Multiple Analysis of Series for Homogenization

(M A S H v3.02)

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PREFACE of Version MASHv3.02

The MASH procedure was developed originally for homogenization of monthly series. It is a relative method and depending on the distribution of examined meteorological element additive (e.g. temperature) or multiplicative (e.g. precipitation) model can be applied. In the earlier program system MASHv2.03 the following subjects were elaborated for monthly series: series comparison, break point (changepoint) and outlier detection, correction of series, missing data complementing, automatic usage of meta data and last but not least a verification procedure to evaluate the homogenization results.

The next version MASHv3.01 was developed for homogenization of daily data furthermore for quality control of daily data and missing data complementing. During the procedure normal distribution and additive model were assumed for daily data that are appropriate for temperature, pressure etc. elements.

The new version MASHv3.02 is extended also for homogenization of daily precipitation data. The procedure developed for daily data is in accordance with the multiplicative (or cumulative) model that is assumed for monthly precipitation sum data. Quality control of daily data and missing data complementing are also performed during the procedure.

Remark 1

The program system for homogenization of monthly series was not changed so the manual of MASH2.03 can be used invariably (pages 1-52). Only exception is the type of usable coordinates that were changed for filambda type, because perhaps it is more general (see pages: 24, 29, 35, 43). The structure of program system (page 21) is completed with the daily data part. The description of procedure for daily data can be found from page 53.

Remark 2

In the Annex (page 64) some new developments for automation are enclosed. These ‘user friendly’ procedures make the homogenization easier for the users.

PREFACE of Version MASHv2.03

The MASH method was developed in the Hungarian Meteorological Service (see References). It is a relative homogeneity test procedure that does not assume the reference series are homogeneous. Possible break points and shifts can be detected and adjusted through mutual comparisons of series within the same climatic area. The candidate series is chosen from the available time series and the remaining series are considered as reference series. The role of series changes step by step in the course of the procedure. Depending on the climatic elements, additive or multiplicative models are applied. The second case can be transformed into the first one by logarithmization.

Several difference series are constructed from the candidate and weighted reference series. The optimal weighting is determined by minimizing the variance of the difference series, in order to increase the efficiency of the statistical tests. Providing that the candidate series is the only common series of all the difference series, break points detected in all the difference series can be attributed to the candidate series.

A new multiple break points detection procedure has been developed which takes the problem of significance and efficiency into account. The significance and the efficiency are formulated according to the conventional statistics related to type one and type two errors, respectively. This test obtains not only estimated break points and shift values, but the corresponding confidence intervals as well. The series can be adjusted by using the point and interval estimates.

Since a MASH program system has been developed for the PC, the application of this method is relatively easy, with emphasis on GAME of MASH (see program MASHGAME.BAT), which is a playful version of MASH procedure for homogenization. This version can be developed towards the automation (see program MASHGAUT.BAT).

Some developments are connected with special problems of the homogenization of climatic time series.

One of them is the relation of monthly, seasonal and annual series. The problem arises from the fact, that the signal to noise ratio is probably less in case of monthly series than in case of derived seasonal or annual ones. Consequently the inhomogeneity can be detected easier at the derived series although we intend to adjust the monthly series (see the SAM system).

Another problem is connected with the usage of Meta Data in the course of homogenization procedure. The developed version of MASH system makes possible to use the meta data information - in particular the probable dates of break points - automatically.

The new version includes a new transformation procedure as well, which has been developed for the multiplicative model on purpose to solve the problem arising from the values coming near to zero.

A new part of MASH system is a verification procedure (MASHVERI.BAT) which makes possible to evaluate the actual or the final stage of the homogenization. We think the verification is an important part of the topic of homogenization since all over the world there are a lot of so called homogenized series however their reliability sometimes is doubtful. The basic conception of the verification procedure is that the confidence in the homogenized series may be increased by the joint comparative mathematical examination of the original and the homogenized series systems.

The last development is connected with certain automation of the procedures (see programs: MASHGAUH.BAT, SAMTEST.BAT).

(MOTTO)

PROBLEM of HOMOGENIZATION

Basis: DATA

Tools:

MATHEMATICS : abstract formulation

META DATA : historical, climatological information

SOFTWARE : automation

SOLUTION = MATHEMATICS + META DATA + SOFTWARE

(i) without SOFTWARE:

MATHEMATICS + META DATA = THEORY WITHOUT BENEFIT

(ii) without META DATA:

MATHEMATICS + SOFTWARE = GAMBLING

(iii) without MATHEMATICS:

META DATA + SOFTWARE = "STONE AGE" + "BILL GATES"

BASIC PRINCIPLES of MASH Procedure

- 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 or cumulative model can be used depending on the climate elements.

- Monthly, seasonal or annual time series can be homogenized.

- In case of having monthly series for all the 12 months, the monthly, seasonal and annual series can be homogenized together.
(SAM procedure: Seasonal Application of MASH)

- The daily inhomogeneities can be derived from the monthly ones.

- META DATA (probable dates of break points) can be used automatically.

- The actual or the final stage of the homogenization can be verified.

PROGRAMMED STATISTICAL PROCEDURE
(SOFTWARE: MASHv2.03)

EXAMPLE. Let us assume that there is a difficult stochastic problem.

In case of having relatively few statistical information:

- an intelligent man is possibly able to solve the problem, but it is time-consuming;

- the solution of the problem can not be programmed.

In case of increasing the amount of statistical information:

- one is unable to discuss and evaluate all the information,

- but then the solution of the problem can be programmed. (CHESS!!)

