Refraction may redirect waves from multiple directions into a harbour: a case study in the Gulf of Riga, eastern Baltic Sea

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Abstract. We analyse the impact of bathymetry on the propagation direction of wind waves near the Port of Ringsu on the island of Ruhnu in the central part of the Gulf of Riga (Gulf of Livonia). Waves propagating towards this port are systematically redirected by underwater features. On most occasions the main direction of the refracted saturated wave fields is towards the harbour entrance. This shows that the port entrance needs a complicated set of breakwaters to cope with wind generated waves from most directions.

Keywords: wave modelling, wave direction, SWAN model, port planning, Gulf of Riga, Baltic Sea.

INTRODUCTION

The main task of both large and small harbours is to provide effective protection for vessels from the impact of wind, waves and currents (Cairns et al. 2016), as well as to offer a safe haven for various operations. Since ancient times (Safadi 2016) this requirement has usually been achieved by a smart choice of the location of the harbour entrance so that it is naturally sheltered against severe waves and/or by the construction of a system of breakwaters that protect the port interior from marine impacts.

Wave refraction may convert seemingly well-sheltered coastal areas into hot spots of wave energy (Kovaleva et al. 2017). In some cases, waves can undergo substantial changes from their deep-water direction of propagation. This kind of ultra-refraction by more than 90 degrees redirects, for example, south-west swells into San Francisco Bay (Hanes and Erikson 2013).

This phenomenon occurs frequently on the downwind side of small islands and shoals where refracted waves may cross each other or enter seemingly sheltered bays. However, the related effects usually do not impact the interior of small ports and marinas that are located on the downwind side of such islands or headlands.

The small island of Ruhnu (Fig. 1) lies in the middle of the Gulf of Riga (Gulf of Livonia in Estonian tradition) and is thus open to all wind directions. In this region, strong winds blow usually either from the south-west or less frequently from the north/north-west (Soomere and Keevallik 2001; Männikus et al. 2019). Easterly winds are much weaker and south-east winds are infrequent and mild. Very little wave energy generated in the Baltic Proper penetrates into the Gulf of Riga. Wave fields in this water body are thus mostly locally generated and, on most occasions, follow the wind patterns. The nearshore of the western side of this island is shallow, rocky and unwelcoming for landing while the eastern shore is steeper, less rocky and more easily accessible from the sea.

The described anisotropy of wind (and wave) fields together with the different characteristics of the shores are evidently the main reasons why all historical boat landing sites were located on the eastern coast of Ruhnu (Fig. 2). Interestingly, one such site lay to the west of natural Cape Ringsu (Rings-Udden), the southern tip of the island, in an area that seems to be fully open to one of the predominant wind directions. Much of historical knowledge about these sites was lost after the 1940s. According to a census taken in 1934, Ruhnu had a

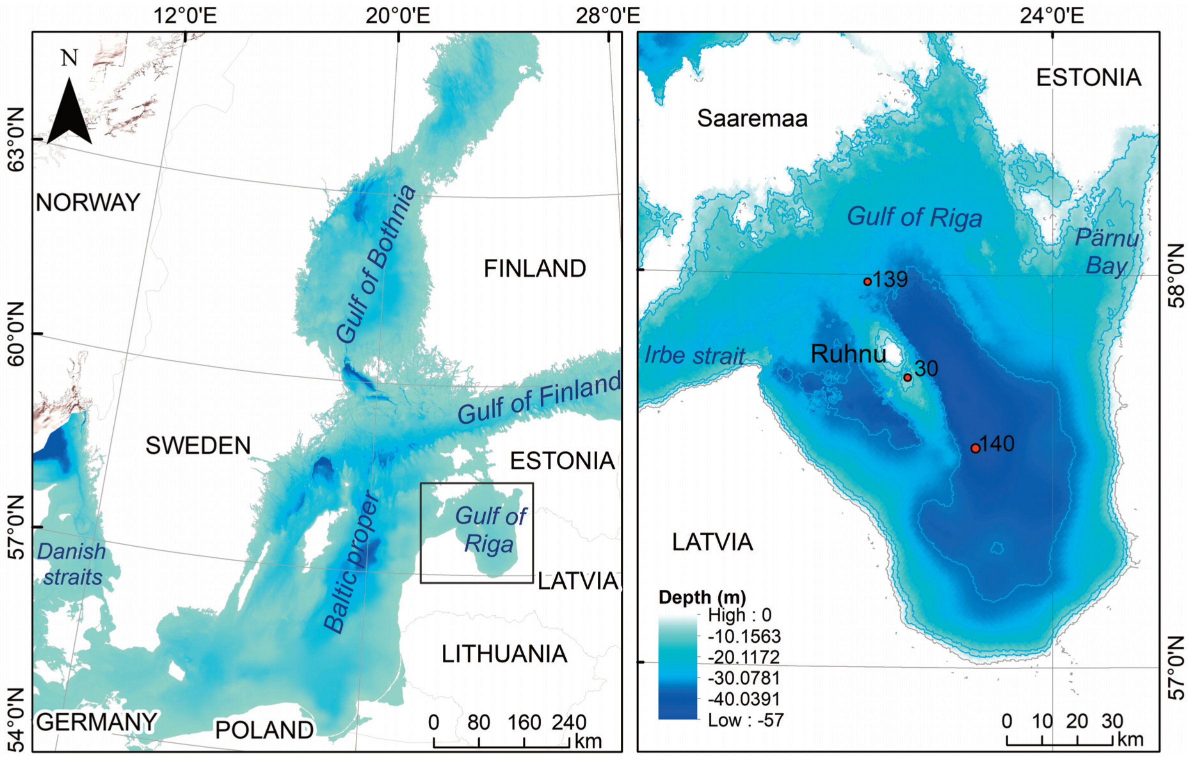

Fig. 1. The Gulf of Riga in the Baltic Sea (left panel) and the island of Ruhnu in the Gulf of Riga (right panel). The right panel shows the area covered by the second-level computational grid of the wave model and the selected grid points (30, 139, 140) for the analysis of wave directions. Point 30 is located at Gretagrund, a shallow area to the south of Ruhnu.

