

Wind speed and velocity at three Estonian coastal stations 1969–1992

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Abstract. Wind climate, based on monthly average values of wind parameters during a 24-year period, is analysed for three data sets – two from surface recordings at meteorological stations and one from aerological measurements at 850 hPa level. Several statistically significant trends in wind properties have been detected in January, March, May and November. It is shown that the average air flow has turned clockwise and intensified in winter and spring. In autumn, the flow weakened and no changes in its direction were detected. Cold and warm air masses have shifted clockwise in January and May. These changes cannot be attributed to long-term climate change and should be regarded as interesting examples of decadal variability.

Key words: regional climate variability, wind speed, wind velocity, average air flow.

1. INTRODUCTION

The increased interest towards climate change has initiated a lot of investigations on trends in single meteorological parameters as well as circulation types and complex climate indicators.

Most popular meteorological quantities to be investigated on regional scales are air temperature and precipitation, snow and ice cover. For the Baltic Sea region, these changes have been summarized in [1,2]. Unfortunately, surface winds are seldom among the meteorological parameters that are investigated with the aim to detect local climate change. Usually the analysis is directed towards detection of the changes in the frequency of storms [3,4]. According to four different indices, there is no long-term (1800–2000) trend in storminess over southern Scandinavia [5]. A temporal increase was still observed in the 1980s and 1990s. This is supported also by counting storm days in the West-Estonian archipelago [6]. Indirect information on possible changes in wind climatology can be drawn from the changes in the number of cyclones and their trajectories over a

certain area. It has been shown that during the second half of the 20th century, the number of cyclones and the frequency of deep depressions in the Baltic Sea region have increased [7]. The trajectories of cyclones have moved northward and this should be accompanied by changes in the wind regime.

Investigation of long-term trends (1953–1999) in the wind speed on the 850 hPa level over the Baltic Sea area shows that the annual mean wind speeds have increased [8]. The increase is more noticeable in winter. Trends in wind speed around the Gulf of Finland have been analysed in [9] from surface data, recorded at meteorological stations during 1961–2000. It was reported that wind speed increased on the northern coast and decreased on the southern coast of the gulf.

Knowledge on wind speed climate is of fundamental importance when wind energy, building construction or storm damages are the topics of interest. On the other hand, wind speed does not give much information on the average air flow that characterizes dynamic processes in the atmosphere. This point of view is covered to some extent in [10] for three Estonian sites where wind speed and direction are analysed together. Annual mean wind speed decreased during 1966–2004. Changes in wind direction are more obvious in Vilsandi, the westernmost station of Estonia. Here the share of SW wind has increased from 15% to 26% (according to the 8-rhumb wind-rose). South winds as well as NE and E winds have become less prevalent all over Estonia. These are interesting findings, but changes in the frequency of winds from different directions are not always related to changes in the intensity of the air flow.

The present paper is focused on the analysis of short-term trends in the average air flow. For this purpose, monthly averaged wind velocity components are calculated from observations at three Estonian coastal stations 1969–1992.

2. WIND DATA

For the present analysis three data sets have been chosen. Sõrve ($57^{\circ}54'50''$ N, $22^{\circ}03'35''$ E) is situated on the Saaremaa Island, on a peninsula that separates the Baltic Proper and the Gulf of Riga (Fig. 1). The altitude of the station is 2 m and the measurement site is open to the sea. Pakri ($59^{\circ}23'37''$ N, $24^{\circ}02'40''$ E) is a coastal meteorological station in North Estonia. It is situated on the klint, at the altitude of 13 m. Unfortunately, the observation site was moved twice: in 1969 and 1992. Therefore, earlier and later data are not taken into account in the present analysis. The data were recorded by wind vane in a 16-rhumb system until 1973 at Sõrve and until 1981 at Pakri. Later, the wind direction was recorded in a 36-rhumb system and wind speed averaged over 10 min [11].

