



Changes in severe storm and high sea level events on the Estonian coast

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Outline

- Introduction and hypotheses
- Objectives of the study
- Data and methods
- Changes in frequency of stormy days
- Changes in mean and maximum sea-level height
- Relationships between atmospheric circulation, storminess and sea-level height
- Conclusions

Climate change impacts in coastal zone (hypotheses)

- Higher temperature in winter related to higher cyclonic activity and stronger westerlies
- Higher storminess in winter
- Longer ice-free period and shorter duration of sea ice
- Higher sea level due to higher wind stress of westerlies
- Intensification of coastal processes (erosion, accumulation)
- Higher frequency of dangerous natural phenomena (floodings, land loss, destruction of harbours, erosion of sandy beaches, accumulation of sediments in harbours and ship fairways)

Objectives

- to analyse long-term fluctuations and trends in the frequency of severe storm and flooding events on the Estonian coast during the whole updated period of observations
- to assess the relationships between severe storms, floodings and parameters of large-scale atmospheric circulation

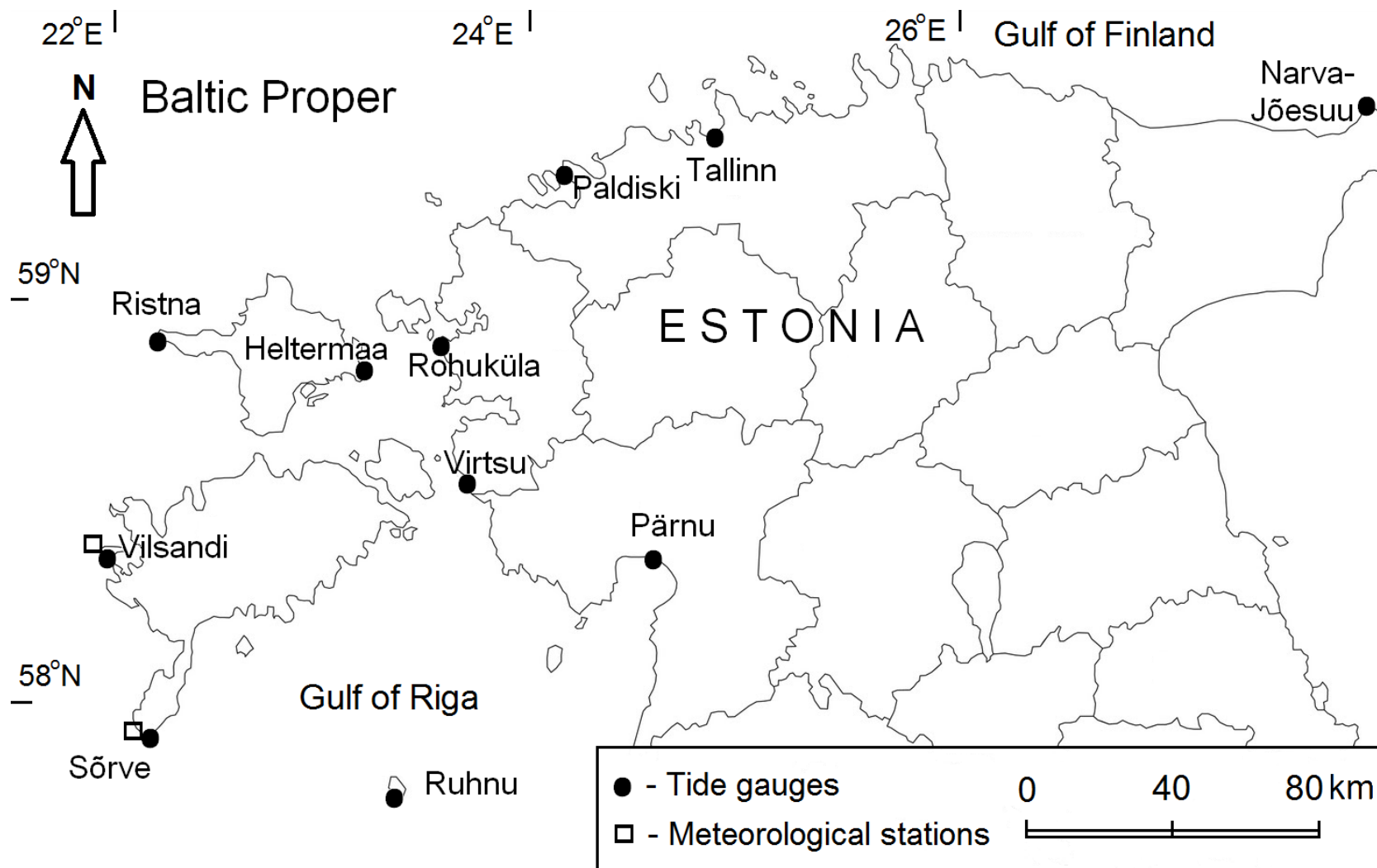
Data

- Number of storm days (10 min wind speed ≥ 15 m/s) in Vilsandi (since 1920) and Sõrve (since 1930)
- Monthly mean and maximum sea-level height at the 11 Estonian tide gauge stations
- Atmospheric circulation: AO and NAO indices, frequency of circulation macro-forms W, E and C according to Vangengeim-Girs classification, Northern Hemisphere teleconnection patterns from NOAA CPC

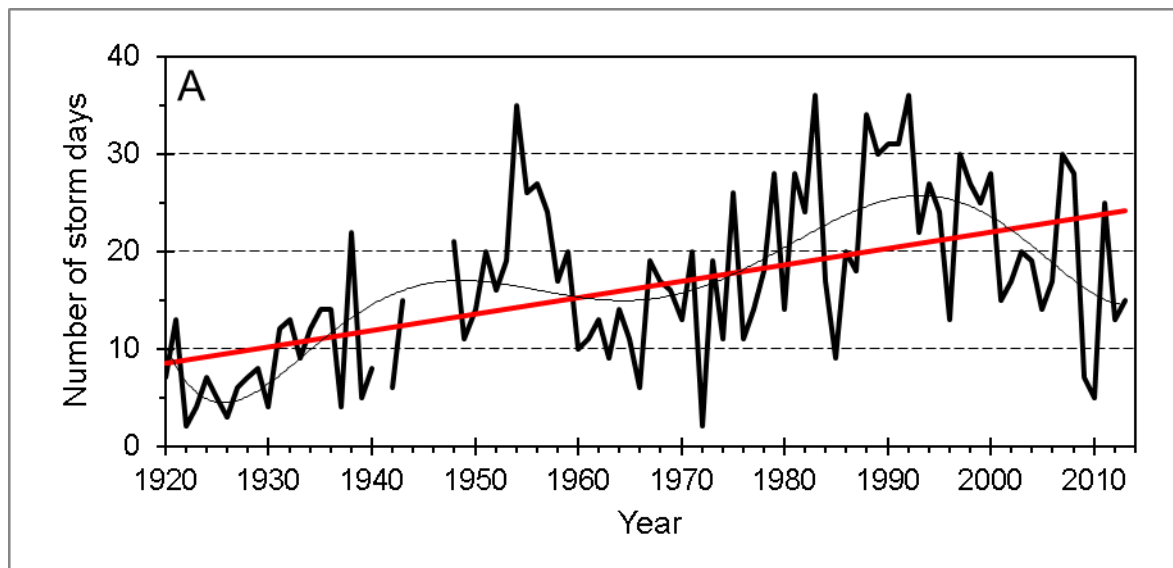
Sea-level measurements

- Sea-level measurements started in the harbour of Tallinn in 1809, continuous measurements since 1842
- Data on maximum sea-level since 1899

