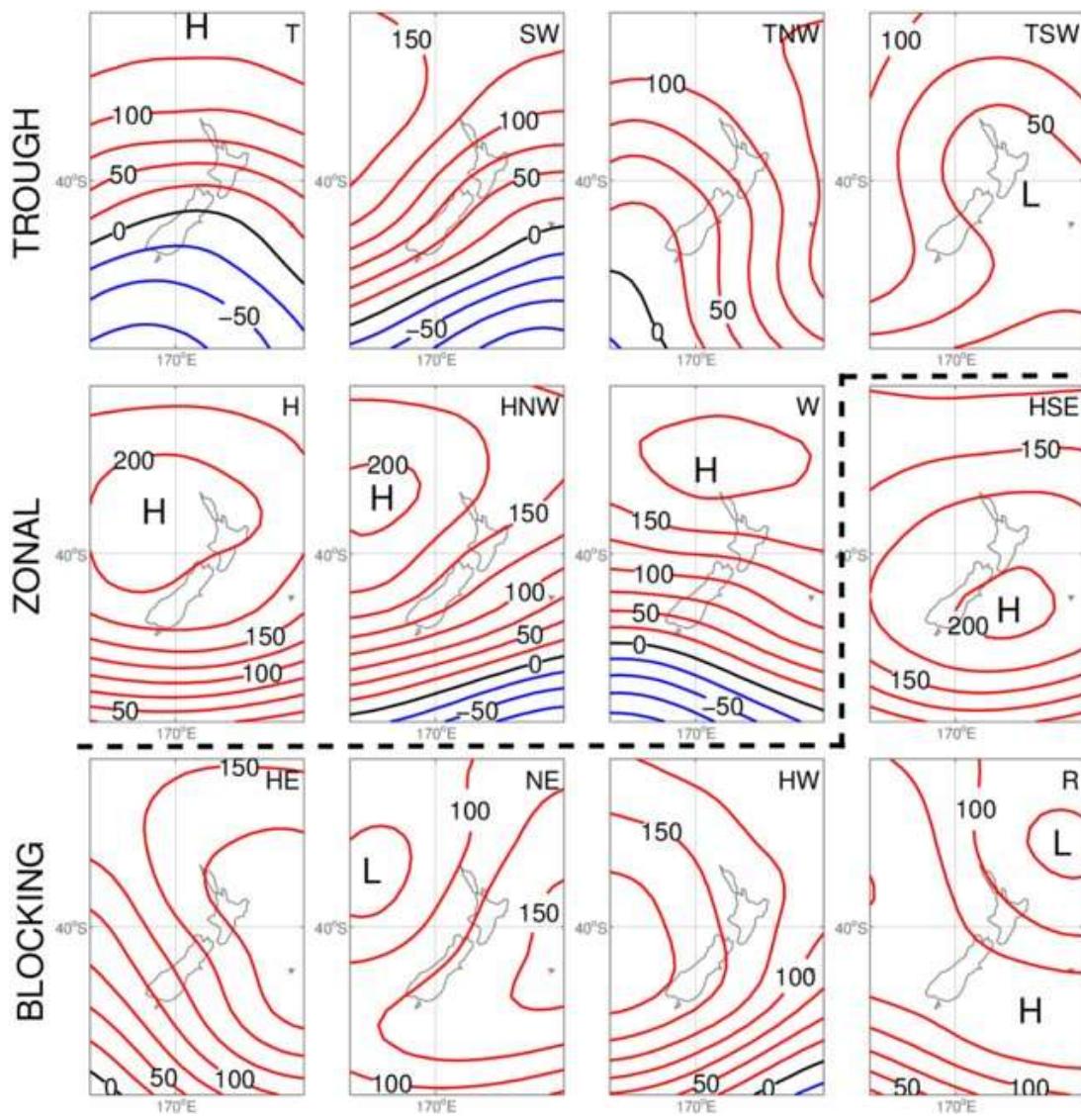
Supplementary Material—Spatial and temporal analysis of extreme sea level and skew surge events around the coastline of New Zealand

