Proc. Estonian Acad. Sci. Eng., 2003, **9**, 3, 209–219

Possibilities of reconstruction of the wind regime over Tallinn Bay

Sirje Keevallik

Marine Systems Institute, Tallinn Technical University, Akadeemia tee 21, 12618 Tallinn, Estonia; sirje.keevallik@ebs.ee

Received 29 April 2003, in revised form 10 June 2003

Abstract. An attempt has been made to reconstruct the wind regime over Tallinn Bay from coastal data. For this purpose, two ideal sites exist – Tallinn harbour and Naissaar Island. They describe the transformation of open sea conditions to the coastal ones. The average wind speed is 5.1 m/s at Naissaar decreasing to the value of 4.7 m/s near the harbour. The most probable wind direction is SW at the entrance of the bay and south for the inner part of it. Strong winds (11 m/s and more) blow mostly from SW at Naissaar and mostly from NW at Tallinn harbour. Such a difference is obviously caused by the topography of the bay as it is open to the NW; other directions are sheltered by islands and peninsulas. The secondary maximum of the strong wind directional distribution at NE seems to be similar for the whole bay. The SE and south winds are mostly weak. As these stations do not function any more, regressions were calculated to estimate the wind vector components on the bay from Harku and Kalbådagrund data. It has been shown that the zonal component of the sea winds in winter, spring, and autumn can be reconstructed from the Harku data. The same cannot be said about the meridional component. To restore the meridional component at Naissaar, Kalbådagrund data offer a better opportunity. The conclusion is that possibilities of reconstruction of the wind field properties based on Harku data are very limited.

Key words: wind regime, Tallinn Bay.

1. INTRODUCTION

The large and complex-shaped water body of the Baltic Sea has a pronounced influence on the local climate in its vicinity and causes high variability in surface-level winds over its basin [1]. The wind regime in the northern Baltic Proper is strongly anisotropic. The directions of the most frequent and strongest winds roughly coincide with the basin axes but are drastically different from the prevailing direction of the geostrophic winds [2,3]. The sub-basins of the Baltic

Sea are not aligned with the wind directions in the Baltic Proper and may have very specific wind climate.

Wind regime in the Gulf of Finland apparently reflects several basin-specific or boundary-layer effects combining dominating SW and north winds with local east and west winds blowing along the axis of the gulf [4]. In most of the gulf area, SW winds are the most frequent, but not necessarily the strongest ones. East winds blow from a very narrow sector, but they may be as strong as SW winds. SE winds are infrequent and weak. The wind patterns show a certain variance within the gulf area. At the northern coast of the gulf, moderate and strong winds mostly blow from south or SW but at the southern coast – from SW or west. At the northern coast the eastern winds blow from east and at the southern coast from ENE. In general, the frequency and intensity of east and north winds decrease in the eastern direction along the gulf.

Recently, it has been suggested that the wind data from the southern coast of the gulf poorly represent the factual wind regime at open sea [4]. On the other hand, model calculations give controversial results [5]. Therefore, the question of description of the basic properties of open sea winds remains open for many practical applications. For example, local wave and current models in such areas of complicated shape give the best results if forced by locally measured winds [6,7]. Another important topic is locating a technically and economically feasible site for meteorological observations that adequately represents sea wind properties in the proximity of vulnerable domains.

The current paper focuses on these tasks for the central part of the Gulf of Finland. This domain hosts the most heavy ship traffic along two ship lanes (the Tallinn-Helsinki line, mostly operated by passenger ships, and the ship lane along the axis of the Gulf of Finland). The traffic is particularly heavy in the central area of the gulf where the lanes cross each other. Evidently, reliable meteorological information is a key parameter in estimates of navigation risks in this region as well as in estimates of natural and anthropogenic wave loads.

