CORRELATION BETWEEN SEA LEVEL AND WAVE HEIGHT
FOR A STUDY ON UNDERKEEL CLEARANCES AT RAAHE WATERWAY

AALLOKON KORKEUDEN JA VEDENKOKEUDEN KORRELAATIO
RAAHEN VÄYLÄN VARAVESISELVITYSTÄ VARTEN

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Tämä Merenkulkuhallituksen tilaama raportti sisältää aallokon korkeuden ja vedenkorkeuden korrelaation Raahen väyläsyynnittelua varten. Analyysi osoittaa ennakko-odotusten mukaisesti, että vuodenaikaisvaihteluihin liittyy positiivinen korrelaatio Ulkokallassa havaitun aallonkorkeuden ja Raahen vedenkorkeuden välillä. Odotusten vastaisesti ei mitään korrelaatiota voitu havaita lyhytaikaisten vedenkorkeus-muutosten ja aallonkorkeuden välillä.

Correlation between sea level at Raahe and significant wave height at Raahe and Ulkokalla.

Background

Because wind generates both waves and changes in the sea level, a positive correlation is possible between these two. A high swell that is uncorrelated with recent wind is rare in the Bothnian Bay, but the sea level is controlled by a number of factors that are not correlated with the local wind. The most important of these is the total amount of water in the Baltic Sea, which is mainly controlled by the wind climate in the Danish Sounds. High winds and waves can occur when the sea level in the Baltic Sea is 0.5 m below the annual mean, so there can be no guarantee that high waves could never occur when the water level is low. Statistically, however, the water level is high during the autumn season, as Table 1 shows. The wave climate is most severe during the the same time, and there thus exists another possible source for a correlation.

This report presents the correlation between the sea level and the significant wave height at Raahe. Because the number of wave measurements at Raahe is small, and because their seasonal coverage in particular is not very representative for this type of correlation analysis, the correlation has been calculated also using the wave data from Ulkokalla.

The data

Hourly sea level data from the tide gauge at Raahe harbour was used in the study. The readings have been transformed to the theoretical mean sea level system given in Vermeer et al. (1988).

The wave measuring point at Raahe (denoted by R in the map) is

close to the shore. While point R is not sheltered by islands, the water depth around the measuring point is variable, and there are shoals where water depth is 7 meters, in some places only 3 m. The wave climate at the point is different from that of the open sea. The wave measuring point near Ulkokalla island (denoted by U in the map) represents conditions in the open sea on the Finnish side of the Bothian Bay.

The wave data were measured by a Datawell Waverider buoy. The measurements were made at standard meteorological observation times every three hours. The length of one run was 15 minutes. The measurements were made in 1980 and 1981.

Significant wave height in this data is calculated by equation

$$Hs = 4 \left[\int_{0.05Hz}^{0.5Hz} E(f) df \right]^{1/2}$$

where E(f) is the wave spectrum.

Correlations

The simultaneous sea level and wave heigth measurements at Raahe are tabulated in Table 2. The correlation between them is not statistically significant. Because the wave data is not sufficiently evenly distributed over the year, this lack of correlation cannot be taken to indicate that there could not be a positive correlation on the annual scale.

The simultaneous sea level measurements at Raahe and wave heigth measurements at Ulkokalla are tabulated in Table 3. During those meteorological situations when a positive correlation between wave height and sea level is expected, the waves in the Raahe - Ulkokalla area are usually duration-limited. Therefore no time delay is expected between them. The

correlation in Table 3 is positive and statistically significant, although the correlation coefficient is as low as 0.18. The linear regression equation with 68% confidence limits for the coefficients is

$$z = (0.071 \pm 0.009)*H_s - 0.027 \pm 0.008$$

where z is the sea level in meters with reference to the theoretical mean sea level, and H_s is the significant wave height in meters.

The theoretical mean sea level at Raahe in 1993 is 0.216tm below the zero of the Finnish levelling system N60. The estimate for the annual change of the theoretical mean sea level in the near future due to the land upheaval at Raahe and the global rise of the oceans is -4.4 mm/year. This means that at Raahe the land is rising with respect to the sea.

The fact that no correlation was found between wave height and sea level at Raahe is probably due to the unrepresentative seasonal distribution of the wave data at Raahe. This, however, suggests that the only reason for the positive correlation between the wave height at Ulkokalla and water level at Raahe is the correlation on a seasonal scale: statistically, the sea levels are high during the autumn, and waves also are high at the same time.