Additionally, wind data recorded at Tallinn (Harku) Aerological Station (during 1953–1977 at $59^{\circ}28'$ N, $24^{\circ}49'$ E, later at $59^{\circ}24'$ N, $24^{\circ}36'$ E) on the 850 hPa isobaric level were used. These data can be regarded as an indicator of regional lower atmospheric flow that is not affected by local land surface inhomogeneities.



Fig. 1. Measurement sites in Estonia.

The aerological soundings were performed from one to four times per day during different time periods. For this analysis, the midnight (00 GMT) soundings were chosen, because during recent years only these soundings were carried out. To match the data, only midnight recordings were used also for the surface data.

Wind is characterized by a two-dimensional vector quantity. This vector may be specified by means of its components in the local Cartesian coordinates [¹²] or by means of its direction and speed [¹³]. In the analysis of instantaneous wind values, there is no difference between these two ways of wind description. On the other hand, several problems require averaged wind data. In these cases the average wind speed and average air flow, calculated from average wind velocity components, are completely different quantities. In the present paper these quantities are analysed and compared. Traditionally, u is the zonal component of the wind vector (positive to the east) and v is the meridional component (positive to the north).

3. WIND CLIMATE

The annual cycle of the wind speed and wind velocity components is similar at all measurement sites (Fig. 2). The wind speed is the strongest from October to January and the weakest from May to August. The average zonal component of the wind velocity generally follows the annual cycle of the wind speed. This feature could be expected in conditions of a prevailing western flow. The average

meridional component is comparable with the zonal component at surface stations, but is systematically less at 850 hPa, where its value is the largest in March (1.9 m/s). At the surface stations, the meridional (southern) flow exceeds the zonal flow during the cold season (November–March). During the warm season (June–September), it is less than the western flow.

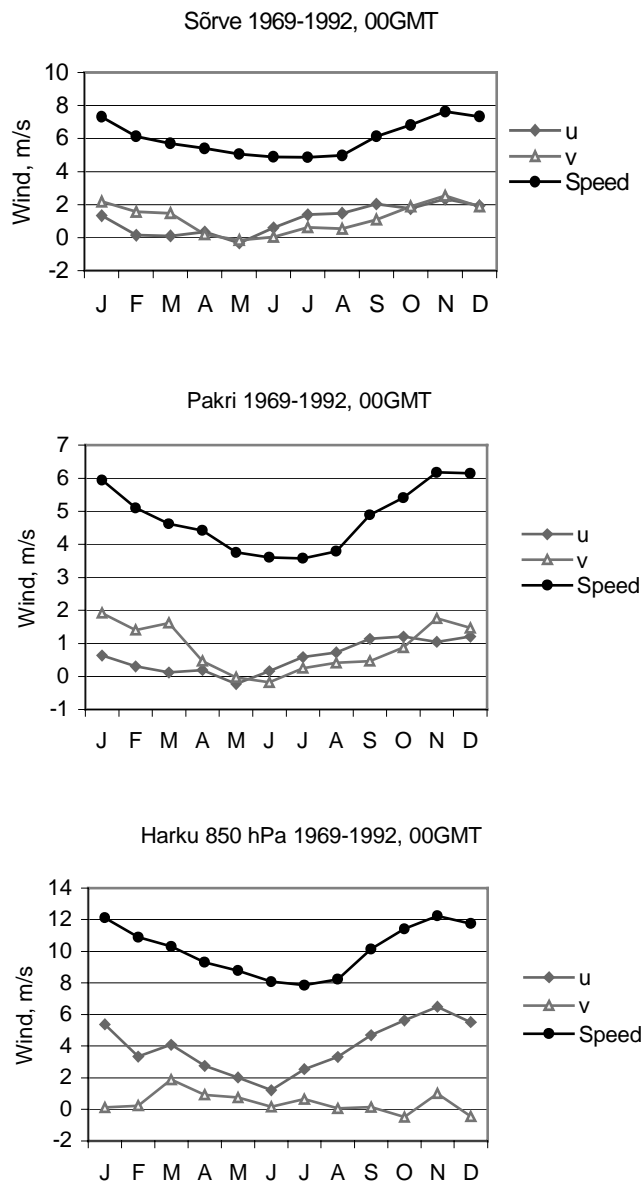


Fig. 2. The annual cycle of the monthly average wind speed, the zonal component (u) and the meridional component (v) at different measurement sites.