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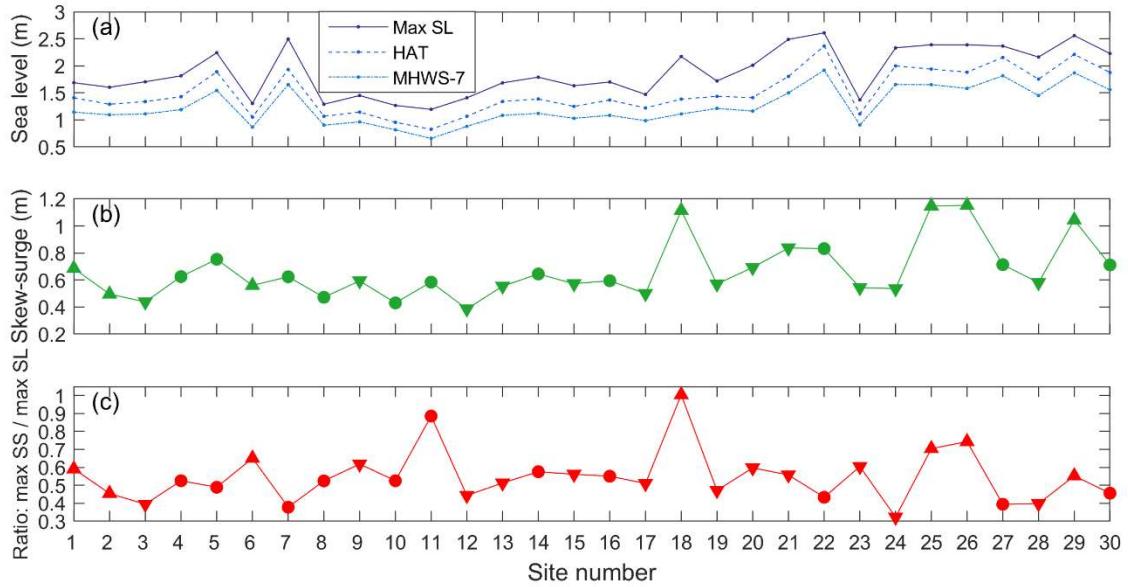
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Supplementary Figures

