On oceanographic aspects of the development of the LNG terminal at NE Pakri Peninsula

Expert opinion

Tarmo Soomere

Institute of Cybernetics at Tallinn University ot Technology

Wave Engineering Laboratory

WAVE ENGINEERING

Tallinn 2012

Introductory remarks

The development of tanker-served LNG terminals is generally connected with a variety of impacts and threats. These affect both the mainland around the terminal (related with the building and maintenance of the terminal itself and the gas pipelines connecting the terminal with the existing gas distribution network), the nearshore (where the re-gasification of the LNG is performed) and the adjacent sea areas that will regularly be used by the LNG tankers serving the terminal.

It has definitely become a cliché to underline that the design of such adventures should account for all possible environmental risks, economical considerations, and associated threats to lives and property of people in the neighbourhood. Although there exist numerous ways to formalise the outcome the relevant analysis of the listed aspects (see, e.g. Morris and Therivel, 2001, for the discussion of the environmental impact assessments), the largest uncertainties in the analysis are usually associated with the virtual impossibility to properly quantify the level of risks associated with infrequently occurring risks of major accidents and the „cost" of potential consequences.

The notion of risk

Contemporary literature uses the term "risk" in many different meanings. To avoid ambiguity and possible (and frequent) confusion of risk with uncertainty, I remind the classical concept of risk understood as a quantitative measure of a potential adverse event. The notion of risk R is expressed as the product $R = P_a \times C_a$ of the probability P_a (of failure or accident) and the properly quantified severity C_a (cost or consequence) of this disaster (Risk Management Standard, 2002). This notion of risk is commonly used in natural sciences, engineering and industry since the planning of the immense Delta Works infrastructure[1]. While it is easy to use this equation for risk for finite values of probability and costs, the analysis becomes complicated when one of the factors (usually the probability) is very small and the other (the potential cost) is very large. Although several mathematical methods (e.g. L'Hospital's Rule) exist for handling such cases, they are usually based on strict assumptions on the asymptotic behaviour of the counterparts and often cannot be used in real situations.

It is important to recognize that large coastal or offshore structures are often so complicated system that even minor defects in its production or errors in its design may result in a significant failure (e.g., Collins et al., 1997). Moreover, a human error or misbehaviour cannot be totally excluded.

Interference of a LNG terminal with densely populated and industrial areas

With my background in mathematics, physical oceanography and coastal engineering, combined with a certain experience in selection of the optimum location of large-scale constructions at the coast (Elken et al., 2001) and in assessment procedures of offshore structures (Soomere, 2009), I am not competent to adequately characterize the mainland

[1] The dawn of this concept stems from coastal engineering. After the devastating storm surge in February 1953 that killed 1,835 people in the Netherlands, the Dutch government triggered the construction of an impressive bulwark megastructure, the Delta Works, to reduce the country's flood vulnerabilities. The most visionary aspect of the Delta Works was the statistical approach that guided the designs. The novelty of the Dutch decision was to include both the properties of storms and the economics of the Netherlands. With the help of renowned mathematician David van Dantzig, the safety levels were calculated using the presented simple risk equation to produce a sequence of economically rational public-safety decisions (Wolman, 2008).

impacts of different options and solutions for the LNG terminal. Here I only take the liberty to note the limited capacity and reaction time of rescue services in Estonia. I am also not competent to compare this capacity for mainland operations in different countries. Still, even for an unarmed eye the well-known difference in similar capacity for marine operations in Estonia (rescue of people, detection and combating oil spills, etc.) compared to that at the northern coast of the Gulf of Finland is drastic. This situation characterises quite limited possibilities of rescue services to effectively interfere in case when a large-scale devastation would occur in Estonia.

