AIDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 117, No. 1, January–March 2013, pp. 143–158

Creation of a homogenized climate database for the Carpathian region by applying the MASH procedure and the preliminary analysis of the data

Mónika Lakatos[1]*****, **Tamás Szentimrey**[1], **Zita Bihari**[1], and **Sándor Szalai**[2]

[1]*Hungarian Meteorological Service,*
P.O. Box 38, H-1525 Budapest, Hungary

[2]*Department on Soil Sciences and Agrochemistry,*
Szent István University,
Páter Károly utca 1, H-2100 Gödöllő, Hungary

**Corresponding author E-mail:lakatos.m@met.hu*

(Manuscript received in final form December 12, 2012)

Abstract–Homogenization of the long term observation series is essential in climate change studies. The most important achievements of the COST Action ES0601 (HOME) are survey and the comparison of the available homogenization methods. A benchmark test was performed in the Action to choose the best recent methods. The MASH (Multiple Analysis of Series for Homogenization; Szentimrey) procedure which was developed at the Hungarian Meteorological Service (OMSZ) produced good results. The Short Term Scientific Missions (STSMs) supported by the COST established the wide usage of MASH in the neighboring countries. This is the main reason why MASH became the common homogenization method used to fulfil the Climate of the Carpathian Region tender service. The aim of the project is to improve the climate data source and data access in the Carpathian Region by creating a daily harmonized gridded dataset during the period between 1961 and 2010. The homogenization process executed and the verification of the homogenization along with the quality control results are introduced in this paper. Preliminary results of trend analysis carried out on the harmonized database are also presented.

Key-words: COST Action ES0601, homogenization, Climate of the Carpathian Region Project, climate indices

1. *Introduction*

Climate change is expected to result in significant changes in the Carpathian region to affect ecosystems and human activities *(UNEP, 2007)*. Investigation of the recent tendencies in the regional climate conditions is essential for coping with the consequences. It is essential that studying the spatio-temporal changes can be implemented through the analysis of the observations which are representative both in time and space. Climate change studies require long term, quality controlled, homogenized, high quality climate data series.

The COST (European Cooperation in Science and Technology) Action ES0601 titled "Advances in homogenization methods of climate series: an integrated approach (HOME)" focused on investigation of the homogenization methods and testing the recent used applications. Hungary contributed to the success of the COST HOME action with the experiences of the MASH (Multiple Analysis of Series for Homogenization; *Szentimrey*, 2011) homogenization procedure, which was developed at the Hungarian Meteorological Service. The main features of MASH are illustrated in this paper by its application in the framework of the "Climate of the Carpathian Region Project" (CarpatClim).

As result of a Hungarian initiative on creation a high quality dataset covering the Carpathian basin, the JRC (European Commission Joint Research Centre) Institute for Environment and Sustainability launched a tender call in 2010 for supplying the data demand of its Desert Action activity (*JRC*, 2010). The consortium lead by the Hungarian Meteorological Service together with 10 partner organizations from 9 countries in the Carpathians region is supported by the Joint Research Centre.

The main aim of the CarpatClim project is to improve a joint climate data source and data access in the Carpathian region for application such kind of regional climate studies like drought monitoring. The CarpatClim project investigates fine temporal and spatial structures of the climate in the Carpathian Mountains and the Carpathian basin with unified methodology. The results are 0.1°(~10 × 10 km) resolution gridded daily time series of various meteorological parameters from 1961 to 2010. The target area is partly includes the territory of Czech Republic, Slovakia, Poland, Ukraine, Romania, Serbia, Croatia, Austria, and Hungary (*Fig. 1*). Uniform process of data homogenization is crucial due to the fact that significant differences might be occurred between the measurements and data handling of participant countries during the examined fifty-year-long period.