We had at our disposal the wind data from Kalbådagrund that represent sea wind properties in the northern part of the area in question. The wind data from the Harku site have a little common with the sea wind regime [4]. Below this discrepancy is analysed in some detail. Two other sources of coastal wind data are analysed. The measurements at Tallinn harbour apparently better represent sea winds, at least, for selected directions and wind speeds. The best location for capturing the open sea wind regime eventually is the northern part of Naissaar Island. This site is open to all prevailing wind directions. Only SE winds may be distorted in this area, but both the frequency and intensity of SE winds is low in the area in question. This site has been used for meteorological observations for a long time but the time series usually has been considered as doubtful. However, it has been speculated [8] that this data might be particularly valuable for mapping the wind regime in the proximity of Tallinn Bay. For this purpose, the data have been recently reanalysed and corrected on the basis of archive files.

2. WIND DATA

To derive the wind regime on Tallinn Bay, Estonian Meteorological and Hydrological Institute uses data recorded at Harku Meteorological Station (59°24′ N, 24°36′ E) that is the only operating weather station in the vicinity of Tallinn Bay. The station is situated approximately 3 km from the coast at an altitude of 33 m (see map on the inside back cover). The station started operating in May 1980. The wind speed and direction are recorded 8 times per day – at 00, 03, 06, 09, 12, 15, 18, and 21 GMT. Wind speed is registered with a resolution of 1 m/s and wind direction with a resolution of 10 deg. The anemorhumbometer is at the height of 10 m from the ground. To get wind speed on the open bay, certain coefficients are used [9]. Usually it has been assumed that wind speed over the sea is by 1.5–1.6 times larger than over the land. In case the wind is strong, this coefficient may be as small as 1.2. Weak wind over land requires a coefficient as large as 2.0. The directional wind distribution is considered to be the same at Harku and on the bay, but earlier comparisons have shown that the wind roses measured at Harku do not represent adequately the situation on the open sea [8].

Some years ago two more points around Tallinn Bay existed where wind data were collected. One of them was Tallinn harbour (59°27′ N, 24°46′ E). Since 1947 the measurements were carried out 4 times a day – at 00, 06, 12 and 15 GMT. In 1980 the weather vane that measured wind at the height of 12.5 m was replaced by anemorhumbometer that started to record wind data at the height of 32 m. During 1992–1995 the observation regime changed several times and in 1996 the station was closed. Wind speed at Tallinn harbour was recorded with a resolution of 1 m/s and wind direction in the 16-rhumb system, i.e., with a resolution of 22.5 degrees.

The other observation site was a meteorological station that was located on the northern cape of Naissaar Island (59°36′ N, 24°31′ E), just at the entrance of Tallinn Bay. This station was closed in 1992. The altitude of the station was 2 m and it was totally open to the sea from SW over north to east. The wind speed was recorded with a resolution of 1 m/s and the wind direction in the 16-rhumb system. The recordings were performed 8 times a day at the height of 12–13 m from the surface. The data of Naissaar station are not complete: there are periods where data are missing. As the station was located on a military territory, it was not easy to check the data earlier and to use them in meteorological analysis. Therefore, the quality of the data set was low. Recently, a reanalysis was carried out. The doubtful data have been removed and non-systematic recordings were verified against the original observation protocols. As a result, a valuable data set has been restored that should describe the wind regime near the southern coast of the Gulf of Finland in the vicinity of Tallinn Bay.

3. WINDS ON THE OPEN SEA NEAR TALLINN BAY

We had at our disposal the wind data recorded at Kalbådagrund (59°59′ N, 25°36′ E). Kalbådagrund is a caisson lighthouse on the northern coast of the Gulf of Finland, about 20 km from the archipelago. The station started operating in 1977. The data are recorded automatically every three hours and the wind direction is measured with a resolution of 10 deg [10].

Figure 1 shows distribution of wind direction for Naissaar and Kalbådagrund for different wind speeds. It should be kept in mind that Kalbådagrund data are recorded at the height of 32 m above the mean sea level. At classical weather stations the measurement height is 10 m. Therefore the wind speed measured at Kalbådagrund should be systematically higher than at Naissaar. The suitable height corrections to reduce the recorded wind speed to the reference height of 10 m are given in [10]. This factor is 0.91 for neutral, 0.94 for unstable, and 0.71 for stable stratification. Data in Fig. 1 are not corrected, because estimation of the stratification requires additionally temperature data.

