IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 118, No. 2, April – June, 2014, pp. 119–132

Homogenization of Hungarian daily wind speed data series

Csilla Péliné Németh[1*], **Judit Bartholy**[2], and **Rita Pongrácz**[2]

[1]*Geoinformation Service of the Hungarian Defence Forces*
Szilágyi Erzsébet fasor 7–9., H-1024 Budapest, Hungary

[2]*Department of Meteorology, Eötvös Loránd University*
Pázmány Péter sétány 1/A, H-1117 Budapest, Hungary

**Corresponding author E-mail: pelinenemeth.csilla@mhtehi.gov.hu*

(Manuscript received in final form October 24, 2013)

Abstract—Reliable long time series have key role in climatological research. Long term observations involve inhomogeneities due to change of measuring methods, sensors, surroundings of stations, or moving into a new location. Therefore, homogenization is necessary in order to make reliable analysis of datasets. In this study, the MASH (Multiple Analysis of Series for Homogenization) procedure developed at the Hungarian Meteorological Service was applied to improve our wind time series. Daily wind datasets were homogenized at 19 Hungarian synoptic stations in the period from 1975 to 2012. This paper discusses the validation of the homogenization process and presents the quality control results.

Key words: wind speed, homogenization, MASH application, Hungarian wind climate, measurement automation

1. Introduction

The existence of long and reliable instrumental climate records is necessary both to assess climate variability and climate change and to validate climate model outputs (*Freitas et al.,* 2013). Analysis of appropriate and good quality datasets may help to mitigate possible negative effects of climate change. Furthermore, besides temperature and precipitation, wind is also a key meteorological element, therefore, it is essential to study average and extreme characteristics and tendencies of present and future wind climate.

Hungarian wind climate research at the Eötvös Loránd University in Budapest is based on the analysis of past, present, and modeled wind field data sets. Projected wind fields are provided by the adapted and validated RegCM3 regional climate model (*Torma et al.,* 2008) experiments for future periods (2021–2050 and 2071–2100) for the Carpathian Basin.

We analyzed present wind climate using measurements of Hungarian synoptic stations, and gridded reanalysis data (*Péliné et al.,* 2011). Hungarian synoptic measurement network has been developed and installed by the Hungarian Meteorological Service taking into account suggestions of the World Meteorological Organisation (*WMO,* 2011). Because of the last decades' developments of measurement and communication technologies, the wind observing network has changed several times, which is unfortunately quite usual. The most significant change was automation – i.e., change traditional measuring instruments into automated measuring systems – during 1995–1996. This major change introduced large variations in the climate signal, and caused inhomogeneities in the data sets. In fact, long instrumental records are very rarely homogeneous because of the changing surroundings of measuring sites (new buildings, vegetation growth, etc.). To avoid misinterpretation due to this inhomogeneity, the available time series can be divided into subsets. For instance, we used two subsets in case of previous (*Péliné et al.,* 2011) wind climate analysis using wind data originating from traditional (1975–1994) and automated (1997–2012) measuring systems.

In addition to automation other causes may also lead to inhomogeneities such as substitution or relocation of weather stations, changing anemometer type or aging of the instruments, changes in measuring height, surroundings (e.g., urbanization), surface coverage, and roughness. Therefore, documentation of metadata is a crucial issue during any kind of meteorological measurement.

The above-mentioned changes could result in inhomogeneities, which cannot be explained by climatological reasons. Brake points in the data sets coincide with change in the probability distribution function of the measurements. These inhomogeneities must be detected and removed before further analyses. For this purpose mathematical methods are widely used, one of them is the Multiple Analysis of Series for Homogenization, MASH v3.03 (*Szentimrey,* 1999, 2011) developed in HMS. This technique is used here for homogenization of available daily wind speed time series between 1975 and 2012 for records of 19 Hungarian synoptic stations.

2. Homogenization with MASH application

A homogeneous climatological time series can be defined as time series where variability is only caused by changes in weather and climate (*Aguilar et al.,* 2003). To decide whether or not a long time series is homogeneous, there are different detection and correction methods available for possible use. These methods are all based on mathematical formulation and climatological experience, however, their performances are different. Objective comparison of these existing methods was carried out in the framework of a scientific programme COST Action HOME ES0601: Advances in Homogenization Methods of Climate Series: an integrated approach (*HOME,* 2011; *Szentimrey,* 2013). The HOME tests concluded that MASH was one of the most successful methods (*Domonkos et al.*, 2012, *Domonkos* 2013, *Venema et al.,* 2012), that is why we used it in this study.

MASH application is a relative homogeneity test procedure (*Szentimrey,* 1999). This tool consists of mathematical formulation, climatological station information (metadata), and software development for automation. Application does not assume that the reference series are homogeneous. The candidate series is chosen from the available time series (for example daily wind speed data), and the remaining series are considered as reference series. As running the application, the role of series changes step by step during the procedure. Depending on the climatic element, additive (for temperature) or multiplicative (for precipitation or wind speed) models can be used.

It is possible to homogenize monthly, seasonal, or annual time series. The daily inhomogeneities can be derived from the monthly ones (*Szentimrey,* 2008). The application provides automatically the probable dates of break points for further usage, and the homogenized, completed and quality controlled time series. Although MASH is able to use metadata (for example the date of relocation) during the break point detection, it was not used during this work.

In this study, daily wind speed data sets for 19 stations (*Fig. 1*) were derived from at least 8 hourly wind speed data a day. Before calculating daily wind speed, hourly data was quality controlled and corrected. Metadata of stations is summarized in *Table 1*. Data are available from 1975 to 2012 at most stations. At station Paks (No. 15), measurements started only on May 1, 1979. Altogether more than one year is missing at Zalaegerszeg (No. 11) during 1993 and 1994. It is also important to note that 50 days are missing at Kecskemét (No. 17) in 2009.