This comment is not meant to hurt anybody. It reflects my individual opinion built on (i) the personal interference into the forecast of the flooding on 8–9 January 2005 (Soomere, 2005), (ii) detailed knowledge of the models underlying the operational marine forecast in Estonian coastal sea (Lagemaa et al., 2011), and public information about substandard and/or delayed reaction to unexpectedly severe (but not extreme) weather conditions during the last years (e.g. snowstorm in Padaorg in December 2010 or flash flooding of Laagna tee in Tallinn in May 2012).

Given the limited resources for handling of exceptional situations during the potential accident or malfunctioning of a LNG terminal, it is an imperative for it to be placed at a sufficient distance from any valuable property or inhabited or industrial area. Most importantly, it should be sufficiently separated from any substances that might support a cumulative expansion of an accident. Large-scale accidents usually occur in situations where a nonlinear combination of very unlikely factors leads to a chain of events that is impossible from the statistical viewpoint. The best way to avoid the virtually unpredictable impact of such combinations is to design the location of the LNG terminal so that even at the worst possible scenario there would be strictly no way for an adverse combination of cumulative effects with other threats to exist. In other words, the best location for such a terminal is as far as possible from inhabited areas, other industrial enterprises, major highways, large vessels, storage areas, etc. In this respect, the location of a planned terminal at the Pakrineeme location would be one of the best sites.

Interference with pipelines at sea bottom

The majority of the research into risks of marine traffic has been focused on the probability of accidents (Fowler and Sørgård 2000; Soares and Teixeira, 2001). The use of the above notion of risk is gradually increasing in professional analysis and modelling (Montewka et al., 2011). Both factors at the right-hand side of this equation have been massively addressed in the scientific and technical literature. For example, the use of contemporary navigation devices and detailed charts, the overall improvement of the construction of ships to withstand the forces of nature, the implementation of real-time control through vessel traffic systems, etc., have considerably decreased the probability P_a of ship accidents. In spite of all these developments, however, major offshore accidents and grounding events continue to happen with some frequency.

To a first approximation, the probability to have of an accident on sea increases with an increase of the sailing line. In this respect, the smallest risk in Estonian coastal waters in the current context offer locations at the coast of Saaremaa and in the NW Estonian mainland. The pool of potential locations for a port capable of serving typical LNG tankers is very limited. According to this criterion only, theoretically, the best option would be NW Saaremaa[2]. This location might be interesting in terms of safety as the density of population

[2] There are almost no reasonable locations at Hiiumaa.

and industrial enterprises is very small in this part of Saaremaa, and because of small distance over Irbe Strait to Latvia. It is, however, interesting mostly theoretically as it is located too far from the existing major distribution networks.

The use of the vicinity of Paldiski (Pakrineeme) for re-gasification or unloading the LNG provides a sensible solution not only in terms of the length of sailing line but also in the context of other factors potentially impacting safety. The potential consequences of a ship accident involving leakage of an underwater gas pipeline were intensively discussed during the analysis of the environmental impact assessment (EIA) of the Nord Stream pipeline, and found to be highly controversial. The estimates for the relevant risks performed by the Nord Stream EIA team deviated from similar estimates made by Estonian scientists by up to four orders of magnitude (up to 10,000 times, Erm, 2009). A part of this discrepancy stems from an underestimation of the length of the section of the sailing line matching the location of the pipeline in the Gulf of Finland (Soomere, 2009).

In the context of extremely large scatter of expert opinions about the threats associated with a gas pipeline at the seabed to passenger traffic and extensive uncertainties in the estimates of both components of the risk in the above notion, it would be irresponsible to route LNG tanker traffic above a major pipeline whenever other options are available.

Qualitatively, the smallest risk would provide solutions where their sailing line is substantially separated from the location of gas pipelines at seabed. This is possible to arrange if the LNG tankers would make a port call in the area to the west of Naissaar. Contrariwise, it would be virtually impossible for tankers that cross the Naissaar-Porkkala line.

The above also suggests that planned pipe connection to Finland, the BalticConnector, should use the shortest possible corridor across the Gulf of Finland; and should be laid, if possible, far from the major shipping lanes. The location of the LNG terminal at Pakri Peninsula (Pakrineeme) seems to be the optimal landing point of the pipeline in this respect.