In a previous paper [8] the author has shown that there may be a systematic error in the registration of the wind direction in the 16-rhumb system and only the 8-rhumb system gives reliable results. Nevertheless, in this paper wind-directional distributions are given in the 16-rhumb system, because otherwise it would have been difficult to compare the results with measurements made in the 36-rhumb system (with an accuracy of 10°).

It is reasonable to expect that wind data at Kalbådagrund represent adequately the wind regime over the central part of the Gulf of Finland and wind data at Naissaar describe situation at the entrance of Tallinn Bay. The features that should be characteristic of the wind regime on the open sea are listed in [4]. Next we analyse different observation sites from this point of view.

First, the wind speed should be around 7 m/s or more [1,11]. Average wind speed at Kalbådagrund for the period of 1981–2003 is 7.9 m/s (Table 1). The value of 5.1 m/s for Naissaar might be underestimated, because during the reanalysis it was detected that in many cases the code “00” (that normally should mean calm) was used as missing data. A lot of such records were removed, but it is possible that a certain quantity of them remained that increase the frequency of “no wind” data. Average wind speed at Tallinn harbour is somewhat lower and at Harku the lowest.

Table 1. Wind data at observation sites around Tallinn Bay

Station	Observation period	Average wind speed, m/s	Daily wind speed variation, %
Kalbådagrund	1981–2003	7.9	6
Naissaar	1966–1991	5.1	8
Harku	1980–2000	3.6	30
Tallinn harbour	1966–1996	4.7	22