A multiplicative model was applied for homogenization of daily wind speed data using the 0.05 significance level. Original series can be described as Eq. (1) affected by climate change, inhomogeneity, and noise effect (*Szentimrey,* 2011).

Original series for multiplicative model is

$$X^*_{O,j}(t) = C^*_j(t) \cdot IH^*_j(t) \cdot \varepsilon^*_j(t), \qquad (j = 1,2,\dots,n), \tag{1}$$

where C^* is the climate change, IH^* is the inhomogeneity, ε^* is the noise.

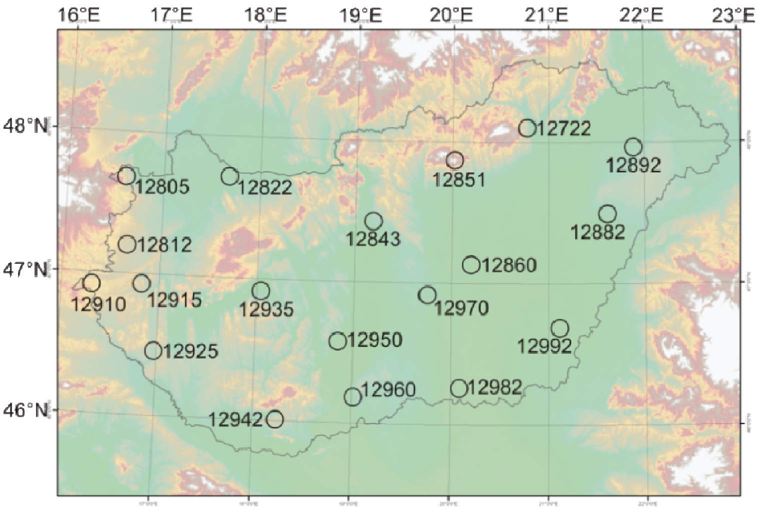


Fig. 1. Hungarian stations used at MASH application for homogenization.

Table 1. Metadata of Hungarian stations used at MASH application for homogenization (in 2012)

No.	WMO	Station name	Lon [° E]	Lat [° N]	Altitude [m]	Anemometer elevation [m]	Missing data [%]
1	12772	Miskolc	20.77	48.10	232.8	16.25	0.0
2	12805	Sopron	16.60	47.68	233.8	18.40	< 0.1
3	12812	Szombathely	16.65	47.20	201.1	10.56	< 0.1
4	12822	Győr	17.67	47.71	116.7	11.16	0.0
5	12843	Budapest Lőrinc	19.18	47.43	139.1	14.68	< 0.1
6	12851	Kékestető	20.02	47.87	1011.3	25.07	< 0.1
7	12860	Szolnok	20.13	47.17	108.1	10.40	< 0.1
8	12882	Debrecen	21.61	47.49	107.6	10.23	0.1
9	12892	Nyíregyháza	21.89	47.96	142.1	15.98	0.2
10	12910	Szentgotthárd	16.31	46.91	311.7	16.61	0.1
11	12915	Zalaegerszeg	16.81	46.93	240.1	10.40	3.3
12	12925	Nagykanizsa	16.97	46.46	139.8	13.69	0.1
13	12935	Siófok	18.04	46.91	108.2	15.10	0.0
14	12942	Pécs	18.23	46.01	202.8	10.55	0.0
15	12950	Paks	18.85	46.57	97.2	9.80	11.4
16	12960	Baja	19.02	46.18	113.0	10.30	0.1
17	12970	Kecskemét	19.75	46.91	114.0	10.40	0.4
18	12982	Szeged	20.09	46.26	81.8	12.25	< 0.1
19	12992	Békéscsaba	21.11	46.68	86.2	6.50	< 0.1

3. *Results*

MASH v3.03 procedure produces quality control results automatically (e.g., the number of days with error, total number of errors; their dates), identifies problematic series, and gives the estimated error values. First, our input data was checked with partially automated self-developed computer codes including basic controlling rules and the detected errors were corrected manually before homogenization. As a result, only 2 errors (on two consecutive days) were detected at one of the stations, Szombathely (No. 3). Normally, file of MASH quality control results contains the detected maximal positive and the minimal negative errors and their dates; however minimal negative error was zero in this work (*Table 2*).

Table 2. Quality control results

Dates of the detected errors	**Maximal positive error [m/s]**
August 9, 1995	0.31
August 10, 1995	0.54

During verification of homogenization, the null hypothesis supposes that the examined series are homogeneous. The homogenization is acceptable if the following condition is true (*Lakatos et al.,* 2013): the test statistic after homogenization (TSA) has to be either near the critical value (20.57, significance level 0.05) or much less than the test statistic before homogenization (TSB). TSA and TSB values are summarized in *Table 3.* Since TSA values are much smaller compared to TSB values, it can be concluded that the homogenizations are acceptable and improve the qualities of the station time series considerably. The smallest TSB value – less than 100.0 – is found in case of station 3 (30.11) where the homogenization could not improve the data quality (station 3 is the only station with this feature among the 19 stations evaluated in this study). In fact, the TSA value of station 3 is larger than the TSB value. The small difference between them suggests that only a slight correction was made in the time series of station 3, since the original time series can be considered homogeneous. However, due to missing data of the original data set at this station, we used the homogenized time series in the analysis.