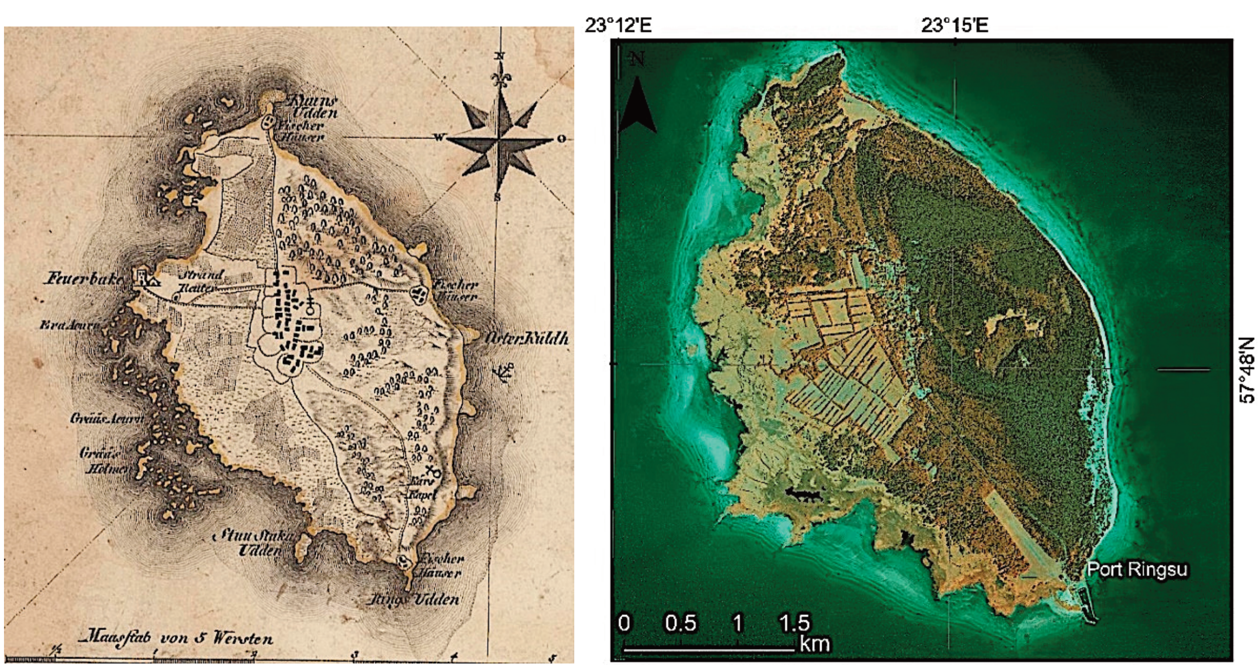

Fig. 2. The island of Ruhnu from the Atlas of Liefland (Livonia) by Ludwig August von Mellin in 1798 (left panel). It is likely that boat landing sites were located by the fishermen's houses (Fischer Häuser). Note that the fishermen's house near Cape Ringsu (Rings-Udden) was located on the western coast of the cape, which is open to one of the predominant wind directions. The Port of Ringsu is located at the south-eastern tip of the island (right panel).

population of 282, among these 277 ethnic Swedes and 5 ethnic Estonians (LinkFang 2021). Most locals (except for two families) had fled from Ruhnu to Sweden by the end of the Second World War.

The contemporary Port of Ringsu was constructed at the end of the 1950s (Orviku 2018). This was the time when knowledge about wave properties was scarce in Estonia and planning activities in the Soviet Union were dictated by military and political considerations rather than economic or scientific reasons. The location along the eastern shore of Cape Ringsu had been used for lifting ships out of water and for unloading ships by using small boats in the past (Orviku 2018), but not as a harbour site.

The contemporary harbour (Fig. 2) was designed to meet the above description of predominant wind patterns. The port and its approach are geometrically sheltered against waves coming from the north-west and north. The port interior is protected from waves that approach from the south-west and west by a shallow-water area and a breakwater. To protect the port waters even better, the tip of the southern breakwater is turned to the south-east. Another breakwater protects the port and its entrance channel from waves from the north, north-east and east. The entrance is oriented to the south-east (about 120° clockwise from the north), that is, to the direction from which winds are infrequent and weak.

In spite of this careful design, the port interior often suffers from inconveniently high waves and sudden changes in the water level. Undesirable wave conditions often occur even during westerly winds, against which the harbour seems to be perfectly protected.

In this article we demonstrate that wave conditions that annoy the port visitors and endanger small vessels in the port are created systematically by wave refraction and perhaps ultra-refraction. To that end, we employ a sequence of wave model runs forced by stationary and homogeneous wind conditions across the entire study area. The simulations are performed until the wave field becomes stationary.

THE WAVE MODEL

We used wave model SWAN (version 40.11) in Delft3D suite to replicate waves under a variety of stationary wind conditions. As the fetch length and propagation distance of waves that reach Ruhnu are both less than 100 km (Fig. 1), this approach gives a reasonable estimate of wind conditions during which waves may affect the harbour interior.