AIM, REQUIREMENT

- Development of mathematical methodology in order to increase the amount of statistical information.

- Development of algorithms for optimal using of both the statistical and the 'meta data' information.

THE MAIN CLIMATOLOGICAL AND STATISTICAL PROBLEMS

Modelling of the stochastic relationship between data series:
additive model, cumulative (multiplicative) model depending on climate elements,
distribution of series elements.

Modelling of "inhomogeneity": break points, shifts, outliers etc..

Comparison of the examined series (Relative Test): methods for multiple comparison of the candidate series with more reference series; selection for "good" reference series systems, weighting of reference series, estimation of weighting factors. ***Multiple Comparison by Optimum Interpolation.***

Missing values: methods for closing gaps in the series.

Break points detection:
mathematical formalization according to the statistical conventions:
- first kind error (significance)
- second kind error (efficiency),

point estimation and interval estimation (confidence interval),
procedure for multiple break points and outliers detection.

Correction (adjusting) of candidate series:
separation of the detected break points and outliers for the candidate series,
point estimation, interval estimation (confidence interval) for the shifts.

Relation of monthly series, seasonal series, annual series:
SAM (Seasonal Application of MASH).

Meta Data: automatic using of station history.

Automation: interactive, automatic procedures for homogenization.

Verification: procedure to evaluate the homogenization results.

I. THE MATHEMATICAL BASIS OF 'MASH' PROCEDURE

(draft version)

1. STATISTICAL MODELLING

1.1 Additive Model (for example temperature)

Examined series

$$X_j(t) = C_j(t) + IH_j(t) + \varepsilon_j(t) \qquad (j = 1,2,\ldots,N\,;\ t = 1,2,\ldots,n)$$

C : climate change; IH : inhomogeneity, ε : noise

1.2 Multiplicative Model (for example monthly or seasonal precipitation)

Examined series

$$X_j^*(t) = C_j^*(t) \cdot IH_j^*(t) \cdot \varepsilon_j^*(t) \qquad (j = 1,2,\ldots,N\,;\ t = 1,2,\ldots,n)$$

C^* : climate change; IH^* : inhomogeneity, ε^* : noise

Logarithmization for Additive Model

$$X_j(t) = C_j(t) + IH_j(t) + \varepsilon_j(t) \qquad (j = 1,2,\ldots,N\,;\ t = 1,2,\ldots,n)$$

where

$$X_j(t) = \ln X_j^*(t) \quad , \quad C_j(t) = \ln C_j^*(t) \ ,$$

$$IH_j(t) = \ln IH_j^*(t) \quad , \quad \varepsilon_j(t) = \ln \varepsilon_j^*(t)$$

Problem

If $X_j^*(t)$ values are near or equal to 0.

This problem can be solved by a Transformation Procedure which increases slightly the little values. Consequently the Multiplicative Model can be transformed into the Additive One.

2. MULTIPLE COMPARISON OF THE EXAMINED SERIES

Candidate series and its inhomogeneity: $X_c(t)$, $IH_c(t)$ $\quad c \in \{1, 2, ..., N\}$

Set of indexes of reference series: $R_c \subset \{1, 2, ..., N\}$ $\left(i \in R_c \quad \text{,if } C_i(t) \approx C_c(t) \right)$

Optimal Difference Series belonging to the subset $R_c^{(m)} \subseteq R_c$ $(m = 1,..,2^{|R_c|} - 1)$
($|\;|$: numerosity)

$$Z_c^{(m)}(t) = X_c(t) - \sum_{i \in R_c^{(m)}} w_i \cdot X_i(t), \quad \text{where} \quad \sum w_i = 1 \;, \quad w_i \geq 0$$

and $\quad V(Z_c^{(m)}) = \text{Variance } (Z_c^{(m)}) = \underset{w}{\text{minimum}}$

Result:

$$Z_c^{(m)}(t) = IH_c(t) - \sum_{i \in R_c^{(m)}} w_i \cdot IH_i(t) + \delta_c^{(m)}(t) = IH_c(t) - IH_{R_c^{(m)}}(t) + \delta_c^{(m)}(t)$$

Example:

If $V(Z_c^{(m)}) = \text{Variance}(\delta_c^{(m)}) = 0$ and $IH_{R_c^{(m)}}(t) \equiv 0$ then $Z_c^{(m)}(t) \equiv IH_c(t)$

Optimal Difference Series System: $Z_c^{(m)}(t)$, $m \in \mathrm{M}^* \subset \left\{ 1,....,2^{|R_c|} - 1 \right\}$, $|\mathrm{M}^*| \geq 2$

(i) $Z_c^{(m)}(t)$: Optimal Difference Series belonging to subset $R_c^{(m)}$ (for efficiency)

(ii) $\bigcap_{m \in \mathrm{M}^*} R_c^{(m)} = \varnothing$ (for identification of inhomogeneity of candidate series)

