SUPPLEMENT No. 405

Kahma Kimmo - Pettersson Heidi - Myrberg Kai - Jokinen Hannu:
Estimated Wave Conditions and Currents during the last Voyage of M/S Estonia.

Finnish Institute of Marine Research.

Helsinki 1996.

ESTIMATED WAVE CONDITIONS AND CURRENTS DURING THE LAST VOYAGE OF M/S ESTONIA

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Finnish Institute of Marine Research

1995

SUMMARY

Wave hindcast for 27th and 28th September, 1994:

Point A: 10 nautical miles north of Osmussaar at 22:00 EET.
The swell has turned into a sea, and the waves are growing steeper.

Significant wave height	ca.	2.5 m
Significant period	ca.	6.5 s
Mean direction of waves	ca.	250°

Point B: North of Hiiumaa (59°25'N 22°35'E) at 23:00 EET.
The sea is growing; the waves are steep.

Significant wave height	ca.	3 m
Significant period	ca.	7 s
Mean direction of waves	ca.	260°

The site of the shipwreck at		01.00	01.30	02.00	08.00 EET
Significant wave height	ca.	4 m	4.2 m	4.4 m	5 m
Significant period	ca.	7.8 s	8 s	8.2 s	8.7 s
Mean direction of waves	ca.	260°	260°	260°	270°

We have not found large areas where bottom effects could have increased wave height significantly at 01.30. At those areas near the shipwreck that are covered by the detailed bathymetric data, there probably were no small focal points at 01.30. The detailed bathymetric data does not cover all the area of concern. We have found that the bathymetry has be known up to details that are not described adequately in the nautical charts.

The current at depth 0...5m at 01:30 has been estimated to have been ca. 10 cm/s in direction 90°...100°.

CONTENTS

1. GENERAL

At the request of the International Research Commission on M/S Estonia, the Finnish Institute of Marine Research (FIMR) has performed a hindcast on the wave and current conditions prevailing during the last voyage of M/S Estonia.

The northern Baltic Proper, in which M/S Estonia met with her accident, has the severest wave climate found in the Baltic Sea. The nearest place from which wave measurements are available is south of Bogskär: there the highest measured individual wave was 12.2 m. This measurement was made on January 14, 1984; the greatest significant wave height during the same storm was 6.7 m, and the average of the highest third of the waves was 7.7 m.

The conditions on September 27th, 1994 were severe but not exceptional. The average wind speed in the area reached 20 m/s just before the accident, but the waves had not grown to their maximum height for the local fetch and wind speed. The wind had changed direction by 80° during the six hours before the accident, and this limited wave growth.

On the other hand, the waves grew long enough to be influenced by the bottom topography. The experience of ship captains regularly plying these waters is that there are "bad spots".

2. WIND DATA

The wind data used for the wave hindcast has been provided by the Finnish Meteorological Institute (FMI). It is presented in Appendix A.

We have used the areal sea wind estimates provided by the Finnish Meteorological Institute. Model comparisons have shown that our wave model hindcasts are more accurate when these estimates are used instead of extrapolating directly observed wind data.

3. WAVE HINDCAST WITHOUT SHALLOW WATER EFFECTS

3.1 The model

Wave growth has been estimated (hindcast) by the parametric wave-ray model developed at the FIMR.

As regards the underlying physics, the FIMR model is a second-generation model. It differs from the standard grid-based models in that it is set up individually for a point, and it takes into account the detailed coastline geometry and its influence on the difference between wind and wave direction, as well as incorporating in parametric form other special factors, if any, affecting wave growth and dissipation in the area.

The model uses a very large grid chosen manually for the locality; wave growth on this grid is then integrated along precomputed wave rays to the single forecasting point. The model uses most recent growth curves by Kahma and Calkoen, (1994). The version used here will predict significant wave height, significant wave period, and direction of the waves. Figure 1 shows the most recent operational model verification in the Gulf of Finland.

The effects of shallow water are not incorporated in the present version of the model. They are estimated separately by the wave refraction model described in the next section.

Setting up this model for a new point and calibrating it usually entails a considerable amount of work. Fortunately, the model had been previously set up for a point sufficiently near the site of the accident that it could be reliably modified for the three points required by the Commission.

The estimated r.m.s. error of the wave hindcast:

r.m.s. error in significant wave height	0.5 m
r.m.s. error in significant period	ca. 1 s
r.m.s. error in mean direction of waves	ca. 10°

Significant wave height is defined as $4\sqrt{\frac{E}{\rho g}}$ where E is the total energy of waves in a unit area and ρ is the density of water and g the acceleration of gravity. Significant wave height is close to the visual estimated of average wave height. Significant period is defined as the peak period of the wave spectrum. In this report the direction of waves means the direction from which the waves arrive, in keeping with the convention for the direction of the wind.

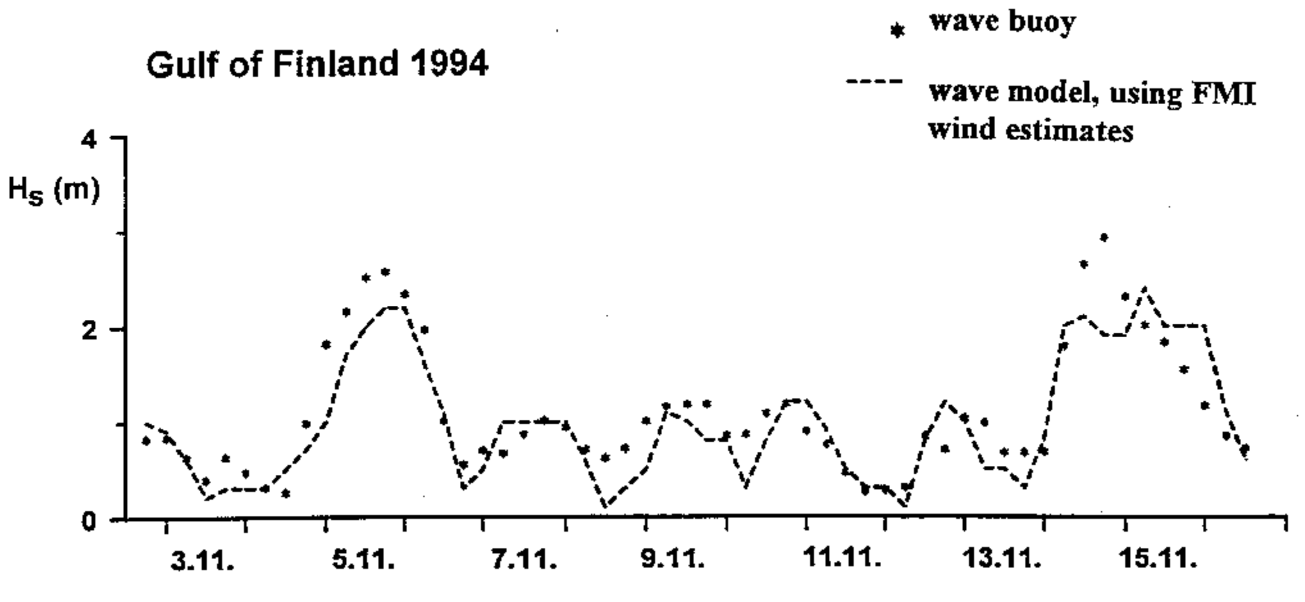


Figure 1. Model verification measurements made in the Gulf of Finland.

3.2 Hindcasts

Point A: 10 nautical miles north of Osmussaar at 22:00 EET

Significant wave height	ca.	2.5 m
Significant period	ca.	6.5 s
Mean direction of waves	ca.	250°

The swell has turned into a sea, and the waves are growing steeper.

Point B: North of Hiiumaa (59°25'N 22°35'E) at 23:00 EET

Significant wave height	ca.	3 m
Significant period	ca.	7 s
Mean direction of waves	ca.	260°

The sea is growing; the waves are steep.

The site of the shipwreck at		01.00	01.30	02.00	08.00 EET
Significant wave height	ca.	4 m	4.2 m	4.4 m	5 m
Significant period	ca.	7.8 s	8 s	8.2 s	8.7 s
Mean direction of waves	ca.	260°	260°	260°	270°

3.3 Other estimates of waves in the area

As was discussed before, the wind had turned 6 hours before the accident, and the waves were still duration-limited. If the wind had remained constant in direction from the beginning of the storm, the waves would had been fetch-limited, and we estimate that significant wave height could have been about 5 m, and the significant wave period about 9.8 s.

For purposes of comparison we also performed the hindcast on the basis of the directly measured station winds extrapolated into the relevant area. The results for 02:00 EET are: significant wave height about 3.6 m, significant wave period about 7.8 s.