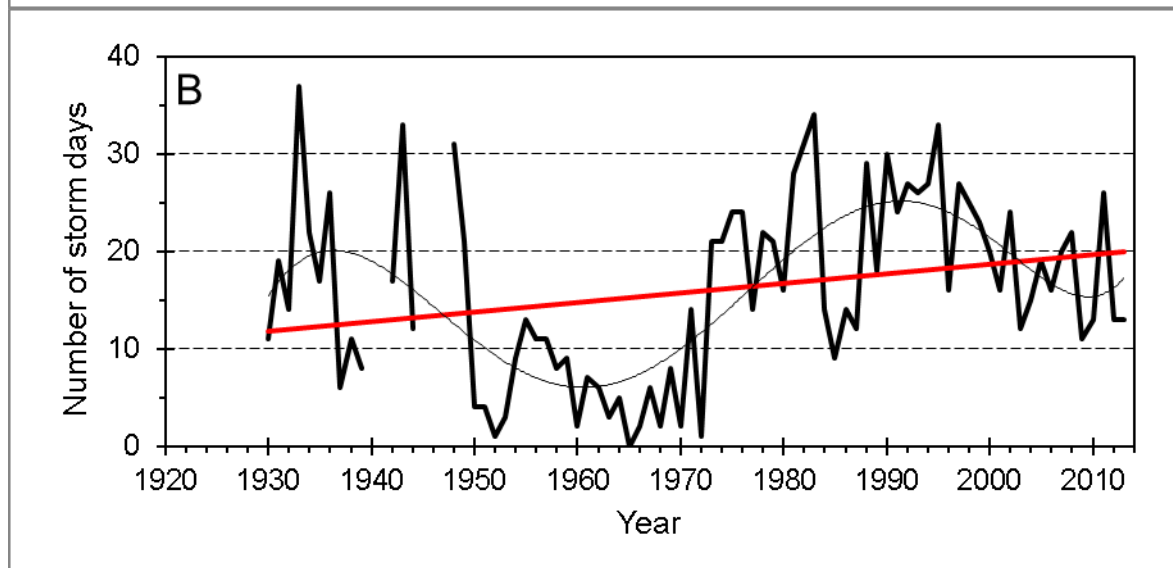
Tallinn (mean)	1842-1882, 1886-1917, 1923-1940, 1945, 1947-1996
Tallinn (max)	1899-1917, 1923-1940, 1945, 1947-1996
Narva-Jõesuu	1899-1915, 1923-1943, 1945-2011
Pärnu	1923-2011
Ristna	1950-2011
Virtsu	1889-1893, 1899-1912, 1947-2011
Rohuküla	1950-2011
Heltermaa	1950-2011
Paldiski	1950-2009
Sõrve	1894-1901, 1907-1914, 1922-1930, 1932-1939, 1950-2003
Ruhnu	1901-1913, 1947-1951, 1953-1988
Vilsandi	1884-1886, 1888-1913, 1924-1944, 1948-1980