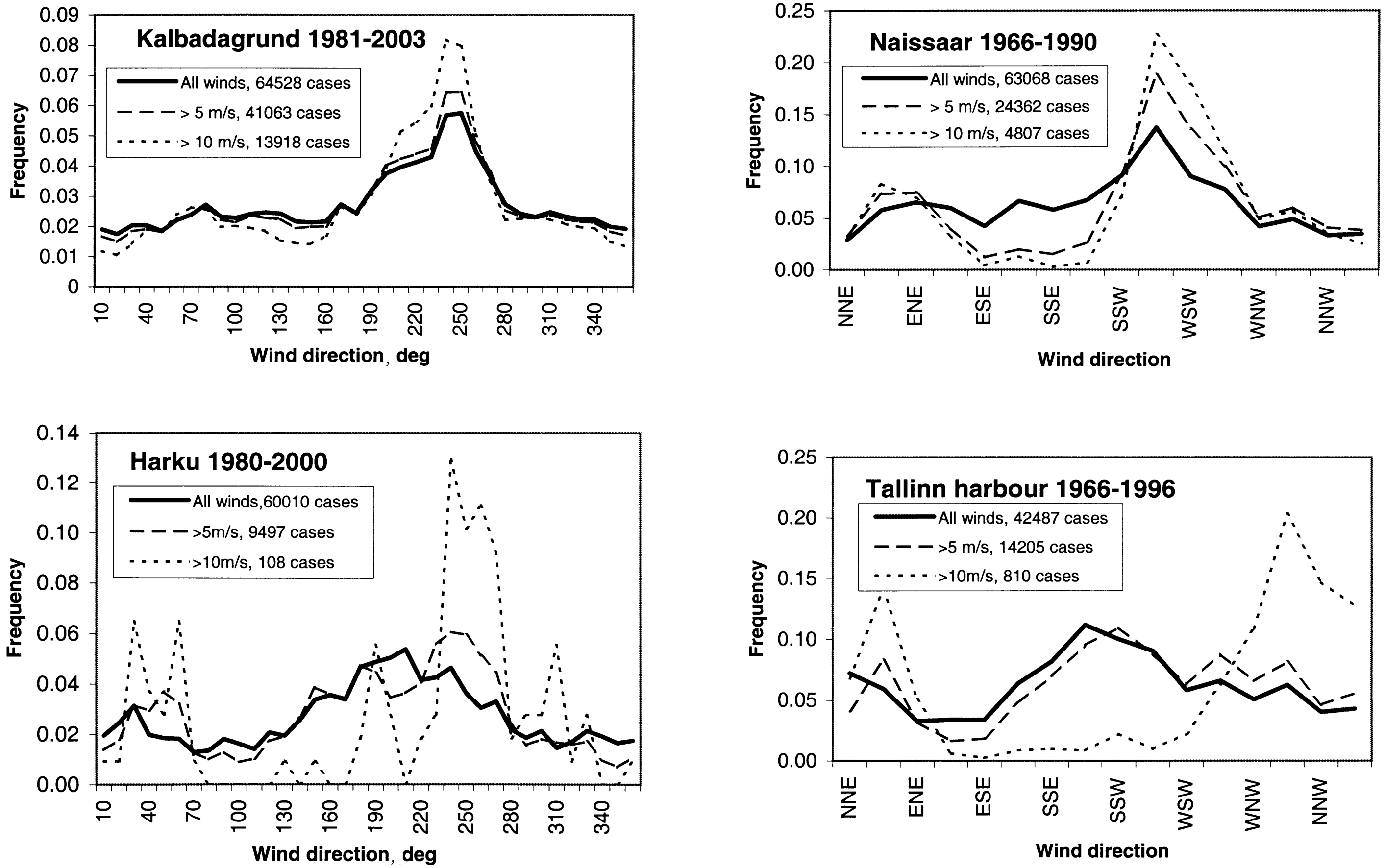

Fig. 1. Directional distribution of winds of different speeds: Kalbådagrund and Harku with angular resolution of 10°, Naissaar and Tallinn harbour with 22.5°. The vertical axis represents the relative frequency of occurrence of winds.

Second, the daily wind speed variation should be small. At Kalbådagrund this is 6% and at Naissaar 8%. According to this characteristic, both stations represent open sea conditions. At Harku and Tallinn harbour the daily variation of the wind speed is characteristic of the continental (coastal) conditions.

Third, the directional distribution of strong winds should not differ from that of all winds. Figure 1 confirms that it is so for Kalbådagrund and Naissaar, but not for Harku and Tallinn harbour.

Comparison of directional wind distributions for Kalbådagrund and Naissaar shows that the most frequent wind direction is SW at the southern coast of the Gulf of Finland and WSW at the northern coast. At Naissaar moderate and strong winds have a secondary maximum in NE or ENE directions. At Kalbådagrund the secondary maximum at ENE can be noticed also in the distribution of all winds. Winds from SE (at Naissaar also from south) are mostly weak. At Naissaar this feature may be amplified by the local conditions: between east and SW the weather station is surrounded by land and forest may reduce the wind speed. At both sites the frequency of (strong) north winds is low.

These data confirm the result of our previous paper [[4]] where the wind regime on the Gulf of Finland was restored from the coastal data.

4. WIND REGIME OF TALLINN BAY

To restore the wind regime of Tallinn Bay we have data from two observation sites that are located at two diametrically different points: Naissaar and Tallinn harbour. They describe the transformation of open sea conditions to the coastal ones and, in the first approximation, the conditions between these two points could be derived by interpolation.

As it could be expected, the average wind speed at the entrance of the bay is higher than near the harbour, decreasing from 5.1 to 4.7 m/s.

The most probable wind direction for all winds is SW at the entrance of the bay and south for the inner part of it.

Strong winds (11 m/s and more) blow mostly from SW at Naissaar and from NW at Tallinn harbour. Such a difference is obviously caused by the topography of the bay as it is open to the NW; other directions are sheltered by islands and peninsulas. The secondary maximum of the strong wind directional distribution at NE seems to be similar for the whole bay.

Figure 1 shows that the frequency of strong winds from the southern directions is extremely low. At Naissaar this is the case for the directions around SE, at Tallinn harbour from east over south to SW. This means that winds from these directions are mostly weak (at Naissaar) or moderate (at Tallinn harbour).

5. RESTORING THE WIND REGIME ON TALLINN BAY FROM HARKU DATA

It was mentioned above that neither station that describe the wind regime at two different points of Tallinn Bay are operating any more. Therefore, the only possibility to get information on the wind conditions on the bay is to use Harku or Kalbådagrund data.