4. WAVE REFRACTION BY SHALLOW WATER

4.1 General

When waves arrive in to shallow water the phase speed is reduced and the waves refract. The refraction model calculates how the waves change direction in water of variable depth. The model follows the progress of waves along a wave ray at right angles to the wave front, starting at the map boundary and continuing until the waves reach the shore or go out of the map area again. The pattern of the wave rays shows where the waves concentrate into a small spot or spread out into a larger area. In the first case the wave height grows; in the second case it decreases.

Calculations indicate that in the Northern Baltic Proper there are focal points where wave refraction in certain conditions can increase the wave height significantly above the surroundings. As an example of phenomenon we show the results at Suomen Leijona, about 25 nm from the place of accident (Fig. 2).

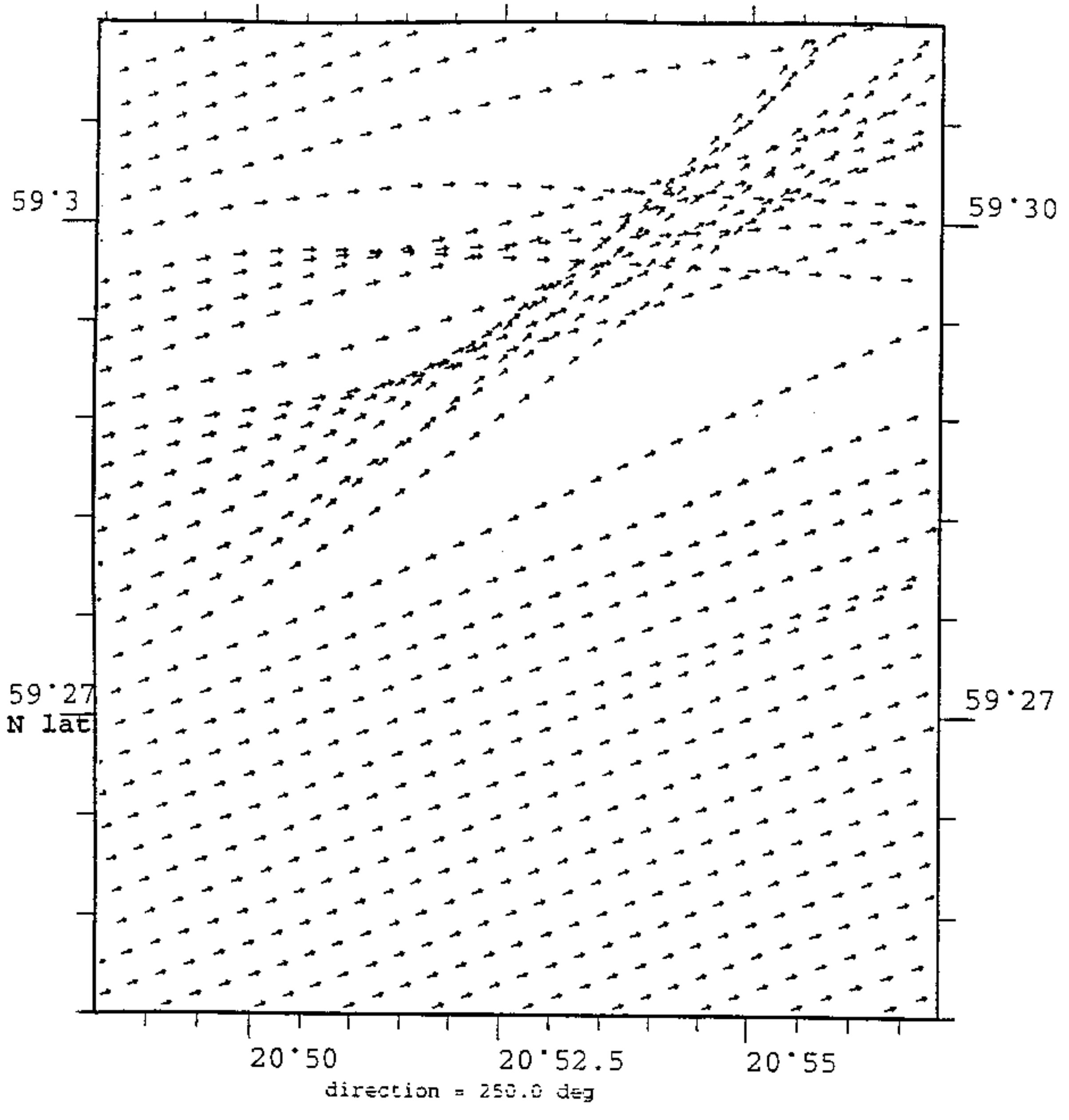


Figure 2a. Refraction of unidirectional waves (log crested swell) over a shoal, wave rays.

The refraction rays describe the behaviour of unidirectional waves. In practice this occurs only when swell is coming into the area from a great distance. When the sea is actively growing under the influence of wind, the direction of the incoming waves is distributed over a broad angle. When the significant wave height is estimated, all these different wave rays have to be taken into account. In our model the Monte-Carlo method proposed by Bouws and Battjes (1982) is used .

Figure 3 shows significant wave height of short crested storm waves behind the same shoal. While the wave height enhancement by refraction is up to double in the case of unidirectional swell (Fig.2.), actively growing wind generated waves are enhanced by factor 1.4 in this case. If the spreading is wider the maximum height is less.

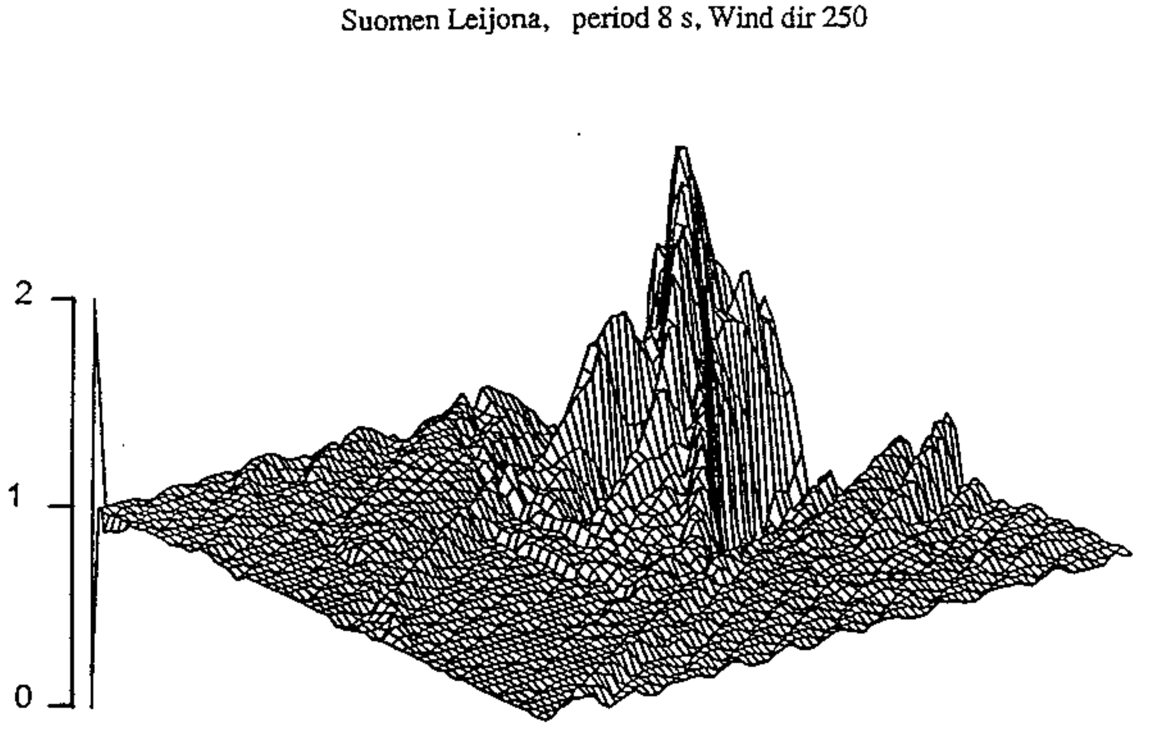


Figure 2b. Refraction of unidirectional waves (log crested swell) over a shoal, the change in wave height.