As a side remark, the use of the Pakri–Inkoo corridor for the BalticConnector pipeline (Balticconnector, 2011) would minimize the interference of the pipeline with ship traffic routes. This not only minimizes risk from surface vessels but preventively decreases the risks associated with a potential leakage of gas from even trenched pipelines on the seabed. Other options of the location of the BalticConnector (e.g. from Paldiski to Vuosaari, Route 4 and 6 according to (Balticconnector, 2011)) mean that both the along-gulf and cross-gulf transport would cross this pipeline whereas the along-gulf traffic would go in parallel and partially just above the pipeline for several dozens of km.

Interference with passenger traffic

The most devastating consequence may happen when a passenger carrier travels through an area filled by leaking gas. A possible explosion could result in loss of many lives. Such disasters have occurred on mainland services (Anonymous/Agence France-Presse, 1989). A disaster of similar magnitude may occur if a gas leak from a LNG tanker would occur in the neighbourhood of a passenger ship. Accidents similar to de-railing of LNG carriers (cf. the events after de-railing of a train, http://news.sky.com/home/world-news/article/15323889) (Anonymous/Sky News, 2009) are possible when a LNG tanker would run aground.

It is possible to separate to some extent the LNG tanker, other cargo and passenger traffic for the locations of the LNG terminal to the west of the Island of Naissaar. For more eastward solutions it is inevitable that the tankers have to cross the area between Tallinn and Helsinki that hosts extremely heavy passenger traffic. A crossing of the sailing line of LNG tankers with this ship lane would provide clear additional risk and should be avoided beforehand by a reasonable location of the terminal.

Semi-sheltered location

A planned site for the quay of LNG tankers at Pakrineeme is relatively well sheltered from the predominant SW winds. The impact of high coastal cliff on these winds normally becomes evident as a considerable decrease in the wind speed (optionally accompanied by an increase in gustiness). This impact is usually clearly identifiable at a distance of 1–2 km from the shoreline (see the analysis for a similar situation in Saaremaa in (Elken, 2001)). The resulting decrease in the wind speed provides a natural shelter for the most frequent directions of storm winds.

The northern tip of the Pakri Peninsula also shelters well the location of the planned quay for the LNG tankers at Pakrineeme from waves exited by SW storms. The basic idea of building an open quay, with no breakwaters around to create a harbour, is also used for the design of the Tamme/Küdema cruise port in the NW Saaremaa. It relies on the favourable match of the geometry of the vicinity of the port and the directional distribution of strong winds (Soomere, 2001). As at Tamme, using the open quay ensures safe operation during a large part of the year at Pakrineeme. The relevant directional distributions of the approach direction of the highest waves are not known for the Pakrineeme area.

A rough estimate of the frequency of occurrence of high seas can be constructed based on published data for the open part of the northern Baltic Proper (Broman et al., 2006). In this area the significant wave height exceeding 1 m (this level might be roughly taken as a threshold for completely safe operation of typical LNG tankers at the quay) occurs with a probability of about 30%. Wave heights are generally clearly lower at the northern coast of Estonia. On top of that, well above 50% of high wave events here are created by SW winds. Therefore, it is very likely that the significant wave height only exceeds 1 m at the location of the planned quay with a probability of <10%. In many cases, the threshold of significant wave heights of 1.5 m is accepted for safe operation of larger vessels. Only about 15% of seas exceed this threshold in the Baltic Proper (Broman et al., 2006) and it is very likely that such wave conditions occur at the planned location of the open quay at Pakrineeme with a probability of well below 5%. These estimates should of course be verified by long-term wave simulations and available observations.

This choice of the quay construction provides substantially smaller interference to the seabed and coast at the site, and is generally preferable in environmental terms. As the littoral flow evidently is almost unidirectional at the site, avoiding changes to the coastline and using solutions that will not stop the littoral flow are environmentally friendly. Eventually no dredging or land reclamation is necessary, which additionally decreases the impact of the entire adventure.