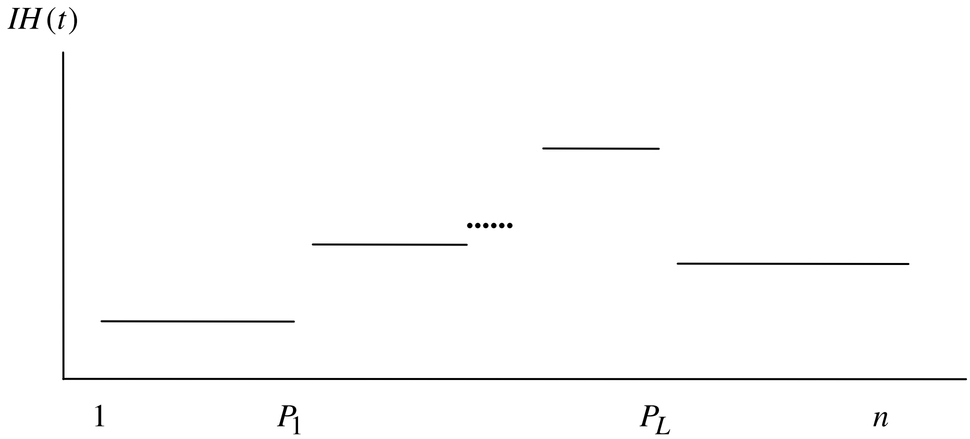
(iii) $\underset{m \in \mathrm{M}^*}{\text{maximum}} \left(\text{Variance}(Z_c^{(m)}) \right) = \underset{\mathrm{M}^*}{\text{minimum}}$ (for efficiency)

(iv) If (i), (ii), (iii) are fulfilled then let $|\mathrm{M}^*|$ be minimal too! (for efficiency)

3. EXAMINATION OF DIFFERENCE SERIES

3.1 Break Points Detection

Difference series: $Z(t) = IH(t) + \delta(t)$ $\quad (t = 1,2,\dots,n)$



<u>The real break points (to the left)</u> : $\{1 \le P_1 < P_2 < \dots < P_L < n\}$

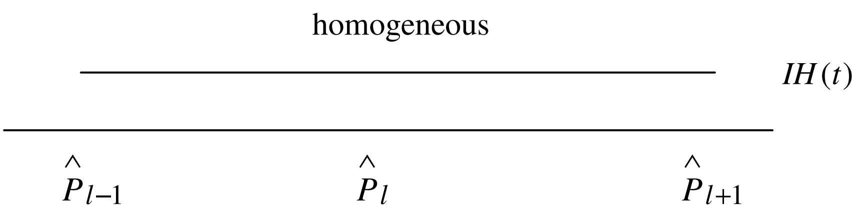
<u>BASIC POSTULATES FOR THE DECISION METHODS (FORMALIZATION)</u>

The detected break points: $\left\{ 1 \le \hat{P}_1 < \hat{P}_2 < \dots < \hat{P}_{\hat{L}} < n \right\}$

(i) <u>Type one error (significance)</u>

There exists such a $\hat{P}_l$:

interval $(\hat{P}_{l-1}, \hat{P}_{l+1}) \cap$ set$\{P_1 < P_2 < \dots < P_L\} = \varnothing$



We have to intend to give the probability of type one error, i.e. the significance level!

(ii) <u>Type two error (efficiency)</u>

There exists such a real break point that we could not detect. As much as possible!

3.2 Significant Procedure for Break Points Detection

Inhomogeneity measure for all the intervals

Statistics: $\mathrm{INH}([k, l]) \geq 0 \qquad \forall\ k, l\ :\ 1 \leq k < l \leq n$

and $\mathrm{INH}([i, j]) \leq \mathrm{INH}([k, l])$, if $[i, j] \subseteq [k, l]$

Test Statistic of difference series

The inhomogeneity of difference series $Z(t)$ can be characterized by the

Test Statistic: TS = $\mathrm{INH}([1, n])$

The critical value (α) (by Monte Carlo Method)

$$\mathrm{P}(\ \mathrm{TS} > \alpha \quad | \quad \text{if } Z(t) \text{ homogeneous}\ ) = \text{sig. level} \ (= 0.1, 0.05, 0.01)$$

Test Statistic can be compared to the critical value and in case of homogeneity it should be less, on the given significance level.

PROPERTIES OF THE DETECTING PROCEDURE

(FOR THE PURPOSE OF SIGNIFICANCE AND EFFICIENCY)

If the detected break points: $\left\{ 1 \leq \hat{P}_1 < \hat{P}_2 < ..... < \hat{P}_{\hat{L}} < n \right\}$, then

$$\underset{l=1,...,\hat{L}+1}{\text{maximum}} \left(\mathrm{INH}\left((\hat{P}_{l-1}, \hat{P}_l\,] \right) \right) \leq \alpha < \underset{l=1,...,\hat{L}}{\text{minimum}} \left(\mathrm{INH}\left((\hat{P}_{l-1}, \hat{P}_{l+1}] \right) \right)$$

i.e. on the given significance level:

- the intervals $(\hat{P}_{l-1}, \hat{P}_{l+1}]$ are not homogeneous, consequently the detected break points $\hat{P}_l$ are not superfluous,
- the intervals $(\hat{P}_{l-1}, \hat{P}_l]$ can be accepted to be homogeneous.

Confidence Intervals

Confidence intervals also can be given for the break points on the confidence level (1-sig. level): $\mathrm{I}_l \qquad l = 1,....,\hat{L}$

3.3 Estimation of Shifts

Point estimation; Confidence intervals for the shifts

4. EVALUATION OF HOMOGENEITY OF CANDIDATE SERIES $X_c(t)$

Based on the Test Statistics (TS) belonging to the Optimal Difference Series:

$$Z_c^{(m)}(t) \qquad (m = 1,..,2^{|R_c|} - 1)$$

5. CORRECTION OF CANDIDATE SERIES $X_c(t)$

Based on the examination of the Optimal Difference Series System:

$$Z_c^{(m)}(t)\ , \quad m \in \mathrm{M}^* \subset \left\{ 1,....,2^{|R_c|} - 1 \right\} \ , \quad \left|\mathrm{M}^*\right| \geq 2$$

<u>BASIC PRINCIPLE OF BREAK POINT DETECTION FOR CANDIDATE SERIES</u>

Let us assume, that

$\hat{P}^{(m)}$ $(m \in \mathrm{M}^*)$: detected Break Points,

$\mathrm{I}^{(m)}$ $(m \in \mathrm{M}^*)$: Confidence Intervals

belonging to the Optimal Difference Series $Z_c^{(m)}(t)$ $(m \in \mathrm{M}^*)$, AND

$$\bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \neq \varnothing \qquad \text{as well as} \qquad \forall\ \hat{P}^{(m)} \in \bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)}$$

<u>DECISION</u>

The „most probable" $\hat{P}^{(m)}$ is a Break Point of the Candidate Series $X_c(t)$.