The wave model SWAN (Booij et al. 1999) is a third-generation phase-averaged spectral wave model that was developed at Delft University of Technology. The waves are described via the two-dimensional wave action density spectrum N, the evolution of which is governed by the wave action balance equation. This equation, in Cartesian coordinates without ambient currents, takes the following form:

$$\frac{\partial N}{\partial t} + \frac{\partial c_x N}{\partial x} + \frac{\partial c_y N}{\partial y} + \frac{\partial c_\sigma N}{\partial \sigma} + \frac{\partial c_\theta N}{\partial \theta} = \frac{S_{tot}}{\sigma}.$$

The terms on the left side of this equation represent the rate of change and the propagation of wave energy in two-dimensional geographical space, as well as the shifting of the angular frequency caused by variations in depth and depth-induced refraction. The x- and y-components of the group velocity are denoted by c_x and c_y. The propagation velocities in the spectral space, which are defined by the angular frequency σ and the propagation direction θ, are c_σ and c_θ, respectively. Expressions for the spectral velocities can be found in the SWAN technical manual (The SWAN team 2021).

The core quantity on the right-hand side S_{tot} denotes the sum of all physical processes that represent generation, dissipation or redistribution of wave energy in SWAN. The deep-water source terms include energy input by wind (Komen et al. 1984), dissipation of waves by white-capping (Komen et al. 1984) and nonlinear transfer of wave energy due to four-wave interactions using the Discrete Interaction Approximation (DIA) (Hasselmann et al. 1985). The whitecapping coefficient δ was set at $\delta = 1$ following Rogers et al. (2003) and Pallares et al. (2014). We used the wind drag parameterisation suggested by Wu (1982). The shallow-water source terms are energy dissipation through bottom friction (Hasselmann et al. 1973), dissipation due to depth-induced wave breaking (Battjes and Janssen 1978) and nonlinear transfer of wave energy through three-wave interactions using the Lumped Triad Approximation (LTA) (Eldeberky 1996). The bottom friction coefficient was set at 0.038 m^2/s^3, as suggested by Zijlema et al. (2012). The values of parameters α and γ for the depth-induced wave breaking source term were set at $\alpha = 1$ and $\delta = 0.73$, respectively. A very similar configuration of the SWAN model has shown excellent results in calculations of the Baltic Sea wave fields (Björkqvist et al. 2018).

We used a four-level nested scheme of rectangular model grids. Even though only very little wave energy created in the Baltic Proper enters the Gulf of Riga, propagation of specific swells into the gulf cannot be excluded. For this reason, a coarse model was run for the whole Baltic Sea on a regular grid with a step of 5000 m (251 × 271 grid points). The second-level regular grid covered the Gulf of Riga with a step of 1000 m (171 × 181 grid points). The third-level grid (Fig. 3) covered the island of Ruhnu with neighbouring waters with a regular step of 100 m (211 × 171 grid points). The innermost (finest) model focused on the Port of Ringsu (Fig. 3) with

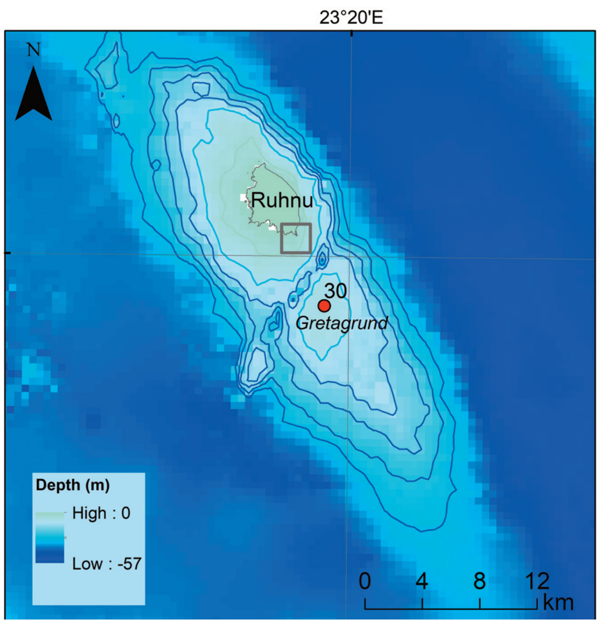

Fig. 3. The location scheme of the third-level (entire panel) and fourth-level (small box on Ruhnu) nested grids.

a varying step of 11 to 3 m (232 × 194 grid points). The resolution of the third- and fourth-level grids is evidently sufficiently fine to replicate refraction of waves in the vicinity of Ruhnu and the Port of Ringsu. The bathymetry was taken from the database of the Estonian Transport Administration and from the Baltic Sea Bathymetry Database by the Baltic Sea Hydrographic Commission (Baltic Sea Hydrographic Commission 2013). At each sea grid point, 864 spectrum components (36 equally spaced directions and 24 frequency bins from 0.05 Hz to 1 Hz) were calculated.

The model was forced with stationary (unidirectional steady) wind at a speed of 5, 10 or 15 m/s until the wave field became saturated. This happens in the Gulf of Riga usually within 2–3 hours for 5 m/s, 3–5 hours for 10 m/s, and within 6 hours for a wind speed of 15 m/s. The wind direction was varied from 15° to 345° with a step of 30°. Hence, there were 36 different situations. The spatial pattern of the resulting wave directions is provided below, mainly from the third-level grid. The location of wave model grid points used below to quantify the impact of refraction on the wave fields in the vicinity of the southern tip of Ruhnu and around Gretagrund (Fig. 3) is presented in Fig. 4.