To see if there indeed is no correlation between wave height and sea level on short time scales, the correlation of wave height and the change in the water level from the mean of the preceeding three days was calculated. Tables 4 and 5 calculated correlation coefficients show that there is no correlation, regardless of whether the wave data comes from Raahe or from Ulkokalla. Analysis of the time series shows that, while high onshore winds create high waves, and usually also a rise the sea level, the time scales of these phenomena are different, and the maxima do not occur at coherent times. This, together with the reasons for changes in sea level that are totally uncorrelated with the local wind, results in the

observed lack of correlation between wave height and short-scale variations in the sea level. This result contradicts what was anticipated before this work was carried out.

Reference

Vermeer, M., Kakkuri, J., Målkki, P., Boman, H., Kahma, K. & Leppäranta, M. 1988: Land uplift and sea level variability spectrum using fully measured monthly means of tide gauge readings. - Finnish Mar. Res. 256:3-75.

1973-1991

Pyhämaa   1973-75
Raahe   1977,1980-81
Rauma   1980
Tahkoluoto   1981,1987
Vuosaari   1990-91

64°16.1 N
23°21.5 E

r

U

Ulkokalla   1977-78
            1980-81

60°56.4 N
20°45.0 E

S

P

Sandbäck 1973-75
         1981

Helsinki 1982-85
         1990-91

Bogskär
1982-86

H

59°58.6 N
25°14.0 E

59°28.0 N
20°21.0 E

B
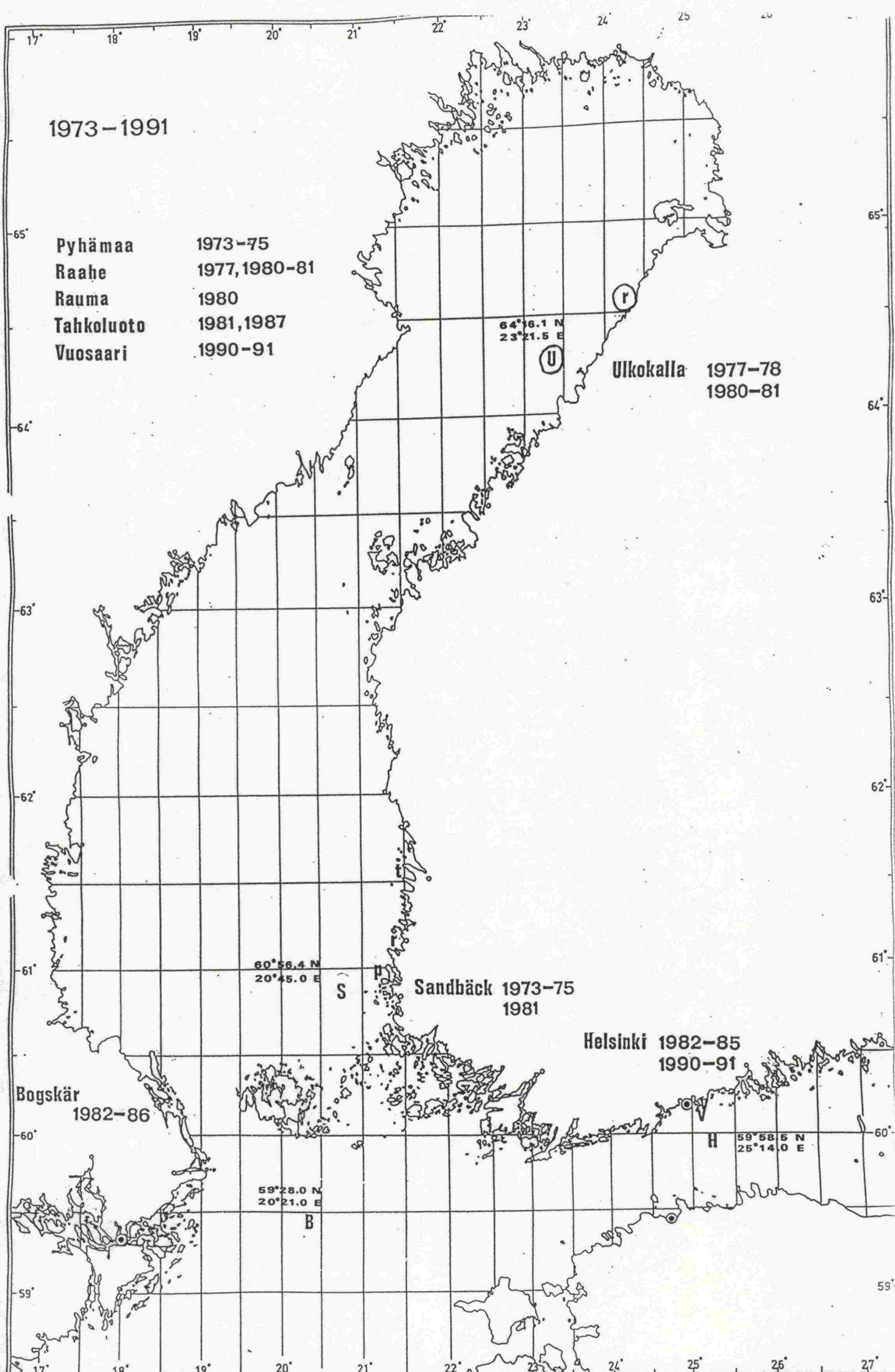
Table 1

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Monthly distribution of sea level at Raahe [cm]

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