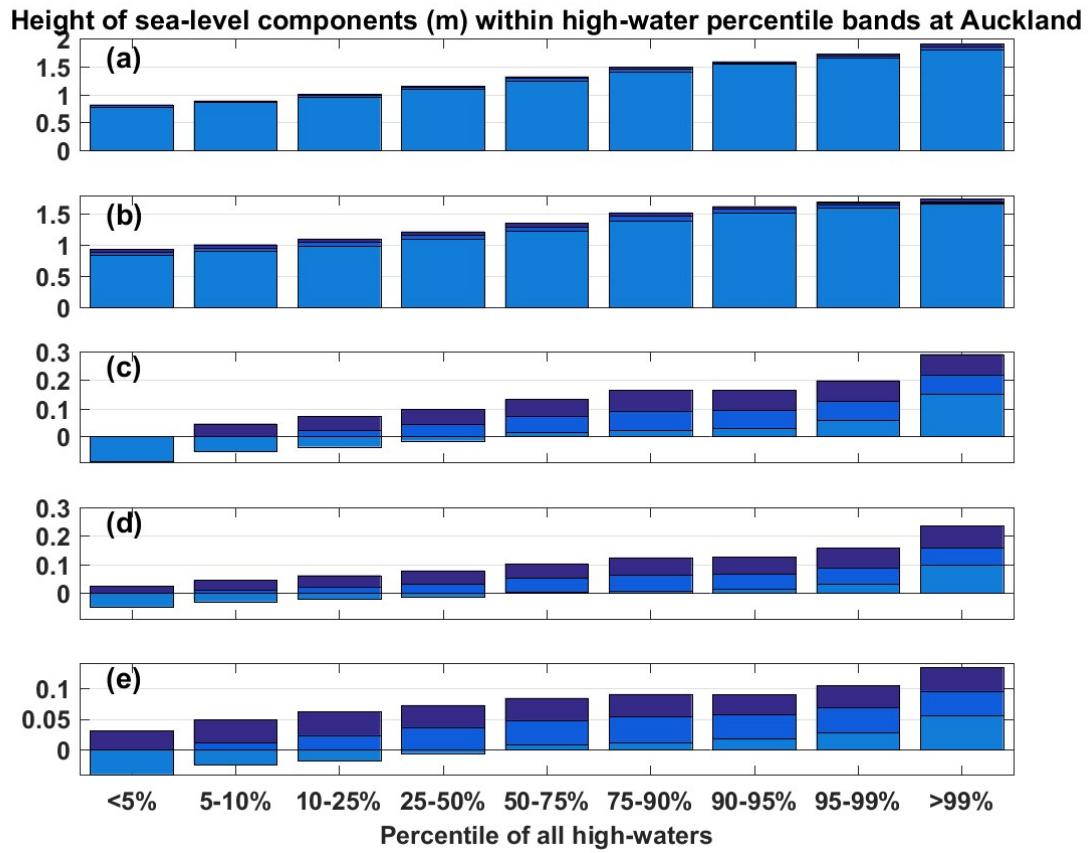


10 **Figure S1.** The twelve Kidson weather types, shown as average patterns of 1000hPa geopotential height (analogous to mean sea-level pressure). Names for the types are indicated in the top right of each panel. Source: Ackerley et al. (2011). The three regimes are indicated at the left: the top row is the trough regime, the first three in the second row are the zonal regime, and the rest form the blocking regime. See Kidson (2000) for further details.



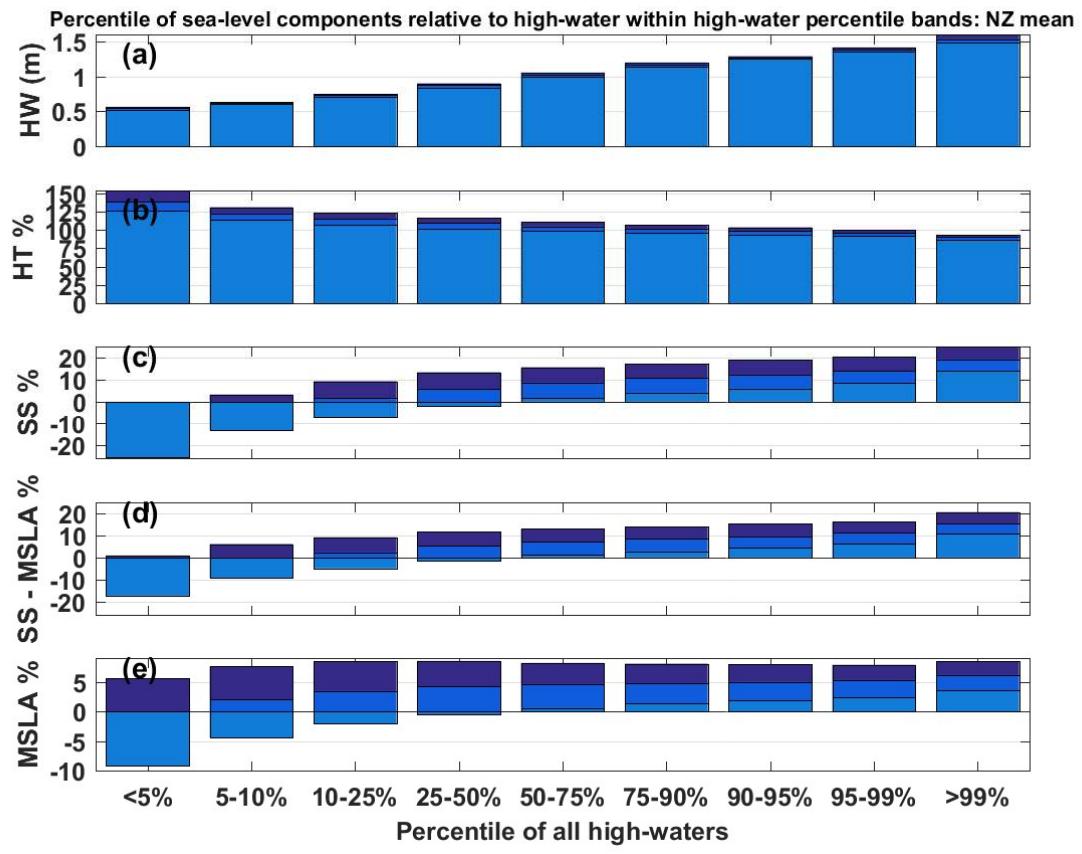
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Figure S2. (a) Maximum sea level; (b) maximum skew-surge; and (c) the ratio of maximum skew-surge to sea level; plotted relative to the distance clockwise around the coast of NZ from the tip of the North Island. Upward-pointing triangles represent small enclosed estuaries, circles represent large harbours or those with wide entrances and downward-pointing triangles represent the open coast.



