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# Regime shifts in the surface-level average air flow over the Gulf of Finland during 1981–2010

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**Abstract.** Abrupt changes in large-scale wind patterns are often masked by local features and are not visible in classical properties of surface-level winds. We explore the potential of the average air flow to reveal such changes from wind data, recorded in the region of the Gulf of Finland during 1981–2010. The monthly average air flow speed is very small in April and does not exceed 2.8 m/s during the rest of the year. The monthly mean wind directional persistency factor has a similar annual course. The direction of the average air flow does not always coincide with the direction of the most frequent winds. In summer, autumn, and winter the air flow direction is relatively stable from SW or WSW to NE or ENE over the whole gulf whereas in spring the direction varies at different measurement sites. Time series analysis by means of the Rodionov regime shift detection technique reveals that changes in the wind speed are mainly caused by changes in the measurement conditions, first of all relocation of the measurement site. Significant shifts in the air flow speed are not related to the changes in the wind speed. The changes are concentrated in the windy months. A significant increase in the air flow speed occurred in January 1988 and a comparable decrease in January 1994–1996 at all measurement sites except for Kotka. In October an abrupt decrease occurred in 1988–1989 at all stations except for Hanko. The identified shifts may be associated with a major change in the geostrophic air flow over the southern Baltic Sea in 1988 and a relaxation of the system back to the pre-1980s situation after a few years. These events do not become evident in the average wind speed.

**Key words:** regime shifts, wind climate, wind speed, air flow, wind persistency factor, Gulf of Finland.

## 1. INTRODUCTION

Along with extensive evidence of internal variability of the climate system over a vast range of scales (Wanner et al., 2001; Kang et al., 2013; Deser et al., 2014; Neukom et al., 2014; Zanchettin et al., 2014) and about gradual changes to the local (wind and wave) climate (BACC, 2008; Lehmann et al., 2011), there exists an increasing pool of data about abrupt changes to some parameters of climatic variables. Following Rodionov and Overland (2005), such changes are often called regime shifts, having in mind rapid reorganizations of climate elements from one relatively stable state to another. One regime may last for some years and then be replaced by another one. In many occasions such regime shifts become evident in easily observable properties, e.g. in the sea surface salinity (Morrow and Kestenare, 2014). Various shifts seem to be an intrinsic property of the North Atlantic large-scale atmospheric circulation (Franzke et al., 2011; Luo et al., 2012) where a drastic expansion and relocation of the area, often visited by strong cyclones, has been observed in the 1980s (Lehmann et al., 2011). Possible consequences of this relocation range from major variations in the halocline depth in the Baltic Sea (Väli et al., 2013) over jumps in the water temperature in certain characteristic layers (Mohrholz et al., 2006) and changes in the course of coastal processes (Viška and Soomere, 2012) down to subtle changes in the transition time from winter to summer circulation type (Keevallik and Soomere, 2008, 2009).

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Identification of such shifts and especially singling out the proper climatic variables (that react first and unambiguously to the changing situation) for their detection is a challenge because of the long reaction time and extensive natural variability of most of the commonly used variables. Different properties of wind and wave fields are eventually useful for this purpose; first of all owing to their relatively short reaction time and memory. Although such changes do become evident in high-resolution distributions of the occurrence of winds or waves from different directions (so-called wind and wave roses) (Jaagus, 2009; Räämet et al., 2010; Jaagus and Kull, 2011; Lehmann et al., 2011), various integrated (possibly multi-component but not multidimensional) properties are preferred as they often allow for better and less ambiguous comparison between different regimes.

Among those, the analysis of changes in air flow (Keevallik and Soomere, 2008, 2009) and net wave-driven sediment transport (Viška and Soomere, 2012) have demonstrated their capacity to highlight several core changes. In particular, the abrupt change in the air flow, evaluated from geostrophic wind fields (Soomere and Räämet, 2014), signals a major change in the air pressure and upper-level wind system over the southern Baltic Sea in 1988. This change was associated with a major perturbation of the geostrophic air flow direction in the northern Baltic Proper that may have affected also coastal waters of Estonia. A similar abrupt and almost simultaneous rotation of the air flow has been detected also for the north-eastern Baltic Sea for single months. For example, an abrupt increase in the upper-air (500 and 850 hPa levels) zonal wind component in January and February took place around 1987 (Keevallik, 2011). Such an increase was accompanied by a shift in the meteorological regime at the surface: zonal wind component and air temperature increased.

In this paper we explore whether the surface-level winds over and around the Gulf of Finland have more extensively responded to this change and whether the coastal zone of Estonia may have experienced some other substantial variations in the surface-level air flow.

## 2. MATERIAL AND METHODS

We use time series of wind speed and direction recorded at six sites around the Gulf of Finland (Fig. 1). Although wind conditions at some of these stations (first of all Kunda and to a lesser extent Kotka) are relatively strongly affected by local features and the measured data not necessarily exactly match the open-sea wind properties (Soomere and Keevallik, 2003), data from these sites can still be considered as representative for major changes to the wind patterns in this water body. The key parameters of wind measurements are given in Table 1. At all sites the wind properties are recorded at least 8 times per day.