6. USING OF META DATA (Meta Data: probable dates of break points)

BASIC PRINCIPLE OF BREAK POINT DETECTION BY USING OF META DATA

Candidate series and its Meta Data:

$$X_c(t) \quad , \quad \Delta_c = \left\{ 1 \le D_1^{(c)} < D_2^{(c)} < .... < D_{K_c}^{(c)} < n \right\}$$

Optimal Difference Series System: $\quad Z_c^{(m)}(t) \;,\quad m \in \mathrm{M}^*, \quad \left|\mathrm{M}^*\right| \ge 2$

Let us assume, that

$\hat{P}^{(m)}$ $(m \in \mathrm{M}^*)$: detected Break Points,

$\mathrm{I}^{(m)}$ $(m \in \mathrm{M}^*)$: Confidence Intervals

belonging to the Optimal Difference Series $Z_c^{(m)}(t)$ $(m \in \mathrm{M}^*)$, AND

$$\bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \ne \varnothing \qquad \text{as well as} \qquad \forall \; \hat{P}^{(m)} \in \bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)}$$

BASIC DECISION RULE

(i) If $\quad \mathrm{Q} := \left(\bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \right) \cap \Delta_c \ne \varnothing$

The „most probable" $D^{(c)} \in \mathrm{Q}$ is a Break Point of the Candidate Series $X_c(t)$.
(Break Point: Meta Data)

(ii) If $\quad \left(\bigcap_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \right) \cap \Delta_c = \varnothing \quad$ but $\quad \left(\bigcup_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \right) \cap \Delta_c \ne \varnothing$

No Decision.

(iii) If $\quad \left(\bigcup_{m \in \mathrm{M}^*} \mathrm{I}^{(m)} \right) \cap \Delta_c = \varnothing$

The „most probable" $\hat{P}^{(m)}$ is a Break Point of the Candidate Series $X_c(t)$.
(Break Point: is not Meta Data, but „undoubtful")

7. EVALUATION OF META DATA
(Meta Data: probable dates of break points)

THE QUALITY OF META DATA CAN BE VERIFIED BY STATISTICAL TESTS!!!

For example: the problem of Missing Meta Data??

In Practice: the statistical Test Results are often verified with the Meta Data.

BUT: the question may be turned round!

<u>Examined series and their Meta Data</u>

$$X_j(t)\,,\quad \Delta_j = \left\{1 \le D_1^{(j)} < D_2^{(j)} < \ldots < D_{K_j}^{(j)} < n\right\} \qquad (j = 1,2,\ldots,N)$$

<u>Candidate series and its Meta Data:</u> $X_c(t)$, Δ_c $\qquad c \in \{1,2,\ldots,N\}$

<u>Optimal Difference Series belonging to the subset</u> $R_c^{(m)} \subseteq R_c$:

$$Z_c^{(m)}(t) = X_c(t) - \sum_{i \in R_c^{(m)}} w_i \cdot X_i(t) = \sum_{i \in R_c^{(m)}} w_i \cdot \left(X_c(t) - X_i(t)\right) = \sum_{i \in R_c^{(m)}} w_i \cdot Z_{ci}(t)$$

<u>Transformation of Difference Series</u> $Z_{ci}(t)$

$$\Delta_{c\vee i} = \Delta_c \bigcup \Delta_i = \left\{1 \le D_1^{(c\vee i)} < D_1^{(c\vee i)} < \ldots < D_{K_{c\vee i}}^{(c\vee i)} < n\right\}$$

$$\tilde{Z}_{ci}(t) = \begin{cases} Z_{ci}(t) - \bar{Z}_{ci}[1, D_1^{(c\vee i)}] & \text{,if} \quad 1 \le t \le D_1^{(c\vee i)} \\ Z_{ci}(t) - \bar{Z}_{ci}(D_{k-1}^{(c\vee i)}, D_k^{(c\vee i)}] & \text{,if} \quad D_{k-1}^{(c\vee i)} < t \le D_k^{(c\vee i)} \quad (k = 2,\ldots,K_{c\vee i}) \\ Z_{ci}(t) - \bar{Z}_{ci}(D_{K_{c\vee i}}^{(c\vee i)}, n] & \text{,if} \quad D_{K_{c\vee i}}^{(c\vee i)} < t \le n \end{cases}$$

$\bar{Z}_{ci}\langle a,b\rangle$: average of $Z_{ci}(t)$ above the interval $\langle a,b\rangle$.

<u>Transformed Optimal Difference Series belonging to the subset</u> $R_c^{(m)} \subseteq R_c$:

$$\tilde{Z}_c^{(m)}(t) = \sum_{i \in R_c^{(m)}} w_i \cdot \tilde{Z}_{ci}(t) \qquad (m = 1,..,2^{|R_c|} - 1)$$

are homogeneous if the inhomogeneities can be explained by the Meta Data!