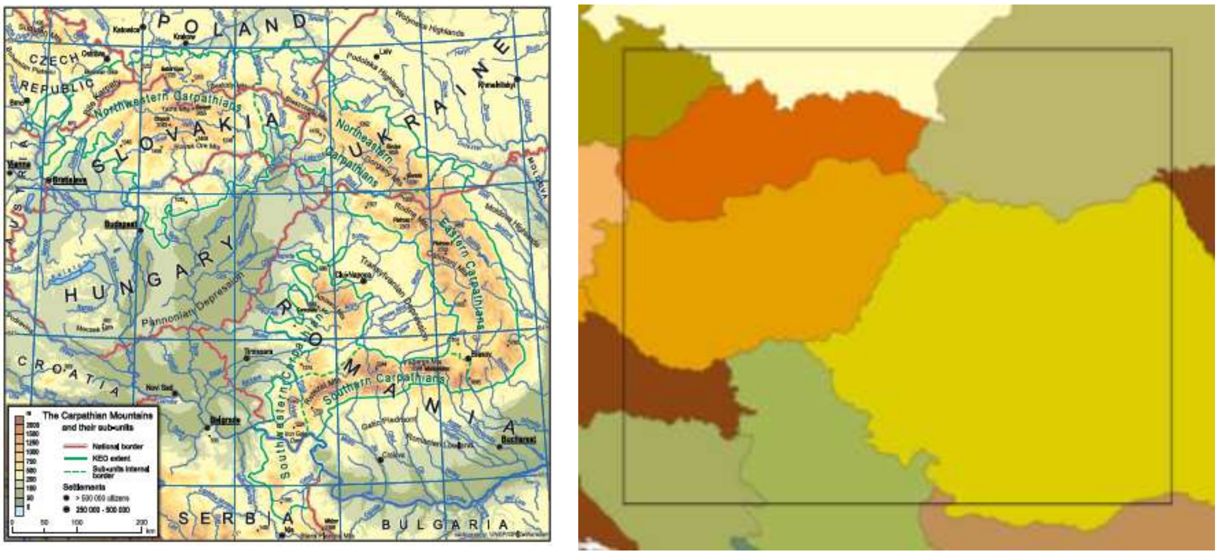

Fig. 1. The target area of the CarpatClim between latitudes 50°N and 44°N, and longitudes 17°E and 27°E approximately (left), and the political boundaries (right).

The project plan consists of three modules. Module 1 focuses on improving the availability and accessibility of homogeneous and spatially representative time series of climate data for the Carpathian Region through data rescue, quality control, and data homogenization. The activities in Module 2 ensure data harmonization with special emphasis on cross-border harmonization and production of gridded values for each country. A digital Climate Atlas as a basis for climate assessment and further applied climatological studies are developed in Module 3. The final outcome of the CarpatClim are the quality controlled, homogenized, in-situ daily time series and gridded data per country and the whole region as well, including a metadata catalogue with the documentation of the existing homogenized datasets. The daily grids with the metadata will be freely accessible for scientific purposes.

The consortium members agreed that the commonly used method for data homogenization and quality control in the project will be the MASH procedure. Using MASH is advantageous, because the COST HOME Action monthly benchmark results denoted that the MASH is one of the best monthly homogenization methods (*Venema et al*, 2012). Furthermore, several COST HOME delegates from the Carpathian region became familiar with the MASH software during STSMs supported by the COST.

The CarpatClim project is a well-accomplished cooperation for applying a single homogenization method in a region fragmented by boundaries and a pioneer work for countervailing against differences in measuring practice and strict data policies. The main features of MASH and the steps of the homogenization process along with the evaluation of the homogenization performed in Module 1 are presented in this study.

2. Methodology

The original MASH (*Szentimrey*, 1999) procedure was developed for homogenization of monthly series. The present version: MASHv3.03 (*Szentimrey*, 2011) has been expanded for daily series as well. The main features of the applied procedure to fulfil the tender service are summarized here**.**

The MASHv3.03 (*Szentimrey*, 2011) software consists of two parts.
Part 1: Quality control, missing data completion, and homogenization of monthly series:

- Relative homogeneity test procedure.
- Step by step procedure: the role of series (candidate or reference series) changes step by step in the course of the procedure.
- Additive (e.g., temperature) or multiplicative (e.g., precipitation) model can be used depending on the climate elements.
- Providing the homogeneity of the seasonal and annual series as well.
- Metadata (probable dates of break points) can be used automatically.
- Homogenization and quality control (QC) results can be evaluated on the basis of verification tables generated automatically during the procedure.

Part 2: Homogenization of daily series:

- Based on the detected monthly inhomogeneities.
- Including quality control (QC) and missing data completion for daily data. The quality control results can be evaluated by test tables generated automatically during the procedure.

These attributes are favorable to achieve the project goals in CarpatClim. The time resolution of variables is daily, the upgraded version of MASH is able to homogenize and control these daily data as well. Certain recently used daily homogenization methods take the monthly results for daily homogenization similarly to MASH (*Vincent*, 2002; *Szentimrey*, 2008). The excellent COST HOME monthly benchmark results and promising outcomes of the daily tests guarantee the high quality of times series got through the MASH procedure.

It has to underline that MASH is an automatically working software. Application of manual homogenization methods would be exceptionally labor intensive in handling huge data series. Moreover, the MASH is able to use the metadata (the date of moving of stations for example) automatically during the break point detection. This facility allows the effective usage of the existing metadata. We note that metadata were not used in CarpatClim.

Furthermore, the test results of the homogenization and quality control (e.g., detected errors, degree of inhomogeneity of the series system, number of break points, estimated corrections, and certain verification results) are documented in automatically generated tables during the homogenization process. Summary results of quality control and the homogenization performed in the project can be followed up and reported based on these tables. Verification statistics can be added to the homogenized series as the newly created metadata.

3. Homogenization process in the CarpatClim

The tasks in Module 1 are the data rescue, the digitization of the analogue datasets of climate observations, quality checking, including the data gap elimination of the existing climate time series, and homogenization of the data series. Completing the digitization of the measurements using MASHv3.03 is a proper way to perform the homogenization and the data quality control.