Anisotropy of wind and wave conditions. Easterly winds

Compared with, for example, the Port of Paldiski, the planned location of the LNG terminal at Pakrineeme is only partially sheltered from predominant winds. As mentioned above, it is sheltered well against the most frequent SW winds in the northern Baltic Proper. It is, however, almost completely open to NNW winds that are somewhat less frequent but that may be even stronger than SW winds (Soomere and Keevallik, 2001)

The wind system in the Gulf of Finland is somewhat more complicated because of the geometry of the basin. A relatively less known property of the gulf is that it occasionally hosts strong eastern winds that blow exactly along the axis of the gulf (Soomere and Keevallik, 2003). These winds are the second or the third strongest in the western Gulf of Finland. While the SW and NNW winds are usually a part of the large-scale atmospheric dynamics over the NE Europe, the eastern winds in the Gulf of Finland apparently are of more local origin.

A challenge for the designers of any offshore installation in this domain is the systematic inability of even the most contemporary atmospheric models to properly forecast certain wind events (Keevallik and Soomere, 2010). This bottleneck naturally affects the ability of existing and emerging operational systems to exactly forecast wave conditions in this basin. The associated inconveniences for the operation at open quays are basically the same at all locations of the entire Gulf of Finland that are open to the east.

Ice conditions

Although our understanding of loads that may occur during severe storms or accompany an ice attack (Kujala and Arughadhoss, 2012) is continuously improving, it is economically unfeasible to design all the ships to fully resist such forces on all occasions. For this reason, the information about ice statistics should be accounted for in estimates of the costs, risks and operability of LNG terminals.

The overall circulation of water masses of the Baltic Sea and in the Gulf of Finland, known since the time of Rolf Witting, is counter-clockwise (Leppäranta and Myrberg, 2009). The more saline water from the Baltic Proper flows, in average, from the southern Baltic along the eastern coast of the sea to the north, enters the Gulf along the Estonian coast, and leaves the gulf along the Finnish coast[3] (Soomere et al., 2008b). This peculiarity of the circulation is one of the main causes the relatively mild ice regime along the NW coast of Estonia. The vicinity of the Pakri Peninsula is directly affected by the associated supply of heat in winter season. Owing to its openness to the described circulation this area hosts one of the shortest lengths of ice coverage along the entire Estonian coast (Sooäär and Jaagus, 2007). Moreover, strong eastern winds (see above) mostly occur in late winter and early spring when they tend to move the drifting ice to the North. The combination of these factors leads to much longer ice seasons in the central and eastern Gulf of Finland compared to the vicinity of the Pakri Peninsula.

It is highly questionable whether it would be acceptable for LNG tankers to sail in a convoy following an icebreaker. The experience with Runner 4 in the eastern Gulf of Finland (which sank in 2006 after being squeezed in the ice and hit by a following ship, and polluted appreciable sections of the northern Estonian coastline) and several similar accidents strongly speak against this solution and for a choice of a maximally ice-free location of the LNG terminal in the NW part of Estonia.

Gaps in the knowledge

Although the Baltic Sea and particularly the Gulf of Finland are among the most studied sea areas in the world, there still exist several gaps in the relevant knowledge of physical oceanography that might considerably impact the LNG tanker traffic and its mooring

[3] There exist of course many local, much more complicated features of this circulation and water exchange between the Gulf of Finland and the Baltic Proper, see, for example (Andrejev et al., 2004).

and unloading conditions. These gaps more or less equally characterise our knowledge along the entire northern coast of Estonia.

(i) The gaps in the knowledge of marine wind climate and, in particular, uncertainties in the estimates of periods and duration of long-term events of high wind speeds that do not allow unloading of LNG tankers at the open quay. A frequently overlooked issue is that the information from mainland meteorological stations often does not represent the marine wind properties (Keevallik, 2003). This issue specifically characterises the northern coast of Estonia and is less evident for the southern coast of Finland (Soomere and Keevallik, 2003). The gaps in this knowledge are to some extent mitigated by short duration and relatively good overall predictability of high wind events.