MAX	162	162	128	79	56	62	56	73	118	125	130	125
%												
0.1	124	108	98	58	42	47	50	58	85	102	112	107
0.2	115	99	86	53	39	43	48	54	74	98	103	102
0.3	110	95	83	50	37	41	46	52	71	92	98	98
0.4	106	93	79	48	36	40	45	50	68	86	95	96
0.5	103	90	77	47	35	39	44	49	66	83	93	94
1.0	93	82	67	42	29	35	41	44	61	74	85	85
2.0	82	72	56	37	24	31	36	39	53	66	74	76
3.0	76	64	48	32	21	27	33	36	50	61	67	71
4.0	71	60	42	29	18	24	31	34	47	57	63	67
5.0	67	56	37	26	16	23	30	32	44	54	59	64
10.0	55	39	23	17	8	15	24	26	36	44	48	53
15.0	46	29	14	11	3	11	19	22	30	38	41	45
20.0	39	22	8	6	-1	8	16	19	27	33	35	39
25.0	32	16	3	2	-5	5	13	16	23	29	31	34
30.0	26	11	-1	-1	-7	3	11	14	20	25	26	30
40.0	17	4	-7	-8	-12	-1	7	9	14	18	18	22
50.0	8	-4	-13	-13	-16	-5	3	4	9	12	12	16
60.0	0	-11	-19	-19	-20	-9	-1	0	4	6	5	9
70.0	-8	-19	-25	-24	-24	-12	-5	-5	-2	-1	-2	2
75.0	-13	-23	-29	-27	-27	-14	-6	-7	-5	-5	-5	-3
80.0	-18	-28	-33	-30	-29	-17	-9	-10	-9	-9	-10	-7
85.0	-24	-33	-37	-34	-32	-20	-11	-13	-13	-14	-15	-13
90.0	-31	-39	-42	-39	-36	-24	-14	-18	-19	-22	-22	-22
95.0	-43	-47	-49	-45	-43	-30	-19	-25	-29	-35	-32	-34
96.0	-46	-49	-51	-48	-45	-32	-20	-27	-32	-38	-36	-37
97.0	-51	-51	-54	-51	-48	-34	-21	-29	-37	-41	-40	-43
98.0	-56	-54	-56	-55	-51	-37	-24	-34	-43	-47	-45	-48
99.0	-64	-60	-62	-62	-56	-41	-28	-40	-51	-54	-54	-60
99.5	-75	-66	-68	-71	-62	-44	-34	-45	-59	-62	-66	-69
99.6	-79	-68	-69	-74	-65	-45	-35	-46	-61	-64	-72	-72
99.7	-83	-71	-72	-78	-69	-46	-37	-49	-66	-68	-76	-75
99.8	-88	-73	-78	-83	-75	-47	-40	-53	-73	-72	-80	-80
99.9	-93	-82	-90	-91	-82	-50	-50	-58	-80	-85	-85	-86
MIN	-128	-127	-110	-102	-110	-59	-55	-67	-93	-129	-101	-98