According to the tender specification, the elements listed in *Table 1* have to be homogenized in the period of 1961–2010. The chosen homogenization model is depending on the distribution of given element. Additive model is used except in case of precipitation and wind speed, where the appropriate model is multiplicative.

Table 1. Set of meteorological variables in daily temporal resolution to be homogenized (JRC, 2010)

Variable	**Description**	**Units**
T_a	2 m mean daily air temperature	°C
T_{min}	Minimum air temperature from 18:00 to 06:00	°C
T_{max}	Maximum air temperature from 06:00 to 18:00	°C
p	Accumulated total precipitation from 06:00 to 06:00	mm
DD	10 m wind direction	0°-360°
VV	10 m horizontal wind speed	m/s
Sunshine	Sunshine duration	hours
cc	Cloud cover	tenths
R_{global}	Global radiation	MJ/m^2
RH	Relative humidity	%
p_{vapour}	Surface vapour pressure	hPa
p_{air}	Surface air pressure	hPa

To ensure the most possible station usage, each contributor executed the necessary work phases individually. The cross border harmonization is guaranteed by bilateral data exchange. As the MASH is a relative homogenization method, the candidate series have to be compared to reference series which are in the nearby, within a given distance.

3.1. Steps of creation of the homogenized station data series in the CarpatClim

I. Compilation of the raw station data series of each country.

1. Selection of the stations (with the help of spherical coordinates: φ, λ).
2. Collecting the daily station data series (missing data are allowed) and the metadata per countries. Exchange of the near border raw data series and the existing metadata between the neighboring countries.

II. Homogenization, quality control, data completion of the station data series by MASH v3.03 on national level, using near border data.

1. Derivation of monthly station data series from the daily station data series collected in step I.2. Homogenization, quality control, data completion of the monthly station data series. Metadata (probable dates of break points) can be used automatically.
2. Daily station data series (step I.2): homogenization, quality control, data completion. This procedure is based on the results of step II.1.
3. Exchange of the near border homogenized data for cross-border harmonization and for gridding (Module 2 of the project: modeling, interpolation).
4. Evaluation of the verification results of the homogenization and quality control. Controlling of the cross-border harmonization of the data series. Note that further cross-border harmonization is achieved after the modeling part of the gridding procedure in Module 2.

Summary of the main steps of homogenization of daily data series with quality control and missing data completion in CarpatClim are as follows:

1. Monthly series derivation from daily series.
2. MASH homogenization procedure for monthly series, estimation of monthly inhomogeneities. (Metadata can be used automatically.)
3. Smooth estimation of daily inhomogeneities on the basis of estimated monthly inhomogeneities.
4. Automatic correction of daily series.
5. Automatic quality control (QC) of homogenized daily data.

6. Automatic missing daily data completion.
7. Monthly series derivation from the homogenized, quality controlled, and completed daily data.
8. Test of homogeneity for the new monthly series with using the automatic verification results.

The original time series of the variables listed in *Table 1* were homogenized, completed, and quality controlled by the participants individually. The automatically generated verification results were gathered and reported to the supporter. The following chapter is an overview of the evaluation of the implemented homogenization process.

4. Verification of the homogenization

Validation is an essential part of the process, to make sure that the data quality increased as a result of homogenization. Hence a verification part is integrated into the MASH system for interpretation of the outcomes, it makes the evaluation of the different phases of the homogenization possible from the initial to the final stage. The basic conception of the verification test is that the confidence in the homogenization may be increased by the joint comparative mathematical examination of the original and the homogenized data series.

Two types of outcomes of the MASH software can be separated. The first type of output is the files containing the homogenized, controlled, and completed series, inhomogeneity series, detected breaks, and detected errors. The second type of output is the files containing the test results and verification tables in order to evaluate the homogenization. The verification tables contain the test statistics values before and after homogenization, measures to characterize the modification of series, the spatial representativity of the station network, and the evaluation of metadata. The quality control results for the daily data are also included.

The verification procedure based on hypothesis test results. The null hypothesis is that examined series are homogeneous. The test statistics can be compared to the critical value before and after homogenization. The critical values belong to different significance levels are built in the MASH software (it is 20.86 on the 0.05 significance level in our case). The homogenization is successful if the test statistics after homogenization is low. The theoretical background and more details of the derivation of the verification statistics can be found in MASH manual (*Szentimrey*, 1999).

The test statistics before (TSb) and after homogenization (TSa) and characteristics of the modified series are presented in this paper. Annual statistics are examined here; though all of them are produced automatically on the monthly and seasonal scales altogether. *Tables 2* to *4* contain the average measures for maximum and minimum temperatures and precipitation for each of the station systems and the QC results alike. Number of the partners in the header lines is as follows: Hungary and Croatia with their jointly handled dataset (1), Serbia (2), Romania (3), Ukraine (4), Slovakia (5), Poland (6), Czech Republic (7). The representativity is about 50 km for climate stations and 25 km for precipitation stations, respectively. Participants have contributed to the project with data of 415 climate stations and 904 precipitation stations in all.