There exists a time period from May 1980 to December 1991 where measurements were carried out at Harku, Naissaar, and Tallinn harbour simultaneously. An attempt has been made to establish regressions between these wind data and to estimate the respective correlations. For this purpose, wind velocity components were calculated as

$$u = -V \sin\varphi , \quad v = -V \cos\varphi .$$

Here u is the zonal wind component that is positive in the eastward direction and v is the meridional component that is positive in the northward direction. The quantities V and φ are the wind speed and direction as recorded at the weather stations, respectively.

Table 2 shows that in January, April, and October the wind components at Tallinn harbour can be restored from the Harku data rather well. The square of the correlation coefficient is approximately 0.7. This means that approximately 70% of the wind variability at Tallinn harbour is determined by the wind variability at Harku. In January and April the regression line of the zonal component nearly crosses the origin of the coordinates and forms a 45° angle with the axes. This means that the zonal wind components recorded at Harku and Tallinn harbour nearly coincide. In July the correlation between wind components at Harku and Tallinn harbour is low and Harku data cannot be used to restore the wind data at Tallinn harbour.

Correlation of Naissaar data with measurements at Harku is significantly lower (Table 3). In January, April, and October, only zonal component can be restored from Harku data. Correlation between meridional components is low for

Table 2. Correlation and regression coefficients for restoring wind velocity components at Tallinn harbour from Harku data

Component	Month	Correlation	Intercept	Slope
Zonal	January	0.86	0.08	0.95
	April	0.86	0.04	0.99
	July	0.64	0.17	0.80
	October	0.83	0.19	0.92
Meridional	January	0.86	−0.13	1.04
	April	0.86	−0.08	1.03
	July	0.62	−0.25	0.77
	October	0.84	−0.77	1.20

all seasons, especially for July when only 30% of variability at Naissaar is determined by the variability at Harku. Therefore, it is possible to restore the zonal wind component at Naissaar from Harku data, but not the meridional one. As a result, the restoration of the wind vector by means of linear regression at the entrance of Tallinn Bay is impossible.

Figure 1 gives an idea that to restore wind velocity vector at the entrance of Tallinn Bay is possible by means of the Kalbådagrund data. Table 4 shows that this possibility works well for both components except in July when the percentage of the variability at Naissaar determined by the variability at Kalbådagrund is approximately 40.

The reason why wind data in July correlate only moderately at different stations conceals most probably in differences in the daily course of wind speed and direction. Figure 2 shows directional wind distributions for day (12 GMT) and night (00 GMT) at Harku, Tallinn harbour and Naissaar. The distributions at Harku and Tallinn harbour show typical sea breeze blowing from the south at night and from the north at daytime. Breeze can be detected also at Naissaar, but here the directional wind distribution is significantly different.

Table 3. Correlation and regression coefficients for restoring wind velocity components at Naissaar from Harku data

Component	Month	Correlation	Intercept	Slope
Zonal	January	0.86	0.69	1.26
	April	0.83	0.21	1.07
	July	0.72	0.28	1.08
	October	0.79	1.153	1.171
Meridional	January	0.70	−0.52	1.04
	April	0.65	0.28	0.69
	July	0.54	0.35	0.64
	October	0.68	−0.15	0.98

Table 4. Correlation and regression coefficients for restoring wind velocity at Naissaar from Kalbådagrund data

Component	Month	Correlation	Intercept	Slope
Zonal	January	0.83	0.38	0.588
	April	0.80	0.46	0.500
	July	0.64	0.33	0.442
	October	0.82	0.99	0.520
Meridional	January	0.78	−0.08	0.545
	April	0.78	0.22	0.529
	July	0.64	−0.03	0.436
	October	0.82	0.31	0.531