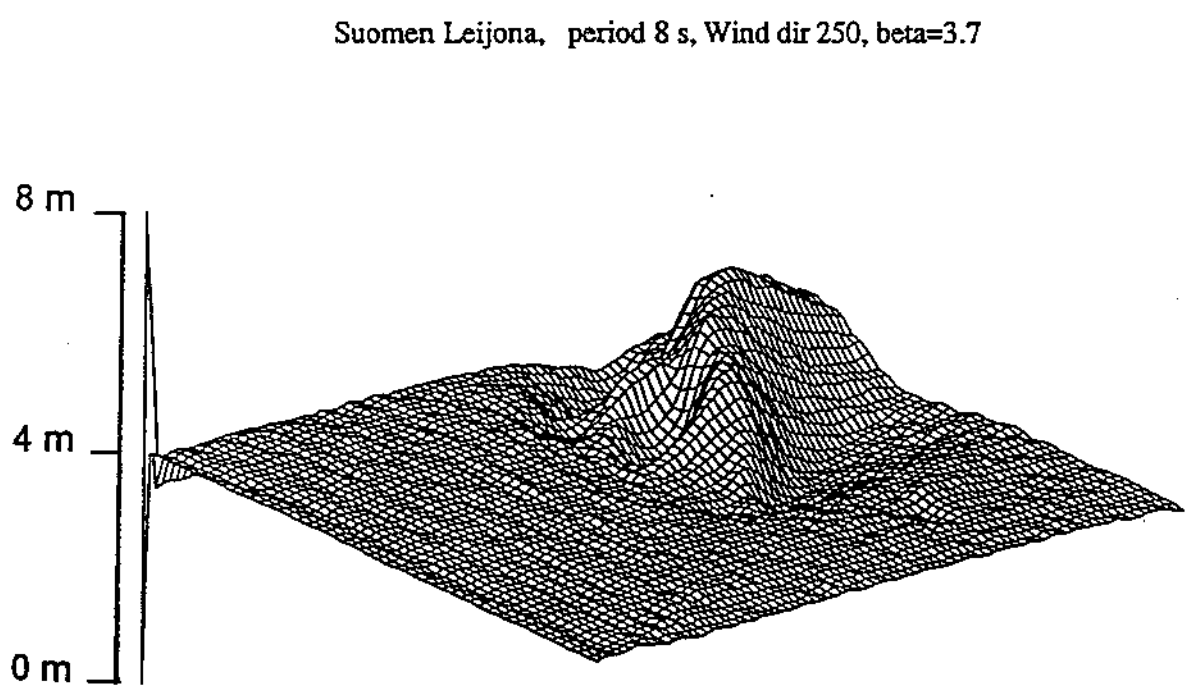


Figure 3. Refraction of wind generated waves (short crested storm waves) over the same shoal. Period 8 s, significant wave height 4 m before the shoal. Wave spreading 14 degrees.

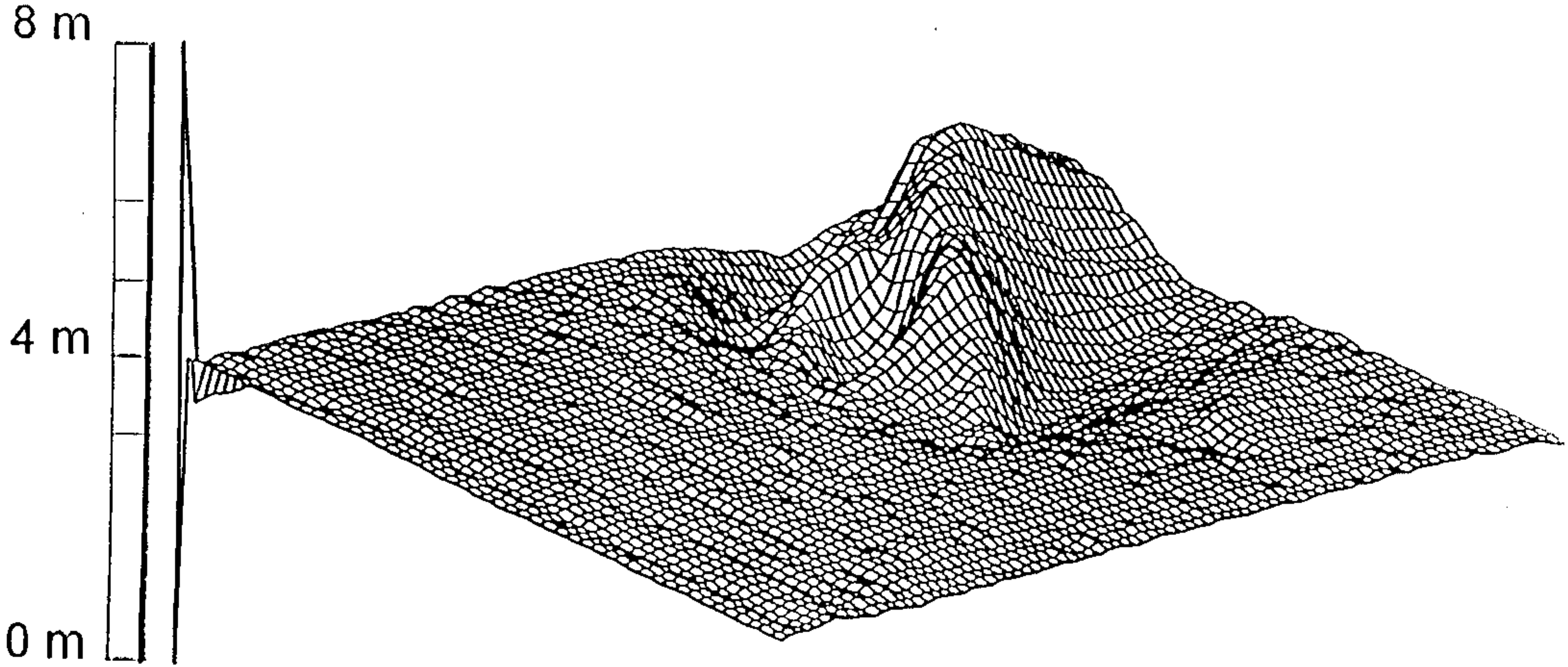


Figure 3. Refraction of wind generated waves (short crested storm waves) over the same shoal. Period 8 s, significant wave height 4 m before the shoal. Wave spreading 14 degrees.

We want to emphasize that the estimates how much the wave height will increase are very sensitive to the details of the topography and the directional properties of the wave spectrum, as well as the assumptions of the physics of the growth of wind generated waves. Estimates of the enhancement of the wave height by refraction are inaccurate when the waves are actively growing by the wind.

4.2 Smoothed large scale bottom topography

Refraction in the whole northern Baltic Proper was first calculated using a grid showing smoothed large scale topography. The grid for the large scale bottom topography is based on nautical charts. Some corrections have been made based on the detailed bathymetric data provided by the Finnish Board of Navigation.

The series of maps in Appendix B shows the wave rays calculated separately for waves coming in from different directions at intervals of 5°, and having different periods in the range 7 s to 9 s. An example is shown as Fig.4. In the refraction map the length of the arrow is directly proportional to the group velocity of the waves.

Figure 4 shows that refraction occurs at 8 second period waves on the northern Baltic Proper. The wave height of unidirectional swell would increase at places where the rays converge. The point of accident is shown by a circle. The waves coming from 270 degrees are enhanced there.

When the angular spreading of growing waves is taken into account the refraction from this large scale bottom topography does not increase the wave height of a growing sea along the assumed route of M/S Estonia (Fig.5). This means that the wave forecasts in section 3 that ignore the refraction can be used to estimate the general wave height along the route. On the other hand the directional properties are changed. This could enhance the refraction if there is a shoal along the route.

Fig.5 also shows how waves arriving from the Baltic Proper would decay as they propagate along the Gulf of Finland. This decay is somewhat overestimated, if the wind is still blowing in the Gulf of Finland.