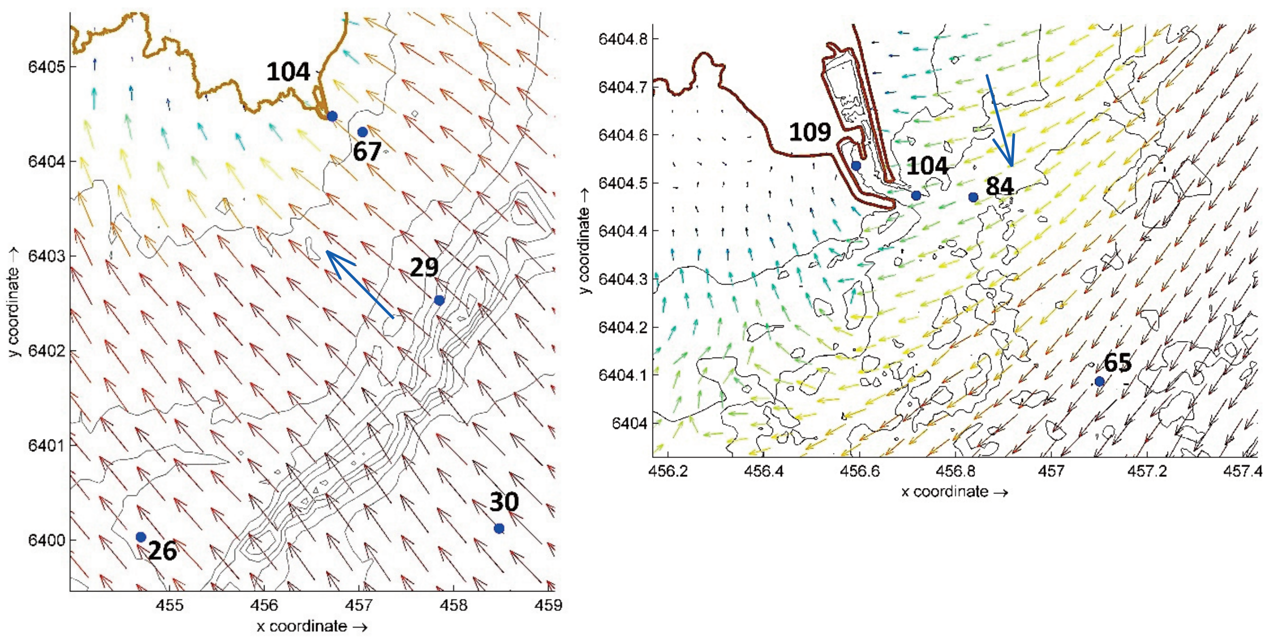

Fig. 4. The wave model grid points for data used in Fig. 4 and in Figs 5–7. Left panel: third-level grid, wind from the direction of 135°. Right panel: innermost fourth-level grid, wind from the direction of 345°. The wave pattern is presented for a wind speed of 15 m/s. The blue large arrows indicate the wind direction. The wave height is represented by colour (brown and red: the highest, yellow: medium, green and blue: lower waves) and the length of small arrows while the wave direction is indicated by the direction of small arrows. The scale is presented in kilometres.

RESULTS

As expected, the simulated wave direction in saturated fetch-limited situations with a relatively low wind speed of 5 m/s follows almost exactly the wind direction in the open area of the Gulf of Riga (Fig. 5A). The deviation of the mean wave direction from the forcing wind direction provided by the SWAN model slightly increases for strong winds (15 m/s) and reaches up to 15° for some wind directions (Fig. 5B). The mean wave direction corresponds even better to the wind direction at the tip of Gretagrund to the south of Ruhnu (Fig. 5). While wave heights at these three locations vary substantially (from 1.88 to 2.73 m for a wind speed of 15 m/s) for different wind directions, the mean period only varies from 4.0 to 5.1 s.

The situation is similar to that in the deep channel between Ruhnu and Gretagrund described above. On most occasions, the mean wave direction follows the wind direction (Fig. 6). The deviation of the wave propagation from the wind direction is up to 20° on both slopes of this channel (Fig. 6). Wave direction on the coastal slope of Ruhnu at a distance of 0.5 km from the entrance of the Port of Ringsu (point 67 in Fig. 4, left panel) corresponds less closely to the wind direction. The deviation of waves from the wind direction exceeds 30° for winds from the