The TSa has to be near to the critical value or much less than the TSb if the homogenization is acceptable. Moreover, the measures of the relative modification are expected to be in accordance with the relative change of the test statistics: (TSb-TSa)/TSb. The applied statistics for the measure of the relative modification is in fact the ratio of the RMSE (root mean square error) and the standard deviation. If the significant modification of series induces weak decreasing in the degree of inhomogeneity, overdrawing the series is unnecessary and erroneous. *Tables 2–4* containing the summary statistics and the complementary diagrams in *Figs. 2–4* support the evaluation of homogenization.

The degree of inhomogeneity of the raw minimum temperatures *(Table 3.)* is substantially higher for Serbia (2) and much higher for the Hungarian and Croatian (1) dataset than in case of the maximum temperatures. The relative modification (42%) for the Hungarian and Croatian (1) series is achieved the most, although the largest improvement (*Fig. 3*.). The Serbian (2) system has been upgraded in the same rate by less relative modification. The Slovakian (5) system is near to homogeneous after processing. Relative changes of the test statistics are small in the Romanian (3) and Ukrainian (4) series, in accordance with the low value of relative modification. At the Czech Republic (7), the degree of homogeneity increased with relatively high modification. It can be found that MASH reduced the inhomogeneity of all systems, but less than in the case of maximum temperatures. The QC results relating the minimum temperatures show that the number of erroneous data per station is the largest in the Ukrainian (4) system. The Romanian (3) and Ukrainian (4) series contained more than 400 (°C) negative error and almost 100 (°C) positive errors in the data. The smallest correction has to be performed in the Czech (7) system, although it is a minor system with 18 stations.

Table 2. Average test statistics and quality control (QC) results for maximum temperature

Maximum temperature							
No. of station system	1	2	3	4	5	6	7
Number of stations	68	39	140	53	59	38	18
Verification results of homogenization							
TS after homog. (TSa)	23.6	55.7	39.0	23.7	26.4	24.8	26.7
TS before homog. (TSb)	190.7	186.2	72.9	154.0	175.6	150.6	184.3
Relative modification (%)	21	14	9	13	23	21	29
Quality control results							
Total number of errors	6307	3811	10241	5444	4542	3288	1400
Maximal positive error (°C)	10.9	13.5	996.6	107.7	11.3	22.7	10.4
Minimal negative error (°C)	–2.3	–7.5	–21.0	–22.0	–14.5	–26.3	–6.2

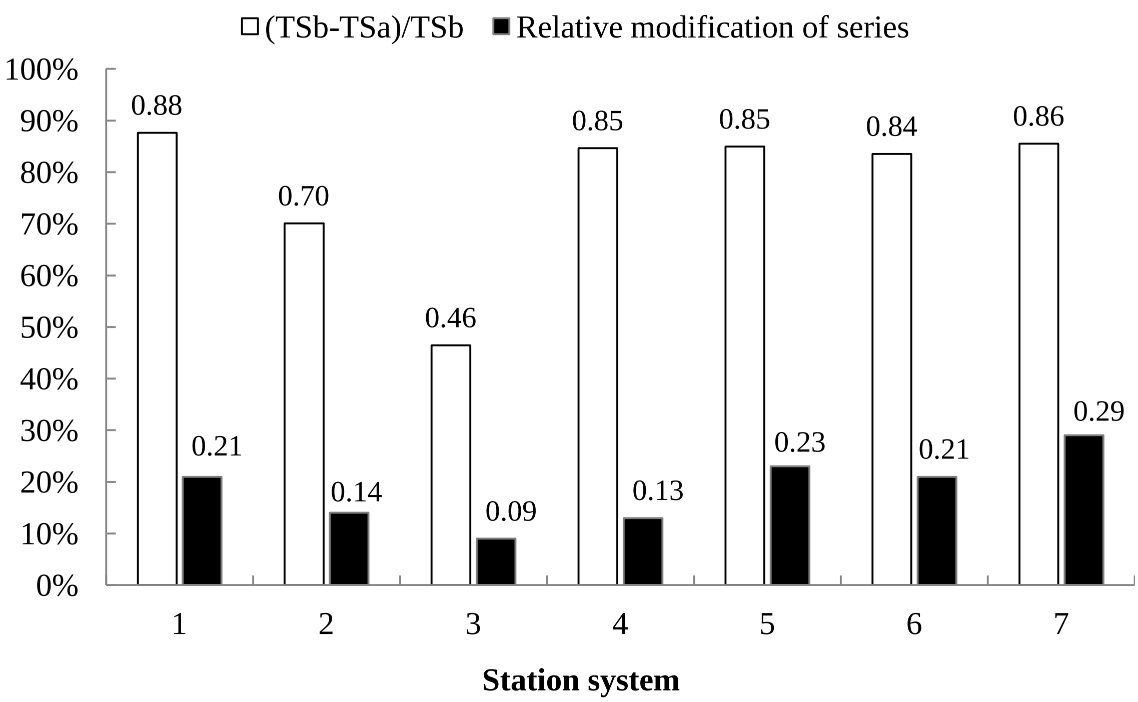

Fig. 2. Verification results for maximum temperature.