<u>EVALUATION OF META DATA:</u> Based on the Test Statistics (TS) belonging to the Transformed Optimal Difference Series $\tilde{Z}_c^{(m)}(t)$.

8. SEASONAL APPLICATION OF MASH (SAM)

Monthly difference series: $Z^{(k)}(t)$ $\quad (k = 1,2,\ldots,K)$

Expectations and Variances: $\mathrm{E}(Z^{(k)}(t)) = IH^{(k)}(t)$, $\quad \mathrm{V}(Z^{(k)})$

Seasonal mean difference series: $\bar{Z}(t) = \frac{1}{K}\sum_{k=1}^{K} Z^{(k)}(t)$

Expectation and Variance: $\mathrm{E}(\bar{Z}(t)) = \overline{IH}(t) = \frac{1}{K}\sum_{k=1}^{K} IH^{(k)}(t)$, $\quad \mathrm{V}(\bar{Z})$

The test results after the Homogenization of monthly series

H_0: $IH^{(k)}(t) \equiv 0 \quad (k = 1,2,\ldots,K)$ can be accepted.

BUT! (sometimes) H_0: $\overline{IH}(t) \equiv 0$ can not be accepted!

The reason of the problem

The efficiency of test depends on the signal to noise ratio, and according to the test results

$$\mathrm{R}(\bar{Z}(t)) = \frac{\left|\overline{IH}(t)\right|}{\sqrt{\mathrm{V}(\bar{Z})}} > \mathrm{R}(Z^{(k)}(t)) = \frac{\left|IH^{(k)}(t)\right|}{\sqrt{\mathrm{V}(Z^{(k)})}} \approx 0 \qquad (k = 1,2,\ldots,K),$$

as a consequence of the general inequality: $\mathrm{V}(\bar{Z}) < \mathrm{V}(Z^{(k)}) \quad (k = 1,2,\ldots,K)$

Deviance series and ratios

$$Z^{(k)}(t) - \bar{Z}(t) \quad , \quad \mathrm{R}\left(Z^{(k)}(t) - \bar{Z}(t)\right) = \frac{\left|IH^{(k)}(t) - \overline{IH}(t)\right|}{\sqrt{\mathrm{V}(Z^{(k)} - \bar{Z})}} \qquad \left(k = 1,2,\ldots,K \right)$$

Lemma 1

If $\mathrm{R}(\bar{Z}(t)) > \mathrm{R}(Z^{(k)}(t)) \quad \left(k = 1,2,\ldots,K \right)$, then

$$\bar{\mathrm{R}}\left(Z(t) - \bar{Z}(t)\right) = \frac{1}{K} \sum_{k=1}^{K} \mathrm{R}\left(Z^{(k)}(t) - \bar{Z}(t)\right) \le \max_{k}\left\{\mathrm{R}(Z^{(k)}(t)\right\} \cdot \sqrt{\frac{\bar{\mathrm{V}}(Z - \bar{Z})}{\bar{\mathrm{V}}_{\mathrm{H}}(Z - \bar{Z})}}$$

where

$\bar{\mathrm{V}}(Z - \bar{Z})$: arithmetic mean of the variances $\mathrm{V}(Z^{(k)} - \bar{Z}) \quad \left(k = 1,2,\ldots,K \right)$,

$\bar{\mathrm{V}}_{\mathrm{H}}(Z - \bar{Z})$: harmonic mean of the variances $\mathrm{V}(Z^{(k)} - \bar{Z}) \quad \left(k = 1,2,\ldots,K \right)$

Consequently if $\mathrm{R}(\bar{Z}(t)) > \mathrm{R}(Z^{(k)}(t)) \approx 0 \quad \left(k = 1,2,\ldots,K \right)$, then the ratios $\mathrm{R}\left(Z^{(k)}(t) - \bar{Z}(t)\right) \quad \left(k = 1,2,\ldots,K \right)$ are probably near to 0.

Test of Hypothesis

$$\mathrm{H}_0 : \ \mathrm{R}\left(Z^{(k)}(t) - \bar{Z}(t)\right) \equiv 0 \qquad \left(\Leftrightarrow \quad IH^{(k)}(t) \equiv \overline{IH}(t) \right) \qquad \left(k = 1,2,\ldots,K \right)$$

The test of hypothesis is based on the examination of the deviance series $Z^{(k)}(t) - \bar{Z}(t) \quad \left(k = 1,2,\ldots,K \right)$.

If H_0 can be accepted, then

$$\overline{\mathrm{R}}\left(Z(t)-\overline{IH}(t)\right)=\frac{1}{K}\sum_{k=1}^{K}\mathrm{R}\left(Z^{(k)}(t)-\overline{IH}(t)\right)\approx 0$$

as a consequence of the following lemma.

Lemma 2

$$\overline{\mathrm{R}}\left(Z(t)-\overline{IH}(t)\right)\leq \max_{k}\left\{\mathrm{R}\left(Z^{(k)}(t)-\overline{Z}(t)\right)\right\}\cdot\sqrt{\frac{\overline{\mathrm{V}}(Z)}{\overline{\mathrm{V}}_{\mathrm{H}}(Z)}}$$

where

$\overline{\mathrm{V}}(Z)$: arithmetic mean of the variances $\mathrm{V}(Z^{(k)})$ $\left(k=1,2,\ldots,K\right)$,

$\overline{\mathrm{V}}_{\mathrm{H}}(Z)$: harmonic mean of the variances $\mathrm{V}(Z^{(k)})$ $\left(k=1,2,\ldots,K\right)$.