The table is based on data from the years 1922...1990

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Table 2

Wave height and sea level at Raahe 64 39.3 N   24 17.4 E

significant wave height [m]	Sea level w.r.t theoretical mean sea level [m]									
	-1.0	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1.0	1.25
0.00 : 0.25	0	0	0	28	98	42	0	0	0	0
0.25 : 0.50	0	0	4	38	137	74	1	0	0	0
0.50 : 0.75	0	0	3	23	40	48	0	0	0	0
0.75 : 1.00	0	0	9	6	11	17	0	0	0	0
1.00 : 1.25	0	0	0	3	7	7	0	0	0	0
1.25 : 1.50	0	0	0	2	5	2	0	0	0	0
1.50 : 1.75	0	0	0	0	1	0	0	0	0	0
1.75 : 2.00	0	0	0	0	1	0	0	0	0	0
2.00 : 2.25	0	0	0	0	1	0	0	0	0	0
2.25 : 2.50	0	0	0	0	0	0	0	0	0	0
2.50 : 2.75	0	0	0	0	0	0	0	0	0	0
2.75 : 3.00	0	0	0	0	0	0	0	0	0	0

correlation coeff r = 0.01, no correlation

Table 3

Wave height and sea level at Ulkokalla 64 16.1 N   23 21.5 E

significant wave height [m]	Sea level w.r.t theoretical mean sea level [m]									
	-1.0	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1.0	1.25
0.00 : 0.25	0	2	1	58	137	43	0	0	0	0
0.25 : 0.50	0	2	11	73	195	115	7	0	0	0
0.50 : 0.75	0	0	6	74	160	85	9	0	0	0
0.75 : 1.00	0	0	3	35	113	68	8	0	0	0
1.00 : 1.25	0	0	4	24	96	37	14	0	0	0
1.25 : 1.50	0	1	5	13	36	30	11	1	0	0
1.50 : 1.75	0	2	1	3	25	21	8	0	0	0
1.75 : 2.00	0	0	0	5	16	15	0	0	0	0
2.00 : 2.25	0	0	2	0	11	13	1	0	0	0
2.25 : 2.50	0	0	0	0	5	6	2	0	0	0
2.50 : 2.75	0	0	0	0	5	6	2	0	0	0
2.75 : 3.00	0	0	0	0	0	0	0	0	0	0

correlation coeff r = 0.18, t_{n-2} = 7.5

correlation very low but statistically significantly different from zero.

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Table 4

Wave height and sea level at Raahe 64 39.3 N 24 17.4 E

significant wave height [m]	Change of sea level from the preceeding 3 days mean [m]									
	-1.0	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1.0	1.25
0.00 : 0.25	0	0	0	16	131	21	0	0	0	0
0.25 : 0.50	0	0	0	27	203	24	0	0	0	0
0.50 : 0.75	0	0	0	14	84	16	0	0	0	0
0.75 : 1.00	0	0	0	10	30	3	0	0	0	0
1.00 : 1.25	0	0	0	2	10	5	0	0	0	0
1.25 : 1.50	0	0	0	1	8	0	0	0	0	0
1.50 : 1.75	0	0	0	0	1	0	0	0	0	0
1.75 : 2.00	0	0	0	0	1	0	0	0	0	0
2.00 : 2.25	0	0	0	0	1	0	0	0	0	0
2.25 : 2.50	0	0	0	0	0	0	0	0	0	0
2.50 : 2.75	0	0	0	0	0	0	0	0	0	0
2.75 : 3.00	0	0	0	0	0	0	0	0	0	0

correlation coeff $r = 0.06$, no correlation

Table 5

Wave height and sea level at Ulkokalla 64 16.1 N 23 21.5 E

significant wave height [m]	Change of sea level from the preceeding 3 days mean [m]									
	-1.0	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1.0	1.25
0.00 : 0.25	0	0	3	18	191	29	0	0	0	0
0.25 : 0.50	0	0	4	47	306	44	2	0	0	0
0.50 : 0.75	0	0	2	43	238	48	3	0	0	0
0.75 : 1.00	0	0	0	28	171	28	0	0	0	0
1.00 : 1.25	0	0	0	25	119	31	0	0	0	0
1.25 : 1.50	0	0	1	15	59	21	1	0	0	0
1.50 : 1.75	0	0	2	5	46	7	0	0	0	0
1.75 : 2.00	0	0	0	4	31	1	0	0	0	0
2.00 : 2.25	0	0	2	4	18	3	0	0	0	0
2.25 : 2.50	0	0	0	4	6	3	0	0	0	0
2.50 : 2.75	0	0	0	1	8	4	0	0	0	0
2.75 : 3.00	0	0	0	0	0	0	0	0	0	0

correlation coeff $r = 0.02$, no correlation