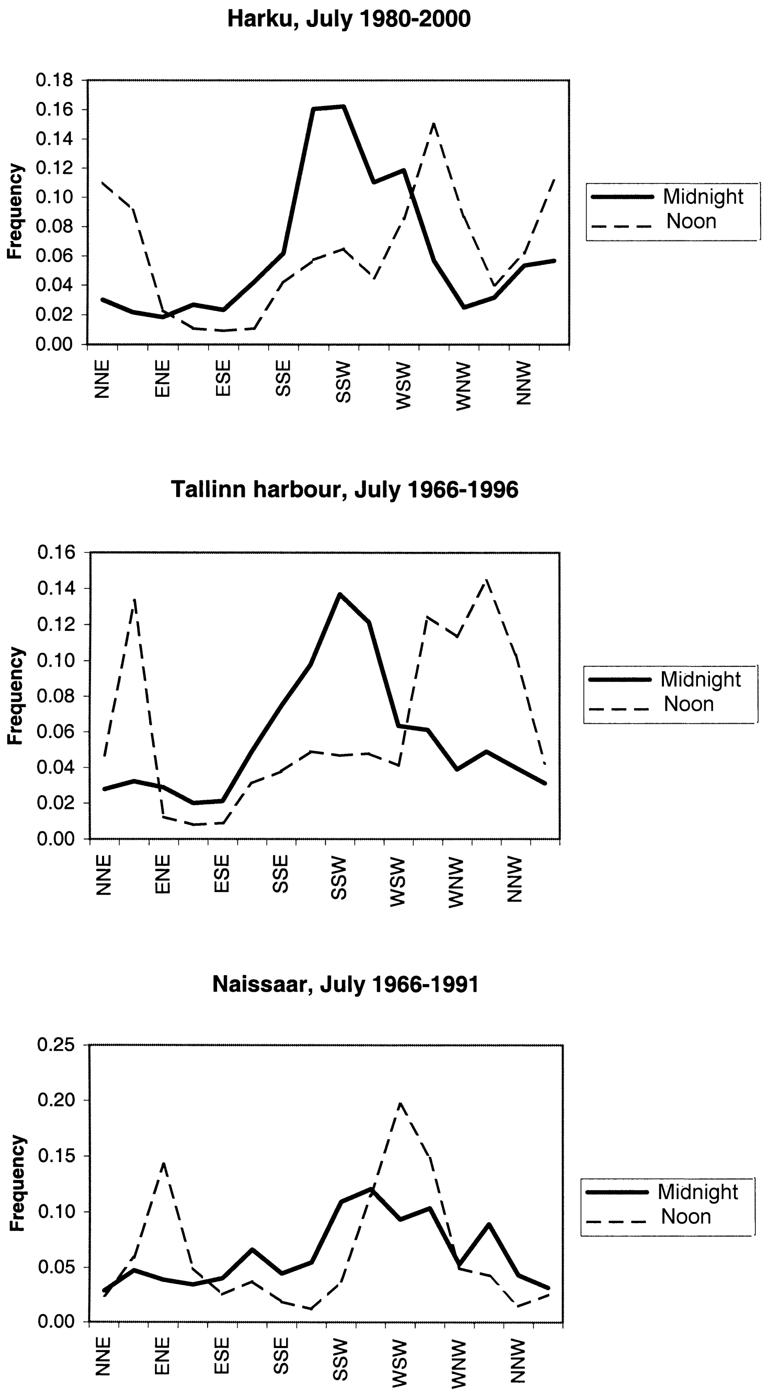

Fig. 2. Directional wind distributions at Harku, Tallinn harbour, and Naissaar in July at midnight (00 GMT) and noon (12 GMT).

6. CONCLUSIONS

Analysis of Kalbådagrund and Naissaar data confirmed the results of our earlier investigation on the wind regime over the Gulf of Finland [4].

Naissaar data show that near the southern coast of the Gulf of Finland the most probable wind direction is SW. Moderate and strong winds have a secondary maximum in NE. Winds from SE and south are mostly weak.

To reconstruct wind regime over Tallinn Bay, at least two measurement sites are needed – one inshore and the other facing the open sea. For these purposes, Naissaar station and Tallinn harbour were nearly ideal. Unfortunately, these stations do not function any more. The only operating station near Tallinn Bay is Harku. Therefore, the only possibility to get information on the wind regime on the bay is to use Harku data.

Regression analysis shows that the zonal wind component at Naissaar and Tallinn harbour can be restored rather successfully from Harku data in winter, spring, and autumn. In July sea breeze and city winds do not permit to establish a trustworthy relationship. Restoration of the meridional wind component from Harku data during the cold season is possible for Tallinn harbour, but not for Naissaar. Therefore, it is not possible to get a true picture about the wind velocity vector at Naissaar from Harku data and restoration of measurements at Naissaar or at some other point at the entrance of Tallinn Bay is necessary.