We consider a 30-year interval of 1981–2010, during which the records are more or less homogeneous. As the measurements at the most representative location (Kalbådagrund in the open sea) started only in 1981, this interval cannot be extended further into the past. The data set also contains several inhomogeneities stemming from changes in the location or mounting height of the sensors (Table 1). The largest of these apparently reflect the relocations of the measurement site at Pakri: on 15 December 1992 it was moved to a relatively sheltered place and on 31 August 2003 a few km to the north, to the tip of the Pakri peninsula (Keevallik and Soomere, 2009). In cases when manual measurements have been replaced by automatic registration during this interval, the measurement times at 00, 03, 06, 09, 12, 15, 18, and 21 UTC are chosen, in order to keep the time series as homogeneous as possible. The resulting time series of wind properties contain several gaps. We have left out the months when data for more than 16 days were missing: June and November 2002 at Kotka, June, July, August, September, October, and November 1981 and September 1999 at Kalbådagrund.

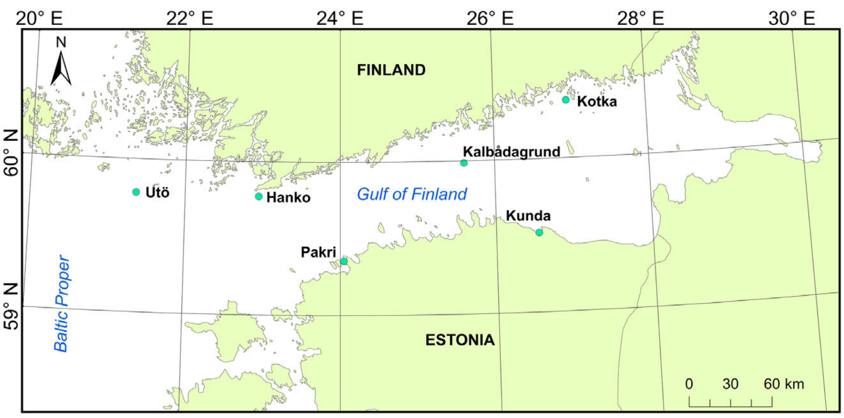


**Fig. 1.** Wind measurement sites in the Gulf of Finland used in this study.

**Table 1.** Geographical coordinates of the measurement sites and the height of the wind sensor above the ground

| Station | Date of the change | Latitude, N | Longitude, E | Measurement height above the ground, m |
|---|---|---|---|---|
| Utö | Until 1992 | 59°47′2″ | 21°22′1″ | 10 |
| | 1992 Nov 4 | – | – | 17 |
| | 1998 Jun 10 | 59°46′51″ | 21°22′4″ | 15 |
| Hanko | Until 1990 | 59°46′24″ | 22°56′56″ | 23 |
| | 1990 | 59°46′24″ | 22°56′34″ | 27 |
| | 2005 Sep 2 | 59°46′0″ | 22°56′54″ | 27 |
| Kalbådagrund | – | 59°59′12″ | 25°36′12″ | 32 |
| Kotka | Until 1992 | 60°22′31″ | 26°57′31″ | 19 |
| | 1992 | 60°22′17″ | 26°37′38″ | 16 |
| | 2003 Sep 5 | 60°22′31″ | 26°57′31″ | 20 |
| Kunda | – | 59°31′4″ | 26°32′43″ | 10 |
| Pakri | Until 1992 1992 | 59°21′15″ | 24°2′53″ | 10 |
| | Dec 15 | 59°21′19″ | 24°3′3″ | 10 |
| | 2003 Sep 1 | 59°23′22″ | 24°2′24″ | 10 |

Wind is a two-dimensional vector quantity $(u, v)$, the instantaneous values of which can be described either in polar coordinates by (means of) its direction $\arctan(v/u)$ and speed $(u^2+v^2)^{1/2}$, or, equivalently, in Cartesian coordinates by its components. We use the traditional notion $u$ for the zonal component of the wind vector (positive to the east) and $v$ for the meridional component (positive to the north). These two representations substantially differ when one has to evaluate average wind properties. The average wind speed is a scalar that does not contain information about wind directions. The average wind direction is usually meaningless and directional wind properties are commonly characterized using wind roses.

The average wind properties, calculated this way, are fundamentally local (Eulerian) quantities and may be largely decoupled from the actual air motion. The wind speed is fundamental in many aspects, e.g., useful characteristic at the wind energy calculations, but it is not suitable for the description of where and how intensively air masses are moving. The average air flow is a vector $(U, V)$, the components of which $U=\overline{u}$, $V=\overline{v}$ are average wind velocity components (here the overbar means a simple arithmetic average over all measured values) and the length and direction of which therefore are interpreted similarly to the instantaneous wind data. It is, in essence, a quasi-Lagrangian quantity: it points to where and how rapidly the air, on average, is moving. The drawback of this quantity is that its both components and therefore also its modulus (average air flow speed $(U^2+V^2)^{1/2}$) may vanish (and the direction may become meaningless) for several realistic wind fields (e.g., perfectly isotropic systems or jets of alternating direction) while the classical wind speed and wind rose provide sensible information for such cases. The use of air flow is at best justified for substantially anisotropic wind fields (with clear prevalence of certain directions) that are typical in the Baltic Sea basin (BACC, 2008)).