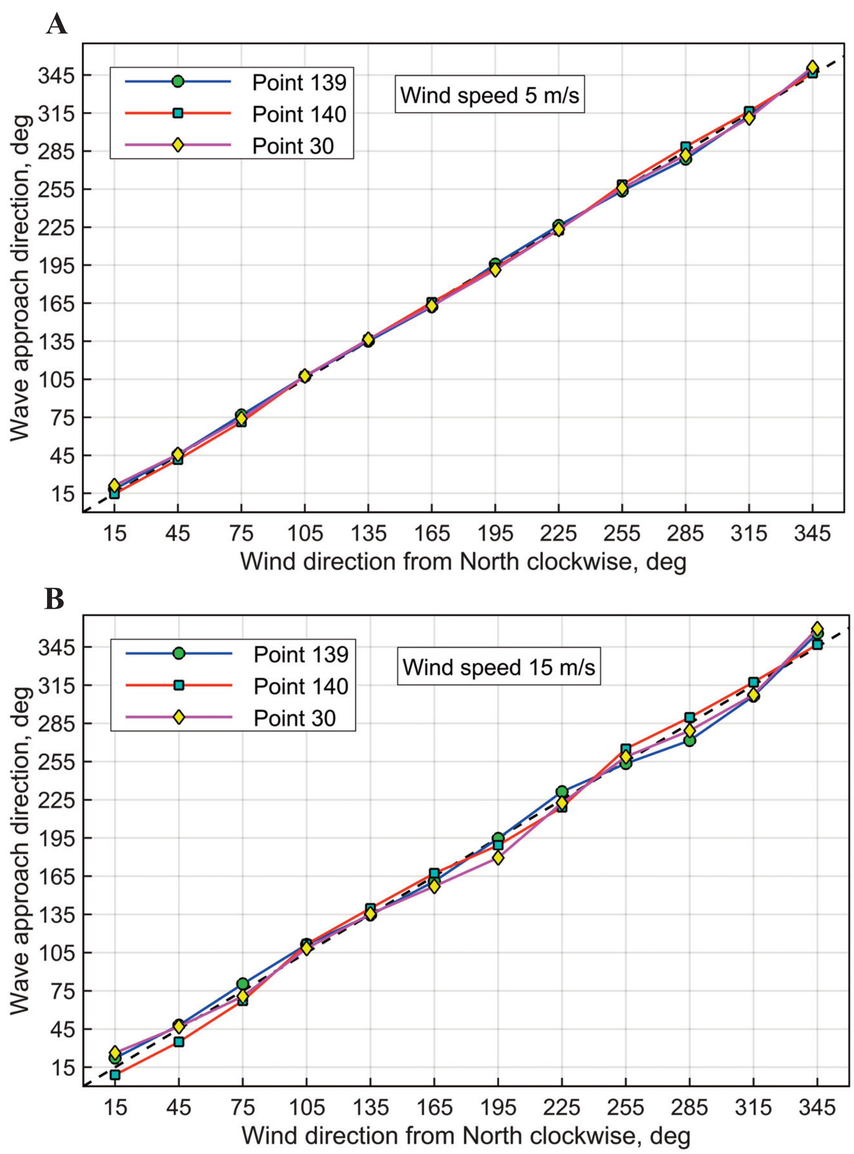

Fig. 5. Comparison of the wind direction and the mean propagation direction of simulated waves in saturated wave fields for wind speeds of 5 m/s (A) and 15 m/s (B) in the open part of the Gulf of Riga to the north (point 139, Fig. 1) and south (point 140, Fig. 1) of Ruhnu, and at the tip of Gretagrund (point 30, Fig. 4) to the south of Ruhnu.