(ii) The associated gaps in the knowledge of the wave climate in the Baltic Sea and along the northern coast of Estonia. The wave climate here is usually described as relatively mild (Soomere and Räämet, 2011; Soomere et al., 2011). It may, however, host extremely severe wave situations (Schmager et al., 2008; Soomere et al., 2008a). A specific feature of the Gulf of Finland (Soomere and Keevallik, 2003) and to a lesser extent in the northern Baltic Proper is that in strongest storms the wind may blow from directions from where the overall frequency of strong winds is not the largest. Such situations may give rise to unexpectedly severe wave conditions at certain sites.

(iii) Recent research (Keevallik and Soomere, 2010) has identified a systematic mismatch between numerically simulated and *in situ* measured wind properties in the Gulf of Finland. This mismatch points to problems with the representation of certain wind events in the Gulf of Finland and associated uncertainties in the forecast of severe windseas. This shortage of the models is to some extent mitigated by the intermittency of windseas and by a short duration of severe wave situations.

(iv) The use traditional concept of the Baltic Sea as a practically non-tidal sea often leads to substantial underestimation of velocities of currents in the nearshore and near the seabed. Although the amplitude of tides is a few cm, the tidal currents are relatively large in the Gulf of Finland. Recent estimates (Lilover, 2012) demonstrate that the average speed of tide-driven flow is about 5 cm/s near Naissaar and thus may reach up to 10 cm/s in spring tides. These values are apparently even larger in the eastern Gulf of Finland where the amplitude of tides may be about twice as high as in the vicinity of Pakri (Schmager et al., 2008). Therefore, it is necessary to account for the related currents in estimates of the potential impact of near-coastal currents to the mooring conditions at the open quay.

It is unlikely that any of approaching strong storms in the Baltic Sea basin would be overlooked in the contemporary weather and water level forecast system. The listed gaps in the scientific knowledge and operational forecast are mostly associated with large uncertainties in some parameters of certain strong wind events. While the wind speed is usually adequately predicted, the forecast of the related wave fields and current velocities (which may affect the work at the open quay) is of much lower quality. This is an intrinsic problem in the entire northern Baltic Sea basin and is largely caused by the complicated geometry, bathymetry and hydrography of the sea.

A large part of such uncertainties could be eliminated by means of more exact evaluation of the wave climate at a particular site, with the key goal to identify typical weather situations in which the actual wave conditions are substantially more severe than the forecast ones. As none of the existing wave models is perfect, the best result would give an analysis of the output of an ensemble of conceptually different models. I would recommend to start from the evaluation of the wave statistics at the quay location using a standard spectral wave model (WAM or SWAN) with a resolution not coarser than 1 km (recommended about 0.5 km). The runs should be made for at least 30 years in order to reach climatologically valid results, and, if possible, using wind information from standard atmospheric models and from high-quality marine wind data in the neighbouring region (e.g. Kalbådagrund (Soomere and Keevallik, 2003)). Alternatively, the time series of wave properties can be extracted from existing modelling efforts. These runs should be complemented using some simpler (e.g. fetch-based, e.g. (Suursaar 2010)) models and performing measurements waves and currents during at least one windy season. A comparison of the results of such modelling and measurement efforts would reveal the majority of potential failures of the standard forecast. Among those, only those are significant for the operational purposes where a large mismatch occurs for relatively high waves at the quay location.

Recommended studies

As there exist several potentially important gaps in our knowledge of the metocean conditions (especially the properties of marine winds and wind waves) in the entire Gulf of Finland and in the adjacent northern Baltic Proper, I recommend to perform a more detailed study of wave fields at the planned terminal location, with the goal to identify typical weather situations in which the actually existing wave conditions tend to be substantially more severe than the forecast ones. This remark is valid for any planned location of the open quays in the Gulf of Finland.