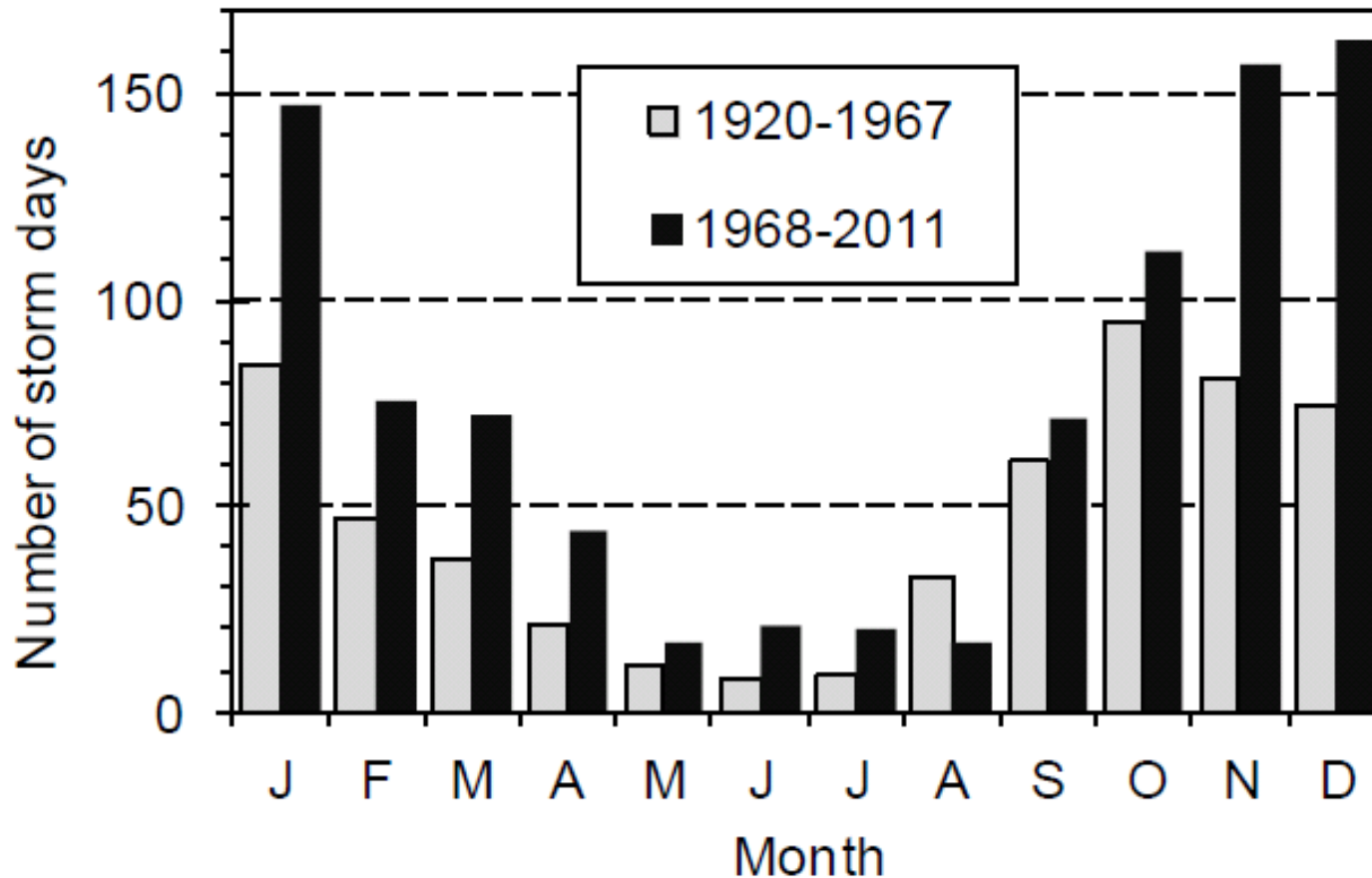
Vilsandi



Sõrve



Storm season from September to March



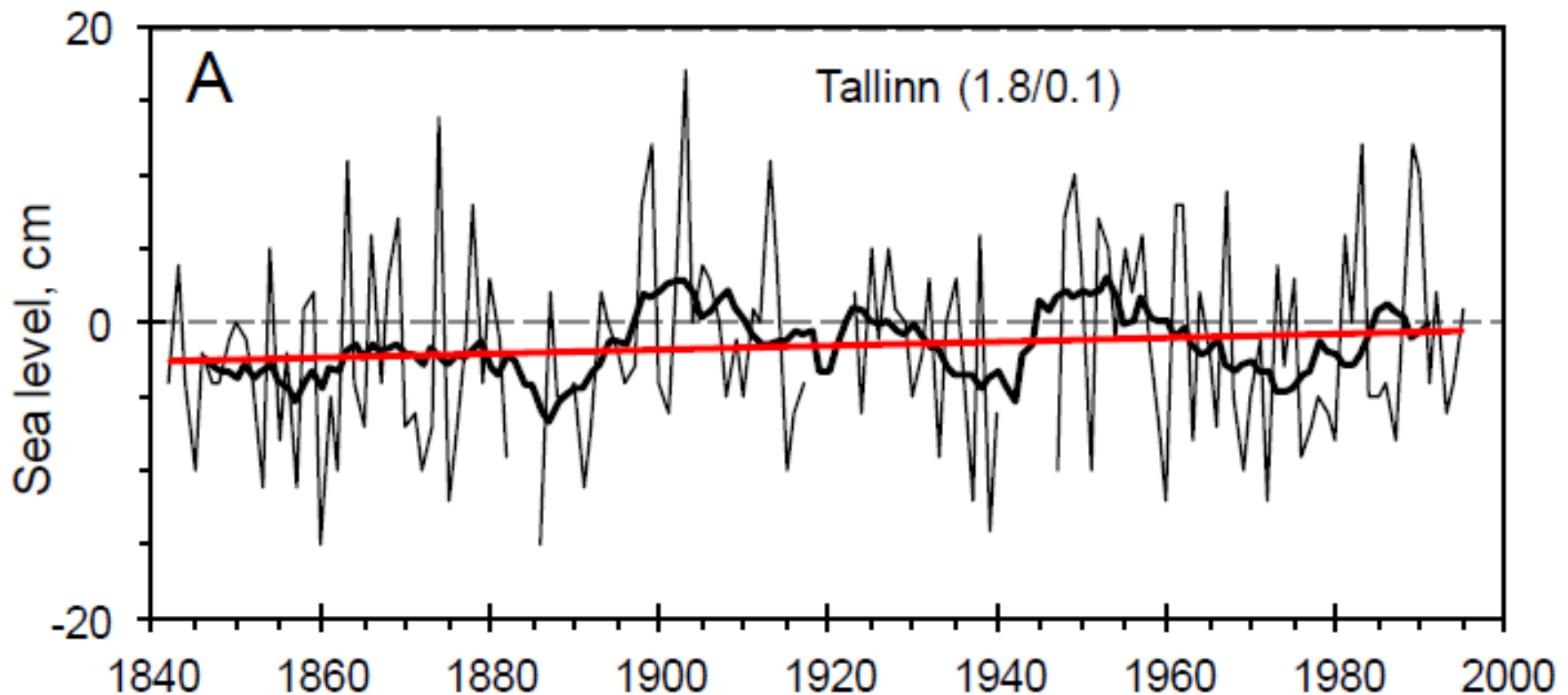
Extremely stormy period

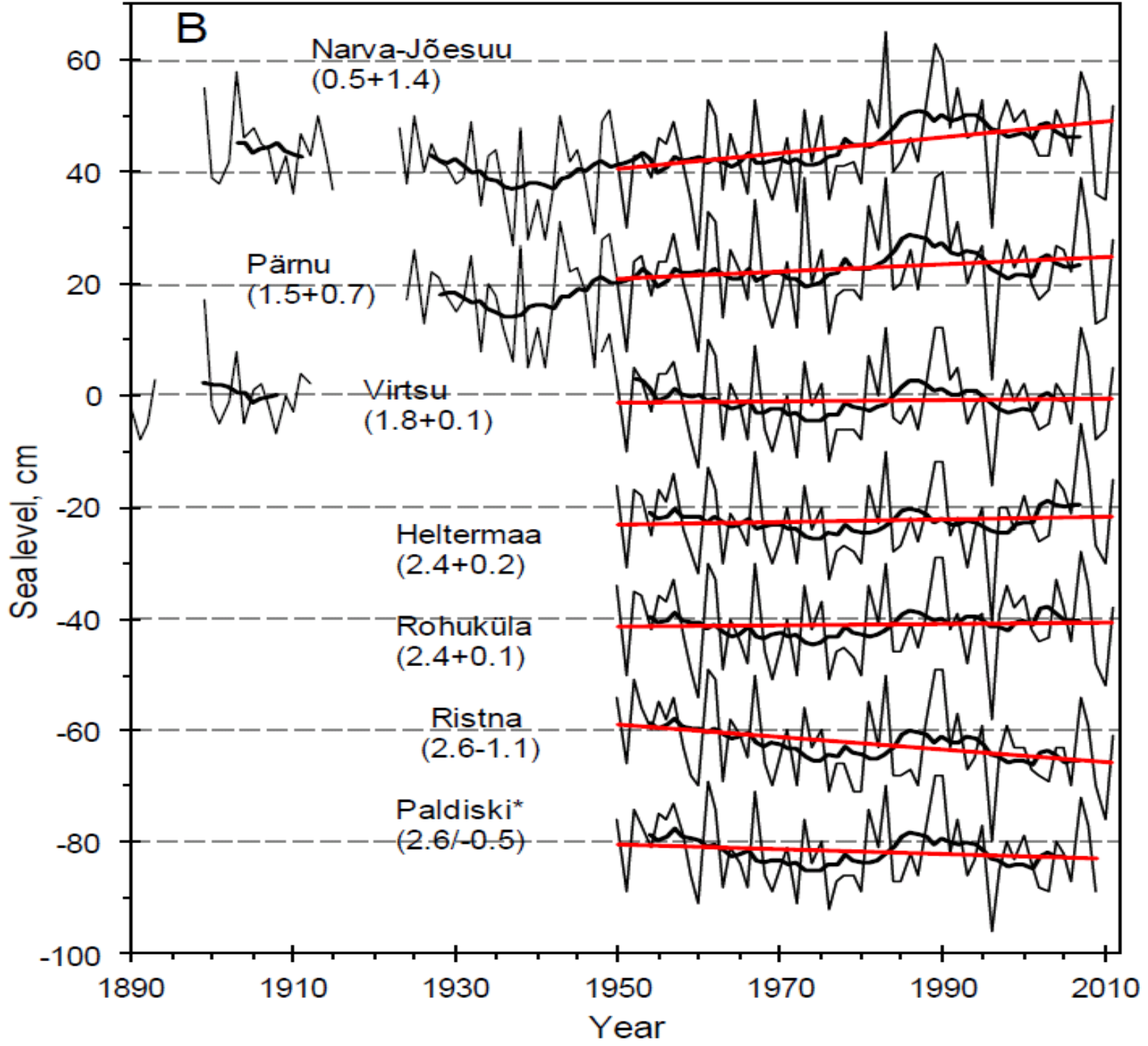
- storm duration of at least 12 days
- storm days constituted at least 20% of all days during the period
- maximum 10-min mean wind speed 20 m/s or above