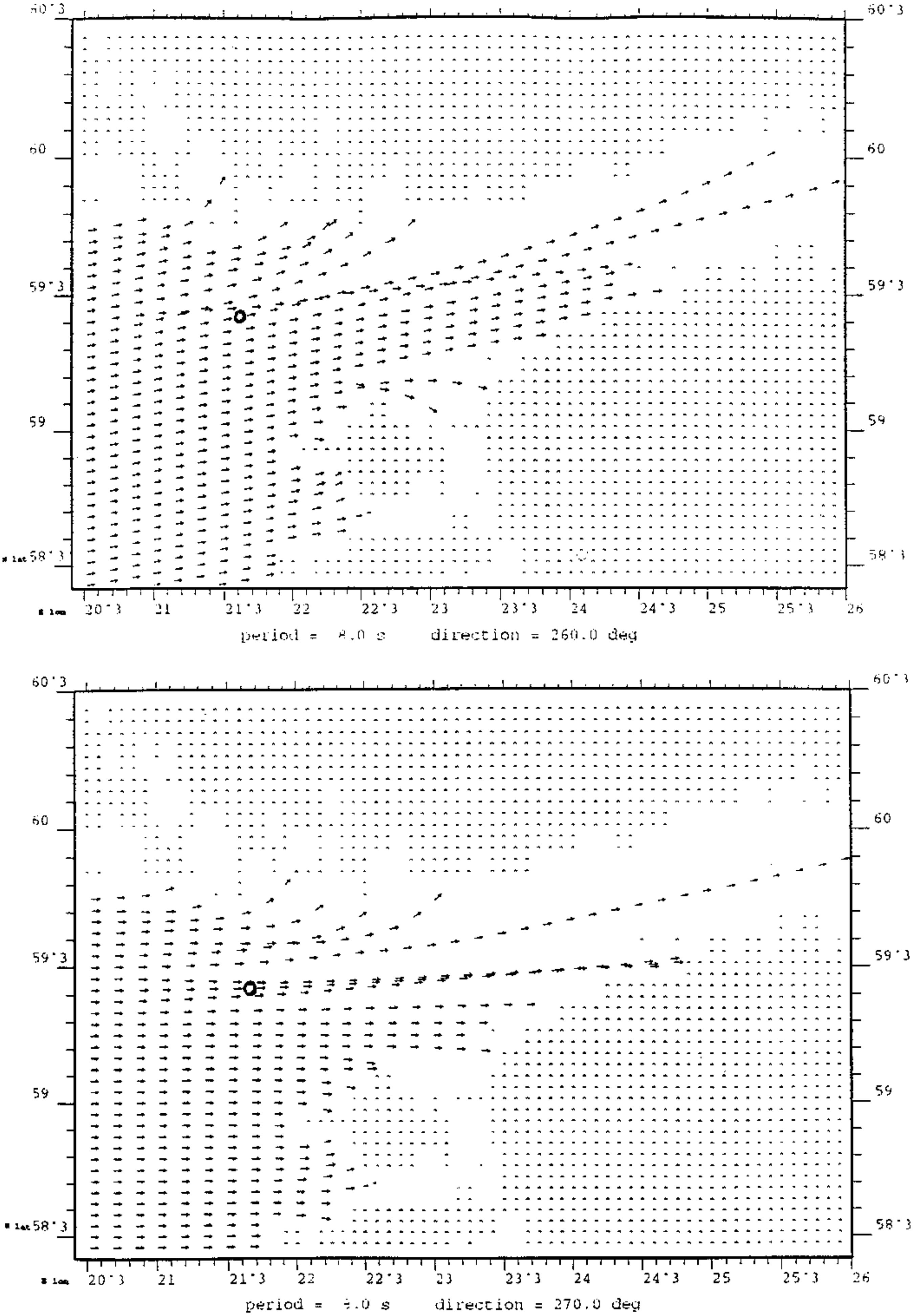
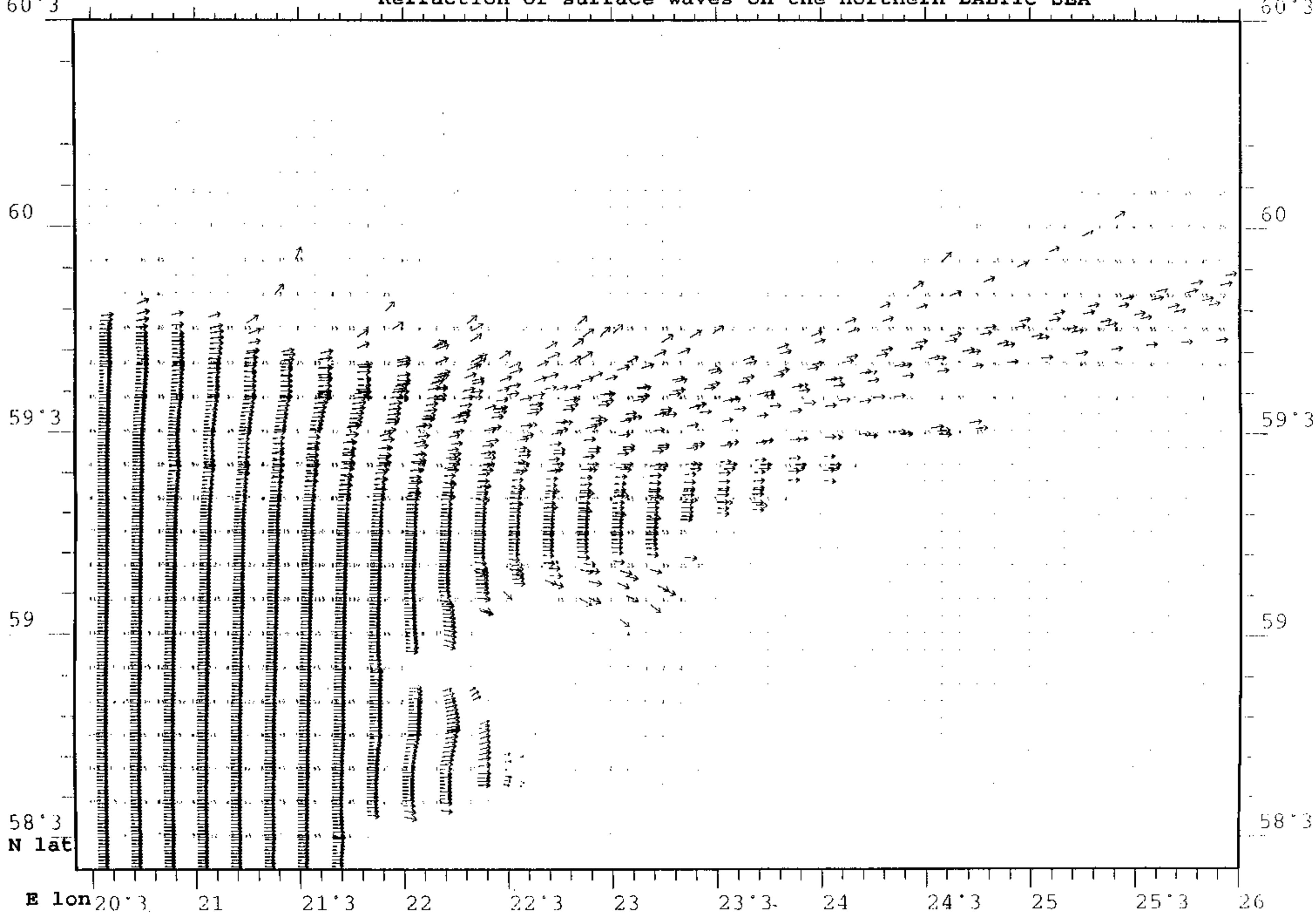


Figure 4. Wave rays, waves coming initially from 260° and 270°, period 8 s.

THE BALTIC SEA

Refraction of surface waves on the northern BALTIC SEA



4.3 Small scale topography

In the area of concern the nautical maps show places that in principle could concentrate wave energy into focal areas of a few nautical miles extent. To be able to calculate the refraction effects of these small scale features a dense grid was made of the site of the shipwreck. The data was obtained from the nautical maps.

It was found that the focusing effect depends on such details of the bathymetry that are not adequately described in the nautical charts. Detailed sounding data have just been obtained the Finnish Board of Navigation for some of the shoals. With a few exceptions the data does not cover areas south from 59° 26' N. There is at least one 17 m shoal indicated in the navigational charts that is not covered by the detailed data.

The detailed bathymetric data have not yet been implemented into the refraction model. Preliminary estimates have been made. They indicate that the shoals near the place of accident are too deep and too small to generate any significant refraction focusing when the wave period is 7.8 s. Especially the shoal nearest to the shipwreck is according to detailed data 38 m deep and only a few hundred meters wide. At that depth the shoal is too small to generate any significant enhancement in the wave height.

These conclusions apply only to the areas covered by the detailed bathymetric data. The nautical charts do not describe the bathymetry accurately enough for the small scale calculations.

5. CURRENTS

The current at depth 0...5 m at the time of the shipwreck is estimated to have been ca. 10 cm/s in direction 90°...100°, Figure 6. The dominate direction surface currents was between 45° and 90°. The speed varied between 10 cm/s and 30 cm/s. At site of the accident the surface current was smaller than nearby.

Surface currents were smaller that one could expect from the maximum wind speed. The reason is variation in the wind direction that also reduced the wave height.