4. TRENDS IN WIND SPEED AND COMPONENTS

Systematic trend analysis for the period 1969–1992 was carried out for all three measurement sites and for all months. Table 1 shows the trend slopes, which are significant at least at the 90% level.

Several statistically significant changes in wind speed and velocity components can be detected in January, March, May and November. The trends are calculated for a 24-year period. Such a short time scale does not allow for the development of conclusions on climate change and these results should be regarded only as an effect of decadal variability.

Wind speed and average air flow seems to be rather sensitive to the period of observations. During 1951–2000, strengthening of the westerlies is impressive in February and March, but not in January [¹⁴]. In the present paper, this conclusion cannot be drawn for 1969–1992. On the other hand, during 1966–2004 the wind speed in Estonia increased in winter and decreased in the warm period [¹⁰] and during 1955–1999 a general increase in wind speed at 850 hPa (focused on the winter season) has been detected over the Baltic region [⁸]. These findings do not contradict to the results of the present paper.

The most interesting changes have taken place in January when the wind speed and zonal component increased and the meridional component decreased. Figure 3 shows that in some cases, the monthly average wind speed mirrors the intensity of the western flow, e.g., at Harku in 1989 there is only a minor difference between the average wind speed (16.7 m/s at the 850 hPa level) and average zonal component (14.0 m/s at the same level). Evidently, in this year, permanent western winds dominated. On the other hand, wind speed in 1979 is 11.44 m/s and both wind velocity components are very small ($u = 0.27$, $v = 1.84$ m/s). This finding shows that wind direction was variable, so that wind speeds from opposite directions mostly cancelled each other in component calculations. Surface recordings at Pakri and Sõrve show that in some cases the zonal wind component was even negative, i.e., easterly flow dominated.

Table 1. Trend slopes (in m/s per year) for wind speed, zonal (u) and meridional (v) components, significant at least at the 90% confidence level

	Sõrve			Pakri			Harku 850 hPa		
	u	v	Speed	u	v	Speed	u	v	Speed
Jan	0.182		0.074	0.143	-0.121				-0.285
Feb			0.074						
Mar		0.073		0.071					
Apr						-0.046			
May	0.079			0.047			0.096		
Oct						-0.054			
Nov			-0.052			-0.081			