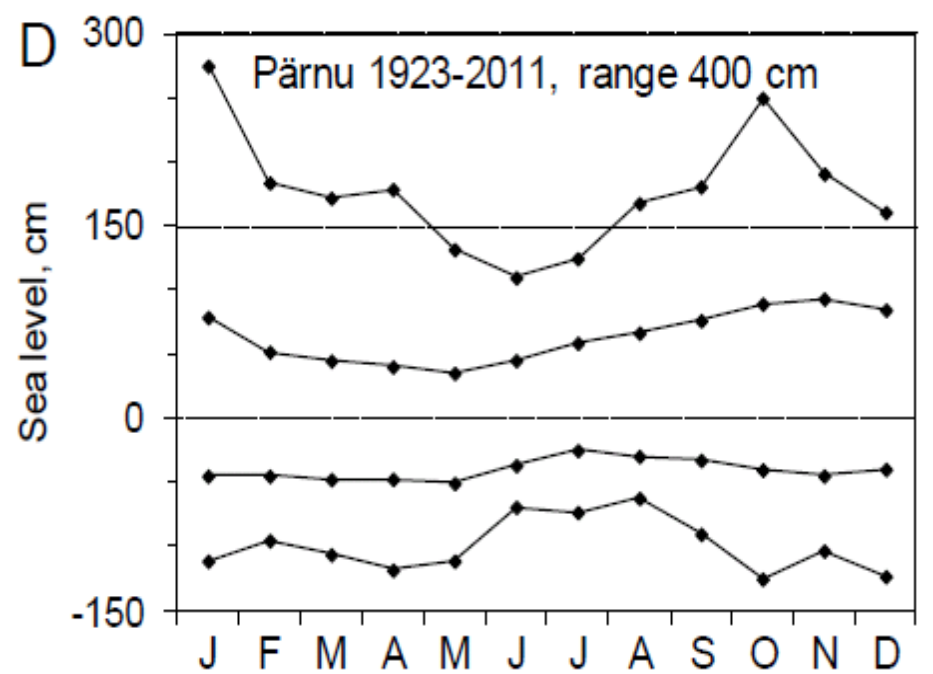
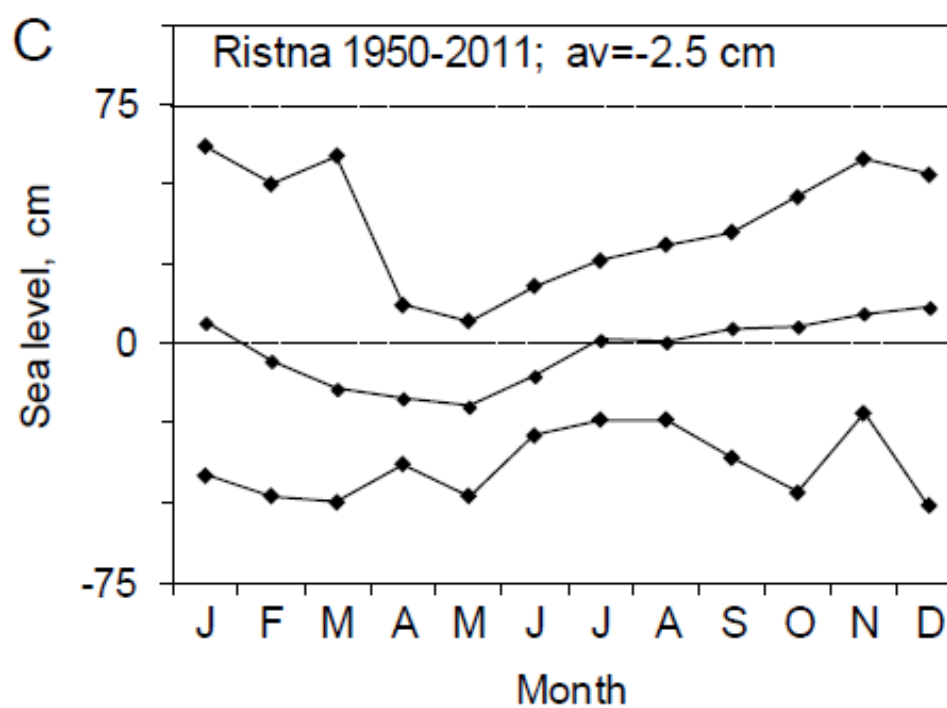
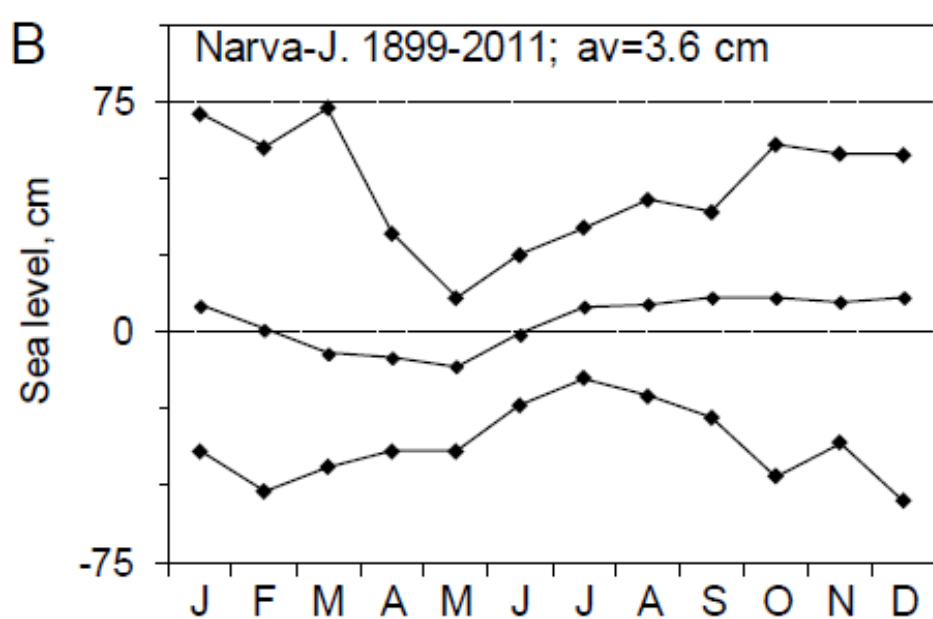
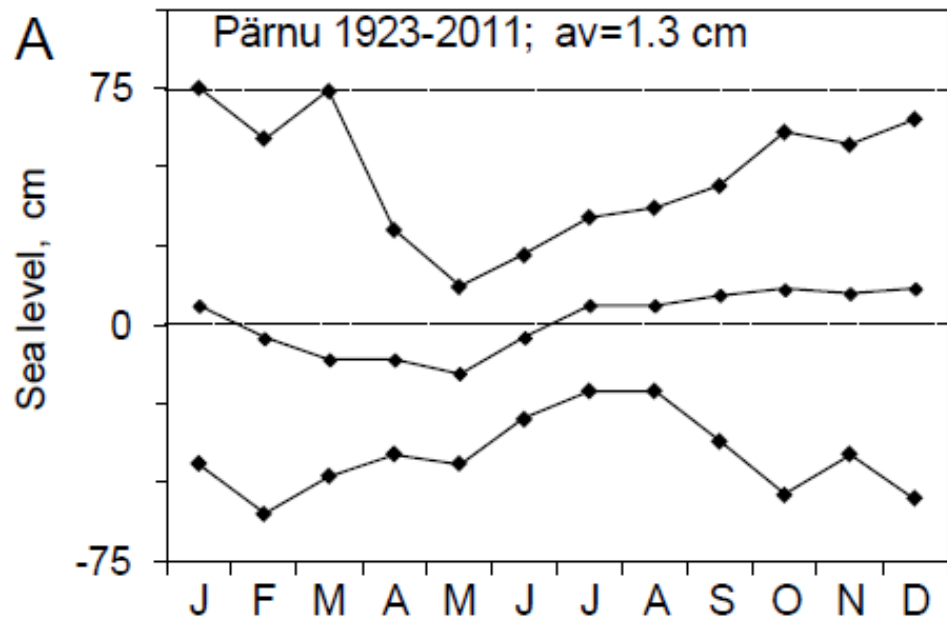
Extremely stormy periods