To reveal abrupt changes in the wind parameters, we used the method of Rodionov (2004). Possible regime shifts are explored, based on the regime shift index (RSI). This quantity represents a cumulative sum of deviations (normalized by the standard deviation of the time series and chosen cut-off length, expressed in years in our case) of the values from the hypothetical mean level of the new regime. The minimal difference between the new and old levels is predetermined by means of the Student's *t*-test and a prescribed level of statistical significance. The RSI is calculated for every next value of the time series that follows the hypothetical regime shift timing. If it remains positive during the entire chosen cut-off length, a shift is declared. The procedure detects all different regimes that last longer than the cut-off length but is also able to highlight regimes of shorter duration. In the present paper the cut-off length was set to 7 years. The Huber's weight parameter was set to 1. This means that the values exceeding one standard deviation from the average of the regime are considered to be outliers and a certain weighing procedure is applied to them to estimate the average values of the regimes. The differences between the mean values of the neighbouring regimes were detected at least at the confidence level of 0.1.

## 3. ANNUAL CYCLE OF THE WIND SPEED AND AVERAGE AIR FLOW

The applicability of the properties of the average air flow speed to characterize the wind climate in the Gulf of Finland can be exemplified by comparison of its annual cycle with a similar course of the classical wind speed (average over its instantaneous values) at two very different locations (Fig. 2). The wind data from the Island of Utö, the westernmost measurement site at the entrance of the Gulf of Finland, are known to adequately represent the wind climate of the northern Baltic Proper whereas wind properties at Kotka, the easternmost measurement site on the northern coast of the Gulf, are much more affected by the presence of mainland (Soomere and Keevallik, 2003).

The difference between these two characteristics is significant in the north-eastern Baltic Sea and the Gulf of Finland. At Utö the average wind speed is systematically and substantially larger than at Kotka, but there is nearly no difference between the average air flow speeds (wind vector moduli). This demonstrates that average air flow speed is less sensitive to the local conditions than the average wind speed. In April the average wind speed is still significant at both stations, but the air flow almost vanishes at both sites showing that the wind field is practically isotropic. Large values of the air flow speed during the cold period from October to January indicate that the prevailing and/or strong winds tend to blow from a certain preferred direction.

A comparison of the average air flow speeds and directions at all six measurement sites suggests that these two observation sites – one located at the entrance to the gulf and the other in its easternmost part – are qualitatively representative for the whole Gulf of Finland (Table 2). The annual variation of both quantities is very similar at all sites. Similarly to the data from Utö and Kotka (Fig. 2), the average air flow speed is very small (0.2–0.4 m/s) in April at all measurement sites. It is natural that such small speeds are accompanied by very large variations in the average wind direction at different sites: the average air flow is directed from south-west to north-east at Utö and Pakri and from south-south-east to north-north-west at other stations. Much larger air flow speeds in July, October,

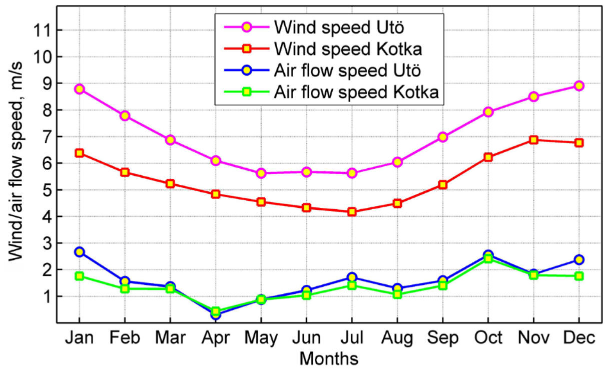


**Fig. 2.** Monthly mean wind speed and average air flow speed at Utö and Kotka during 1981–2010.

and January are accompanied with much more organized directional structure of the average air flow from the south-west or west-south-west to the north-east and east-north-east. The largest deviations from the overall average are at Kunda and Pakri, where in January and October the average air flow is deviated to the north compared to the directions at other stations. This feature evidently reflects the presence of Estonian mainland. It is likely that this deviation is lost after a few tens of kilometres and that the open-sea air flow is almost unidirectional along the entire northern coast of the Gulf of Finland. The largest exception is Pakri in July when the average air flow is from the west to the east. This is in concordance with the earlier analyses (Soomere and Keevallik, 2003; Keevallik, 2003) that demonstrate that only the stations on the northern coast of the Gulf of Finland adequately reflect the qualitative properties of marine winds over this water body. The speed of the average air flow is the largest at Kalbådagrund evidently because the wind is measured at a higher altitude (32 m) above the underlying surface than at the coastal stations. The other reason is that Kalbådagrund is without any doubt the most open measurement site, as the automatic weather station is mounted on a lighthouse.