Summary

The presented considerations may be shortly summarised as follows:

- In order to minimise mainland threats, it is an imperative for the LNG terminal to be placed at a sufficient distance not only from any valuable property or densely populated or industrial area but, even more importantly, from any substances that might support a cumulative expansion of an accident.
- It is important to avoid crossing of the sailing line of LNG tankers and the location of major gas pipelines on the seabed
- It is highly desirable to avoid crossing of the sailing line of the LNG tankers with major ship lanes hosting intense passenger traffic.
- For LNG tankers entering the Baltic Sea from the North Sea the shortest sailing line and associated probability of failures owing to major metocean factors offer solutions in the NW of Saaremaa or in the NW of Estonia.
- The use of standard (i.e. without ice class) LNG tankers in the presence of ice cover is a highly controversial issue and evidently is connected with largely increased risks of a failure or an accident. Thus, a sensible solution provide locations with clearly shorter length of ice period in NW of Saaremaa or in the NW of Estonian mainland.
- Under otherwise equal conditions, the use of an open quay would provide a solution with the least interference with coastal processes and a minimum impact to the areas “downstream” of the littoral drift.

References

Andrejev O., Myrberg K., Alenius P., Lundberg P.A. 2004. Mean circulation and water exchange in the Gulf of Finland – a study based on three-dimensional modelling. *Boreal Environment Research*, **9**, 1–16.

Anonymous (Agence France-Presse) 1989. Toll up to 645 in Soviet train blast. Chicago Sun-Times, July 26, 1989; see also http://en.wikipedia.org/wiki/Ufa_train_disaster

Anonymous (Sky News) 2009. Fireball engulfs homes after train explodes, Tuesday June 30, 2009, see also http://news.sky.com/home/world-news/article/15323889

Balticconnector Executive Summary, February 2011, 2004G122/04TREN/05/TENE– S07.51598, Gasum.

Broman B., Hammarklint T., Rannat K., Soomere T., Valdmann A. 2006. Trends and extremes of wave fields in the north–eastern part of the Baltic Proper. *Oceanologia*, **48** (S), 165–184.

Collins M.P., Vecchio F.J., Selby R.G., Gupta P.R. 1997. The failure of an offshore platform, *ASI Concrete International*, **19** (8), 28–35.

Elken J. 2001. Modelling of coastal circulation and oil drift at possible deep harbour sites, north-western Saaremaa Island. *Proceedings of the Estonian Academy of Sciences. Engineering*, **7** (2), 141–156.

Elken J., Kask J., Kõuts T., Liiv U., Perens R., Soomere T. 2001. Hydrodynamical and geological investigations of possible deep harbour sites in north-western Saaremaa Island: Overview and conclusions. *Proceedings of the Estonian Academy of Sciences. Engineering*, **7** (2), 85–98.

Erm, A. 2009. Nord Stream on kõikide pommide ema. *Eesti Ekspress*, 26.06.2009

Fowler T.G., Sørgård E. 2000. Modeling ship transportation risk. *Risk Analysis*, **20** (2), 225–245.

Keevallik S. 2003. Possibilities of reconstruction of the wind regime over Tallinn Bay. *Proceedings of the Estonian Academy of Sciences. Engineering*, **9** (3), 209–219.

Keevallik S., Soomere T. 2010. Towards quantifying variations in wind parameters across the Gulf of Finland. *Estonian Journal of Earth Sciences*, **59** (4), 288–297.

Kujala P., Arughadhoss S. 2012. Statistical analysis of ice crushing pressures on a ship's hull during hull-ice interaction. *Cold Regions Science and Technology*, **70**, 1–11.

Lagemaa P., Elken J., Kõuts T. 2011. Operational sea level forecasting in Estonia. *Estonian Journal of Engineering*, **17** (4), 301–331.