Table 3. Average test statistics and quality control (QC) results for minimum temperature

Station Sytem	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Number of stations	68	39	140	53	59	38	18
TS after homog. (TSa)	24.3	52.5	52.5	51.9	28.5	43.5	37.8
TS before homog. (TSb)	227.5	484.7	128.3	120.3	179.7	141.3	93.9
Relative modification (%)	42	28	14	13	22	23	21
Total number of errors	4110	2161	6689	4111	3197	2592	375
Maximal positive error (°C)	23.7	11.8	95.1	79.3	14.9	15.9	0.7
Minimal negative error (°C)	–9.7	–8.0	–416.6	–417.6	–9.9	–10.0	–1.1

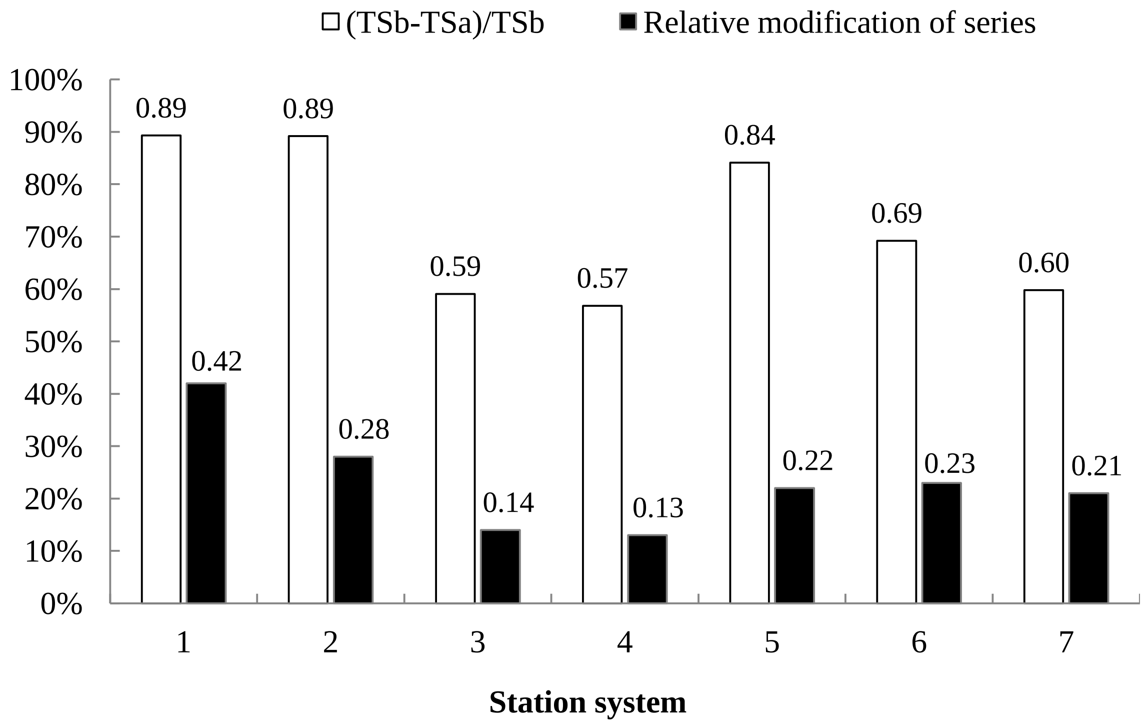

Fig. 3. Verification results for minimum temperature.

Analyzing the precipitation results, we have to take into consideration that the MASH procedure carefully detects the break points. Lower inhomogeneity arose for the precipitation series than for temperatures *(Table 4)*. During the homogenization, all of the networks became more homogeneous; nevertheless, the modification was precautious. The test statistics indicates that the Polish (6) system was the most inhomogeneous, and the improvement is also little afterward, although the similar relative modification caused higher improvement than in the Romanian (3) system *(Fig. 4.)*. The Slovakian (5) dataset passed through the most advance, at the expense of remarkable modifications of the series comparing to the others. Resulting from the QC numerous errors were detected, about in the rate of the amount of contributed stations. The amplitude of the errors in several systems is higher towards extremely heavy precipitations.