Table 3. Yearly test statistics for inhomogeneity of series

Station No.	**TSA**	**TSB**	**Station No.**	**TSA**	**TSB**
1	151.21	2590.78	11	42.39	953.13
2	26.69	137.10	12	100.19	218.26
3	39.76	30.11	13	69.66	395.84
4	29.49	113.96	14	16.70	492.12
5	23.93	285.97	15	50.67	574.81
6	147.45	229.40	16	47.14	512.55
7	53.85	1715.00	17	35.86	490.28
8	60.62	116.63	18	57.82	178.88
9	49.72	1680.52	19	84.57	359.90
10	36.61	578.96			
			Average	**59.17**	**613.38**

Table 4 lists annual relative estimated inhomogeneities (REI) and annual relative modification of wind speed data sets (RMS). They are proportional to standard fluctuation based on their definitions (*Szentimrey,* 2011).

Fluctuation of series is

$x(t)(> 0)y(t)(> 0)\ (t = 1,2, \dots, n)$:

$$F(x) = \left(\prod_{t=1}^{n} max\left(\frac{x(t)}{y(t)}, \frac{y(t)}{x(t)}\right)\right)^{\frac{1}{n}}. \quad (2)$$

Standard fluctuation of series is

$x(t)(> 0)\ (t = 1,2, \dots, n)$:

$$SF(x) = \left(\prod_{t=1}^{n} max\left(\frac{x(t)}{\bar{x}_G}, \frac{\bar{x}_G}{x(t)}\right)\right)^{\frac{1}{n}}, \quad (3)$$

where G is the geometric mean.
Relative estimated inhomogeneity (REI) is

$$SF\left(I\widehat{H}^*\right) \approx SF(X_0^*)^{REI}. \quad (4)$$

Relative modification of series (RMS) is

$$F(X_0^*, X_H^*) \approx SF(X_0^*)^{RMS}. \quad (5)$$

Annual variability of wind speed is definitely smaller than other meteorological parameters such as maximum temperature or sunshine duration. Seasonal REI of daily wind speed time series shows an annual cycle with very small amplitude. Analysis of time dependence of REI suggests that averaged values for all stations are slightly larger in spring (0.46) and summer (0.55) than in winter (0.39) and autumn (0.44). Seasonal REI values vary from zero to 1.01 (*Fig. 2*), the smallest values appear in autumn and summer at stations 3 and 4, respectively, whereas the largest REI values can be found in summer at station 7 (in Szolnok). The maximum difference between the seasonal REI values is in Sopron (station 2), where REI is eight times larger in summer than in spring (the difference is 0.36). Considering the monthly RMS values (*Fig. 3*), the average adjustments were higher during those months when natural variability of wind speed is larger (due to higher thunderstorm frequency). *Fig. 3* illustrates the RMS analysis at three stations, i.e., Szombathely (station 3), Zalaegerszeg (station 11), and Kecskemét (station 17), where annual REI and RMS are minimum, maximum, and around the multi-station mean values, respectively.

Table 4. Annual relative estimated inhomogeneities (REI) and annual relative modification of series (RMS)

Station name	REI	Station name	RMS
Zalaegerszeg	0.90	Zalaegerszeg	1.57
Szolnok	0.90	Szolnok	1.30
Miskolc	0.88	Nyíregyháza	1.07
Nyíregyháza	0.80	Miskolc	1.06
Pécs	0.61	Pécs	0.90
Szentgotthárd	0.60	Siófok	0.77
Paks	0.53	Békéscsaba	0.70
Siófok	0.51	Szentgotthárd	0.67
Kecskemét	0.51	Paks	0.66
Baja	0.51	Kecskemét	0.63
Békéscsaba	0.50	Baja	0.61
Debrecen	0.36	Debrecen	0.58
Nagykanizsa	0.33	Nagykanizsa	0.45
Kékestető	0.23	Szeged	0.31
Szeged	0.19	Kékestető	0.27
Sopron	0.17	Sopron	0.18
Budapest Lőrinc	0.11	Budapest Lőrinc	0.13
Győr	0.06	Győr	0.08
Szombathely	0.06	Szombathely	0.07
Average	**0.46**	**Average**	**0.64**

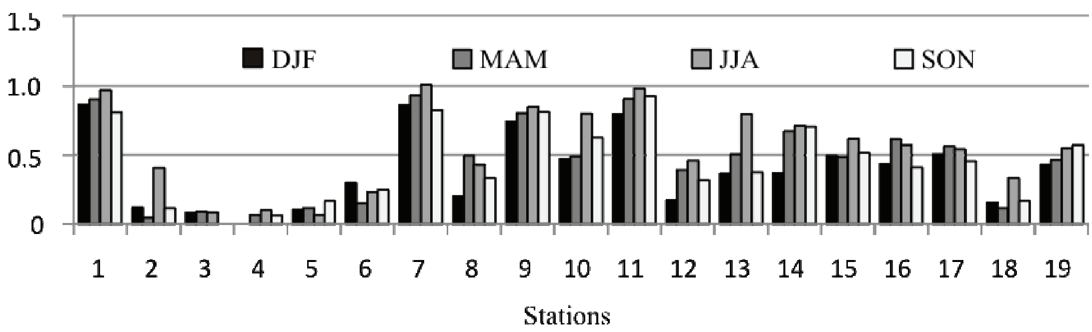


Fig. 2. Seasonal relative estimated inhomogeneity in different stations.