Consequently the ratios

$\mathrm{R}\left(Z^{(k)}(t)-\overline{IH}(t)\right)$ $\left(k=1,2,\ldots,K\right)$

are probably near to 0, i.e. the monthly inhomogeneities $IH^{(k)}(t)$ $\left(k=1,2,..,K\right)$

can be estimated with the estimation of the seasonal inhomogeneity $\overline{IH}(t)$.

9. VERIFICATION OF HOMOGENIZATION

9.1 Additive Model (for example temperature)

Original Series

$X_{O,j}(t) = C_j(t) + IH_j(t) + \varepsilon_j(t) \qquad (j = 1,2,\ldots,N;\ t = 1,2,\ldots,n)$

C : climate change; IH : inhomogeneity, ε : noise

Estimated Inhomogeneity Series $\hat{IH}_j(t)$

Homogenized Series $X_{H,j}(t) = X_{O,j}(t) - \hat{IH}_j(t)$

Residual Inhomogeneity Series $IH_{res,j}(t) = IH_j(t) - \hat{IH}_j(t)$

Optimal Interpolation of Series

Interpolation of Original Series: $\hat{X}_{O,j}(t) = w_0 + \sum_{i \in R_j} w_i \cdot X_{O,i}(t)$,

where R_j is the reference index set, $\sum_{i \in R_j} w_i = 1$ and

$ERR = \mathrm{E}\left(\left(X_{O,j}(t) - \hat{X}_{O,j}(t)\right)^2\right) = \underset{w_0, w_i}{\text{minimum}}$.

Interpolation of Homogenized Series: $\hat{X}_{H,j}(t) = w_0 + \sum_{i \in R_j} w_i \cdot X_{H,i}(t)$,

where $\sum_{i \in R_j} w_i = 1$ and $ERR = \mathrm{E}\left(\left(X_{H,j}(t) - \hat{X}_{H,j}(t)\right)^2\right) = \underset{w_0, w_i}{\text{minimum}}$.

Regression of $\hat{IH}_j(t)$ by Meta Data (probable dates of break points)

Meta Data: $\Delta_j = \left\{1 \le D_1^{(j)} < D_2^{(j)} < \ldots . < D_{K_j}^{(j)} < n\right\}$

$$\hat{IH}_{Mreg,j}(t) = \begin{cases} \left(\overline{\hat{IH}_j}\right)_A [1, D_1^{(j)}] & ,\text{if } \quad 1 \le t \le D_1^{(j)} \\ \left(\overline{\hat{IH}_j}\right)_A (D_{k-1}^{(j)}, D_k^{(j)}] & ,\text{if } \quad D_{k-1}^{(j)} < t \le D_k^{(j)} \quad (k = 2,\ldots,K_j) \\ \left(\overline{\hat{IH}_j}\right)_A (D_{K_j}^{(j)}, n] & ,\text{if } \quad D_{K_j}^{(j)} < t \le n \end{cases}$$

$\left(\overline{\hat{IH}_j}\right)_A \langle a,b \rangle$: arithmetic mean of $\hat{IH}_j(t)$ above the interval $\langle a,b \rangle$.

9.2 Multiplicative Model (for example monthly or seasonal precipitation)

Original Series

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

C^* : climate change; IH^* : inhomogeneity, ε^* : noise

Logarithmization for Additive Model

$$X_{O,j}(t) = C_j(t) + IH_j(t) + \varepsilon_j(t) \qquad (j = 1,2,\ldots,N;\ t = 1,2,\ldots,n)$$

where

$$X_{O,j}(t) = \ln X^*_{O,j}(t)\ ,\ C_i(t) = \ln C^*_j(t)\ ,\ IH_j(t) = \ln IH^*_j(t)\ ,\ \varepsilon_j(t) = \ln \varepsilon^*_j(t)$$

Problem

If $X^*_{O,j}(t)$ values are near or equal to 0. This problem can be solved by a Transformation Procedure which increases slightly the little values. Consequently the Multiplicative Model can be transformed into the Additive One.

Estimated Inhomogeneity Series

$$I\hat{H}^*_j(t)\ (>0) \qquad , \qquad I\hat{H}_j(t) = \ln I\hat{H}^*_j(t)$$

Homogenized Series

$$X^*_{H,j}(t) = \frac{X^*_{O,j}(t)}{I\hat{H}^*_j(t)} \qquad , \qquad X_{H,j}(t) = \ln X^*_{H,j}(t) = X_{O,j}(t) - I\hat{H}_j(t)$$

Residual Inhomogeneity Series

$$IH^*_{res,j}(t) = \frac{IH^*_j(t)}{I\hat{H}^*_j(t)} \qquad , \qquad IH_{res,j}(t) = \ln IH^*_{res,j}(t) = IH_j(t) - I\hat{H}_j(t)$$

'Optimal' Interpolation (multiplicative)

Interpolation of Original Series: $\hat{X}^*_{O,j}(t) = \exp\left(\hat{X}_{O,j}(t)\right) = e^{w_0} \cdot \prod_{i \in R_j} \left(X^*_{O,i}(t)\right)^{w_i}$

where $\hat{X}_{O,j}(t)$ is the optimally interpolated series of $X_{O,j}(t)$.

Interpolation of Homogenized Series: $\hat{X}^*_{H,j}(t) = \exp\left(\hat{X}_{H,j}(t)\right) = e^{w_0} \cdot \prod_{i \in R_j} \left(X^*_{H,i}(t)\right)^{w_i}$

where $\hat{X}_{H,j}(t)$ is the optimally interpolated series of $X_{H,j}(t)$.