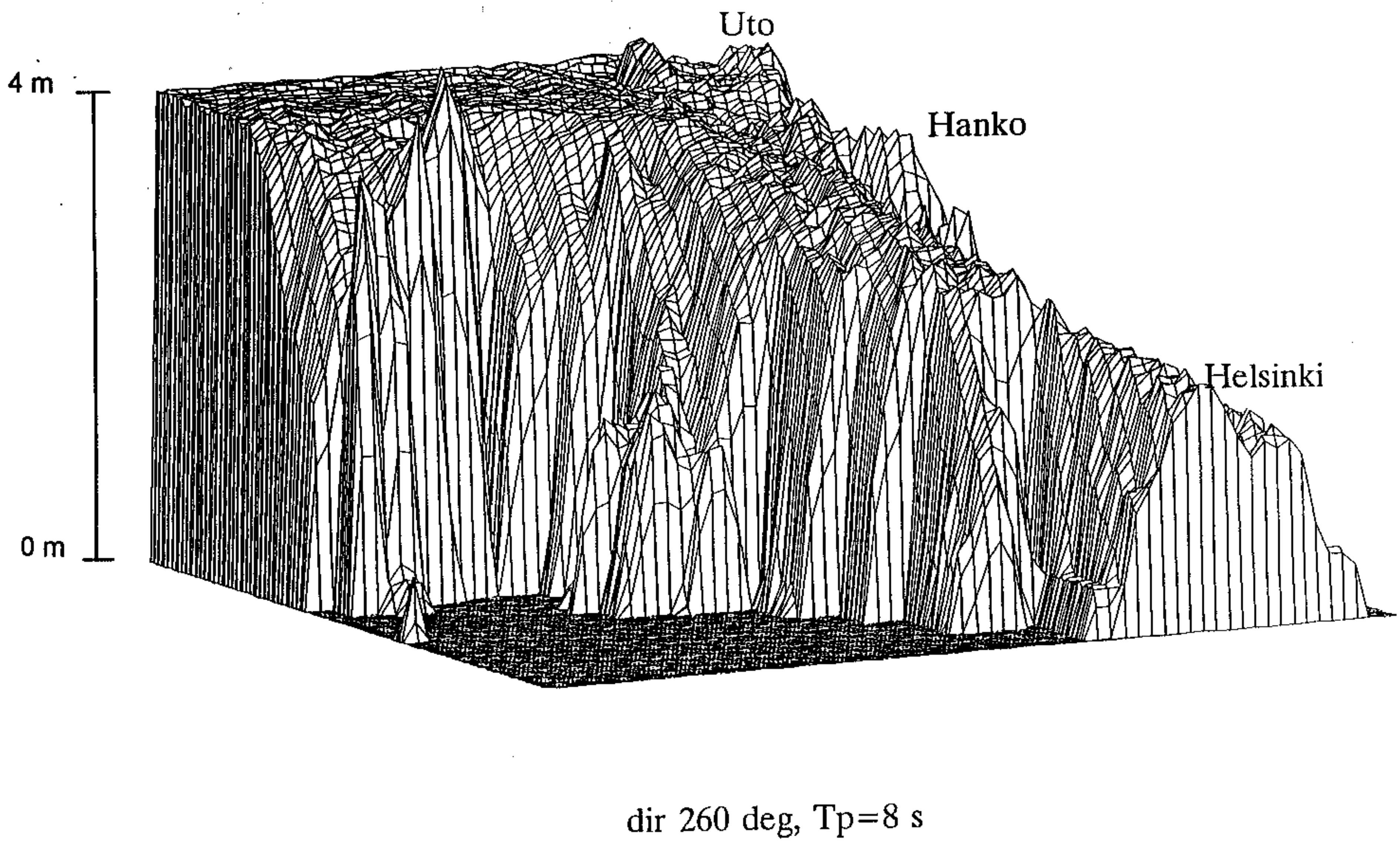


Figure 5. Significant wave height, predicted by the large scale refraction model.

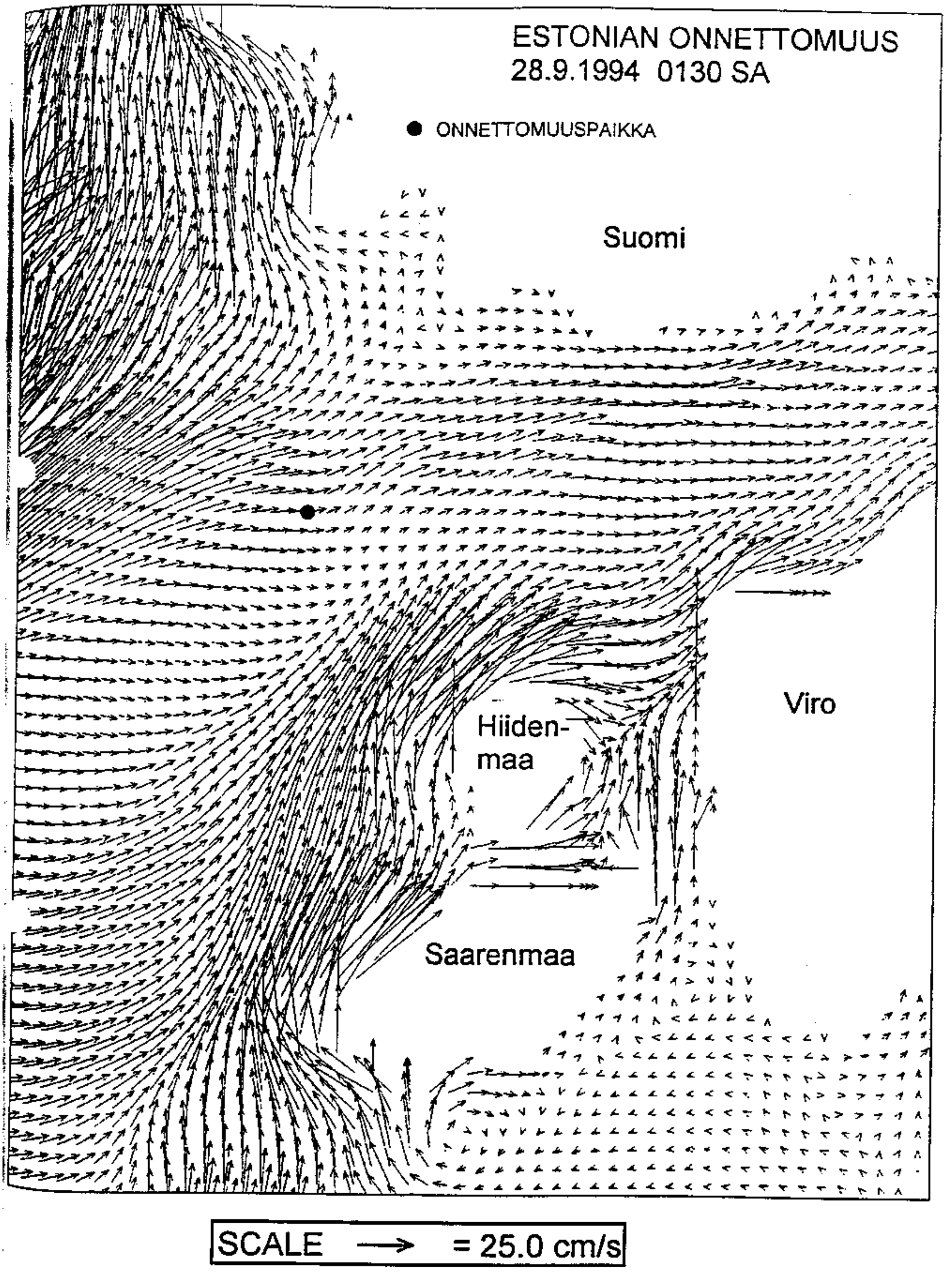


Figure 6. Surface currents at depth 0...5 m at September 28 1994 01:30 EST.

REFERENCES

Bouws, E. and J. A. Battjes, 1982: A Monte Carlo Approach to the Computation of Refraction of Water waves. - J. Geophys. Res. 87(8) 5718-5722.

Kahma, K.K. and C.J.Calkoen, 1994: Growth curve observations. - In Komen et al. Dynamics and Modelling of Ocean Waves. Cambridge University Press, 532 pp.

SUPPLEMENT No. 406

Merkitsevän aallonkorkeuden todennäköisyydet M/V Estonian käyttämillä reiteillä.

Merentutkimuslaitos

Helsinki 11.4.1997

Significant wave height probabilities on the routes operated by MV ESTONIA.

Finnish Institute of Marine Research.

Helsinki 11.4.1997

Merentutkimuslaitos Dno 43/24/97

Estonian kansainvälisen tutkimuskomission tilaus 4.4.1997 .

Merkitsevän aallonkorkeuden todennäköisyydet M/V Estonian käyttämillä reiteillä

Todennäköisyydet on laskettu kausipainotetuista suuntaluokitelluista aaltotilastoista avovesikaudelle.