Stormy period	Maximum wind speed	Number of stormy days	Maximum sea level
25.11.51 - 17.01.52	24	22	64
12.08 - 4.12.54	24	27	46
25.08 - 4.12.56	21	20	42
18.09 - 22.12.57	22	21	44
6.08 - 29.12.67	29	26	176
17.09 - 11.11.69	24	18	75
11.10 - 29.12.71	21	22	68
9.10 - 12.12.73	24	18	73
20.11 - 31.12.75	24	15	74
26.10.80 - 15.01.81	28	24	95
23.09.83 - 19.01.84	22	42	111
7.11 - 9.12.86	22	13	114
18.09.88 - 26.03.89	22	51	112
26.01 - 24.03.90	25	22	166
2.11.91 - 13.03.92	28	34	99
28.11 - 26.12.99	25	15	132
21.10-17.11.01	25	12	132
25.01-10.03.02	23	15	133
14.12.04-13.01.05	22	12	209
5.12.06-28.01.07	23	20	152

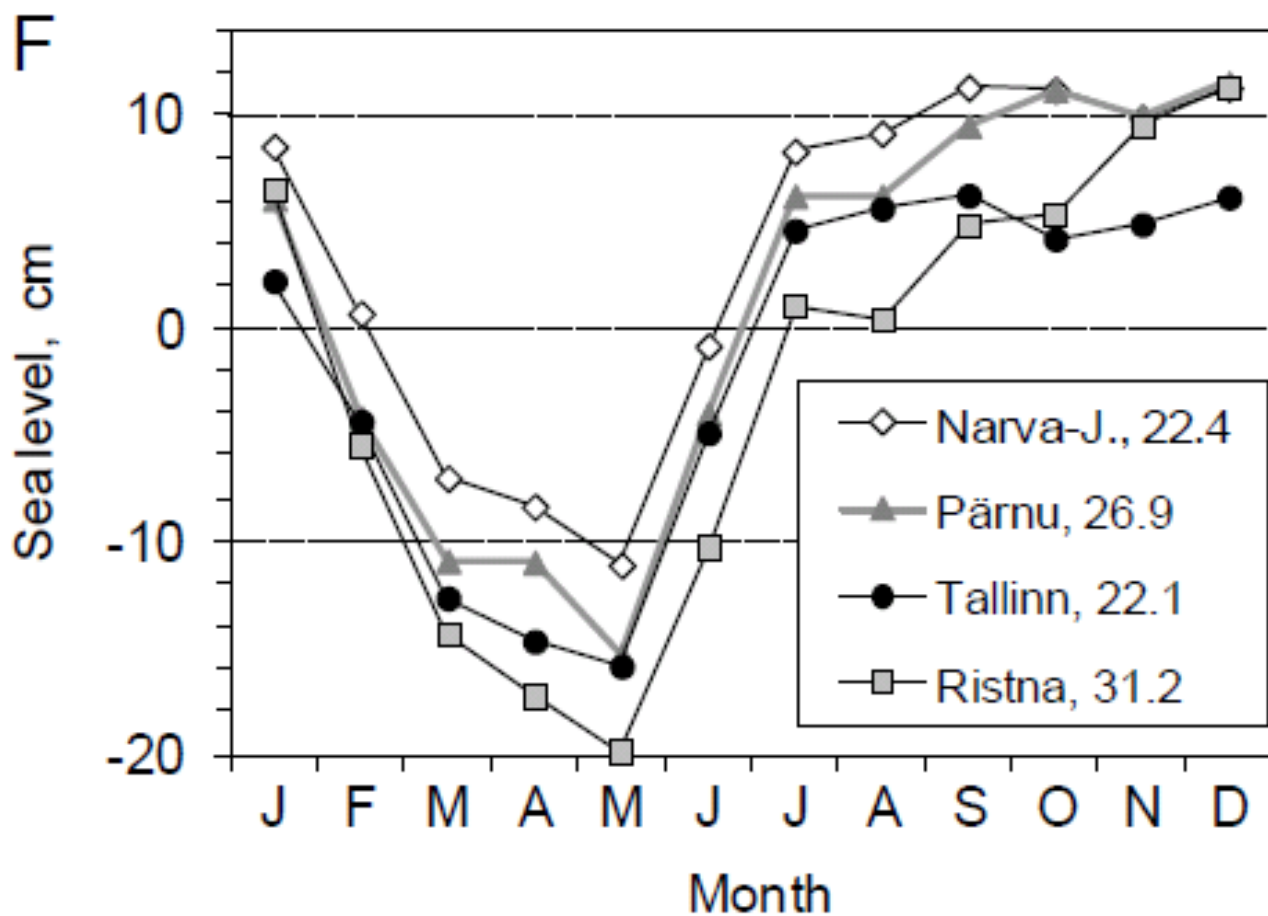
Time series of annual mean water level along the Estonian coast



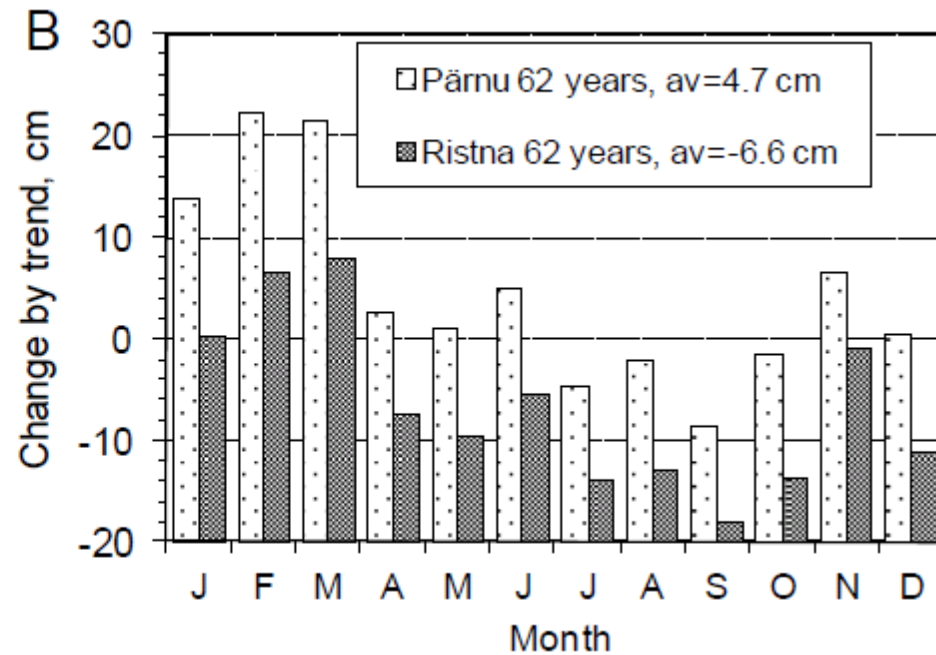
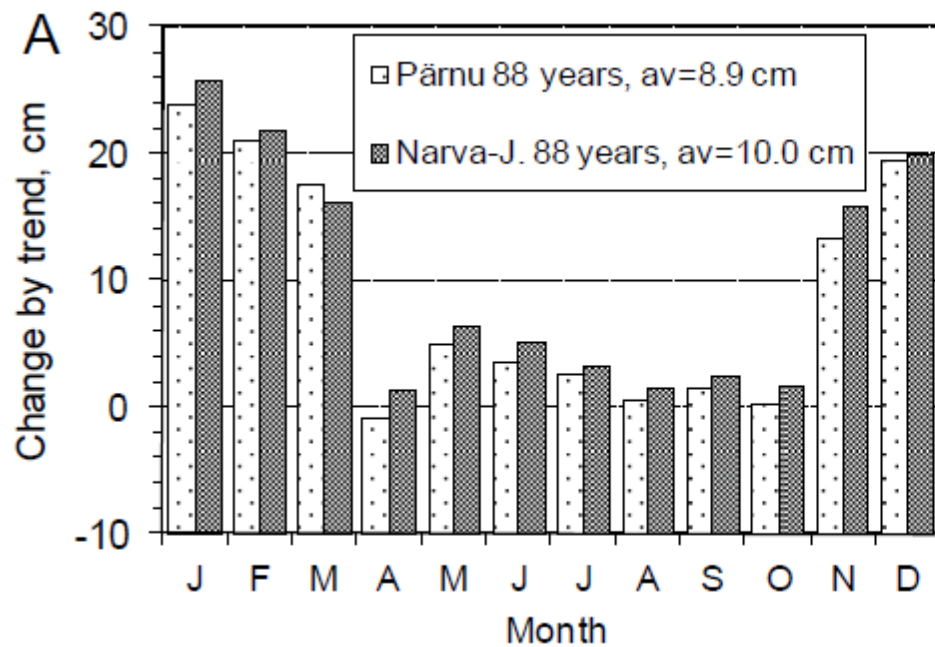