ACKNOWLEDGEMENTS

The author is grateful to Finnish Meteorological Institute for Kalbådagrund data (Contract No. 8/410/03) and to the graduate student of Tartu University Miina Krabbi who digitized the Tallinn harbour data and made some calculations. The work was partly carried out with the help of the Estonian Science Foundation (grant No. 4347).

REFERENCES

1. Mietus, M. (coordinator) *The Climate of the Baltic Sea Basin, Marine Meteorology and Related Oceanographic Activities*. Report No. 41. World Meteorological Organisation, Geneva, 1998.
2. Troen, I. and Petersen, E. L. *European Wind Atlas*. Risø National Laboratory, Roskilde, Denmark, 1989.
3. Soomere, T. and Keevallik, S. Anisotropy of moderate and strong winds in the Baltic Proper. *Proc. Estonian Acad. Sci. Eng*., 2001, **7**, 35–49.
4. Soomere, T. and Keevallik, S. Directional and extreme wind properties in the Gulf of Finland. *Proc. Estonian Acad. Sci. Eng*., 2003, **9**, 73–90.
5. Ansper, I. and Fortelius, C. HIRLAM – mudeli tuuleproovi hindamine Läänemerel. *Publicationes Instituti Geographici Universitas Tartuensis*, 2003, **93**, 195–205.
6. Elken, J. Modelling of coastal circulation and oil drift at possible deep harbour sites, north-western Saaremaa island. *Proc. Estonian Acad. Sci. Eng*., 2001, **7**, 141–156.

7. Soomere, T. Tallinna lahe looduslike lainete režiimist. *Publicationes Instituti Geographici Universitas Tartuensis*, 2003, **93**, 227–241.
8. Keevallik, S. Tuuled Tallinna lahel. *Publicationes Instituti Geographici Universitas Tartuensis*, 2003, **93**, 217–226.
9. *Guide to the Applications of Marine Climatology*. WMO Publication 781, Geneva, 2001.
10. Launiainen, J. and Laurila, T. Wind characteristics at Finnish automatic marine weather stations in the Northern Baltic Sea. *Finnish Marine Res.*, 1984, **250**, 52–86.
11. Niros, A., Vihma, T., and Launiainen, J. Marine meteorological conditions and air–sea exchange processes over the Northern Baltic Sea in 1990s. *Geophysica*, 2002, **38**, 59–87.

Tallinna lahe tuulerežiimi rekonstrueerimise võimalikkusest

Sirje Keevallik

Tallinna lahe tuulerežiimi kirjeldamiseks on kasutatud kahe mõõtekoha – Tallinna sadama ja Naissaare meteoroloogiajaama – andmeid. Need lubavad väita, et tuule keskmine tugevus kahaneb sisemaa poole liikudes, olles 5,1 m/s Naissaarel ja 4,7 m/s sadamas. Kõige sagedamini puhub tuul lõunakaartest – Naissaarel edelast ja sadamas lõunast. Tugevad tuuled (11 m/s ja enam) puhuvad Naissaarel samuti edelast, ent sadamas loodest. Selline erinevus on ilmselt tingitud lahe kujust, mis on avatud loodesse ja põhja ning varjatud saarte ja poolsaartega teistest külgedest. Mõõdukate ja tugevate tuulte teine sagedasem suund, kirre, on terve lahe jaoks ühesugune. Kagu- ja lõunatuuled on enamasti nõrgad. Et mõlemad vaatluskohad on tänaseks suletud, tehti katse taastada tuulevektori komponendid Harku ja Kalbådagrundi andmete alusel. Selleks arvutati komponentidevahelised regressioonid, mis näitasid, et lahe tsonaalkomponendi taastamine Harku andmete põhjal annab talvel, kevadel ja sügisel usaldatavaid tulemusi, meridionaalkomponendi taastamine aga mitte. Viimase taastamiseks on sobivam kasutada Kalbådagrundi andmeid. Kokku võttes võib järeldada, et Harku jaama andmed sobivad Tallinna lahe tuulerežiimi iseloomustama vaid osaliselt.