Table 4. Average test statistics and quality control (QC) results for precipitation

Station sytem	1	2	3	4	5	6	7
Number of stations	233	114	182	57	165	102	51
TS after homog. (TSa)	21.6	31.27	28.09	25.61	21.89	38.97	35.53
TS before homog. (TSb)	27.93	34.73	31.88	28.98	38.17	46.29	39.77
Relative modification (%)	4	5	6	3	10	5	4
Total number of errors	1531	672	975	313	803	408	223
Maximal positive error (mm)	71.94	230.27	10.27	179.46	94.29	93.36	60.38
Minimal negative error (mm)	23.24	–36.87	–1.52	–5.68	–59.46	–25.47	–11.41

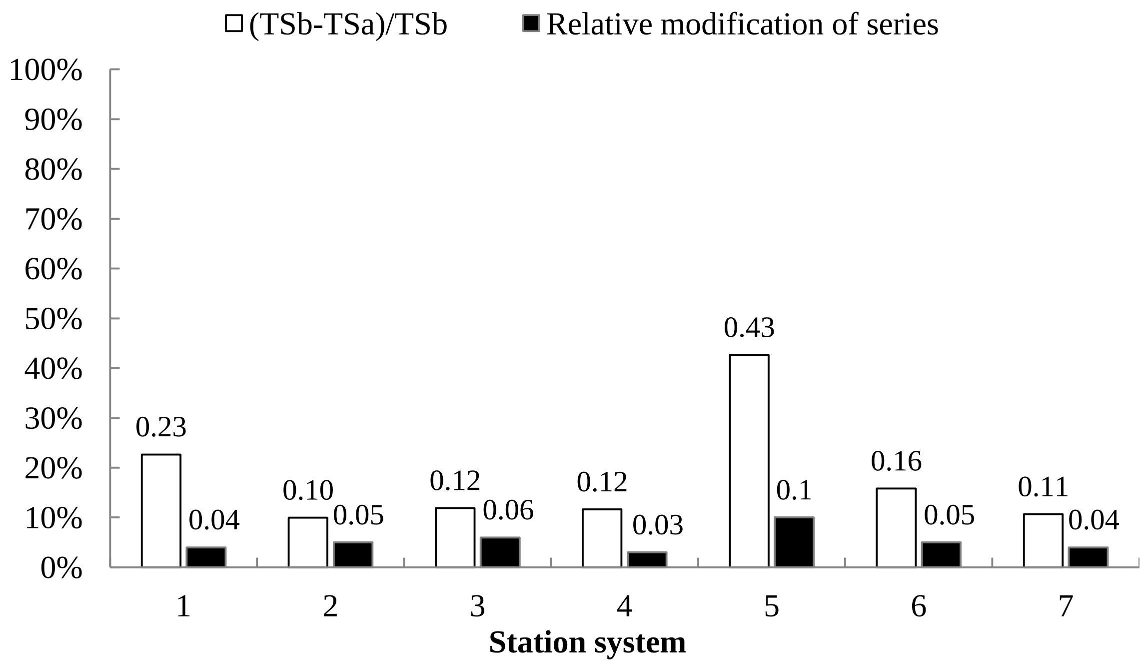

Fig. 4. Verification results for precipitation

Verification results for all the 12 elements can be followed up in the project deliverables related to the issues of the homogenization process *(D1.12)*. The data rescue and digitization activity in Module 1, and the data homogenization and QC performed by applying MASH procedure guarantee the availability of the high quality daily time series for the basic climate elements in the Carpathian region in the period of 1961–2010.

5. Analysis of the climate trends on the harmonized gridded dataset

The final outcome of the CarpatClim tender service is a ~10 × 10 km resolution gridded dataset on daily scale for elements listed in *Table 1*. Interpolation of the homogenized time series is carried out by applying the MISH (Meteorological Interpolation based on Surface Homogenized data basis; *Szentimrey* and *Bihari*, 2007) method. The MISH method was developed for interpolation of meteorological data, and an adequate mathematical background was also developed (*Szentimrey et al*., 2011) for the purpose of efficient use of all the valuable meteorological and auxiliary model information. The main difference between MISH and the usual geostatistical interpolation methods is the application of the meteorological data series for modeling. In geostatistics (*Cressie*, 1991), the sample for modeling is only the predictor data, which is a single realization in time, while in meteorology there are data series, i.e., a sample in time and space as well.

5.1. Data harmonization with the homogenized data exchange

The cross border harmonization is essential in the project to avoid breaks at the boundaries on climate maps based on the gridded data. It can be ensured by the changes of the homogenized series across the borders as it was in case of the raw data exchange. The cross border harmonization is acceptable if some improvement appears in test statistics (*D2.5*). The gridding of the harmonized series was executed on national level by applying MISH, and the merging of the separate but harmonized grid parts followed up in the end.

5.2. Trend estimation based on the created dataset

Investigation of the climate extremes, observed trends, changes in frequency and intensity could contribute to the establishment of the adaptation strategies in the region. Climate indices are used in several projects on climate change as prevailing indicators of changes in extremes. Spatial interpolation of indices values for station locations is a difficult task, as the distribution functions of the several derived values are unknown. However, the basic variables, such as temperature and precipitation can be gridded by the knowledge of their statistical properties, thus higher quality gridded datasets can be constructed for further analysis, as it was created in CarpatClim (*Lakatos et al.*, 2010). The gridded database produced in daily temporal resolution provides relevant outcomes for studying extremes.