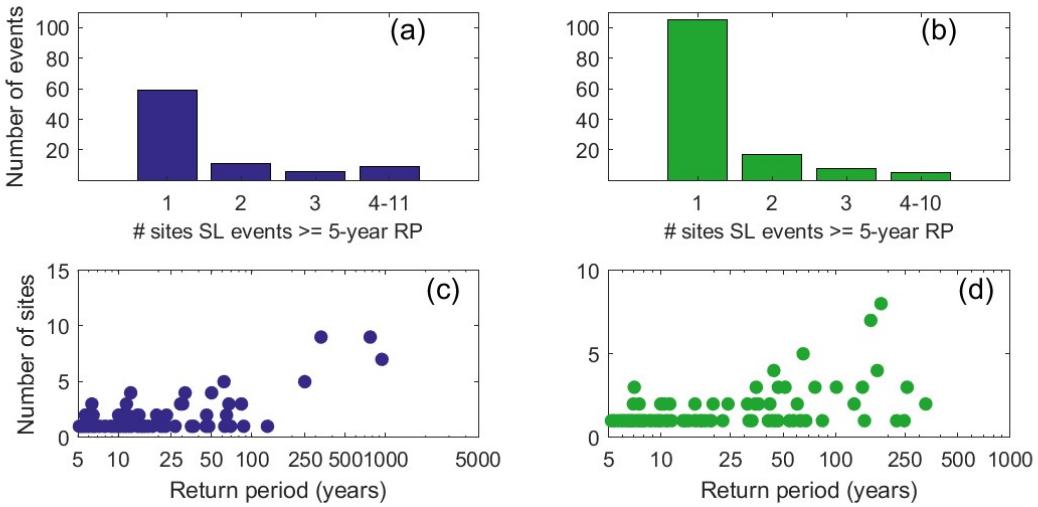
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Figure S3. Heights of sea-level components (m) within high-water percentile bands at Auckland NZ. (a) sea-level at high-water (b) high-tide (c) skew-surge (d) skew-surge minus mean sea-level anomaly (MSLA) (e) MSLA. The coloured bars from light to dark respectively mark the height of the 50th, 75th and 90th percentile of the sea-level components that match the high-waters within the percentile bands along the horizontal axis. The general pattern of behaviour shown here for Auckland is seen everywhere in NZ.



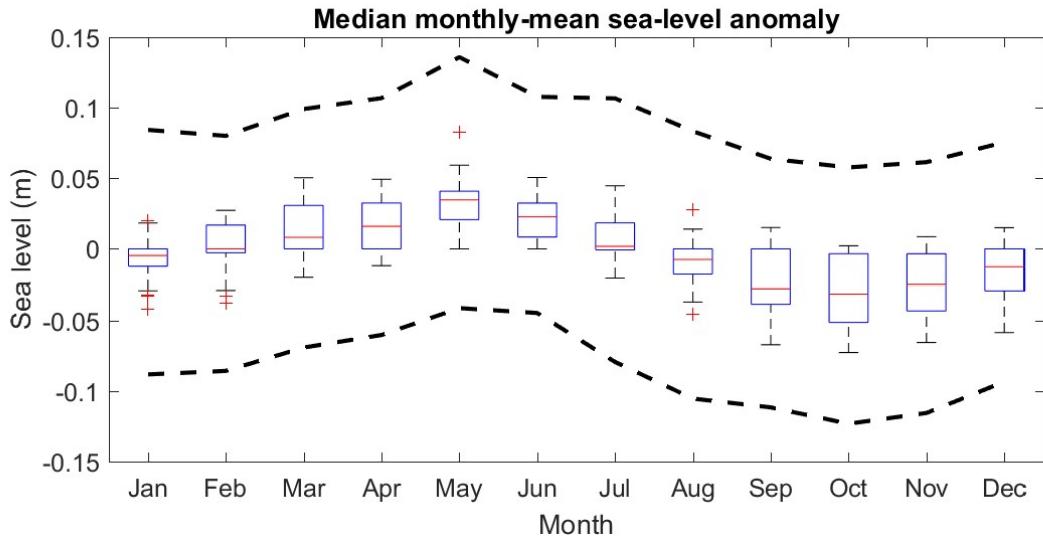
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Figure S4. Percentile of sea-level component height relative to high-water height within high-water percentile bands—NZ mean. (a) high-water height (m) (b) high-tide (c) skew-surge (d) skew-surge minus mean sea-level anomaly (MSLA) (e) MSLA. The coloured bars from light to dark respectively mark the height of the 50th, 75th and 90th percentile of the sea-level components that match the high-waters within the percentile bands along the horizontal axis. The mean patterns reflect those at individual sites.