**Table 2.** Speed and direction of the average air flow at different sites during different months. The direction is counted from the east counterclockwise

| | January | | April | | July | | October | |
|---|---|---|---|---|---|---|---|---|
| | Speed, m/s | Direction, deg | Speed, m/s | Direction, deg | Speed, m/s | Direction, deg | Speed, m/s | Direction, deg |
| Utö | 2.7 | 24 | 0.3 | 33 | 1.7 | 28 | 2.6 | 34 |
| Hanko | 2.1 | 36 | 0.3 | 116 | 1.5 | 26 | 2.2 | 36 |
| Kotka | 1.8 | 41 | 0.4 | 98 | 1.4 | 37 | 2.4 | 37 |
| Kalbådagrund | 2.7 | 37 | 0.4 | 104 | 2.0 | 26 | 2.8 | 29 |
| Kunda | 1.6 | 58 | 0.2 | 109 | 0.4 | 24 | 1.4 | 57 |
| Pakri | 1.7 | 47 | 0.4 | 30 | 1.0 | 5 | 1.4 | 42 |

The discussed similarity of the air flow regime over the entire study area can be further exemplified using the annual cycle of the directional persistency factor – the ratio of the average air flow speed to the average wind speed (Fig. 3), called simply persistency below. Such a ratio highlights the cases when strong winds (e.g., breeze) blowing often alternatively from opposing directions and weak winds from similar directions result in equal average air flow speeds. In other words, the wind persistency factor shows the proportion of winds that contribute to the average airflow, therefore, implicitly indicates the contribution of the large-scale relocation of air masses into the wind patterns at a particular site.

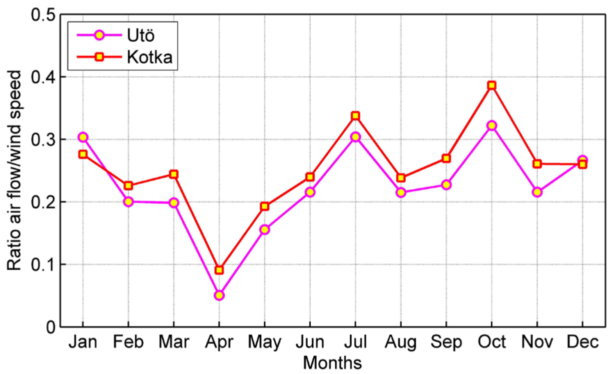


**Fig. 3.** Monthly mean wind persistency factor during 1981–2010.

The cycles of the wind persistency factor at the sites at different ends of the Gulf of Finland are amazingly similar. The persistency is very weak in April, much stronger in other months and the largest in October. The values of this parameter for Utö are systematically lower than those for Kotka. This feature can be explained by the fact that the wind regime at Utö is a superposition of two systems – that of the Baltic Proper and that of the Gulf of Finland (Soomere and Keevallik, 2001, 2003). These wind systems interfere in the northern part of the Baltic Proper and one cannot expect a stable air flow in one direction. In January and December the situation is reversed: the persistency factor at Kotka is less than that at Utö. Most probably the reason is that the sea around Utö remains annually free of ice much longer than at Kotka. From Fig. 3 and Table 2 it may be concluded that large-scale transport of the atmospheric matter (and energy) is most effective in October and July, but very weak in April.

Similarly to the large difference between the values of average wind speed and average air flow speed (Fig. 2), the most frequent wind direction and the air flow direction are generally different. As an example, two classical wind roses are presented in Fig. 4, one for Utö in January, the other for April. Converting the polar angle given in Table 2 to the traditional wind direction used in meteorology gives the average air flow direction in January 246° and in April 237°.

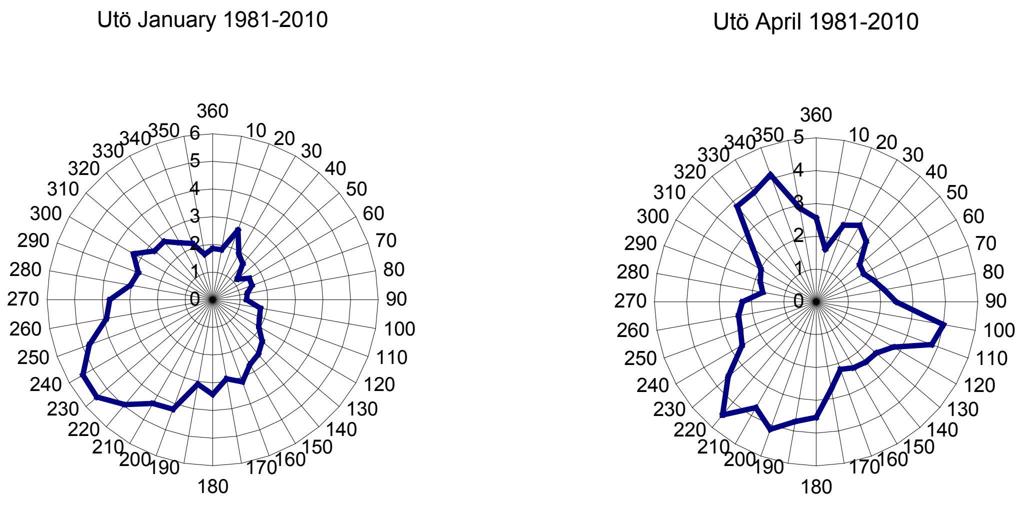


**Fig. 4.** Wind roses for Utö in January and April. Frequency is given in percents.

## 4. CHANGES IN THE WIND SPEED AND AIR FLOW DURING 30 YEARS

The time series of the monthly average wind speed for all stations are presented in Fig. 5 and those of the average air flow speed in Fig. 6. These figures demonstrate that changes in the average air flow speed are relatively highly correlated and more or less in-phase over the observation area. The changes in the monthly mean wind speed are less coherent. This sup-