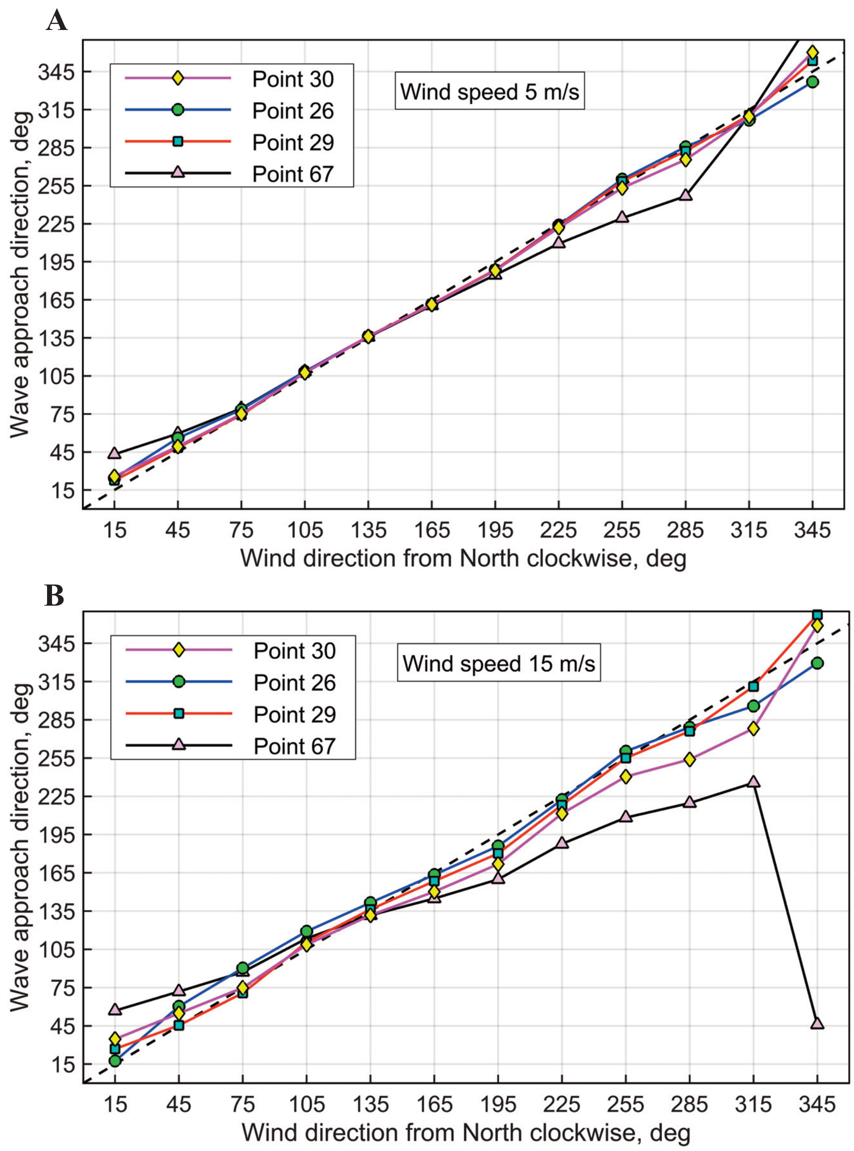

Fig. 6. Comparison of the wind direction and the mean direction of simulated wave propagation in saturated wave fields for wind speeds of 5 m/s (A) and 15 m/s (B) on the northern slope of Gretagrund (point 30, water depth 7.7 m), in the shallow area to the west of the grid (point 26, water depth 13 m), in the deep channel (point 29, water depth 21 m), and on the fairway to the Port of Ringsu (point 67). The locations of grid points are indicated in Fig. 4.

west to the north at this particular point (point 67 in Fig. 4, left panel). As expected, the deviation is larger for stronger winds and reaches 90° for north-west and north winds.

Wave propagation direction often deviates significantly from the wind direction in the immediate vicinity of the Port of Ringsu, even for weak winds (Fig. 7A). The mean wave direction corresponds to the wind direction only for south-east winds (115°) near the entrance to the Port of Ringsu (Fig. 7). Basically, these winds blow right into the port entrance. For a low wind speed (5 m/s), the wave direction follows the wind direction to some extent for east, south and west winds. The deviation of wave propagation from the wind direction increases with the increase in wind speed because longer waves driven by stronger winds experience more intense refraction. This deviation is usually of the order of 30° at a distance of about 0.5 km (point 65 in Fig. 4, right panel) from the port entrance for winds of 15 m/s from the east, south and west. The deviation increases to 60°–90° for north-west and north winds (Fig. 7). This pattern of changes evidently represents the impact of refraction on wave propagation in the shallow nearshore of Ruhnu.

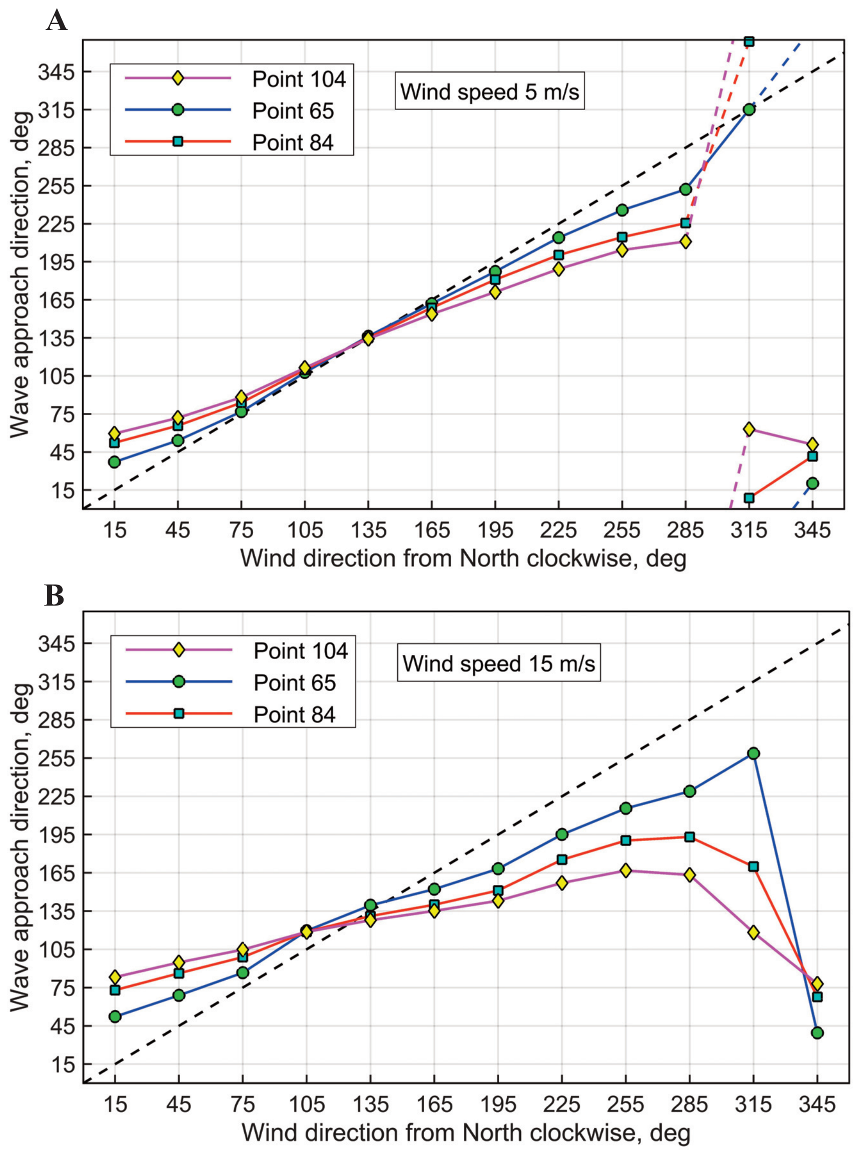

Fig. 7. Comparison of the wind direction and the mean direction of simulated wave propagation for wind speeds of 5 m/s (A) and 15 m/s (B) in saturated wave fields to the south-east of Ruhnu (point 65), on the fairway to the Port of Ringsu (point 84), and at the entrance to the Port of Ringsu (point 104). The locations of grid points are indicated in Fig. 4.