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Figure S5. Histograms showing the number of sites where the 1 in 5-year return level was reached or exceeded for (a) extreme sea-level events and (b) skew-surge events. The offset return period of the (c) highest sea levels in each of the 155 extreme sea-level observations, and (d) the highest skew-surge return periods for each of 191 skew-surge observations, plotted against the number of sites where the 1 in 5-year return period was reached or exceeded during an event.



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Figure S6. Median (all 30 sites) monthly-mean sea-level anomaly (MSLA). Red line marks median, blue box marks interquartile range (25–75%), whiskers mark 2.7–99.3% coverage for normally-distributed data and red crosses mark outliers beyond the whisker range. Black dashed lines mark the median (all 30 sites) of the upper and lower 95% confidence intervals for each site.

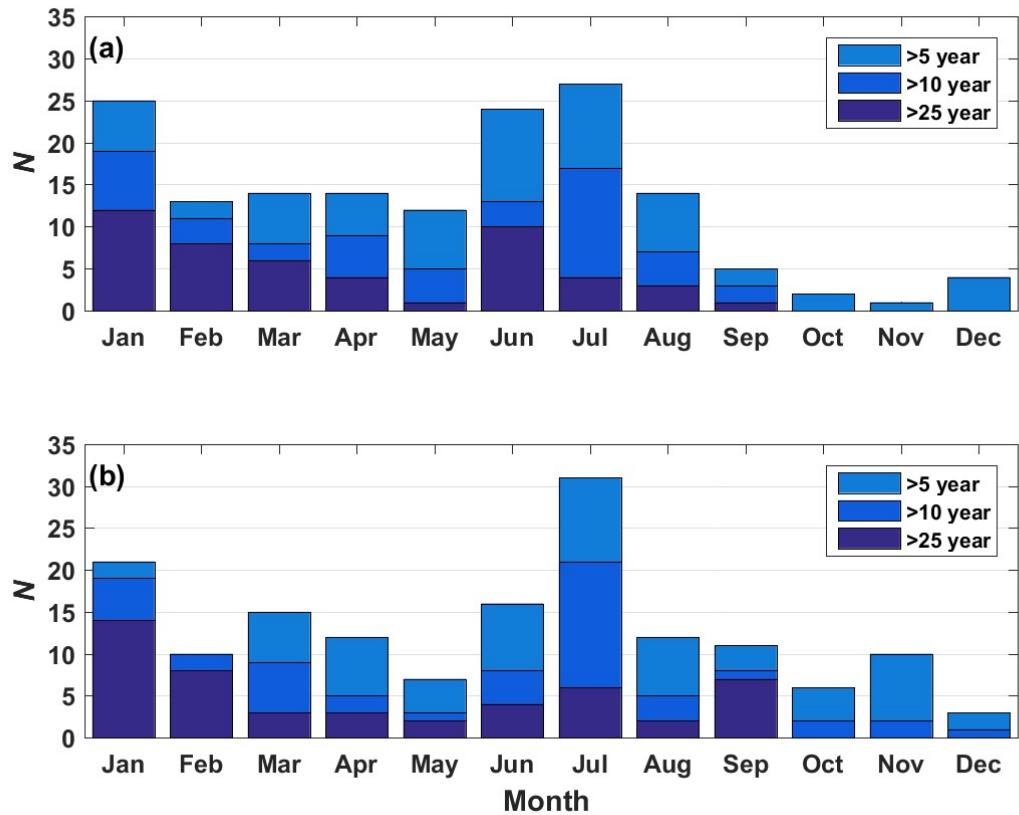


Figure S7. Seasonal distribution of extreme sea-level events. (a) Extreme Sea Level (b) Extreme Sea Level after first removing MSLA. N = number of occasions.