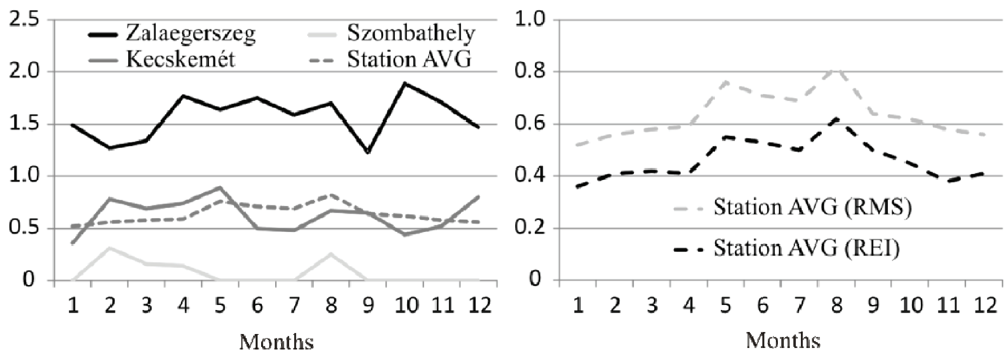


Fig. 3. Monthly RMS at three stations and station average (*left*), and average monthly RMS and average monthly REI calculated from values of the 19 stations (*right*).

During the homogenization process, time series can be modified in any year. Break points usually were found throughout the whole period, however, data series of some stations were corrected only in a shorter period. *Fig. 4* demonstrates annual number of stations where break points were detected.

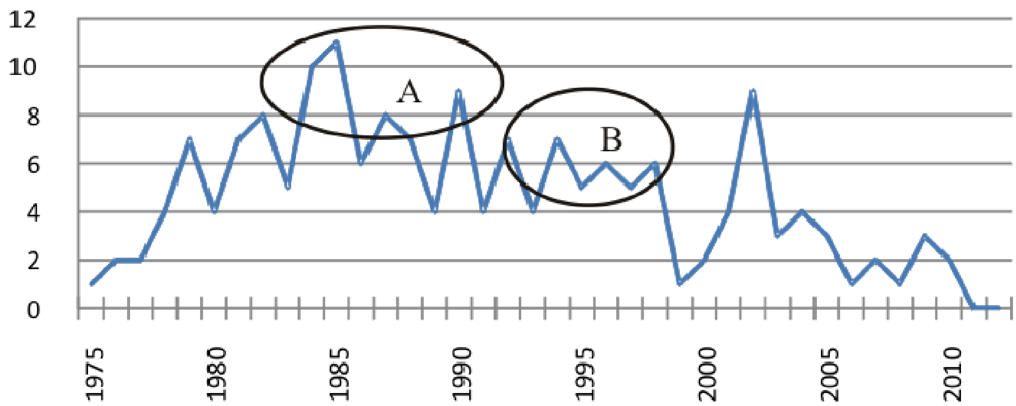


Fig. 4. Number of stations of annually detected break points. (Ellipse A: missing values during the 1980's. Ellipse B: inhomogeneity due to automation.)

In general, there is a decreasing trend towards fewer break points in recent times. Metadata may be valuable either during the homogenization or the validation procedure (*Auer et al.,* 2005). Based on documented metadata, missing values were found frequently mainly at night in most of the analyzed stations in the 1980's (ellipse A). Consequently, daily average wind speed was calculated from less number (at least eight) of measurement records. Automation process obviously caused inhomogeneity in data series at almost every station (ellipse B). Moreover, relocated stations and changed height of the measuring sensors also could cause break points (after 2000). In these latter cases, the modification factors suggest that the inhomogeneity is often more explicit than the effect of automation. Therefore, it is important to take into account these effects in planning and installation of measurement systems, moreover, it is essential to document any changes in meteorological measurement network.

After completing the homogenization process, the distribution of daily wind speed changed considerably. *Fig. 5* shows the relative frequencies of wind speed at three stations before and after homogenization. The REI and RMS at Zalaegerszeg (station 11) are the largest, while the minimum values can be found at Szombathely (station 3). Therefore, the largest difference between pre- and post-homogenized distributions is at Zalaegerszeg, where the distribution shifted to a higher wind speed regime.