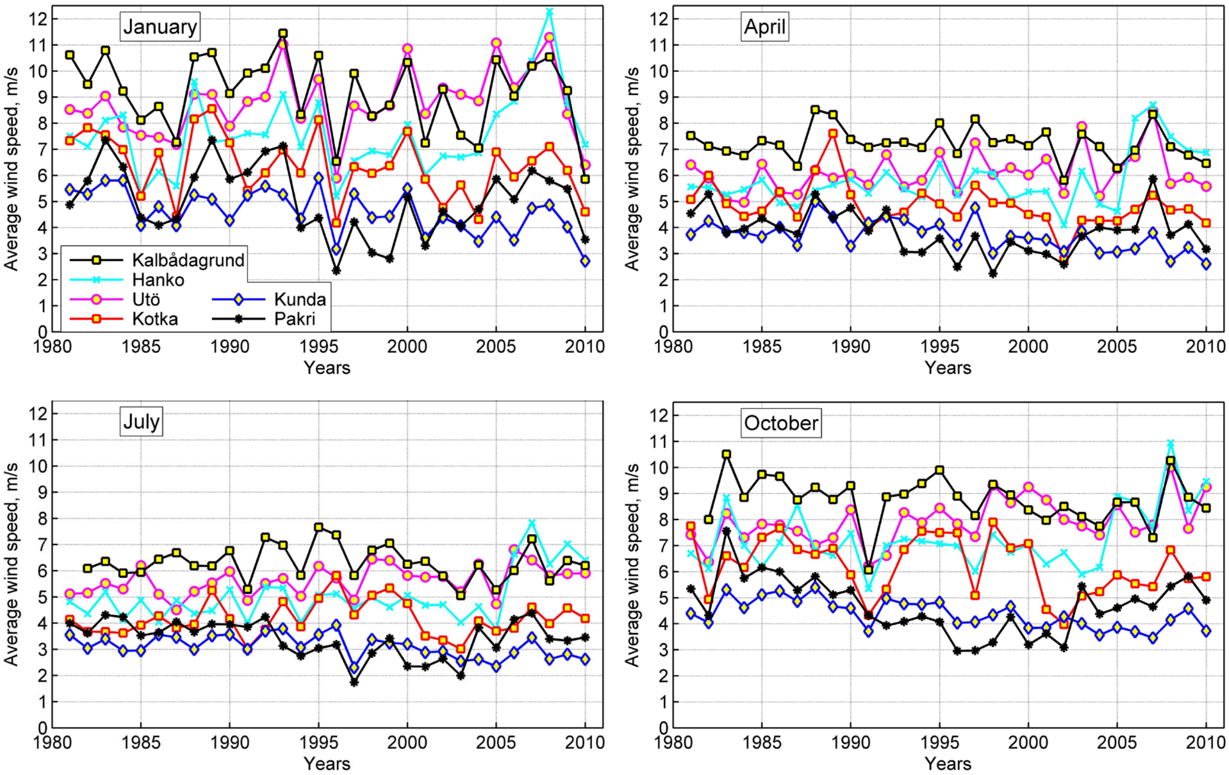


**Fig. 5.** Monthly average wind speed at different stations.

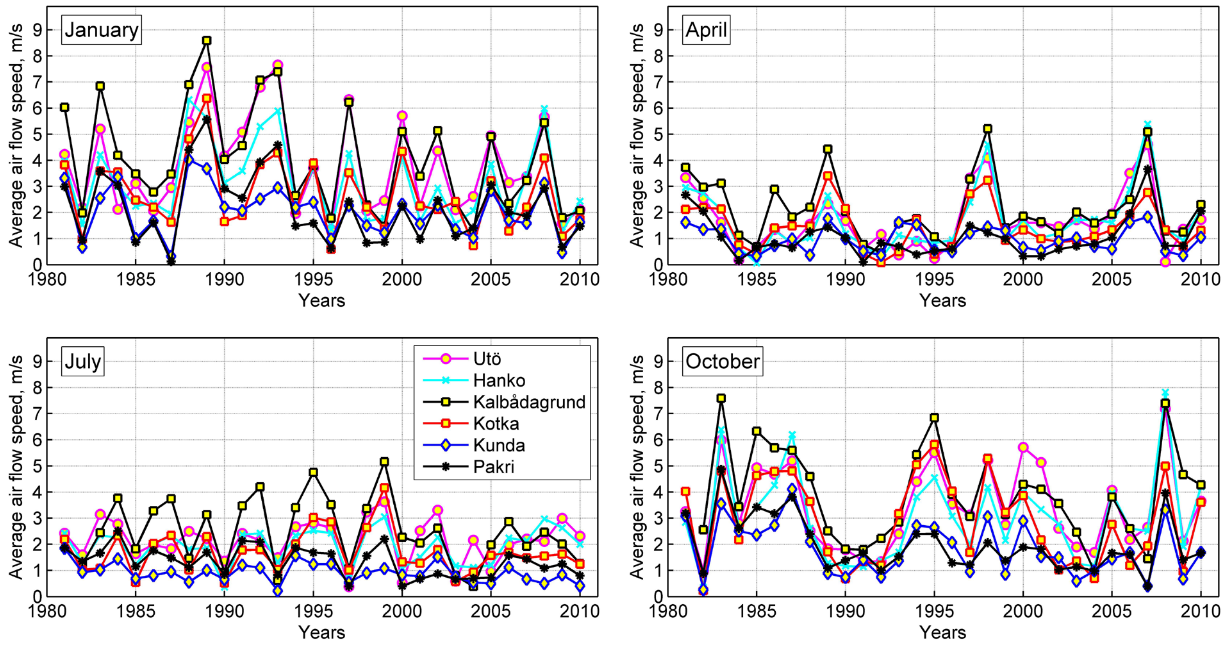


**Fig. 6.** Monthly average air flow speed at different stations.

ports the above-discussed conjecture that while the wind speed may markedly vary from one coastal location of the Gulf of Finland to another, the air flow speed is a much more robust feature that reflects possible changes in the large-scale atmospheric patterns in the study area. Besides, this quantity seems to be less affected by the changes in the measurement site relocation. At Pakri the average wind speed decreased drastically in 1993, but the average air flow increases and decreases more or less together with the changes in other stations.

Furthermore, the appearance of the time series of the average air flow suggests that there may have been several abrupt (quasi)simultaneous changes in the whole wind field. To check this, the Rodionov regime shift test was applied to all time series. Table 3 shows the detected regime shifts for the average wind speed in single months. The shift timings seem to be rather scattered with two exceptions: the increase at Hanko around 2005 and two changes at Pakri (a decrease around 1992 and an increase around 2003) mirror the relocation of the measurement sites (Table 1).

Differently from the wind speed, the detected regime shifts in the average air flow speed demonstrate several coherent changes (Fig. 7, Table 4). An increase has taken place in January in 1987–1988 and a decrease in 1993–1996 at all measurement sites except Kotka. The years of 1987–1989 can be noticed also in October when the air flow speed abruptly decreased in all stations except Hanko. Importantly, even major changes in the measurement locations at Pakri and Hanko (that produced evident shifts in the wind speed) do not become evident in the analysis of regime shifts of the air flow speed. In April and July the shifts are rare and random. Consistently with the results presented in Keevallik (2011) and Lehmann et al. (2011) such changes are concentrated in relatively windy months.