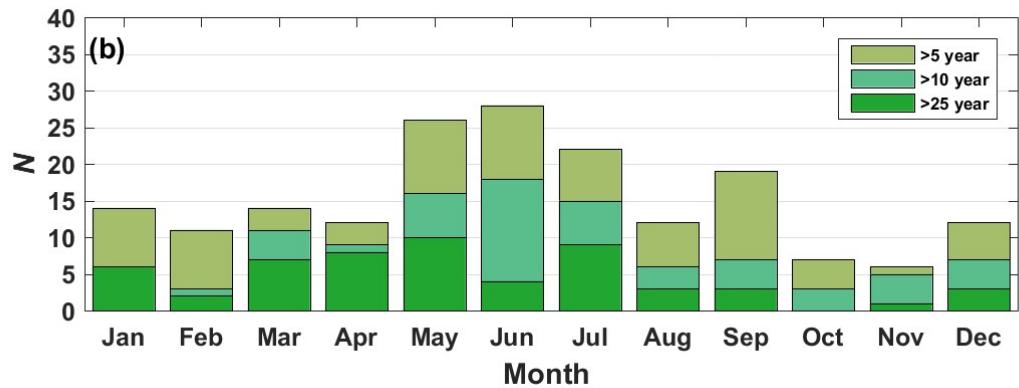
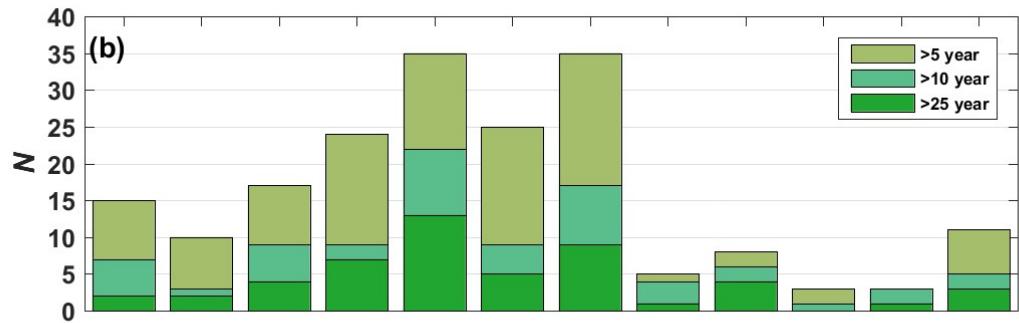


Figure S8. Seasonal distribution of extreme skew-surge events. (a) extreme skew-surge (b) extreme skew-surge after first removing MSLA. N = number of occasions.