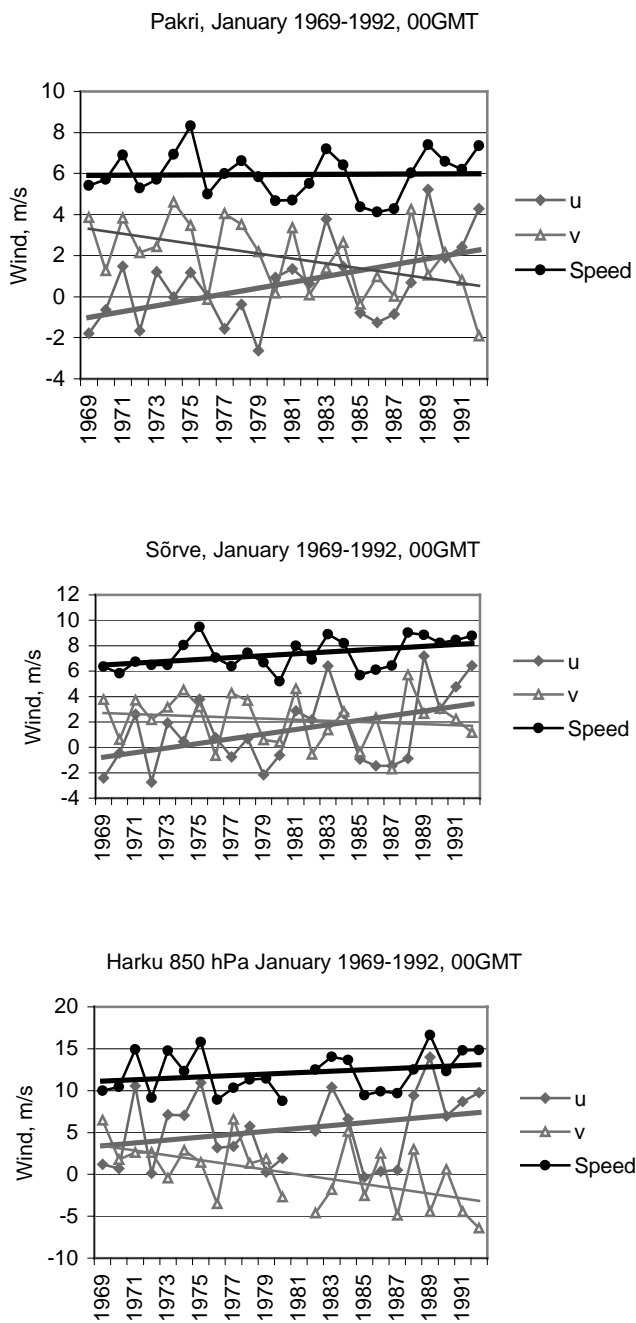


Fig. 3. Trends in wind speed, zonal (u) and meridional (v) components in January.

5. CHANGES IN THE AVERAGE AIR FLOW

For further analysis of wind velocity components, average air flow vectors have been drawn according to linear trends in wind components. Figure 4 shows that in January the average air flow has turned clockwise at all sites under consideration.

Information, drawn from Fig. 4, cannot be detected by means of trend analysis of the wind speed. Wind speed in Pakri does not show any trend during 1969–1992, but the average air flow has turned by approximately 90 deg. At the beginning of the period it was directed to NNW and at the end of the period to ENE. At 850 hPa (Harku) the average air flow has intensified and turned. At the beginning of the period under observation, it was directed from SW to NE and at the end of the period from WNW to ESE. Therefore, wind component analysis enables one to attain a complex view on the changes in the average air flow. Increases in the wind speed and in the frequency of SW winds have been detected at Vilsandi during 1966–2004 [10]. This is in accordance with our finding for Sõrve that is situated not far from Vilsandi, where the average air flow has intensified and turned, from SSE to NNW at the beginning of the period to WSW to ENE at the end of it. These changes confirm also other findings in [10] – the decreased frequency of S, E and NE winds.