Regression of $\hat{IH}_j^*(t)$ by Meta Data (probable dates of break points)

Meta Data: $\Delta_j = \left\{ 1 \le D_1^{(j)} < D_2^{(j)} < .... < D_{K_j}^{(j)} < n \right\}$

$$\hat{IH}_{Mreg,j}^*(t) = \exp\left(\hat{IH}_{Mreg,j}(t)\right) =$$

$$= \begin{cases} \left(\overline{\hat{IH}_j^*}\right)_G [1, D_1^{(j)}] & ,\text{if} \quad 1 \le t \le D_1^{(j)} \\ \left(\overline{\hat{IH}_j^*}\right)_G (D_{k-1}^{(j)}, D_k^{(j)}] & ,\text{if} \quad D_{k-1}^{(j)} < t \le D_k^{(j)} \ \ (k = 2,.,K_j) \\ \left(\overline{\hat{IH}_j^*}\right)_G (D_{K_j}^{(j)}, n] & ,\text{if} \quad D_{K_j}^{(j)} < t \le n \end{cases}$$

$\left(\overline{\hat{IH}_j}\right)_G \langle a,b \rangle$: geometric mean of $\hat{IH}_j(t)$ above the interval $\langle a,b \rangle$.

9.3 Series for Verification Procedure

	'Additive' Series	'Multiplicative' Series
Original Series:	$X_O(t)$	$X_O^*(t) = \exp(X_O(t))$
Estimated Inhomogeneity :	$\hat{IH}(t)$	$\hat{IH}^*(t) = \exp\left(\hat{IH}(t)\right)$
Homogenized Series:	$X_H(t)$	$X_H^*(t) = \exp(X_H(t))$
Residual Inhom. (unknown):	$IH_{res}(t)$	$IH_{res}^*(t) = \exp(IH_{res}(t))$
Opt. Int. of Orig. Series:	$\hat{X}_O(t)$	$\hat{X}_O^*(t) = \exp\left(\hat{X}_O(t)\right)$
Opt. Int. of Hom. Series:	$\hat{X}_H(t)$	$\hat{X}_H^*(t) = \exp\left(\hat{X}_H(t)\right)$
Regr. of Est. Inh. by Meta:	$\hat{IH}_{Mreg,j}(t)$	$\hat{IH}_{Mreg,j}^*(t) = \exp\left(\hat{IH}_{Mreg,j}(t)\right)$

At the additive model we have additive series only, while in case of the multiplicative model we have additive and multiplicative series alike.

9.4 Basic Statistical Functions for Verification Procedure

Statistical Functions for 'Additive' Series

Deviaton of series $x(t)$, $y(t)$ $(t = 1,2,\ldots,n)$: $D(x,y) = \sqrt{\frac{1}{n}\sum_{t=1}^{n}(x(t) - y(t))^2}$

Standard Deviaton of series $x(t)$ $(t = 1,2,\ldots,n)$: $S(x) = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(x(t) - \overline{x(t)}_A\right)^2}$

Deviation Error of estimation $\hat{x}(t)$ ($t = 1,2,...,n$): $ERR(x,\hat{x}) = D(x,\hat{x})$

<u>Statistical Functions for 'Multiplicative' Series</u>

Fluctuation of series $x(t)(>0),\ y(t)(>0)$ ($t = 1,2,\ldots,n$):

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

Standard Fluctuation of series $x(t)(>0)$ ($t = 1,2,\ldots,n$):

$$SF(x) = \left(\prod_{t=1}^{n} \max\left(\frac{x(t)}{\bar{x}_G}\ ,\ \frac{\bar{x}_G}{x(t)}\right)\right)^{\frac{1}{n}} \qquad (G\text{: geometric mean})$$

Fluctuation Error of estimation $\hat{x}(t)(>0)$ ($t = 1,2,...,n$): $FERR(x,\hat{x}) = F(x,\hat{x})$

Lemma

Connection between the additive and multiplicative statistical functions:

$$SF(y) \approx SF(x)^{\frac{S(\ln y)}{S(\ln x)}} \qquad \text{and} \qquad F(x,y) \approx SF(x)^{\frac{D(\ln x,\ln y)}{S(\ln x)}}$$

9.5 The Verification Statistics

For both model the calculation of verification statistics is based on the 'additive' series, but in case of multiplicative model the verification statistics can be interpreted for the 'multiplicative' series too according to the lemma.

<u>I. Test Statistics for Series Inhomogeneity</u>

I.1. Test Statistic After Homogenization (TSA)

Examined series: $Z_H(t) = X_H(t) - \hat{X}_H(t)$

I.2. Test Statistic Before Homogenization (TSB)

Examined series: $Z_O(t) = X_O(t) - \hat{X}_O(t)$

I.3. Statistic for Estimated Inhomogeneity (IS)

Examined series: $I\hat{H}(t)$

The homogenization can be considered is successful if the Test Statistic After Homogenization is little and the Statistic for Estimated Inhomogeneity is in accordance with the Test Statistic Before Homogenization.