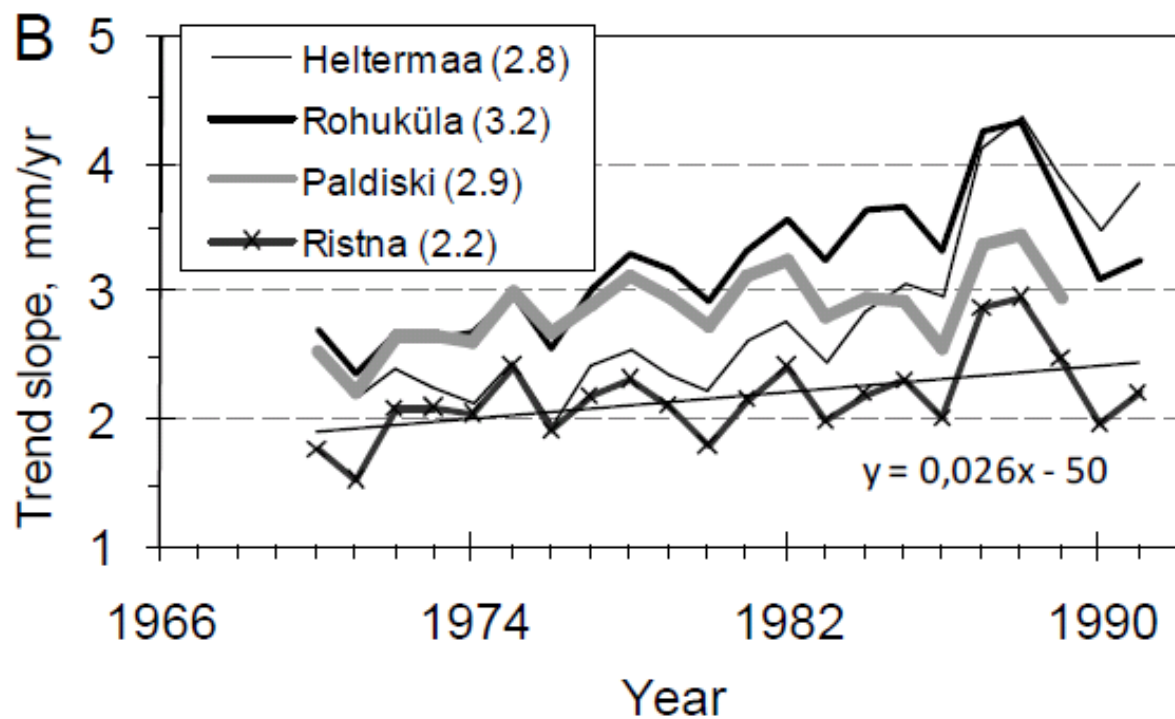
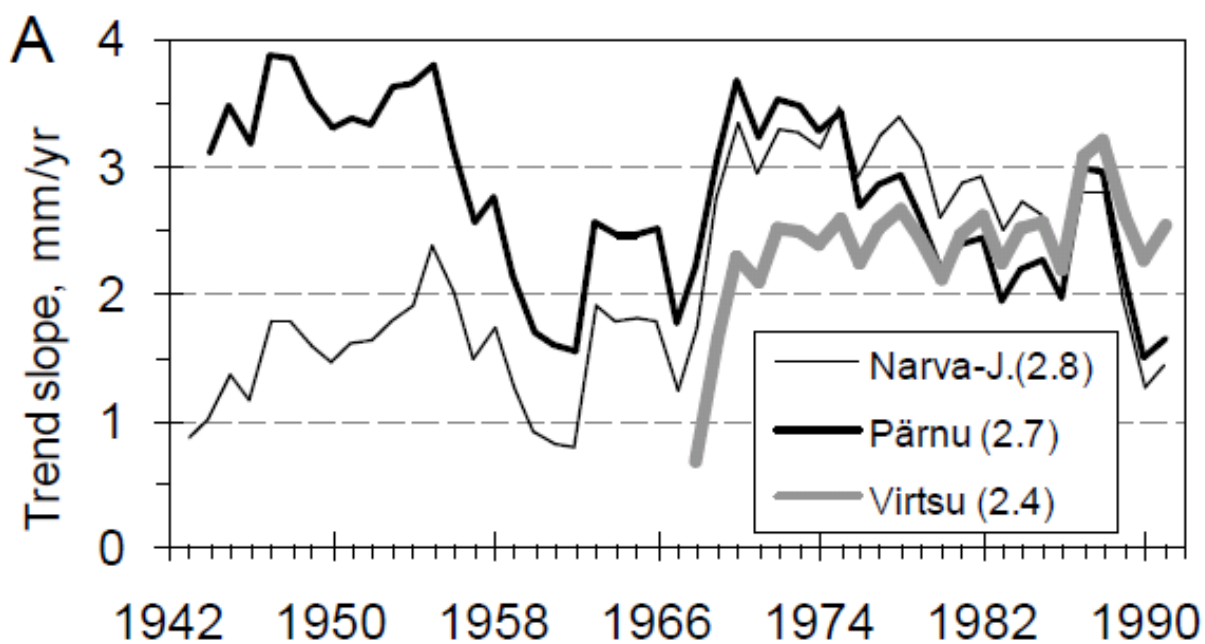