Pohjoinen Itämeri ja Ahvenanmeri

Pohjoisella Itämerellä todennäköisyydet ovat Utön eteläpuolelta ja Ahvenanmerellä Lågskärin läheltä väylän itäpäästä.

Todennäköisyyksien laskemisessa on käytetty Bogskärin eteläpuolella (1982-1986) tehtyjä mittauksia. Tilastoihin on lisätty tammikuun 1984 etelämyrskyn arvot Almagrundetista, koska Bogskärin mittalaite hiljeni hiukan ennen myrskyn huippua. Etelätuulilla aallonkorkeus Bogskärissä on verrattavissa Almagrundetin havaintoihin.

Tilastot on siirretty halutuille paikoille pyyhkäisymatkojen sekä tuulen kestoajan jakauman avulla. Lågskärin todennäköisyyksissä on otettu huomioon pohjan kitka ja refraktio.

Pohjoinen Selkämeri

Todennäköisyydet on laskettu väylän Vaasa-Sundsvall avomeriosuudelle joka on aallokon kannalta väylää Vaasa-Umeå pahempi. Selkämeren (Sandbäck) tilastot on peilattu vastaamaan olosuhteita pohjoisella Selkämerellä ottaen huomioon tuulen suuntajakaumat.

Todennäköisyydet 2, 3 ja 4 metriä ylittäville merkitseville aallonkorkeuksille

Hs (m)	pohj. Itämeri	Ahvenanmeren eteläosa	Selkämeren pohjoisosa
2	24.6 %	5.7 %	12.6 %
3	11.1 %	0.4 %	3.9 %
4	4.2 %	0.04 %	1.2 %

Todennäköisyyksien virhe annetuista arvoista arvioidaan pienemmäksi kuin 30 %.

Helsingissä 11.4.1997

osastonjohtaja Jouko Launiainen

tutkija Heidi Pettersson

SUPPLEMENT No. 407

Kahma Kimmo - Pettersson Heidi:

Wave Height - Wave Period. Distribution from the Northern Baltic Proper.

Finnish Institute of Marine Research.

Helsinki 1996.

WAVE HEIGHT - WAVE PERIOD DISTRIBUTION FROM THE NORTHERN BALTIC PROPER

Kimmo K. Kahma and Heidi Pettersson

Finnish Institute of Marine Research

1996

Wave height - Wave period distribution from the Northern Baltic Proper

This report presents the wave height and wave period distribution from Bogskär in the Northern Baltic Proper. The distribution is based on a reprocessed dataset from the years 1982 - 1986. Reprocessed data from year 1986 have not been available before.

The measuring point, denoted as B on the map, is about 2.5 nautical miles south of the lighthouse at Bogskär. The place represents well the conditions in the open sea in the Northern part of Baltic proper. The wave climate at Bogskär is not representative for the conditions to the north of latitude 59°45' N, where shallow water effects and islands create a wave climate that varies rapidly from place to place. This also applies to a smaller area behind the lighthouse Suomen Leijona.

The wave data were measured as a joint operation with the Finnish Institute of Marine Research (FIMR) and the Swedish Meteorological and Hydrological Institute (SMHI). FIMR provided the measuring instruments and deployed the wave buoy. SMHI provided the telecommunication link from the lighthouse Svenska Björn and the first processing of the data at SMHI. The data in this first format have been distributed by SMHI under a measuring place title Svenska Björn.

There are small differences in the basic processing of the wave data in SMHI and FIMR. While the differences are not very significant, the SMHI dataset is not consistent with FIMR wave data from other places, and therefore the data has been reprocessed. One of the changes made in the reprocessing was to remove the wave energy at frequencies lower than 0.05 Hz (period over 20 s), as shown below in the equation for significant wave height. The peak frequency is also defined slightly differently.

The data were measured by a Datawell Waverider buoy. The measurements were made every hour. The length of one run was 10 minutes. The measurements used here were made in 1982...1986. The wind was measured at Svenska Björn by SMHI.

Significant wave height in this data is calculated by the equation

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

where E(f) is the wave spectrum.

The peak wave period is defined as

$$T_p = 1 / f_p$$

where f_p is the frequency of the dominant maximum of the spectrum. The peak frequency was determined by a parabolic fit.

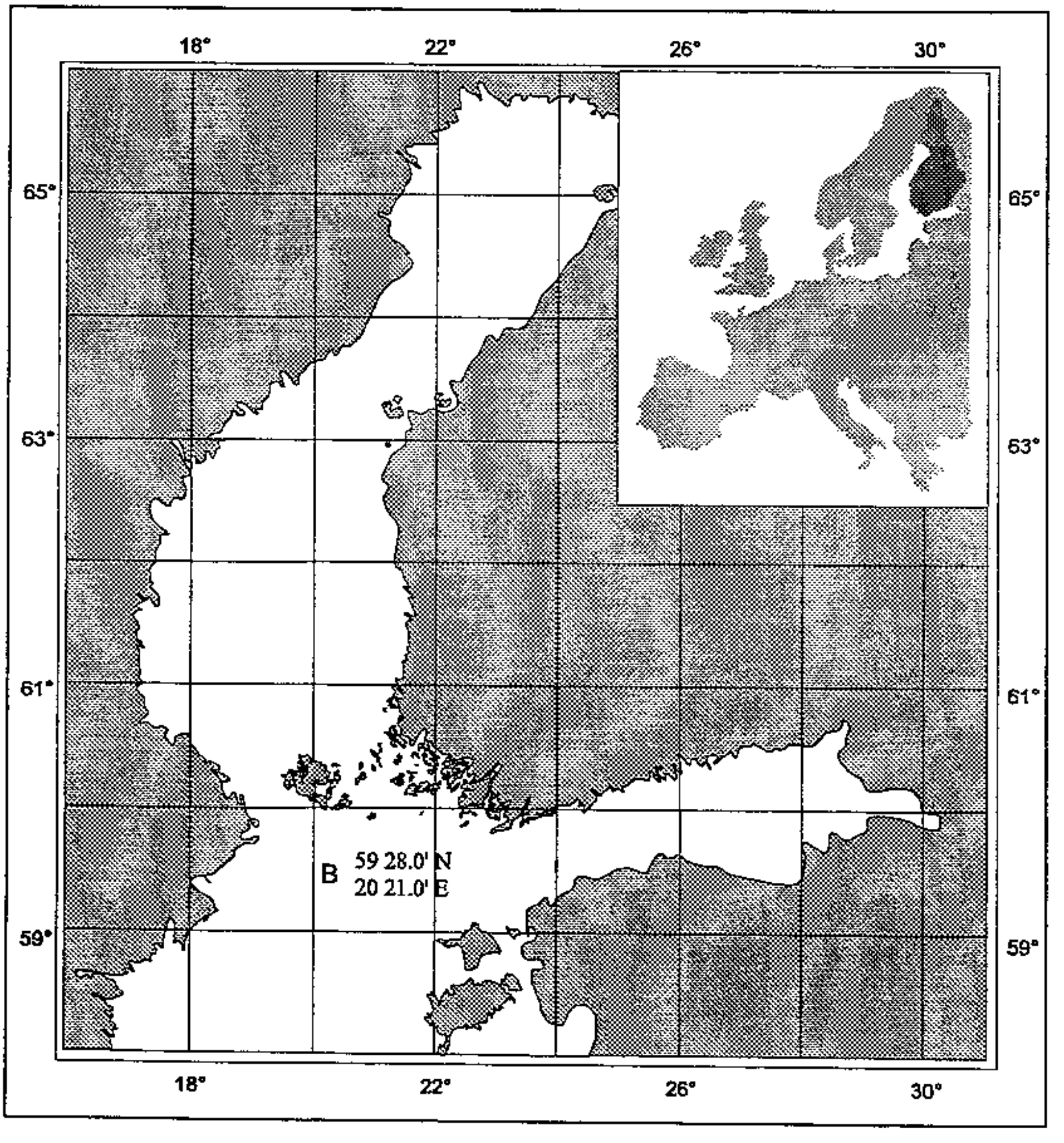


Figure 1. The wave measuring place (B), about 2.5 nautical miles south of the lighthouse of Bogskär.

The statistics are presented in two sets: The first set shows the actual measured data. The second set is an unbiased prediction for the average ice free period. In this data set the missing values have been predicted using seasonally stratified distributions of the data.

The significance of the second set is the following: The Northern part of the Baltic Proper is ice-free on average from the 5th of April to the 11th of February. It is not feasible to make continuous wave measurements with a Waverider when there is risk of ice damaging the buoy. Therefore the actual measuring times are considerably shorter than the ice-free period. In addition, instrument failures have resulted in gaps. The measured data has more measurements in the autumn season than there would be if the measurements covered the whole ice free period uniformly.