Leppäranta M., Myrberg K. 2009. *Physical oceanography of the Baltic Sea*. Springer Praxis, Berlin–Heidelberg–New York, 378 pp.

Lilover M.-J. 2012. Tidal currents as estimated from ADCP measurements in „practically non-tidal" Baltic Sea, *Proceedings of the IEEE/OES Baltic 2012 International Symposium "Ocean: Past, Present and Future. Climate Change Research, Ocean Observation & Advanced Technologies for Regional Sustainability," May 8–11, Klaipėda, Lithuania*, IEEE 978-1-4673-1414-5/12, PID2324151, 4 pp.

Montewka J., Krata P., Goerlandt F., Mazaheri A., Kujala P. 2011. Marine traffic risk modelling - an innovative approach and a case study. *Proceedings of the Institution of Mechanical Engineers, Part O-Journal of Risk and Reliability*, **225** (O3), 307–322.

Morris P., Therivel R. (Eds.) 2001. *Methods of Environmental Impact Assessment.* 2nd edn. UK: Spon Press.

Risk Management Standard 2002. The Institute of Risk Management, London, 14 pp. http://www.theirm.org/publications/documents/Risk_Management_Standard_030820.pdf

Schmager G., Fröhle P., Schräder D., Weisse R., Müller-Navarra S. 2008. Sea state, tides. In: Feistel R., Nausch G., Wasmund N. (Eds.). *State and Evolution of the Baltic Sea 1952–2005.* Wiley pp. 143–198.

Soares C.G., Teixeira A.P. 2001. Risk assessment in maritime transportation, *Reliability Engineering & System Safety*, **74** (3), 299–309.

Soomere T. 2001. Wave regimes and anomalies off north-western Saaremaa Island. *Proceedings of the Estonian Academy of Sciences. Engineering*, **7** (2), 157–173.

Soomere T. 2005. Estonia got storm warning from newspaper. *Scandinavian Shipping Gazette*, No 4, 25.02.2005, 26–29.

Soomere T. 2009. Nord Stream eirab tundliku Läänemere eripära (Nord Stream ignores the specific features of the vulnerable Baltic Sea, presentation to the Estonian Parliament on 27.10.2009). *Postimees* 249 (5729), 28.10.2009, pp. 12–13 (in Estonian).

Soomere T., 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.

Soomere T., Keevallik S. 2003. Directional and extreme wind properties in the Gulf of Finland. *Proceedings of the Estonian Academy of Sciences. Engineering*, **9** (2), 73–90.

Soomere T., Räämet A. 2011. Spatial patterns of the wave climate in the Baltic Proper and the Gulf of Finland. *Oceanologia*, **53** (1-TI), 335–371.

Soomere T., Behrens A., Tuomi L., Nielsen J.W. 2008a. Wave conditions in the Baltic Proper and in the Gulf of Finland during windstorm Gudrun. *Natural Hazards and Earth System Sciences*, **8** (1), 37–46.

Soomere T., Myrberg K., Leppäranta M., Nekrasov A. 2008b. The progress in knowledge of physical oceanography of the Gulf of Finland: a review for 1997–2007. *Oceanologia*, **50**(3), 287–362.

Soomere T., Zaitseva-Pärnaste I., Räämet A., Kurennoy D. 2010. Spatio-temporal variations of wave fields in the Gulf of Finland. *Fundamental and Applied Hydrophysics*, 4(10), 90–101 (in Russian).

Sooäär J., Jaagus J. 2007. Long-term variability and changes in the sea ice regime in the Baltic Sea near the Estonian coast. *Proceedings of the Estonian Academy of Sciences. Engineering*, **13** (3), 189–200.

Suursaar Ü. 2010. Waves, currents and sea level variations along the Letipea–Sillamäe coastal section of the southern Gulf of Finland. *Oceanologia*, **52** (3), 391–416.

Wolman D. 2008. Before the levees break: a plan to save the Netherlands. Wired Magazine, 17.01.2008.