Monthly mean relative sea levels in 1950-2011



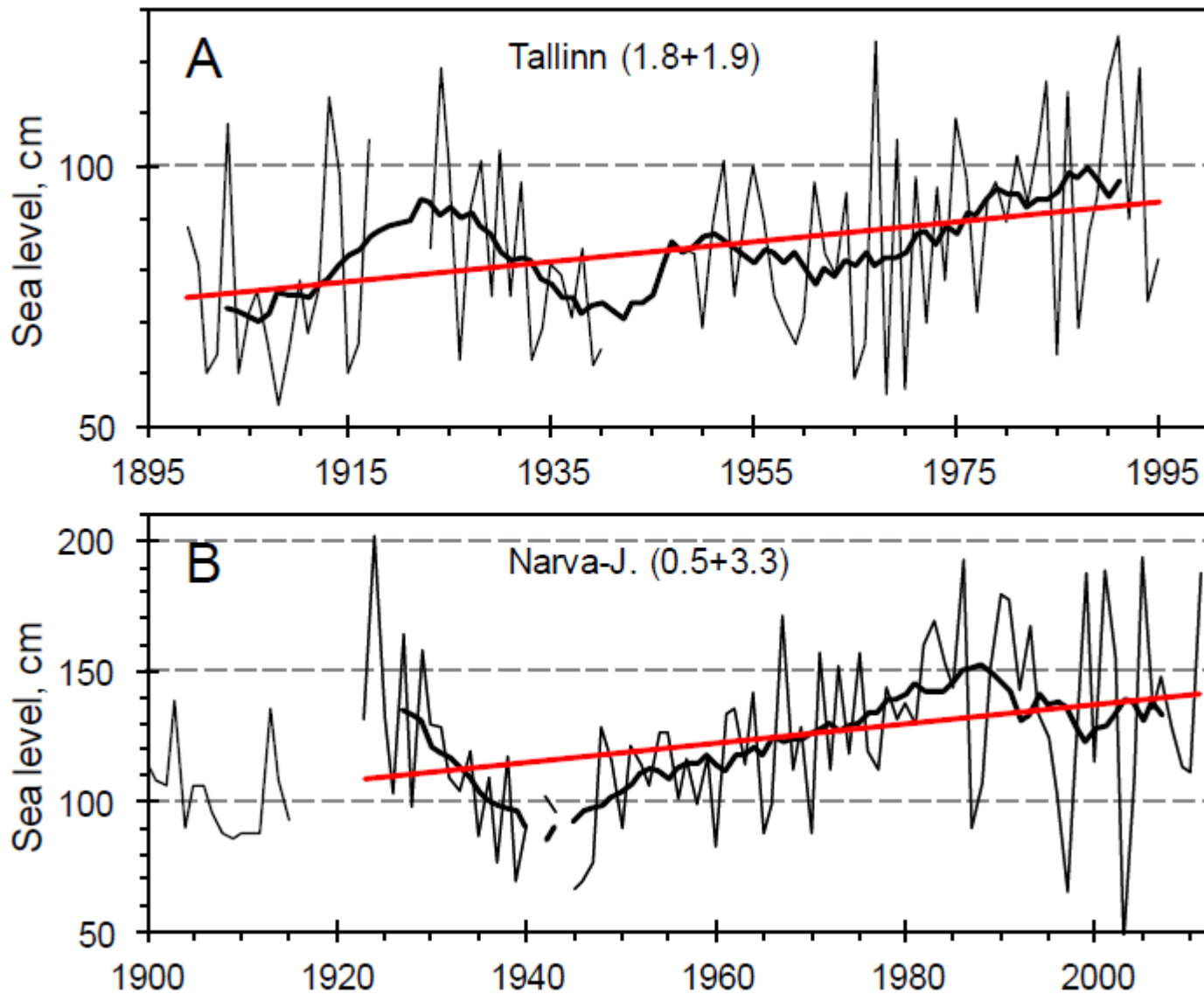
Changes by trend in monthly mean water level in 1924-2011 (A) and 1950-2011 (B)



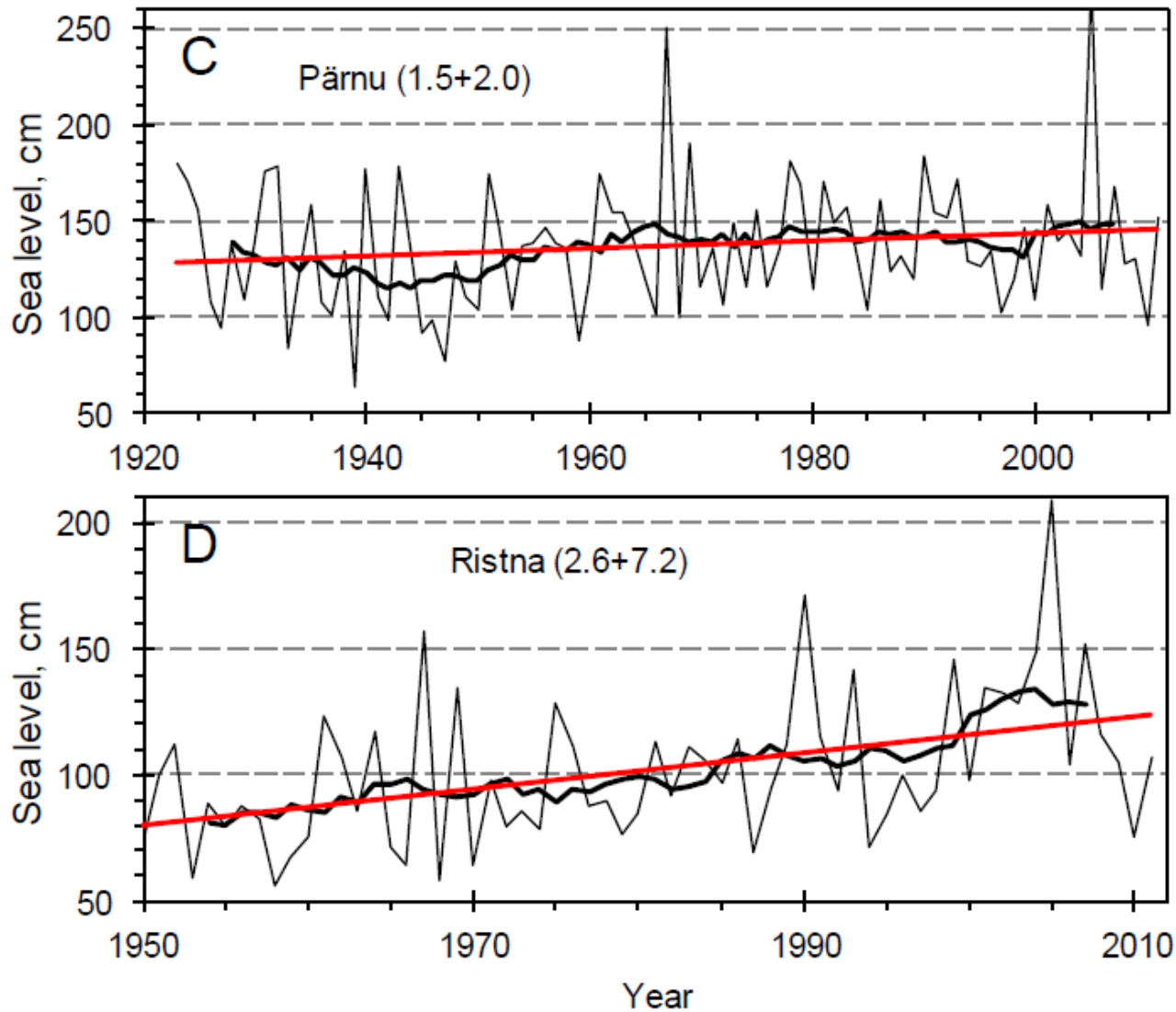


Time series of slopes of (corrected with land uplift rates) trend lines for 41 year periods, where the value is assigned to the middle year of the running window; for example, 1970 for 1950–1990 and 1991 for 1971–2011.