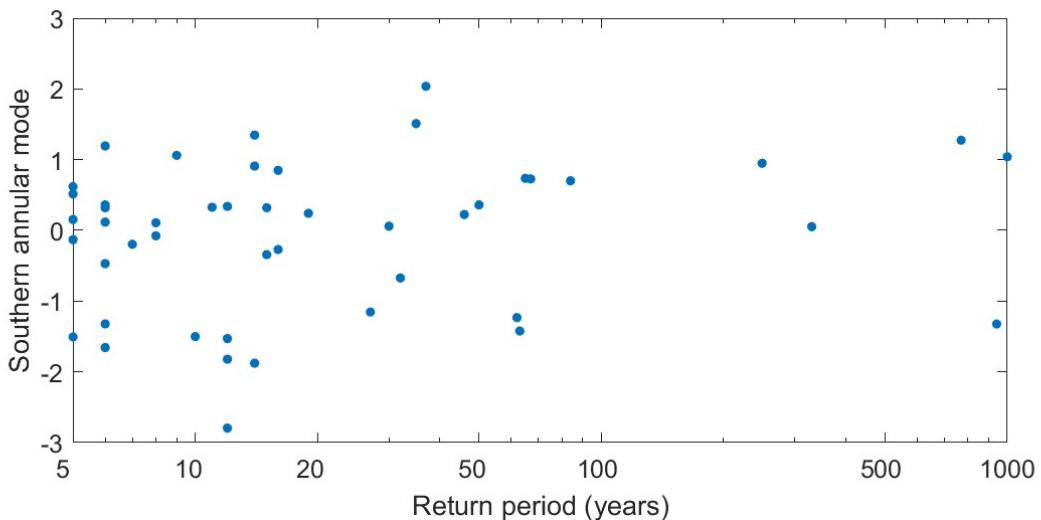
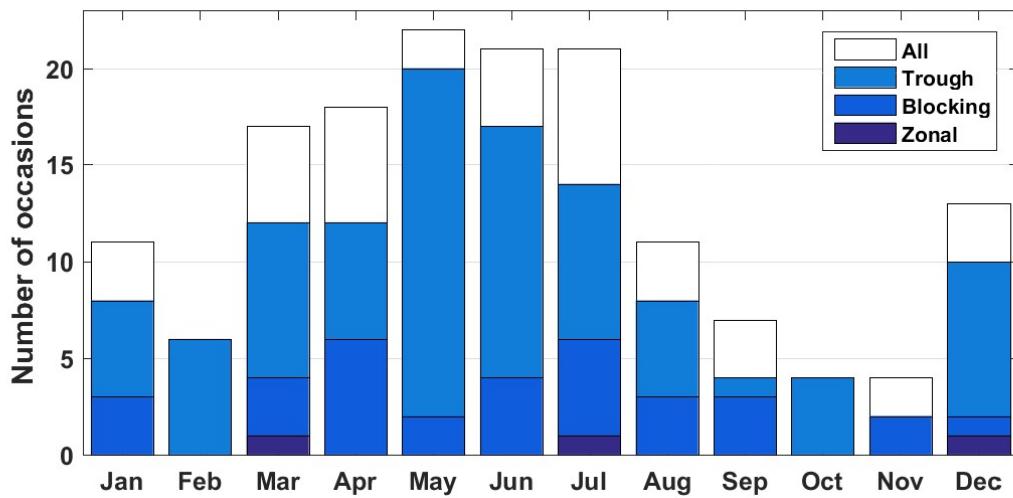
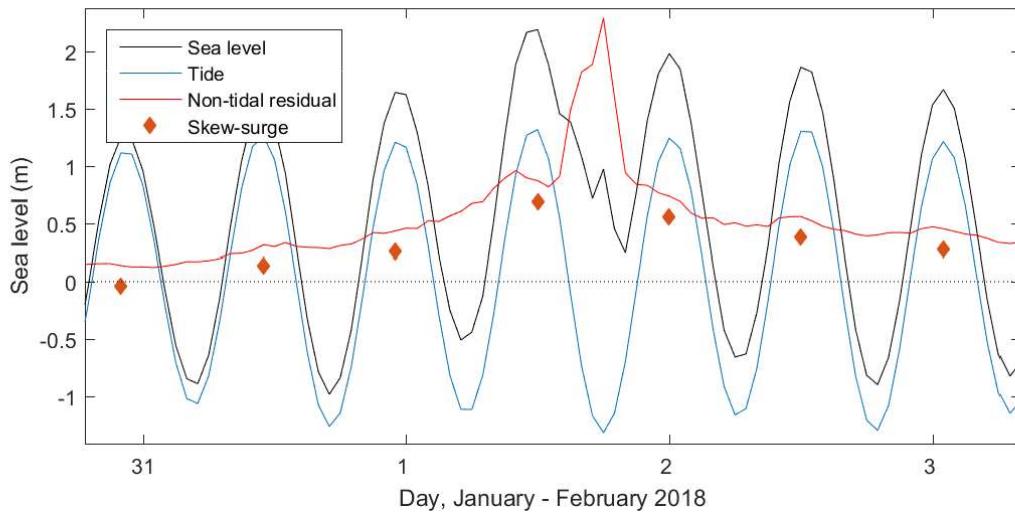


Figure S9. Extreme sea-level return period versus Southern Annular Mode (SAM) climate index.



55 **Figure S10.** Kidson (2000) weather type associated with unique storm events that contributed to ≥ 5 -year return level sea-level or skew-surge. Kidson types are available for 155 storm events since 1948, so the occurrence distribution shown here differs from that in Figure 7 which covers 191 storm events with effects observed in any of the sea-level gauge records. [Selected ≥ 5 -year return level sea-level and skew-surge events including MSLA].



60 **Figure S11.** Sea level at Jackson Bay (site 20; Figure 1a) during ex-tropical cyclone Fehi.