One temperature and one precipitation index was chosen to show the first results of the trend analysis based on the high quality dataset covering the region. These are the number of hot days per year (daily maximum ≥ 30 °C) and the number of days with heavy rainfall (daily precipitation amount > 20 mm).The changes obtained from the linear trend estimation are demonstrated on the grid defined in the specification (*JRC*, 2010). The maps indicate the changes in the examined period, i.e., the slope of the estimated linear trend multiplied with the length of the changing period.

Fig. 5 strengthens the warming trend in the entire region. The changes are in strong correspondence with the orography. The growth is less at higher mountains than at lower altitudes. More hot days occur in the basin, especially in the territory between Danube and Tisza rivers, by 18–22 days from 1961 to 2010. The Transylvanian basin shows fewer rises. The region is lying under the south and east Carpathians turned up the largest growing in the number of hot days (over 24) during the examined period.

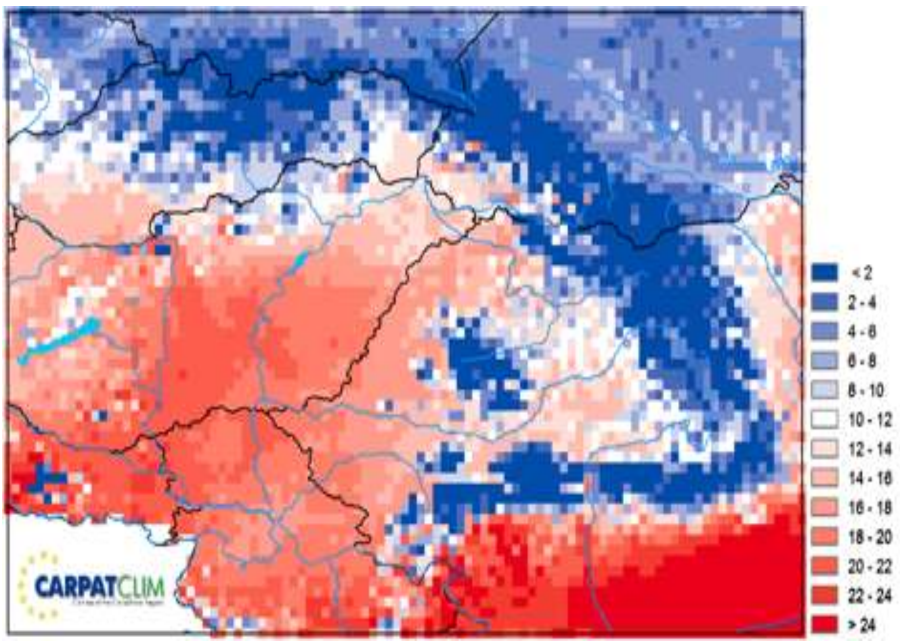

Fig. 5. Change in the number of hot days per year (daily maximum ≥ 30 °C) in the Carpathian region in the period of 1961–2010.

Fig. 6 visualizes the changes in the days above 20 mm precipitation during the whole 50 years period. The estimated changes indicated varied spatial distribution. The topographical effects are not so evident than in hot day's changes. The changes are between –2 and 3 days in the extended area of the region. More intense decreasing or increasing was found mostly on small territories. The highest increase was indicated in the northeast Carpathians and the Bihor Mountains with 7 days.

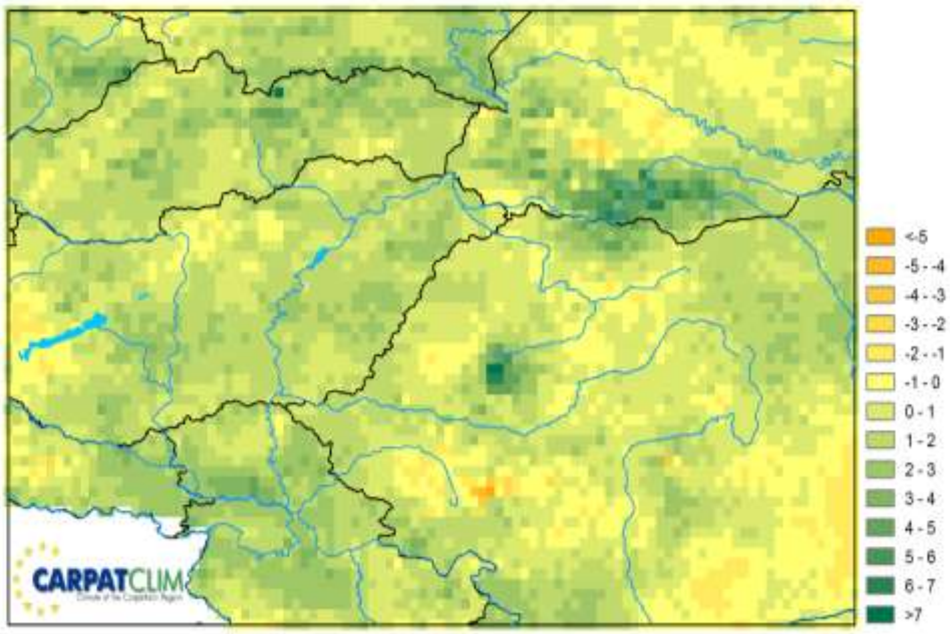

Fig. 6. Change in the number of days with heavy rainfall (daily sum > 20 mm) in the Carpathian region during the period from 1961 to 2010