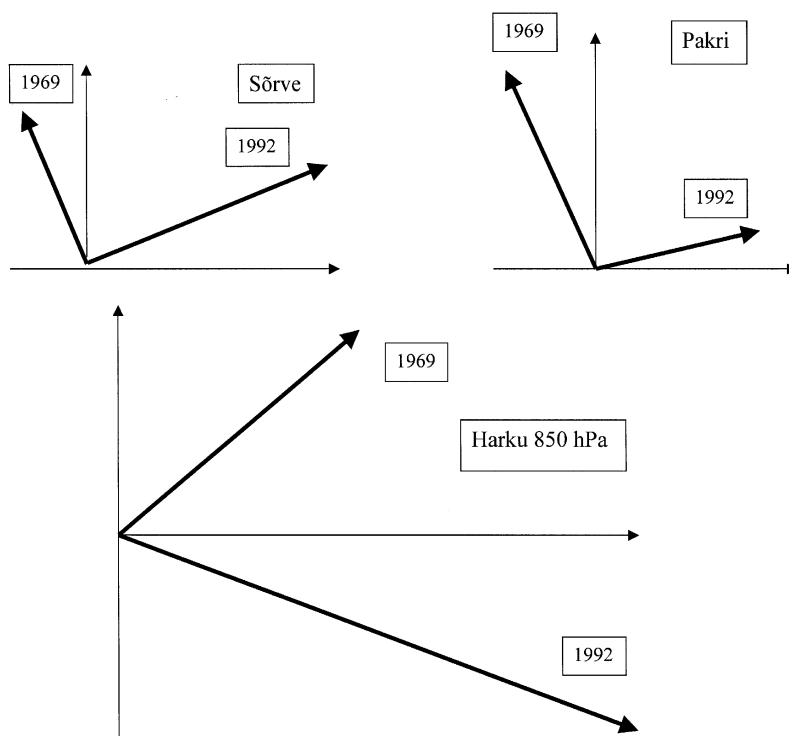


Fig. 4. Changes in the average air flow according to the trend lines in January.

Average air flow in May is weak (Fig. 2), although the wind speed is considerable. A significantly increasing zonal component results in a drastic change in the average air flow (Fig. 5). At Sörve, the wind vector has rotated by 180 deg and at Pakri by more than 90 deg. The case of Sörve is also an interesting example demonstrating that the magnitude of the average air flow is not always connected with the average wind speed. According to Table 1, there is no change in the average wind speed, but Fig. 5 shows that intensity of the average air flow has drastically decreased.

Average air flow in March at surface stations has rotated clockwise, while gaining strength. At 850 hPa (Harku), no change in the direction can be noticed, but the air flow (from WSW) has intensified by about two times (Fig. 6). Differences in the changes of the direction of average air flow at the surface and at 850 hPa are most likely caused by changes in the ice cover [15].

In November, the air flow at the surface does not show any changes in the direction, although the flow at 850 hPa has rotated clockwise. The intensity of the air flow has decreased everywhere (Fig. 7).

The average wind velocity vectors permit the use of the concept of thermal wind for the determination of the temperature advection in the atmospheric layer under 850 hPa level. As the distance between Harku and Pakri is approximately 40 km, the respective air flow vectors can be used (surface measurements at Harku started only in 1980). In January, the cold air mass was in the north at the beginning of the period and in the north-east at the end of it. Accordingly, average warm advection was directed from the south to the north around 1970 and from the south-west (or even WSW) to the north-east (ENE) around 1990. In May, the average warm advection was from the south-east at the beginning of the period and from the south at the end of it. In other months the changes were not as apparent.

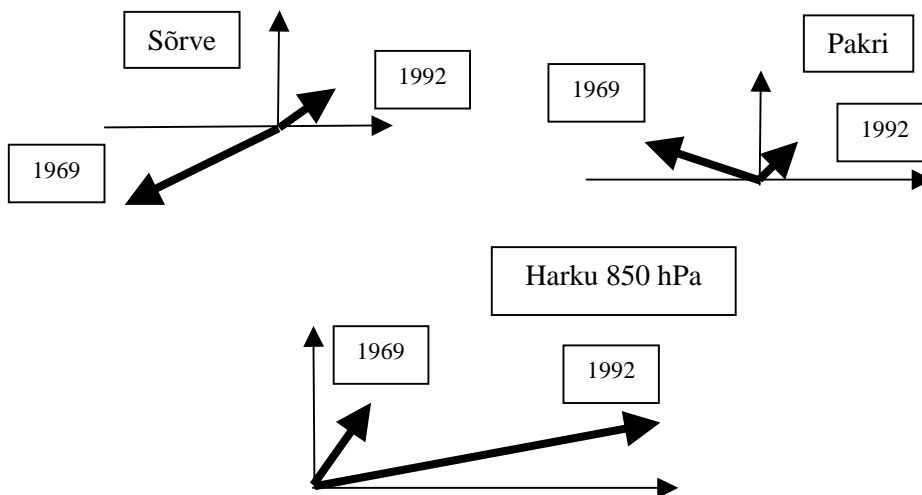


Fig. 5. Changes in the average air flow according to the trend lines in May.