The measurements used in this analysis are from the years 1982...1986. Because the data from 1985 covers a very short period, the seasonally averaged data is normalized to represent the ice-free period over three years.

On 13 Jan 1984 the system failed before the peak of a severe storm. Significant wave height at that time was 6.7 m and peak period 9.8 s. The highest waves ever recorded in the Baltic Sea were measured at Almagrundet some hours later at the peak of that storm.

The following data were collected during the storm:

Wave data from Bogskär and wind data from Svenska Björn

			wind		waves		
			dir	U	Hs	fp	Tp
mm	dd		deg	m/s	m	Hz	s
1	13	10.00	208	14.4	3.43	0.121	8.3
1	13	11.00	206	14.9	3.17	0.131	7.6
1	13	12.00	206	15.6	3.17	0.131	7.6
1	13	13.00	203	15.8	3.58	0.122	8.2
1	13	14.00	196	15.7	3.95	0.123	8.1
1	13	15.00	190	18.3	4.31	0.114	8.8
1	13	16.00	183	18.5	4.31	0.114	8.8
1	13	17.00	181	20.9	4.94	0.116	8.6
1	13	18.00	182	20.9	6.24	0.107	9.3
1	13	19.00	184	22.6	6.24	0.107	9.3
1	13	20.00	177	21.6	6.67	0.102	9.8

Buoy failed at Bogskär

Wave data from Almagrundet and wind data from Svenska Björn

mm	dd		deg	m/s	m	Hz	s
1	13	21.00			5.90	0.092	10.9
1	13	22.00	164	18.9	6.10	0.092	10.9
1	13	23.00	185	22.6	6.00	0.092	10.9
1	13	24.00	163	18.1	5.90	0.092	10.9
1	14	1.00	185	19.7	7.20	0.092	10.9
1	14	2.00	194	21.5	7.00	0.092	10.9
1	14	3.00	205	22.5	7.10	0.084	11.9
1	14	4.00	211	20.0	7.70	0.078	12.8
1	14	5.00	214	19.4	6.40	0.084	11.9

Because Bogskär is down-fetch from Almagrundet, estimates based on the wind field show that at the peak of the storm waves at Bogskär were at least as high as at Almagrundet. If the highest waves that cause the system to fail are just left out, the statistics will be biased. Therefore, values for the period from the time when the buoy failed until the end of this particular storm have been taken from the data measured at Almagrundet. Data values from Almagrundet are enclosed in parenthesis in the tables.

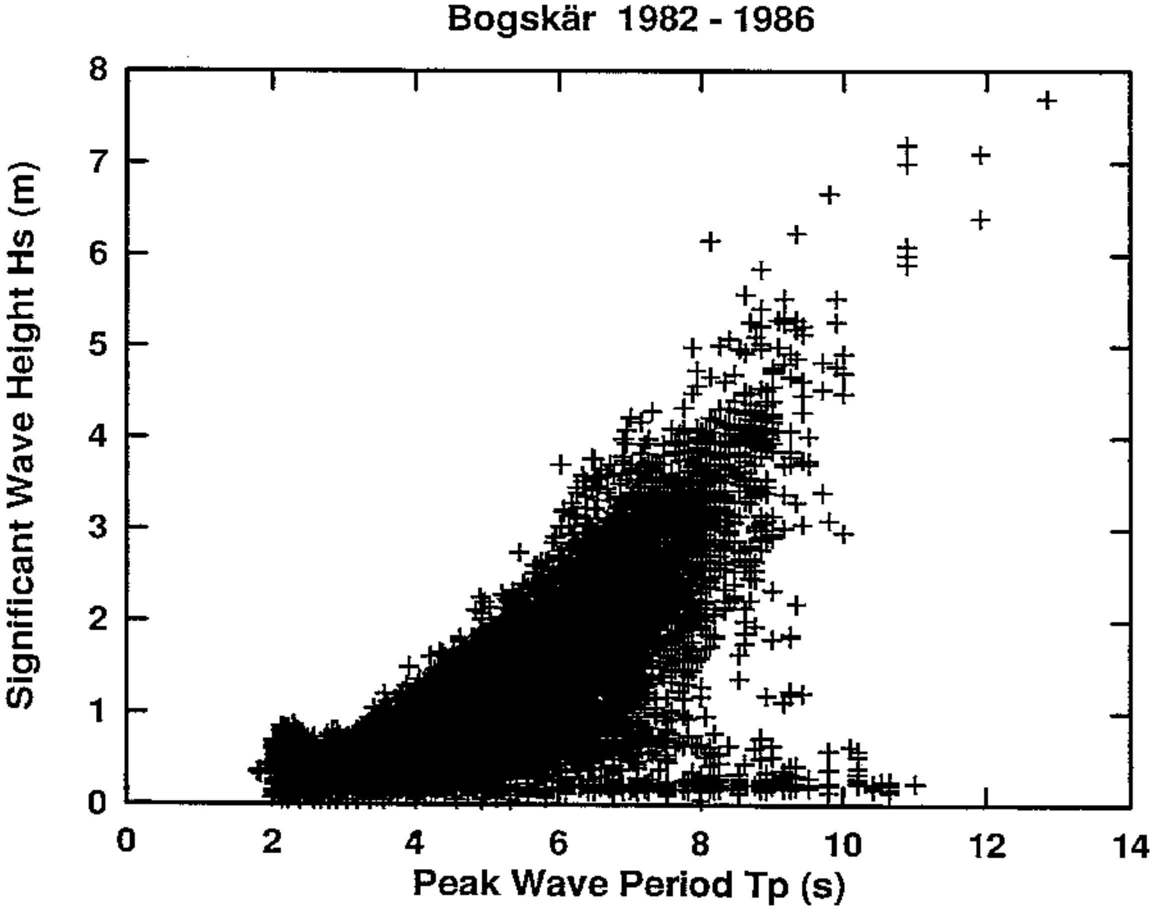


Figure 2. Scattering diagram of peak wave period and significant wave height from wave data collected at Bogskär in 1982...1986.

Finnish Institute of Marine Research

Wave data from Bogskär 59°28.0 N 20° 21.0 E

1982 - 1986
All directions

significant wave height [m]	number of observations	%	cumulative %
0.00 : 0.25	1096	7.4909	7.4909
0.25 : 0.50	1822	12.4530	19.9440
0.50 : 0.75	2310	15.7884	35.7323
0.75 : 1.00	2024	13.8336	49.5660
1.00 : 1.25	1751	11.9677	61.5337
1.25 : 1.50	1349	9.2201	70.7539
1.50 : 1.75	963	6.5819	77.3358
1.75 : 2.00	730	4.9894	82.3252
2.00 : 2.25	682	4.6613	86.9865
2.25 : 2.50	481	3.2875	90.2741
2.50 : 2.75	343	2.3443	92.6184
2.75 : 3.00	315	2.1530	94.7714
3.00 : 3.25	238	1.6267	96.3981
3.25 : 3.50	177	1.2098	97.6078
3.50 : 3.75	108	0.7382	98.3460
3.75 : 4.00	87	0.5946	98.9406
4.00 : 4.25	60	0.4101	99.3507
4.25 : 4.50	32	0.2187	99.5694
4.50 : 4.75	17	0.1162	99.6856
4.75 : 5.00	12	0.0820	99.7676
5.00 : 5.25	9	0.0615	99.8291
5.25 : 5.50	8	0.0547	99.8838
5.50 : 5.75	3	0.0205	99.9043
5.75 : 6.00	1+(2)	0.0205	99.9248
6.00 : 6.25	3+(2)	0.0342	99.9590
6.25 : 6.50	(1)	0.0068	99.9658
6.50 : 6.75	1	0.0068	99.9727
6.75 : 7.00	0	0.0000	99.9727
7.00 : 7.25	(3)	0.0205	99.9932
7.25 : 7.50	0	0.0000	99.9932
7.50 : 7.75	(1)	0.0068	100.0000
7.75 : 8.00	0	0.0000	100.0000

Data in parenthesis are from Almagundet 1984-01-13 21:00 - 01-14 05:00

Finnish Institute of Marine Research

Wave data from Bogskär 59°28.0 N 20°21.0 E
Missing values predicted by seasonal distributions