25	Kawhia	174.82	-38.07	2008–2018	10	9
26	Raglan	174.88	-37.79	2008–2018	10	6
27	Onehunga	174.52	-37.05	2001–2018	18	16
28	Anawhata	174.45	-36.93	1999–2011	13	13
29	Helensville	174.45	-36.67	2005–2014	9	8
30	Pouto Point	174.18	-36.36	2002–2018	17	14

Event Number	Date and Time	Return Period (years)	Skew-surge (m)	Water level (m LVD)	Astronomical Tide (m)	MSLA (m)	Site ID	Number of Sites
81	13/04/2001 10:00	5	0.53	1.30	0.77	0.06	9	1
82	23/08/1989 00:00	5	0.45	1.60	1.15	0.17	4	1
83	4/12/1951 08:00	5	0.29	1.03	0.75	0.08	11	1
84	17/11/2016 09:00	5	0.21	2.13	1.92	-0.01	7	1
85	11/05/2012 22:00	5	0.33	1.18	0.85	0.11	10	1

Event Number	Date and Time	Return Period (years)	Skew-surge (m)	Water level (m LVD)	Astronomical Tide (m)	Site ID of maximum return period	Number of Sites
125	18/06/2012 22:00	6	0.61	1.63	1.02	21	1
126	14/07/1918 19:00	6	0.47	1.20	0.73	16	1
127	9/04/1966 19:00	5	0.46	1.31	0.84	16	1
128	8/04/1969 20:00	5	0.52	1.50	0.98	14	1
129	22/09/2014 10:00	5	0.57	1.84	1.27	27	1
130	11/05/1916 01:00	5	0.48	1.40	0.92	5	1
131	24/01/2006 15:00	5	0.48	1.38	0.90	5	1
132	7/06/2008 16:00	5	0.91	1.89	0.98	18	1
133	11/12/2001 21:00	5	0.55	1.41	0.86	20	1
134	9/04/1982 20:00	5	0.47	1.48	1.01	4	1
135	13/12/2002 02:00	5	0.49	1.40	0.91	7	1

27	5/01/2018 13:00	Onehunga	17	2.37	1.95	0.42
28	17/04/1999 10:00	Anawhata	249	2.16	1.58	0.58
29	19/09/2005 00:00	Helensville	14	2.56	2.10	0.46
30	18/09/2005 23:00	Pouto Point	19	2.23	1.80	0.43

26	6/05/2013 07:00	Raglan	28	1.15	2.17	1.02
27	6/05/2013 08:00	Onehunga	147	0.71	1.96	1.25
28	17/04/1999 10:00	Anawhata	49	0.58	2.16	1.58
29	6/05/2013 08:00	Helensville	95	1.04	2.34	1.30
30	21/05/2016 22:00	Pouto Point	47	0.71	1.98	1.27

28	Anawhata	1.05	0.29	0.20	0.05	0.01	1.46	1.74
29	Helensville	1.37	0.33	0.23	0.05	0.00	1.89	2.22
30	Pouto Point	1.14	0.28	0.21	0.04	0.01	1.56	1.84

25	Kawhia	0.59	0.66	0.77	0.85	0.95	1.02	1.06	1.09	1.18	1.25	1.31
26	Raglan	0.58	0.68	0.83	0.95	1.15	1.31	1.41	1.49	1.76	1.99	2.25
27	Onehunga	0.47	0.51	0.57	0.60	0.65	0.68	0.69	0.70	0.73	0.75	0.77
28	Anawhata	0.40	0.44	0.49	0.52	0.56	0.58	0.59	0.60	0.63	0.64	0.66
29	Helensville	0.58	0.65	0.76	0.83	0.92	0.99	1.03	1.05	1.13	1.18	1.23
30	Pouto Point	0.43	0.48	0.54	0.60	0.67	0.72	0.75	0.77	0.84	0.90	0.95

24	Taranaki	2.49	2.00	0.54	2.53	2.33
25	Kawhia	2.60	1.94	1.15	3.09	2.66
26	Raglan	2.54	1.88	1.15	3.04	2.67
27	Onehunga	2.65	2.16	0.71	2.87	2.57
28	Anawhata	2.28	1.75	0.58	2.34	2.12
29	Helensville	2.83	2.21	1.04	3.26	2.86
30	Pouto Point	2.38	1.88	0.71	2.59	2.32

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