The impact of refraction becomes, as expected, stronger for higher and longer waves produced by higher wind speeds. Refraction redirects waves excited by wind speeds of 15 m/s so that the mean direction of waves is confined to the range of directions 80–190° (Fig. 7B). Only waves excited by easterly winds follow the wind direction towards the entrance to the Port of Ringsu. Importantly, wave directions generated by most strong (15 m/s) winds are reshaped by the bathymetry so that waves approach the fairway and the port entrance from the south-east, that is, heading directly for the port entrance.

DISCUSSION

The central conjecture from the presented analysis is that refraction of wind waves on underwater slopes of the island of Ruhnu and possibly on the slopes of Gretagrund to the south of Ruhnu systematically redirects the waves so that intense waves enter the Port of Ringsu during virtually any strong wind event. This transformation is relatively mild for weak winds but becomes more significant for strong winds. This feature simply reflects an increase in the wave period and length under stronger winds, which leads to an associated increase in refraction. It is therefore likely that in the case of very strong storms the range of wave approach directions is even narrower, converging around 120°, that is, along the fairway that enters the port.

This outcome is not completely unexpected as refraction often reshapes nearshore wave fields. This phenomenon may cause an inhomogeneous distribution of wave heights along some coastal segments as demonstrated, e.g., by the classic ray diagram for the mouth of the Hudson River on the Atlantic coast of the USA (Kinsman 1965). It is, however, surprising and instructive that this mechanism can create a massive wave energy flux, on average, straight from the direction where winds are the weakest and least frequent.

It might be necessary to design more extensive protection of the entrance to the Port of Ringsu to ensure safety in its interior. It could be realised, for example, in the form of an island-style breakwater located in the prevailing approach direction of waves. Such an island or breakwater could be either a stationary (Cox and Czlapinski 2016) or anchored floating structure (Davis et al. 2013). The existing harbour jetties have also been designed to avoid siltation of the port. A modified shelter structure will eventually influence the sediment transport pattern in the vicinity of the harbour. It is therefore important to check whether it could lead to silting of the harbour entrance.

Finally, we note that the wave heights approaching from the south and south-west could, to some extent, be underestimated by the SWAN model as this model tends to underpredict wave energy when waves are penetrating into bathymetries with shallow areas traversed by channels (Groeneweg et al. 2015). Such effects are characteristic of tidal inlets. They can occur here because of the presence of a deep channel between Ruhnu and Gretagrund to the south of the island. This channel evidently plays a role similar to that of dredged navigation channels where refraction leads to the concentration of wave energy on the sides of the channel (Li et al. 2000). The energy of waves approaching from the south, south-west or west is redirected to the south along the southern side of the channel. The concentrated wave energy that propagates along the northern side of the channel, on the other hand, may propagate directly towards the entrance to the Port of Ringsu.

CONCLUSION

We have shown that underwater slopes of small islands and nearby shallows may systematically and radically redirect wind waves so that they regularly impact coastlines and coastal engineering structures from an unexpected direction, independent of the wind direction. In the case of the Port of Ringsu located on the island of Ruhnu, it is the direction from which storm winds are infrequent and weak.

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REFERENCES

Baltic Sea Hydrographic Commission. 2013. *Baltic Sea Bathymetry Database Version 0.9.3*. http://data.bshc.pro/legal (accessed 2121-04-01).

Battjes, J. A. and Janssen, J. P. F. M. 1978. Energy loss and set-up due to breaking of random waves. In *Proceedings of the 16th International Conference on Coastal Engineering, Hamburg, Germany, August 27 – September 3, 1978*. American Society of Civil Engineers, 569–587. https://doi.org/10.1061/9780872621909.034

Björkqvist, J.-V., Lukas, I., Alari, V., van Vledder, G. Ph., Hulst, S., Pettersson, H., Behrens, A. and Männik A. 2018. Comparing a 41-year model hindcast with decades of wave measurements from the Baltic Sea. *Ocean Engineering*, **152**, 57–71. https://doi.org/10.1016/j.oceaneng.2018.01.048

Booij, N., Ris, R. C. and Holthuijsen, L. H. 1999. A third-generation wave model for coastal regions: 1. model description and validation. *Journal of Geophysical Research – Oceans*, **104**(C4), 7649–7666. https://doi.org/10.1029/98JC02622

Cairns, A., Carel, J. M. and Li, X. 2016. Port and harbor design. In *Springer Handbook of Ocean Engineering* (Dhanak, M. R. and Xiros, N. I., eds). Springer, Cham, 685–710. https://doi.org/10.1007/978-3-319-16649-0_31

Cox, J. C. and Czlapinski, R. E. 2016. Engineering of an island-style breakwater system for the Fort Pierce marina. *Proceedings of the Institution of Civil Engineers – Maritime Engineering*, **169**(1), 37–43. https://doi.org/10.1680/jmaen.15.00014

Davis, J., Phillips, J., Czlapinski, R., Seissiger, E. and Cignarella, P. 2013. Breakwater island creation: A 3-fold system. In *Design and Practice of Geosynthetic-Reinforced Soil Structures. International Symposium on Design and Practice of Geosynthetic-Reinforced Soil Structures / 26th Italian National Conference on Geosynthetics, Bologna, Italy, October 14–16, 2013* (Ling, H. I., Gottardi, G., Cazzuffi, D., Han, J. and Tatsuoka, F., eds). DEStech Publications, Lancaster, PA, 708–718.

Eldeberky, Y. 1996. *Nonlinear transformation of wave spectra in the nearshore zone*. PhD Thesis. Delft University of Techology, Netherlands.