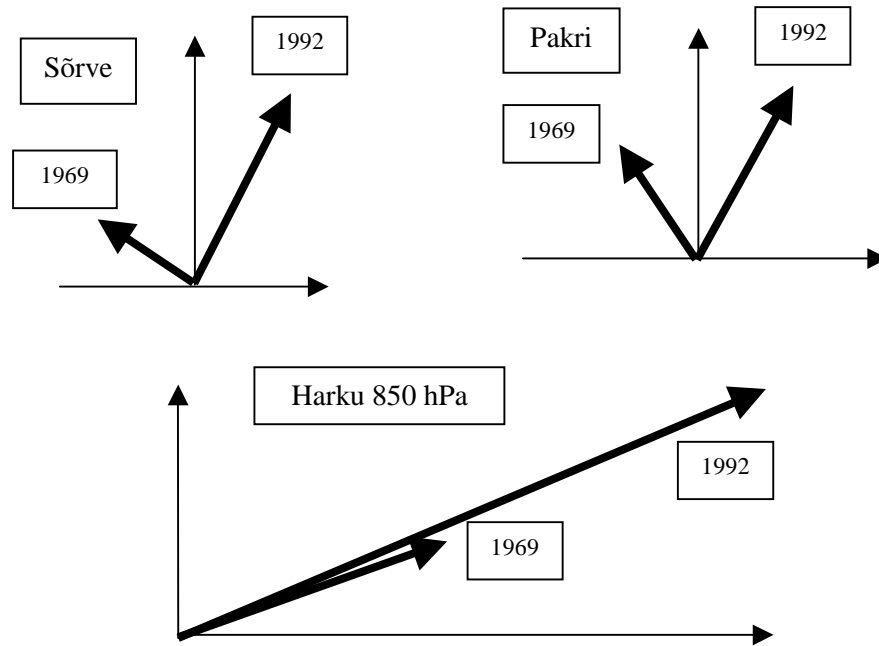


Fig. 6. Changes in the average air flow according to the trend lines in March.