Time series of annual maximum sea level



Time series of annual maximum sea level



Extremely high sea-level events

Year	Month	Pärnu	Narva-Jõesuu	Tallinn	Vilsandi	Ristna
1903	Feb		113	108	61	
1913	Dec		136	113	79	
1917	Nov			105		
1923	Nov	183	109	84		
1924	Sep	174	202	119	94	
1927	Nov	81	164	74	52	
1931	Oct	179	128	75	56	
1932	Apr	179	35	17	16	
1951	Apr	175	63	27	27	28
1952	Jan	147	114	101	91	112
1961	Mar	175	134	90	74	95
1962	Jan	142	95	82	107	107
1962	Feb	155	84	70	107	95
1963	Nov	155	114	65	92	86
1967	Oct	250	171	124	206	157
1969	Nov	191	128	105	177	135



Extremely high sea-level events

1975	Jan	156	157	109	97	128
1975	Dec	129	154	105	74	109
1978	Sep	181	91	75	63	77
1981	Nov	170	130	102		113
1982	Dec	149	160	93		81
1983	Jan	133	163	100		109
1983	Nov	146	169	104		106
1984	Jan	132	153	116		106
1986	Dec	161	193	114		114
1990	Jan	140	157	116		171
1990	Feb	184	179	98		166
1990	Mar	154	146	116		112
1991	Jan	155	177	125		115
1993	Jan	172	167	119		142
1999	Nov	100	188			76
2001	Nov	159	189			146
2005	Jan	275	194			209
2007	Jan	168	148			152
2011	Dec	152	188			107

Correlation between the number of storm days, and mean (above) and maximum (below) sea-levels

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vilsandi												
Mean	0.80	0.75	0.54	0.35	0.14	0.32	0.15	0.20	0.48	0.55	0.64	0.67
Max	0.69	0.70	0.55	0.40	0.25	0.45	0.40	0.22	0.53	0.65	0.64	0.74
Sõrve												
Mean	0.72	0.66	0.66	0.49	0.01	0.13	0.11	0.23	0.40	0.20	0.54	0.58
Max	0.72	0.67	0.72	0.51	0.27	0.21	0.46	0.26	0.62	0.39	0.62	0.69



Correlation between parameters of atmospheric circulation and number of storm days in Vilsandi (above) and Sõrves (below)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W	0.51	0.74	0.35	0.04	0.25	-0.08	-0.01	0.17	0.23	0.44	0.39	0.52
	0.51	0.71	0.42	0.21	0.45	0.23	-0.08	0.19	0.27	0.19	0.49	0.40
E	-0.45	-0.60	-0.33	-0.16	-0.22	0.18	0.13	-0.04	-0.14	-0.52	-0.44	-0.39
	-0.42	-0.52	-0.34	-0.47	-0.21	-0.15	0.15	-0.03	-0.04	-0.02	-0.44	-0.26
C	0.05	-0.17	0.09	0.13	0.09	-0.32	-0.17	-0.12	-0.10	0.16	0.19	-0.10
	-0.01	-0.25	0.02	0.38	-0.11	-0.03	-0.13	-0.19	-0.24	-0.25	0.08	-0.14
AO	0.63	0.62	0.46	0.24	0.13	-0.02	-0.14	0.01	0.27	0.27	0.38	0.63
	0.68	0.56	0.46	0.24	-0.23	-0.24	-0.09	0.02	0.27	0.01	0.36	0.52
NAO-G	0.51	0.67	0.41	0.14	-0.14	0.12	0.02	0.12	0.31	-0.22	0.28	0.49
	0.56	0.57	0.38	-0.11	-0.21	-0.19	-0.04	-0.23	0.36	0.09	0.19	0.36
NAO-C	0.57	0.64	0.44	0.10	-0.02	0.08	0.10	-0.03	0.24	0.14	0.31	0.61
	0.53	0.54	0.43	-0.01	-0.21	-0.17	-0.07	-0.04	0.16	0.14	0.41	0.50
NAO-P	0.62	0.63	0.44	0.21	0.08	0.00	-0.13	0.03	0.19	0.12	0.41	0.63
	0.61	0.56	0.44	0.01	-0.32	-0.21	-0.09	-0.11	0.20	0.15	0.36	0.53
NAO-T	0.45	0.52	0.34	0.04	-0.02	-0.23	-0.15	0.02	0.05	-0.11	0.22	0.64
	0.50	0.47	0.43	-0.12	-0.22	-0.32	-0.10	-0.15	0.15	-0.09	0.17	0.55
SCAND	-0.64	-0.68	-0.58	-0.43	-0.17	-0.34	-0.18	-0.25	-0.44	-0.58	-0.63	-0.35
	-0.63	-0.61	-0.44	-0.58	-0.07	-0.28	-0.11	-0.34	-0.42	-0.16	-0.51	-0.36

Correlation between circulation parameters and mean (above) and maximum (below) sea-level

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W	0.58	0.62	0.52	0.37	0.44	0.49	0.35	0.47	0.52	0.50	0.62	0.57
	0.51	0.53	0.53	0.33	0.47	0.47	0.20	0.29	0.44	0.44	0.51	0.45
E	-0.45	-0.59	-0.40	-0.20	-0.26	-0.38	-0.15	-0.27	-0.24	-0.43	-0.64	-0.45
	-0.36	-0.49	-0.38	-0.15	-0.28	-0.23	-0.15	-0.15	-0.09	-0.37	-0.46	-0.34
C	-0.10	0.04	-0.10	-0.13	-0.05	0.00	-0.11	-0.25	-0.33	-0.11	0.25	-0.04
	-0.12	0.04	-0.13	-0.13	-0.06	-0.18	0.02	-0.14	-0.39	-0.12	0.10	-0.06
AO	0.66	0.54	0.55	0.22	0.31	0.22	0.03	0.12	0.42	0.50	0.29	0.56
	0.61	0.52	0.52	0.17	0.12	0.10	-0.10	-0.03	0.41	0.38	0.30	0.49
NAO-G	0.70	0.57	0.52	-0.08	0.32	0.42	0.16	0.37	0.44	0.36	0.06	0.41
	0.65	0.55	0.50	-0.08	0.17	0.28	0.05	0.16	0.39	0.25	0.05	0.35
NAO-C	0.69	0.56	0.55	-0.02	0.27	0.31	0.15	0.37	0.45	0.43	0.16	0.54
	0.64	0.53	0.54	-0.01	0.11	0.15	-0.03	0.20	0.42	0.35	0.17	0.49
NAO-P	0.69	0.56	0.52	0.06	0.25	0.25	0.06	0.25	0.39	0.45	0.20	0.54
	0.65	0.53	0.53	0.03	0.06	0.08	-0.09	0.13	0.37	0.30	0.17	0.49
NAO-T	0.55	0.44	0.51	-0.12	-0.03	0.06	-0.18	-0.09	0.13	0.21	0.04	0.54
	0.53	0.42	0.54	-0.11	-0.08	-0.10	-0.23	-0.06	0.15	0.07	-0.04	0.50
SCAND	-0.70	-0.70	-0.66	-0.65	-0.53	-0.58	-0.45	-0.61	-0.70	-0.66	-0.72	-0.39
	-0.60	-0.60	-0.57	-0.55	-0.36	-0.39	-0.31	-0.34	-0.57	-0.55	-0.60	-0.36

Conclusions

- The number of storm days has very likely increased on the western coast of Saaremaa since 1920, especially in winter
- Trends in sea-level height depend very much on the post-glacial isostatic land uplift. They are negative where the uplift has been higher (Ristna), and positive where the uplift has been lower (Narva-Jõesuu, Pärnu)
- Eliminating the influence of the land uplift the sea-level rise have been 2.2-3.2 mm per year during 1950-2011 that is higher than the global mean sea-level rise 1.7 mm/year. Mostly the increase has taken place in November-March
- Annual maximum sea-level height has increased much faster than the mean sea-level

Conclusions

- There are observed 35 extremely high sea-level events while 31 of them have occurred from October to March and 25 since the 1960s. Three most severe events were observed 9.01.2005, 15.10.1967 and 23.09.1924
- Correlation between storminess and sea level is highly positive, especially in winter and autumn, exceeding 0.6. Mostly, the correlation is higher for maximum sea levels than the mean values, but not in winter
- Atmospheric circulation has significant correlations with storminess and sea level during the cold period from November to March. They are positively correlated with the characteristics of the intensity of the westerly circulation and negatively with southerly and easterly circulation

Thank you for your attention!





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