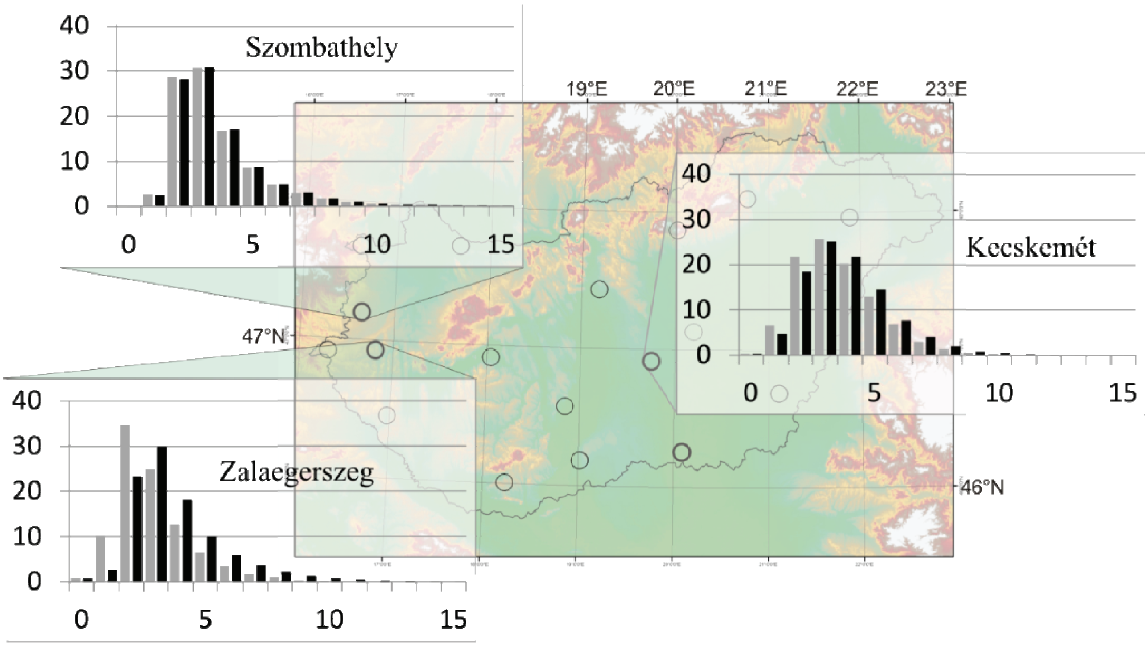
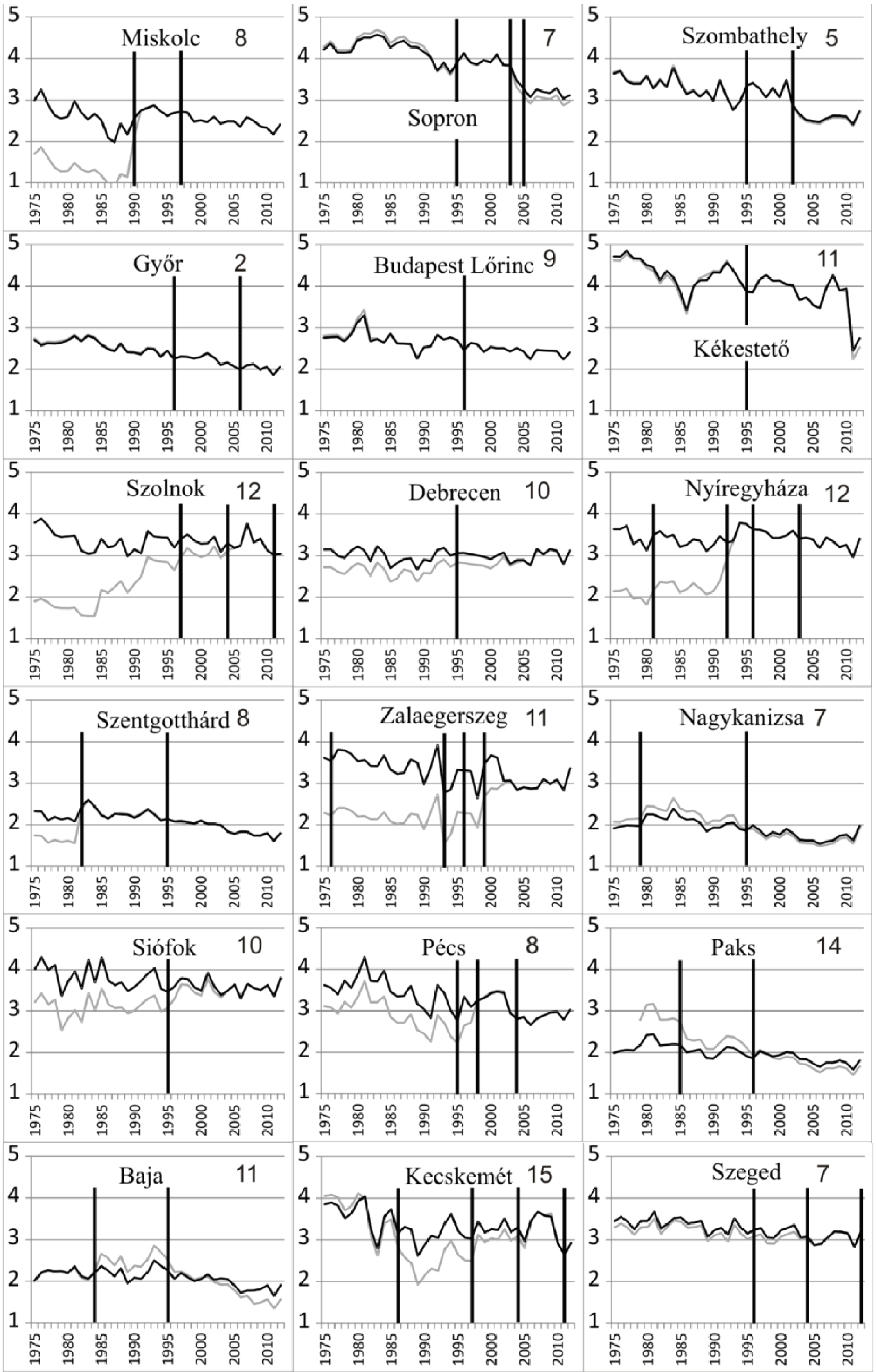


Fig. 5. Relative frequencies [%] of daily wind speed [m/s] at different stations before (grey) and after (black) homogenization (1975–2012).

The original and homogenized average yearly wind speed time series are shown in *Fig. 6* for all analyzed stations. Detected numbers of annual break points are indicated at the upper right corner of each diagram. Most of the break points can be identified from the documented metadata, however, the actual required adjustments cannot be quantified from metadata (*Menne et al.,* 2005).