Groeneweg, J., van Gent, M., van Nieuwkoop, J. and Toledo, Y. 2015. Wave propagation into complex coastal systems and the role of nonlinear interactions. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, **141**(5). https://doi.org/10.1061/(ASCE)WW.1943-5460.0000300

Hanes, D. M. and Erikson, L. H. 2013. The significance of ultra-refracted surface gravity waves on sheltered coasts, with application to San Francisco Bay. *Estuarine, Coastal and Shelf Science*, **133**, 129–136. https://doi.org/10.1016/j.ecss.2013.08.022

Hasselmann, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K. et al. 1973. Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Deutsche Hydrographische Zeitung,* **8**(12).

Hasselmann, S., Hasselmann, K., Allender, J. H. and Barnett, T. P. 1985. Computations and parameterizations of the nonlinear energy transfer in a gravity-wave spectrum. Part II: parameterizations of the nonlinear energy transfer for application in wave models. *Journal of Physical Oceanography*, **15**(11), 1378–1391. https://doi.org/10.1175/1520-0485(1985)015<1378:CAPOTN>2.0.CO;2

Kinsman, B. 1965. *Wind Waves: Their Generation and Propagation on the Ocean Surface*. Prentice-Hall, Englewood Cliffs, NJ.

Komen, G. J., Hasselmann, S. and Hasselmann, K. 1984. On the existence of a fully developed wind-sea spectrum. *Journal of Physical Oceanography*, **14**(8), 1271–1285. https://doi.org/10.1175/1520-0485(1984)014<1271:OTEOAF>2.0.CO;2

Kovaleva, O., Eelsalu, M. and Soomere, T. 2017. Hot-spots of large wave energy resources in relatively sheltered sections of the Baltic Sea coast. *Renewable and Sustainable Energy Reviews*, **74**, 424–437. https://doi.org/10.1016/j.rser.2017.02.033

Li, Y. S., Liu, S.-X., Wai, O. W. H. and Yu, Y.-X. 2000. Wave concentration by a navigation channel. *Applied Ocean Research*, **22**(4), 199–213. https://doi.org/10.1016/S0141-1187(00)00013-4

LinkFang. 2021. *Ruhnu*. https://en.linkfang.org/wiki/Ruhnu (accessed 2021-12-21).

Männikus, R., Soomere, T. and Kudryavtseva, N. 2019. Identification of mechanisms that drive water level extremes from in situ measurements in the Gulf of Riga during 1961–2017. *Continental Shelf Research*, **182**, 22–36. https://doi.org/10.1016/j.csr.2019.05.014

Orviku, K. 2018. *Rannad ja rannikud* (*Beaches and Shores*). Tallinna ülikooli kirjastus, Tallinn (in Estonian).

Pallares, E., Sánchez-Arcilla, A. and Espino, M. 2014. Wave energy balance in wave models (SWAN) for semi-enclosed domains – Application to the Catalan coast. *Continental Shelf Research*, **87**, 41–53. https://doi.org/10.1016/j.csr.2014.03.008

Rogers, W. E., Hwang, P. A. and Wang, D. W. 2003. Investigation of wave growth and decay in the SWAN model: three regional-scale applications. *Journal of Physical Oceanography*, **33**(2), 366–389. https://doi.org/10.1175/1520-0485(2003)033<0366:IOWGAD>2.0.CO;2

Safadi, C. 2016. Wind and wave modelling for the evaluation of the maritime accessibility and protection afforded by ancient harbours. *Journal of Archaeological Science: Reports*, **5**, 348–360. https://doi.org/10.1016/j.jasrep.2015.12.004

Soomere, T. and Keevallik, S. 2001. Anisotropy of moderate and strong winds in the Baltic Proper. *Proceedings of the Estonian Academy of Sciences. Engineering*, **7**(1), 35–49. https://doi.org/10.3176/ENG.2001.1.04

The SWAN team. 2021. *SWAN scientific and technical documentation*. Technical Report. Delft University of Technology. http://swanmodel.sourceforge.net/download/zip/swantech.pdf (accessed 2021-12-20).

Wu, J. 1982. Wind-stress coefficients over sea surface from breeze to hurricane. *Journal of Geophysical Research – Oceans*, **87**(C12), 9704–9706. https://doi.org/10.1029/JC087iC12p09704

Zijlema, M., van Vledder, G. Ph. and Holthuijsen, L. H. 2012. Bottom friction and wind drag for wave models. *Coastal Engineering*, **65**, 19–26. https://doi.org/10.1016/j.coastaleng.2012.03.002

Näiliselt kaitstud väikesadamat võib ohustada lainete refraktsioon: Ringsu sadam Ruhnu saarel Liivi lahes

Rain Männikus, Tarmo Soomere ja Fatemeh Najafzadeh

Madalmeres levivate lainete suund muutub refraktsiooni tõttu süstemaatiliselt nõnda, et laineharjad muutuvad järjest enam paralleelseks mere samasügavusjoontega. Ringsu sadam Ruhnu saarel on avatud kagusse, kust tugevaid tuuli puhub harva. Ruhnu saart ümbritsev madalmeri ja sellest lõunas paiknev Gretagrundi madal mõjutavad aga lainelevi suunda nii, et Liivi lahel mistahes suunast puhuvate tugevamate tuulte (15 m/s) korral levivad kõrged lained valdavalt otse Ringsu sadamasse. Ohutuse tagamiseks tuleb sadama suuet kaitsta just kagu poolt.