**Table 3.** Average values of the wind speed in different months in the Gulf of Finland before and after the regime shifts

| | January | | April | | July | | October | |
|---|---|---|---|---|---|---|---|---|
| | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s |
| Utö | 1981–2004<br>2005–2010 | 8.6<br>9.7 | 1981–2010 | 6.0 | 1981–1997<br>1998–2010 | 5.4<br>6.0 | 1981–1997<br>1998–2007<br>2008–2010 | 7.6<br>8.3<br>9.2 |
| Hanko | 1981–2005<br>2006–2010 | 7.2<br>9.3 | 1981–2005<br>2006–2010 | 5.5<br>7.6 | 1981–2005<br>2006–2010 | 4.7<br>6.8 | 1981–2004<br>2004–2010 | 6.8<br>8.9 |
| Kotka | 1981–2009 | 6.5 | 1981–2010 | 4.8 | 1981–1994<br>1995–2000<br>2001–2010 | 4.0<br>5.0<br>3.9 | 1981–2000<br>2001–2007<br>2008–2010 | 6.8<br>5.1<br>6.1 |
| Kalbådagrund | 1981–2009 | 9.4 | 1981–2010 | 7.2 | 1982–2010 | 6.3 | 1982–2010 | 8.8 |
| Kunda | 1981–2000<br>2001–2009 | 5.0<br>4.1 | 1981–1997<br>1998–2010 | 4.0<br>3.3 | 1981–2000<br>2001–2009 | 3.3<br>2.7 | 1981–1995<br>1996–2010 | 4.8<br>4.0 |
| Pakri | 1981–1993<br>1994–2004<br>2005–2010 | 6<br>3.9<br>5.4 | 1981–1992<br>1993–2003<br>2004–2010 | 4.3<br>3.1<br>4.1 | 1981–1992<br>1993–2003<br>2004–2010 | 3.9<br>2.7<br>3.6 | 1981–1991<br>1992–2002<br>2003–2010 | 5.6<br>3.7<br>5.0 |

**Table 4.** Average values of the air flow speed in different months in the Gulf of Finland before and after the regime shifts

| | January | | April | | July | | October | |
|---|---|---|---|---|---|---|---|---|
| | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s |
| Utö | 1981–1987<br>1988–1993<br>1994–2010 | 3.1<br>6.1<br>3.1 | 1981–2010 | 1.7 | 1981–2010 | 2.2 | 1981–1987<br>1988–1993<br>1994–2010 | 4.2<br>1.9<br>4.4 |
| Hanko | 1981–1987<br>1988–1993<br>1994–2010 | 2.8<br>5.0<br>2.6 | 1981–2010 | 1.5 | 1981–2010 | 2.0 | 1981–2007<br>2008–2010 | 2.8<br>4.6 |