In many cases (Miskolc, Szolnok, Siófok), time series were modified (see vertical lines in *Fig. 6*) in the first half of the entire period. Measuring station in Miskolc moved to another place in 1990, this change caused a significant increase in wind speed. Other documented changes include the automation, during which both the type of the anemometer (from Fuess to Vaisala) and the method of measurement have changed. Moreover, this modernization usually coincided with change of the sensor's height. For example, stations at Miskolc and Szolnok were automated in 1997, and at Siófok in 1995. At Miskolc, the sensor was installed from 10 meter (standard elevation of anemometers) to 16.25 meter. Station Siófok is located at the waterfront of Balaton (the biggest lake in Central Europe), the measurements were automated in 1995, when the height of the anemometer was lifted to 15.10 meters. After automation in 1997 at Szolnok, the type of the anemometer was changed twice, in 2004 and 2011.

However, there are some stations, such as Szombathely and Sopron, where smaller modifications were applied during the homogenization process. The automation in both stations was completed in 1995. Other effects also influenced the homogeneity, namely, (i) station of Szombathely was moved in 2002 with unchanged sensor's height, (ii) station of Sopron was reinstalled twice, in 2003 and 2005, when height of the anemometer was lifted from 15.64 to 18.40 meter.



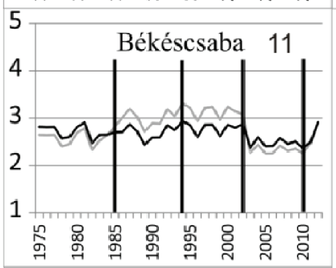


Fig. 6. Average yearly wind speed [m/s] at different stations before (grey) and after (black) homogenization. Vertical lines show years when any metadata is documented at national climate data base between 1975 and 2012. Detected numbers of annual break points are indicated at the upper right corner of the diagrams.

MASH procedure homogenizes monthly and daily time series and completes missing data for further analysis, e.g., extreme value evaluation or model output verification. In this study, different yearly and seasonal percentile values (median, 0.90 and 0.99) were calculated for 19 stations from 38-year-long time series (1975–2012) before and after homogenization. *Fig. 7* and *8* show that the largest difference was found at Zalaegerszeg. At this station the yearly homogenized percentile values (0.50, 0.90, and 0.99) were increased by 131%, 128% and 140%, respectively. The highest decreasing was at station 19 (Békéscsaba), where homogenized percentiles are 98%, 96%, and 95% compared to percentiles of original time series. Median decreased at six stations, 0.90 and 0.99 percentiles were decreased in eight cases each. The smallest correction was applied to station data at Szombathely, No. 3 (100.0%, 99.8% and 98.3%) and in Kékestető, No. 6 (100.0%, 100.4% and 104.5%). Moreover, some smaller differences are demonstrated in *Fig. 8* comparing seasonal percentile values.

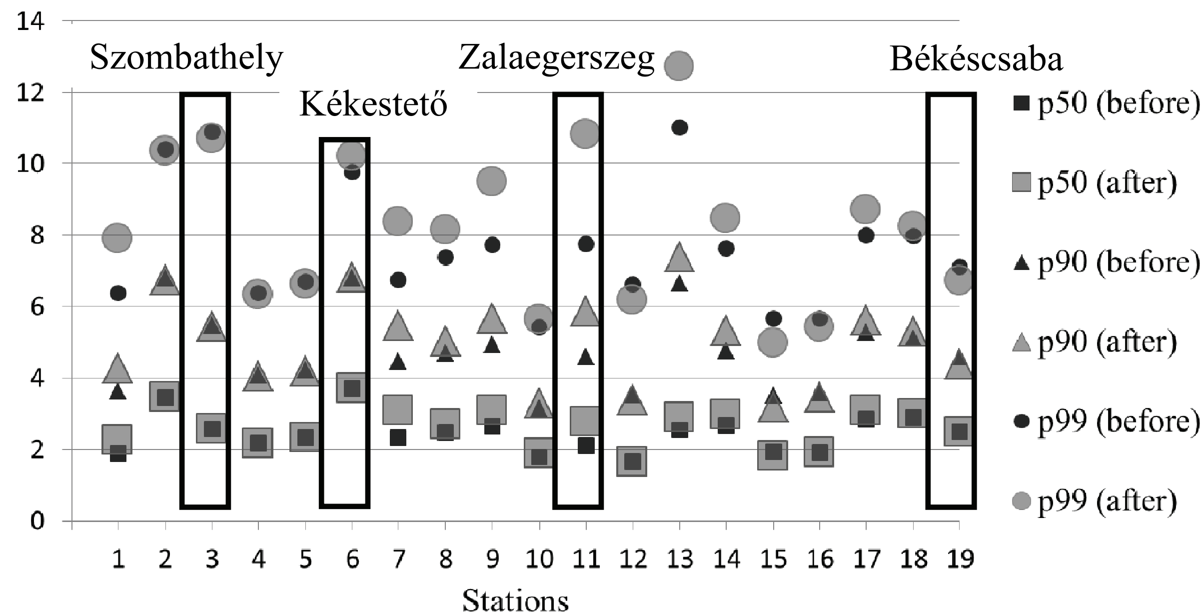


Fig. 7. Different yearly percentile values before and after homogenization for involved 19 stations calculated from 38-year time series (1975–2012).

Average yearly wind speed was modified significantly by homogenization procedure (*Fig. 6*). Consequently, the fitted linear trends of average and different percentile values also changed at many stations. In this paper, three stations (Szolnok, Zalaegerszeg, and Siófok) were chosen to demonstrate these differences emphasizing that inhomogeneities may lead to misinterpretations. *Fig. 9* shows monthly linear trend coefficients of 0.9 percentile values for two periods (1975–2012 and 1997–2012) calculated from daily wind speed data before (left) and after (right) homogenization for the three stations. Decreasing trends dominate in the homogenized datasets analyzing the whole period (1975–2012), and most of the increasing trends of the non-homogenized data disappeared. Smaller differences were found between homogenized and original data after automation (1997–2012). For instance, in case of Siófok, both in November and December the detected trends are significant and similar for the homogized and non-homogenized times series.