6. Conclusion

The COST HOME Action had drawn the attention to the importance of data homogenization and recent methods. The monthly benchmark results of COST HOME denoted that MASH is one of the best monthly homogenization methods. The COST participants from the Carpathian region started the work with MASH during the STSMs supported by the COST. These STSMs established a common project for creating a homogenized dataset covering the region.

There are many advantageous attributes of MASH. Due to the automatic execution it allows performing the data homogenization, quality control, and data completion for the entire Carpathian region within a reasonable time. The MASH was used for numerous stations, 1319 climate and precipitation stations together, and 12 elements for a fifty-year long period in the Climate of the Carpathian Region tender service. The consortium members implemented the homogenization separately by the common procedure. The cross border harmonization was guaranteed by near border data exchange. The automatically generated verification results presented in this paper confirm that the quality of the data highly improved during the homogenization and quality control procedure.

The Climate of the Carpathian Region Project contributes to the availability of a set of homogeneous and spatially representative data to prepare climate change studies relevant in the region. The warming trend is obvious on the harmonized, gridded data in the period of 1961–2010 as indicated from the preliminary trend analysis. The changes in the number of days with precipitation above 20 mm show significant decrease or increase only on small areas of the region in the examined 50-year long period.

Acknowledgements–This work was supported by the COST (European Cooperation in Science and Technology) Action ES0601 titled "Advances in homogenization methods of climate series: an integrated approach (HOME)" (2007–2011) and by JRC Desert Action in the framework of the "Climate of the Carpathian Region (CarpatClim)" Project. The authors take this opportunity to thank the following members of the CarpatClim Homogenization and Interpolation Group for data homoginization:
Austria: Ingeborg Auer, Johann Hiebl
Croatia: Janja Milković
Czech Republic: Pavel Zahradníček, Petr Štěpánek, Radim Tolasz
Hungary: Tamás Szentimrey, Zita Bihari, Mónika Lakatos, Tamás Kovács, Ákos Németh, Sándor Szalai
Poland: Piotr Kilar, Robert Pyrc, Danuta Limanowka
Romania: Sorin Cheval, Monica Matei
Serbia: Dragan Mihic, Predrag Petrovic, Tatjana Savic
Slovakia: Peter Kajaba, Gabriela Ivanakova, Oliver Bochnicek, Pavol Nejedlik, Pavel Šastný
Ukraine: Oleg Skrynyk, Yurii Nabyvanets, Natalia Gnatiuk,
and Annamari Marton for depection of maps.

References

Cressie, N., 1991: Statistics for Spatial Data. Wiley, New York.

D1.12: Final report on quality control and data homogenization measures applied per country, including QC protocols and measures to determine the achieved increase in data quality. http://www.carpatclim-eu.org/pages/deliverables/

D 2.5: Report with final results of the data harmonization procedures applied, including all protocols, per country. http://www.carpatclim-eu.org/pages/deliverables/

JRC, 2010: Climate of the Carpathian Region. Technical Specifications (Contract Notice OJEU 2010/S 110-166082 dated 9 June 2010). http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=550

Lakatos, M., *Szentimrey, T.*, and *Bihari, Z.*, 2010: Application of gridded daily data series for calculation of extreme temperature and precipitation indices in Hungary. *Időjárás 115*, 99–109.

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. and *Bihari, Z.*, 2007: Mathematical background of the spatial interpolation methods and the software MISH (Meteorological Interpolation based on Surface Homogenized Data Basis). Proceedings from the Conference on Spatial Interpolation in Climatology and Meteorology, Budapest, Hungary, 2004, COST Action 719, COST Office, 17–27.

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, 2006; WCDMP-No. 71, WMO/TD-NO. 1493, 2008, 123–130.

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

Szentimrey, T., Bihari, Z., Lakatos, M., and *Szalai, S.*, 2011: Mathematical, methodological questions concerning the spatial interpolation of climate elements. Proceedings from the Second Conference on Spatial Interpolation in Climatology and Meteorology, Budapest, Hungary, 2009, Időjárás 115, 1–2, 1–11.

UNEP, 2007: Carpathians Environment Outlook. Geneva. http://www.grid.unep.ch.

Venema, V., Mestre, O., Aguilar, E., Auer, I., Guijarro, J.A., Domonkos, P., Vertacnik, G., Szentimrey, T., Štěpánek, 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.

Vincent, LA, Zhang, X, Bonsal, BR, and *Hogg, WD.*, 2002: Homogenization of daily temperatures over Canada. *J. Climate 15***,** 1322–1334.