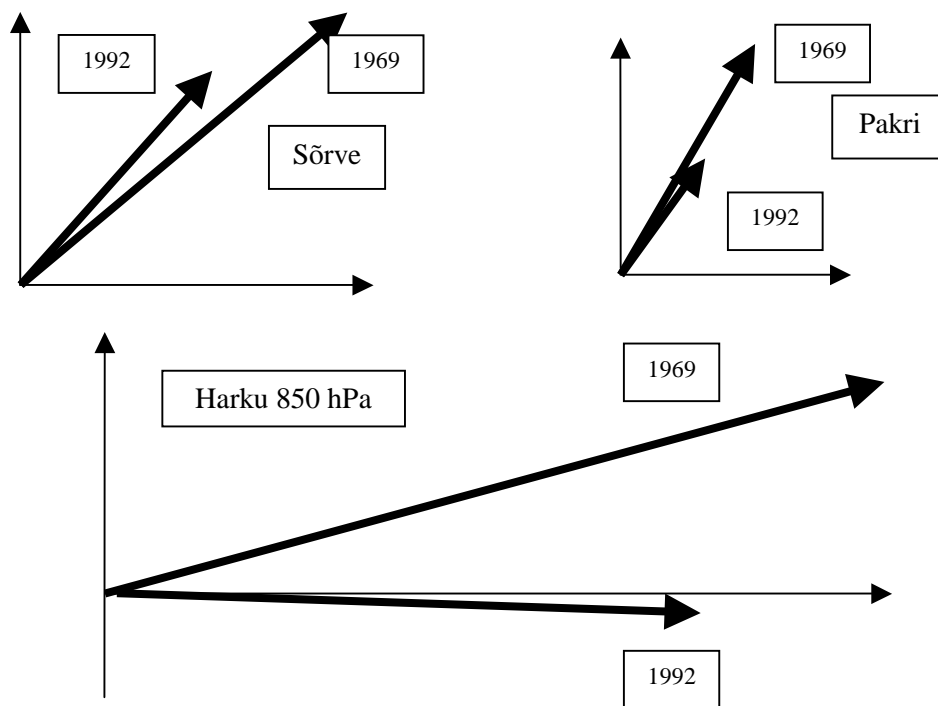


Fig. 7. Changes in the average air flow according to the trend lines in November.

6. DISCUSSION AND CONCLUSIONS

Analysis of wind data shows that the wind vectors enables the derivation of information that better reflects the dynamical processes in the atmosphere than that achieved when speed and direction are assessed separately. Monthly average wind velocity components show both the strength and the direction of the average air flow. The latter cannot be detected from wind speed data. As an example, one can see that at Sõrve the average wind speed during the 24-year period in November was 7.63 m/s, but the absolute value of the air flow vector was only 3.43 m/s (Fig. 2). This means that wind direction at Sõrve (as well as at other sites of Estonia) is rather variable, most likely due to numerous cyclones that pass through the territory. Traditional wind roses may also lead to misinterpretations when average air flow is considered. At Sõrve in March, the 24-year wind rose shows that the easterlies are the most frequent. Winds from the south and south-west only form the second maximum. According to Fig. 2, the average air flow is directed to the north. Apparently, easterlies are weak and do not contribute much to the average air flow.

Analysis of wind vectors leads to several interesting conclusions on changes in wind parameters at three Estonian coastal stations during 1969–1992. Significant increases were noticed in wind speed in January–February and in the zonal component in January and May. Significant decreases have taken place in the wind speed in October–November and the meridional component in January. Wind velocity components have also increased in March. The trends can be understood better when changes in the average air flow are presented as vectors, constructed from the beginning and the end of the trend lines. This analysis reveals that changes in wind velocity components result in changes in the direction of the average air flow. This change is generally clockwise in the winter and spring when the average air flow also intensified. In autumn, the flow weakened and no changes in the air flow direction were detected.

Having wind vectors on two levels, one may use the thermal wind concept to estimate temperature advection in the layer between the surface and 850 hPa. The changes in warm advection were detected in January and May when the location of cold and warm air masses changed by nearly 45 deg and the direction of the warm advection rotated clockwise.

As a result, some interesting features of wind climate and atmospheric dynamics became apparent through wind vector analysis in the present paper. These changes occurred over a relatively short period of 24 years and should be interpreted as decadal variations.

This paper should be regarded as a pilot study of average air flow climatology and related problems. Further, the geography of the research should be extended and the results should be related to the climatology of other meteorological parameters, starting with pressure patterns.

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Tuule kiirus ja vektor kolmes Eesti rannikujaamas aastail 1969–1992

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Tuulekliima analüüsiks kuu keskmiste tuuleparameetrite alusel 24-aastase perioodi jooksul on kasutatud kolme andmestikku, millest kaks on saadud maa-pealsetest meteoroloogiajaamadest ja üks aeroloogilistest mõõtmistest 850 hPa nivool. On täheldatud mitmeid statistiliselt olulisi trende tuule kiiruses ja vektori komponentides, enamasti jaanuaris, märtsis, mais ning novembris. On näidatud, et ajavahemikul 1969–1992 tugevnes keskmine õhuvool talvel ja kevadel ning pöördus päripäeva. Sügisel õhumassi liikumise suund ei muutunud, kuid selle intensiivsus kahanes. Jaanuaris ja mais nihkusid külm ning soe õhumass päripäeva. Kirjeldatud muutusi ei saa klassifitseerida pikaajalisteks trendideks ja neid tuleb vaadelda kui huvitavaid näiteid õhuvoolude muutlikkuse kohta.