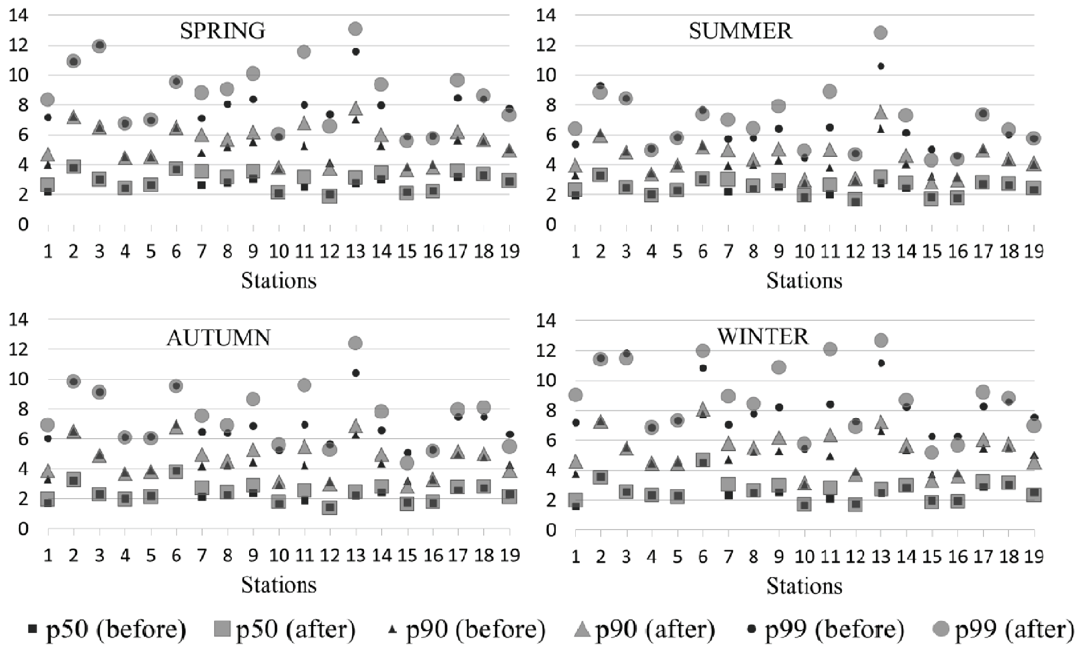


Fig. 8. Different seasonal percentile values [m/s] before and after homogenization for the 19 stations calculated from 38-year time series (1975–2012).

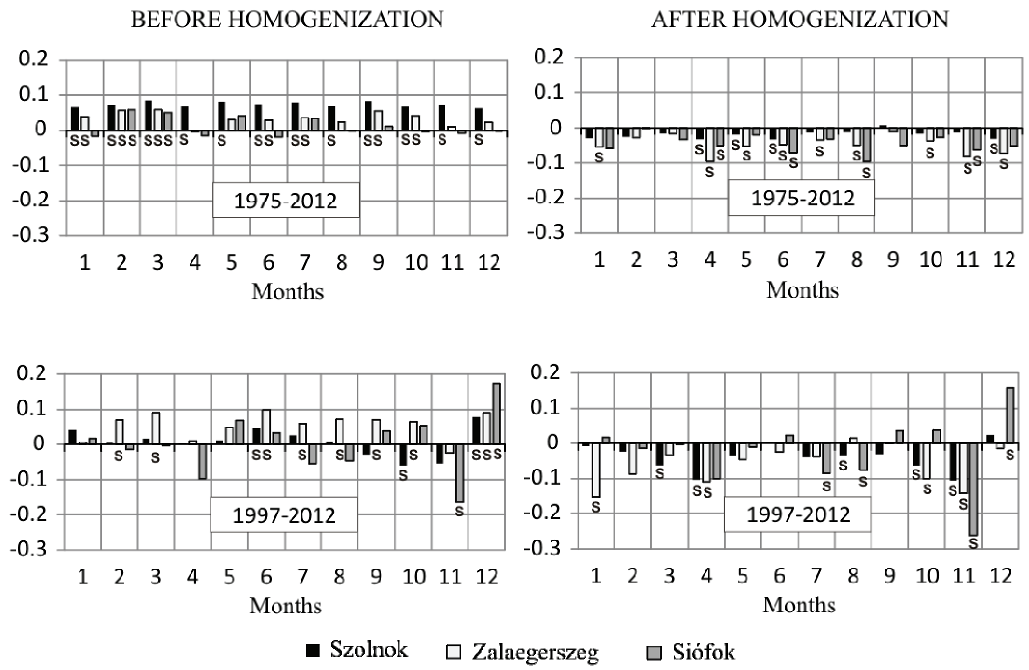


Fig. 9. Monthly linear trend coefficients of 0.9 percentile value for periods 1975–1912 and 1997–2012 calculated from daily wind speed data before (left) and after (right) homogenization for 3 stations. The significant changes are marked with letter "S".