**Table 4.** *Continued*

| | January | | April | | July | | October | |
|---|---|---|---|---|---|---|---|---|
| | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s | Years | Speed, m/s |
| Kotka | 1981–2010 | 2.6 | 1981–1990 | 1.7 | 1981–2010 | 1.6 | 1981–1988 | 3.9 |
| | | | 1991–2010 | 1.1 | | | 1989–1993 | 1.6 |
| | | | | | | | 1994–2000 | 4.3 |
| | | | | | | | 2001–2009 | 1.7 |
| Kalbådagrund | 1981–1987 | 3.9 | 1981–1990 | 2.5 | 1982–2010 | 2.5 | 1982–1988 | 5.1 |
| | 1988–1993 | 6.5 | 1991–2010 | 1.7 | | | 1989–2007 | 3.1 |
| | 1994–2010 | 3.2 | | | | | 2008–2010 | 5.3 |
| Kunda | 1981–1987 | 1.8 | 1981–2010 | 0.9 | 1981–2010 | 0.9 | 1981–1988 | 2.7 |
| | 1988–1995 | 2.7 | | | | | 1989–2010 | 1.4 |
| | 1996–2009 | 1.7 | | | | | | |
| Pakri | 1981–1987 | 1.9 | 1981–2010 | 0.9 | 1981–1999 | 1.6 | 1981–1987 | 3.2 |
| | 1988–1993 | 4.0 | | | 2000–2010 | 0.9 | 1988–2010 | 1.6 |
| | 1994–2010 | 1.6 | | | | | | |

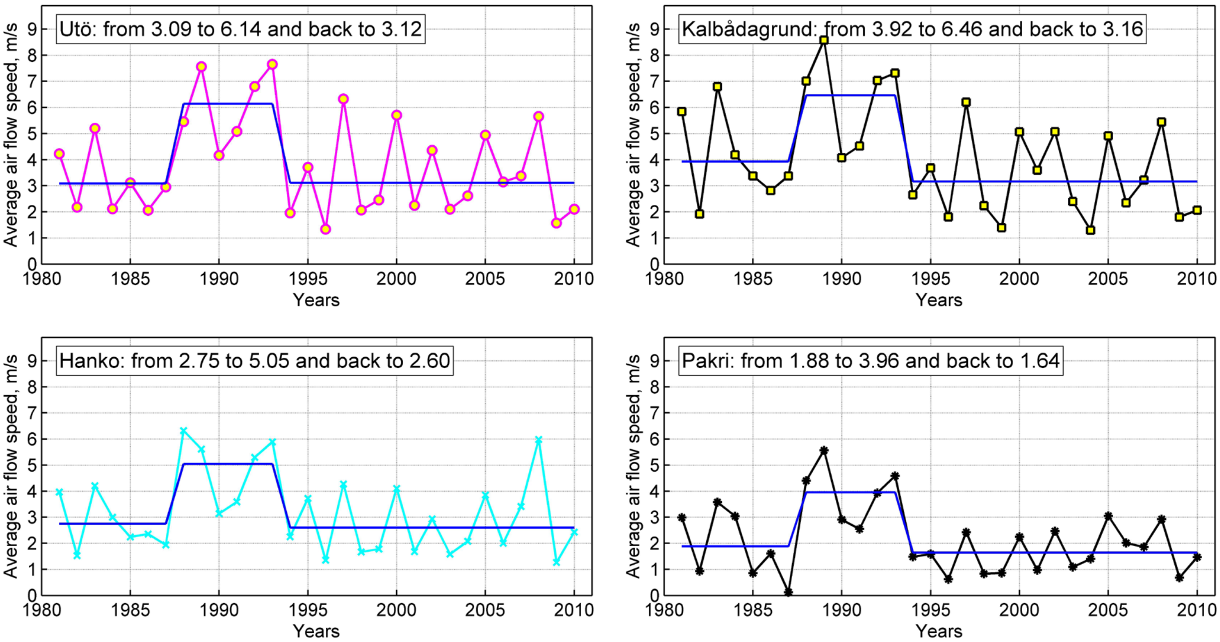


**Fig. 7.** Shifts in the monthly average air flow speed at different stations in January.

## 5. DISCUSSION AND CONCLUSIONS

Our analysis first demonstrates that both the speed and direction of air flow are robust quantities that can be used to characterize substantial changes in the large-scale wind patterns in situations when the local wind speed or predominant direction provide only very limited information. For example, the monthly mean wind speed markedly decreases along the Gulf of Finland from the west to the east, but the average air flow insignificantly varies from the entrance of the gulf until its eastern end. It is intriguing that in spite of large differences in the average wind speed at largely different measurement sites the average air flow at these sites is almost equal. The background of this difference can be explained by the radically different nature of these quantities. Wind speed is a local (Eulerian) variable that can be driven and affected by a multitude of localized three-dimensional factors. It is, for example, considerable in sea breeze and may be very strong in a thunderstorm. Its instantaneous values are often weakly connected with similar values at a certain distance and may represent, for example, a local strong vortex.