1982 - 1986
All directions

significant wave height [m]	number of hours/year	%	cumulative %
0.00 : 0.25	1542	6.8622	6.8622
0.25 : 0.50	2639	11.7440	18.6062
0.50 : 0.75	3329	14.8146	33.4209
0.75 : 1.00	2899	12.9011	46.3219
1.00 : 1.25	2668	11.8731	58.1950
1.25 : 1.50	2107	9.3765	67.5715
1.50 : 1.75	1527	6.7954	74.3670
1.75 : 2.00	1174	5.2245	79.5915
2.00 : 2.25	1131	5.0332	84.6246
2.25 : 2.50	795	3.5379	88.1625
2.50 : 2.75	610	2.7146	90.8771
2.75 : 3.00	585	2.6034	93.4805
3.00 : 3.25	445	1.9803	95.4608
3.25 : 3.50	347	1.5442	97.0050
3.50 : 3.75	226	1.0057	98.0108
3.75 : 4.00	152	0.6764	98.6872
4.00 : 4.25	104	0.4628	99.1500
4.25 : 4.50	59	0.2626	99.4126
4.50 : 4.75	31	0.1380	99.5505
4.75 : 5.00	22	0.0979	99.6484
5.00 : 5.25	18	0.0801	99.7285
5.25 : 5.50	16	0.0712	99.7997
5.50 : 5.75	5	0.0223	99.8220
5.75 : 6.00	1+(6)	0.0312	99.8531
6.00 : 6.25	9+(6)	0.0668	99.9199
6.25 : 6.50	(3)	0.0134	99.9332
6.50 : 6.75	3	0.0134	99.9466
6.75 : 7.00	0	0.0000	99.9466
7.00 : 7.25	(9)	0.0401	99.9866
7.25 : 7.50	0	0.0000	99.9866
7.50 : 7.75	(3)	0.0134	100.0000
7.75 : 8.00	0	0.0000	100.0000

Data in parenthesis are from Almagundet 1984-01-13 21:00 - 01-14 05:00

Finnish Institute of Marine Research

Wave data from Bogskär 59° 28.0 N 20°21.0 E

1982 - 1986
All directions

significant wave height [m]	peak wave period Tp [s] 2	3	4	5	6	7	8	9	10	11	12	13	total
0.00 : 0.25	185	321	224	103	65	58	73	50	11	6	0	0	1096
0.25 : 0.50	192	692	562	206	74	25	31	27	10	3	0	0	1822
0.50 : 0.75	147	443	918	559	162	50	21	5	5	0	0	0	2310
0.75 : 1.00	25	54	914	723	241	58	9	0	0	0	0	0	2024
1.00 : 1.25	0	2	416	852	400	68	7	6	0	0	0	0	1751
1.25 : 1.50	0	0	81	708	465	78	16	1	0	0	0	0	1349
1.50 : 1.75	0	0	9	351	441	138	23	1	0	0	0	0	963
1.75 : 2.00	0	0	0	127	373	188	35	7	0	0	0	0	730
2.00 : 2.25	0	0	0	38	312	261	67	4	0	0	0	0	682
2.25 : 2.50	0	0	0	9	169	223	75	5	0	0	0	0	481
2.50 : 2.75	0	0	0	0	83	172	80	8	0	0	0	0	343
2.75 : 3.00	0	0	0	1	39	145	117	12	1	0	0	0	315
3.00 : 3.25	0	0	0	0	17	83	126	11	1	0	0	0	238
3.25 : 3.50	0	0	0	0	5	49	105	17	1	0	0	0	177
3.50 : 3.75	0	0	0	0	5	37	52	13	1	0	0	0	108
3.75 : 4.00	0	0	0	0	3	10	44	29	1	0	0	0	87
4.00 : 4.25	0	0	0	0	0	3	23	33	1	0	0	0	60
4.25 : 4.50	0	0	0	0	0	1	9	21	1	0	0	0	32
4.50 : 4.75	0	0	0	0	0	0	6	9	2	0	0	0	17
4.75 : 5.00	0	0	0	0	0	0	1	8	3	0	0	0	12
5.00 : 5.25	0	0	0	0	0	0	2	7	0	0	0	0	9
5.25 : 5.50	0	0	0	0	0	0	0	7	1	0	0	0	8
5.50 : 5.75	0	0	0	0	0	0	0	2	1	0	0	0	3
5.75 : 6.00	0	0	0	0	0	0	0	1	0	(2)	0	0	1+(2
6.00 : 6.25	0	0	0	0	0	0	1	2	0	(2)	0	0	3+(2
6.25 : 6.50	0	0	0	0	0	0	0	0	0	0	(1)	0	(1
6.50 : 6.75	0	0	0	0	0	0	0	0	1	0	0	0	1
6.75 : 7.00	0	0	0	0	0	0	0	0	0	0	0	0	0
7.00 : 7.25	0	0	0	0	0	0	0	0	0	(2)	(1)	0	(3
7.25 : 7.50	0	0	0	0	0	0	0	0	0	0	0	0	0
7.50 : 7.75	0	0	0	0	0	0	0	0	0	0	0	(1)	(1
7.75 : 8.00	0	0	0	0	0	0	0	0	0	0	0	0	0
total	549	1512	3124	3677	2854	1647	923	286	41	9+(6)	(2)	(1)	1463

In this table the middle of the range of the peak wave period Tp is shown: 2s means Tp < 2.5s, 3s means 2.5s < Tp < 3.5s etc.
Data in parenthesis are from Almagrundet 1984-01-13 21:00 - 01-14 05:00

Finnish Institute of Marine Research

Wave data from Bogskär 59 28.0 N 20 21.0 E
Missing values predicted by seasonal distributions
1982 - 1986
All directions

peak wave period Tp [s]

significant wave height [m]	2	3	4	5	6	7	8	9	10	11	12	13	total
0.00 : 0.25	260	464	324	146	86	75	95	67	16	9	0	0	1542
0.25 : 0.50	254	998	806	314	128	43	41	38	13	4	0	0	2639
0.50 : 0.75	190	668	1319	787	240	79	30	7	9	0	0	0	3329
0.75 : 1.00	32	87	1311	1017	352	86	14	0	0	0	0	0	2899
1.00 : 1.25	0	6	666	1290	575	103	11	17	0	0	0	0	2668
1.25 : 1.50	0	0	151	1128	671	119	35	3	0	0	0	0	2107
1.50 : 1.75	0	0	24	582	657	214	47	3	0	0	0	0	1527
1.75 : 2.00	0	0	0	222	573	298	64	17	0	0	0	0	1174
2.00 : 2.25	0	0	0	79	500	420	124	8	0	0	0	0	1131
2.25 : 2.50	0	0	0	21	279	353	132	10	0	0	0	0	795
2.50 : 2.75	0	0	0	0	167	283	145	15	0	0	0	0	610
2.75 : 3.00	0	0	0	3	76	261	219	23	3	0	0	0	585
3.00 : 3.25	0	0	0	0	34	141	248	19	3	0	0	0	445
3.25 : 3.50	0	0	0	0	14	98	206	28	1	0	0	0	347
3.50 : 3.75	0	0	0	0	13	86	107	17	3	0	0	0	226
3.75 : 4.00	0	0	0	0	4	25	76	44	3	0	0	0	152
4.00 : 4.25	0	0	0	0	0	5	44	54	1	0	0	0	104
4.25 : 4.50	0	0	0	0	0	3	18	35	3	0	0	0	59
4.50 : 4.75	0	0	0	0	0	0	15	12	4	0	0	0	31
4.75 : 5.00	0	0	0	0	0	0	1	14	7	0	0	0	22
5.00 : 5.25	0	0	0	0	0	0	4	14	0	0	0	0	18
5.25 : 5.50	0	0	0	0	0	0	0	15	1	0	0	0	16
5.50 : 5.75	0	0	0	0	0	0	0	4	1	0	0	0	5
5.75 : 6.00	0	0	0	0	0	0	0	1	0	(6)	0	0	1+(6)
6.00 : 6.25	0	0	0	0	0	0	3	6	0	(6)	0	0	9+(6)
6.25 : 6.50	0	0	0	0	0	0	0	0	0	0	(3)	0	(3)
6.50 : 6.75	0	0	0	0	0	0	0	0	3	0	0	0	3
6.75 : 7.00	0	0	0	0	0	0	0	0	0	0	0	0	0
7.00 : 7.25	0	0	0	0	0	0	0	0	0	(6)	(3)	0	(9)
7.25 : 7.50	0	0	0	0	0	0	0	0	0	0	0	0	0
7.50 : 7.75	0	0	0	0	0	0	0	0	0	0	0	(3)	(3)
7.75 : 8.00	0	0	0	0	0	0	0	0	0	0	0	0	0
total	736	2223	4601	5589	4369	2692	1679	471	71	13+(18)	(6)	(3)	22471

In this table the middle of the range of the peak wave period Tp is shown: 2s means Tp < 2.5s, 3s means 2.5s < Tp < 3.5s etc.
Data in parenthesis are from Almagrundet 1984-01-13 21:00 - 01-14 05:00