4. Conclusions

Daily wind speed data sets of 19 Hungarian synoptic stations were homogenized for 1975–2012. Our preliminary results are summarized in this paper, based on them the following conclusions can be drawn. (1) Automation, relocated stations, and changed height of measurement sensors could cause break points in time series. Analyzing the modification factors, the inhomogeneity is often larger due to relocations than automation. Therefore, it is important to take into account these effects in planning and installation of measurement systems, moreover, it is essential to document any changes in meteorological measurement network. (2) Homogenization process determined the main break points of stations' time series. Most of the break points could be identified from documented metadata, however, it is not possible to deduce the number of break points from the metadata only. Consequently, non-climatic biases cannot be quantified solely from documented metadata. (3) Spatial variability of wind speed is high, but the temporal variability is small compared to other meteorological parameters (e.g., maximum temperature, sunshine duration). Seasonal relative estimated inhomogeneities of daily wind speed suggest very small changes within the year. (4) Values of RMS are higher when thunderstorm events occur more frequently, i.e., from spring to autumn.

Acknowledgement—We would like to express our very great appreciation to *Tamás Szentimrey* (Hungarian Meteorological Service) for providing MASH application, moreover, for his guidance and help in analyzing the results of homogenization. We are grateful to the Hungarian Meteorological Service and the Geoinformation Service of the Hungarian Defence Forces for the wind data of the Hungarian synoptic meteorological stations. This work was partially supported by the European Union and the European Social Fund through the project FuturICT.hu (grant no.: TÁMOP-4.2.2.C-11/1/KONV-2012-0013). Research leading to this paper has been supported by the Hungarian National Science Research Foundation under grant K-78125, and projects KMR_12-1-2012-0206 and GOP-1.1.1.-11-2012-0164.

References

Aguilar, E., Auer, I., Brunet, M., Peterson, T.C., and *Wieringa, J.,* 2003: Guidelines on climate metadata and homogenization. *WCDMP-No. 53, WMO-TD No. 1186.* World Meteorological Organization, Geneve.

Auer, I., Böhm, R., Jurković, A., Orlik, A., Potzmann, R., Schöner, W., Ungersböck, M., Brunetti, M., Nanni, T., Maugeri, M., Briffa, K., Jones, P., Efthymiadis, D., Mestre, O., Moisselin, J.- M., Begert, M., Brazdil, R., Bochnicek, O., Cegnar, T., Gajić-Čapka, M., Zaninović, K., Majstorović, Ž., Szalai, S., Szentimrey, T., and Mercalli, L., 2005: A new instrumental precipitation dataset for the greater Alpine region for the period 1800–2002. *Int. J. Climatol. 25,* 139–166.

Domonkos, P., Venema, V., and *Mestre, O.,* 2012*:* Efficiencies of homogenization methods: our present knowledge and its limitation*.* In *Proceedings of the 7th Seminar for Homogenization and Quality Control in Climatological Databases in press,* www.c3.urv.cat/publicacions/publicacions2012.html

Domonkos, P., 2013: Measuring performances of homogenization methods. *Időjárás 117*, 91–112

Freitas, L., Gonzalez Pereira, M., Caramelo, M., Mendes, M., and *Nunes, L.,* 2013: Homogeneity of monthly air temperature in Portugal with HOMER and MASH. *Időjárás 117*, 69–90

HOME, 2011: Homepage of the COST Action ES0601 - *Advances in Homogenisation Methods of Climate Series: an Integrated Approach* (HOME), http://www.homogenisation.org.

Lakatos, M., Szentimrey, T., Bihari, Z., and *Szalai, S.,* 2013: Creation of a homogenized climate database for the Carpathian region by applying the MASH procedure and the preliminary analysis of the data. *Időjárás 117,* 143–158.

Menne, M.J., and *Williams Jr. C.N.*, 2005: Detection of undocumented changepoints using multiple test statistics and composite reference series. *J. Climate 18*, 4271–4286.

Péliné, N. Cs., Radics, K., and *Bartholy, J.*, 2011: Seasonal Variability of Wind Climate in Hungary. *Acta Silv. Lign. Hung. 7*, 39–48.

Szentimrey, T., 1999: Multiple Analysis of Series for Homogenization (MASH). Proceedings of the Second Seminar for Homogenization of Surface Climatological Data, Budapest, Hungary; WMO, WCDMP-No. 41, 27–46.

Szentimrey, T., 2008: Development of MASH homogenization procedure for daily data, *Proceedings of the Fifth Seminar for Homogenization and Quality Control in Climatological Databases,* Budapest, Hungary, 2006; *WCDMP-No. 68, WMO-TD No. 1434*, 116–125.

Szentimrey, T., 2011: Manual of homogenization software MASHv3.03. *Hungarian Meteorological Service*, Budapest.

Szentimrey, T., 2013: Theoretical questions of daily data homogenization, Special Issue of the COST-ES0601 (HOME) ACTION, *Időjárás 117*, 113–122.

Torma, Cs., Bartholy, J., Pongrácz, R., Barcza, Z., Coppola, E., and *Giorgi, F.,* 2008: Adaptation and validation of the RegCM3 climate model for the Carpathian Basin. *Időjárás 112*, 233–247.

Venema, V., Mestre, O., Aguilar, E., Auer, I., Guijarro, J.A., Domonkos, P., Vertacnik, G., Szentimrey, T., Stepanek, P., Zahradnicek, P., Viarre, J., Müller-Westermeier, G. Lakatos, M., Williams, C.N., Menne, M., Lindau, R., Rasol, D., Rustemeier, E., Kolokythas, K., Marinova, T., Andresen, L., Acquaotta, F., Fratianni, S., Cheval, S., Klancar, M., Brunetti, M., Gruber, C., Duran, M.P., Likso, T., Esteban, P., and *Brandsma, T.,* 2012: Benchmarking monthly homogenization algorithms. *Climate of the Past 8*, 89–115.

World Meteorological Organization, 2011: Guide to Climatological Practices, WMO/No. 100, Geneva.