On the contrary, air flow is a reflection of global or at least large-scale Lagrangian transport phenomena. Large air masses with a thickness of several kilometres moving over the sea and over mainland have to obey, at least approximately, the continuity (or volume conservation) law in two dimensions. This means that even if some parts of such masses flow relatively rapidly (e.g., over the sea surface), they cannot cover, on average, much larger distance than their neighbouring masses (e.g., moving over mainland). This feature tends to smooth out the differences between the average air flow speeds over different regions. For this reason the properties of air flow, calculated from measurements at a single site, are often characteristic of relatively large regions, but usually poorly characterize more rapid and local processes.

The comparison first signals that one must be careful when choosing a suitable wind characteristic for a practical task. The analysis has shown that the properties of air flow are virtually unusable in calm months such as April when the average air flow speed almost vanishes. This feature shows that the wind field is practically isotropic and signals very limited Lagrangian transport of air masses during such time intervals. During all other seasons the average air flow is directed from the south-west or west to the north-east or east. The annual cycle of the wind directional stability (persistency) factor – the ratio of average air flow speed and the average wind speed – is almost the same over the entire gulf. The persistency of the air flow is very low in April and the largest in October and July when the Lagrangian transport of air masses and associated energy is the most effective.

The large differences between the average wind field and average air flow field are not surprising. Winds blowing from different directions often compensate each other at averaging in time and the average air flow speed is systematically smaller than the average wind speed. In most cases also the traditional wind roses show the direction of the average airflow only approximately whereas calculating it from average values of wind vector components shows more precisely the direction of the advection of matter and energy.

Time series of the monthly average wind speed and air flow speed show rather random behaviour and extensive interannual variability. They reveal also some statistically significant abrupt changes that may be called regime shifts. These shifts are scarce in the average wind speed and can mostly be explained by relocation of the measurement devices. The shifts in the average air flow are mostly concentrated in the months with the strongest air flow and changes in the average air flow speed. Importantly, these shifts are largely correlated and more or less in-phase over the whole Gulf of Finland. These properties are vividly present for January where the time series of the air flow speed contain an increase around 1988 and a decrease around 1994. In October a decreasing shift was detected around 1988. The strong shifts that occurred almost simultaneously in all regions in 1987–1989 may be associated with a major abrupt change in the geostrophic air flow direction over the southern Baltic Sea in 1988 (Soomere and Räämet, 2014) when the average air flow vector turned clockwise by more than 30°. The related “shake” of the geostrophic air flow system apparently extended to the entrance of the Gulf of Finland but was relaxed back to the pre-1980s situation in a few years. These events are not present in the average wind speed.

To summarize, the presented arguments confirm that the use of the concept of average air flow speed and direction enables one to filter out local peculiarities and to detect several important features of the wind field that are characteristic for the whole Gulf of Finland such as likely regime shifts. The identified major regime shifts in the average air flow speed around 1988 could be related to the abrupt change in the geostrophic wind vector over the southern Baltic Proper.

## ACKNOWLEDGEMENTS

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## Režiiminihked keskmises pinnalähedases õhuvoolus Soome lahel aastatel 1981–2010

Sirje Keevallik ja Tarmo Soomere

Klassikalised tuule parameetrid sõltuvad suuresti kohalikest oludest ja sageli ei võimalda need tuvastada järske muutusi suuremõõtmelistes tuuleväljamustrites. Artiklis on näidatud võimalusi selliste muutuste leidmiseks Soome lahel keskmise õhuvoolukiiruse ja -suuna abil. Ajavahemikul 1981–2010 registreeritud andmete põhjal on kuu keskmine õhuvool aprillis väga väike, kuid ülejäänud kuude jooksul ulatub väärtuseni 2,8 m/s. Tuule kuu keskmine stabiilsusfaktor muutub aasta jooksul analoogiliselt. Keskmise õhuvoolu suund ei tarvitse kõige sagedasemate tuulte suunaga kokku langeda. Suvel, sügisel ja talvel on see enam-vähem ühesugune kogu Soome lahe ulatuses, olles suunatud edelast või lääneedelast kirdesse või idakirdesse. Rodionovi režiiminihete tuvastamise test näitab, et järsud muutused kuu keskmises tuulekiiruses on põhiliselt seletatavad mõõtmispaiga asukoha muutusega. Muutused keskmises õhuvoolus erinevad oluliselt muutustest keskmises tuulekiiruses ja on paremini väljendunud tuuliste kuude puhul. Jaanuaris toimus kõigis vaatluskohtades statistiliselt oluline režiimimuutus 1988. aastal, mil õhuvoolukiirus kasvas järsult. Õhuvoolu järsk nõrgenemine toimus kõigis jaamades peale Kotka aastatel 1993–1996. Oktoobris oli kõigis jaamades peale Hanko järsk õhuvoolukiiruse langus aastatel 1988–1989. Need nihked, mis ei kajastu tuule keskmises kiiruses, on tõenäoliselt seotud suurema muutusega geostroofilises tuules Läänemere lõunaosa kohal 1988. aastal ja varasema režiimi taastumisega mõne aasta pärast.