II. Characterization of Inhomogeneity

II.1. Relative Estimated Inhomogeneity: $\mathrm{RI1} = \frac{S\left(I\hat{H}\right)}{S(X_O)}$

Multiplicative interpretation: $SF\left(I\hat{H}^{\,*}\right) \approx SF\left(X_O^{\,*}\right)^{\mathrm{RI1}}$

II.2. Relative Modification of Series: $\mathrm{RI2} = \frac{D(X_O, X_H)}{S(X_O)}$

Multiplicative interpretation: $F\left(X_O^{\,*}, X_H^{\,*}\right) \approx SF\left(X_O^{\,*}\right)^{\mathrm{RI2}}$

II.3. Lower Confidence Limit (RI3) for Relative Residual Inhomogeneity:

$$\mathrm{P}\left(\frac{S(IH_{res})}{S(X_H)} \geq \mathrm{RI3} \right) \geq 1 - \text{ sig. level } \left(= 0.9, 0.95, 0.99 \right)$$

Multiplicative interpretation: $\mathrm{P}\left(SF\left(IH_{res}^{\,*}\right) \geq SF\left(X_H^{\,*}\right)^{\mathrm{RI3}} \right) \geq 1 - \text{ sig. level}$

III. Representativity of Station Network

$$\mathrm{RS} = 1 - \frac{ERR\left(X_H, \hat{X}_H\right)}{S(X_H)}$$

Multiplicative interpretation: $FERR\left(X_H^{\,*}, \hat{X}_H^{\,*}\right) \approx SF\left(X_H^{\,*}\right)^{1-\mathrm{RS}}$

IV. Test Statistic for Meta Data

Examined series: $Z_O(t) = X_O(t) - \hat{X}_O(t)$ with Meta Data.

V. Representativity of Meta Data

$$\mathrm{RM} = 1 - \frac{ERR\left(I\hat{H}, I\hat{H}_{Mreg}\right)}{S\left(I\hat{H}\right)}$$

Multiplicative interpretation: $FERR\left(I\hat{H}^{\,*}, I\hat{H}_{Mreg}^{\,*}\right) \approx SF\left(I\hat{H}^{\,*}\right)^{1-\mathrm{RM}}$

CRITICAL VALUES FOR TEST STATISTICS (by Monte Carlo Method)

Significance level: 0.1
Length of series: critical value for the Test statistic of inhomogeneity

```
 10: 15.902 ;  20: 15.845 ;  30: 16.160 ;  40: 16.765;
 50: 17.156 ;  60: 17.697 ;  70: 18.059 ;  80: 18.369;
 90: 18.655 ; 100: 18.843 ; 110: 19.008 ; 120: 19.101;
130: 19.220 ; 140: 19.397 ; 150: 19.526 ; 160: 19.609;
170: 19.678 ; 180: 19.749 ; 190: 19.789 ; 200: 19.950
```

Significance level: 0.1
Length of series: critical value for the outliers Test statistic

```
 10:  5.495 ;  20:  5.530 ;  30:  5.898 ;  40:  6.126;
 50:  6.330 ;  60:  6.486 ;  70:  6.613 ;  80:  6.719;
 90:  6.802 ; 100:  6.914 ; 110:  7.009 ; 120:  7.089;
130:  7.145 ; 140:  7.234 ; 150:  7.294 ; 160:  7.343;
170:  7.387 ; 180:  7.434 ; 190:  7.512 ; 200:  7.558
```

Significance level: 0.05
Length of series: critical value for the Test statistic of inhomogeneity

```
 10: 23.602 ;  20: 20.924 ;  30: 20.530 ;  40: 20.574;
 50: 20.861 ;  60: 20.914 ;  70: 21.313 ;  80: 21.395;
 90: 21.534 ; 100: 21.599 ; 110: 21.731 ; 120: 21.760;
130: 21.933 ; 140: 21.936 ; 150: 22.052 ; 160: 22.063;
170: 22.078 ; 180: 22.193 ; 190: 22.288 ; 200: 22.362
```

Significance level: 0.05
Length of series: critical value for the outliers Test statistic

```
 10:  9.263 ;  20:  7.445 ;  30:  7.442 ;  40:  7.582;
 50:  7.710 ;  60:  7.797 ;  70:  7.901 ;  80:  7.996;
 90:  8.028 ; 100:  8.076 ; 110:  8.147 ; 120:  8.202;
130:  8.295 ; 140:  8.344 ; 150:  8.403 ; 160:  8.433;
170:  8.484 ; 180:  8.518 ; 190:  8.531 ; 200:  8.607
```

Significance level: 0.01
Length of series: critical value for the Test statistic of inhomogeneity (over-estimated values)

```
 10: 52.000 ;  20: 37.000 ;  30: 33.000 ;  40: 32.000;
 50: 31.000 ;  60: 30.000 ;  70: 30.000 ;  80: 29.000;
 90: 29.000 ; 100: 29.000 ; 110: 29.000 ; 120: 28.000;
130: 28.000 ; 140: 28.000 ; 150: 28.000 ; 160: 28.000;
170: 28.000 ; 180: 28.000 ; 190: 28.000 ; 200: 28.000
```

Significance level: 0.01
Length of series: critical value for the outliers Test statistic (over-estimated values)

```
 10: 32.000 ;  20: 14.000 ;  30: 12.000 ;  40: 12.000;
 50: 12.000 ;  60: 12.000 ;  70: 12.000 ;  80: 11.000;
 90: 11.000 ; 100: 11.000 ; 110: 11.000 ; 120: 11.000;
130: 11.000 ; 140: 11.000 ; 150: 11.000 ; 160: 11.000;
170: 11.000 ; 180: 11.000 ; 190: 11.000 ; 200: 11.000
```

Remark: The critical values are built in the program system.

II. THE STRUCTURE OF PROGRAM SYSTEM

Main Directory **MASHv3.02**:

Directory **MASHDAILY** (See Page **57**)

Directory **MASHMONTHLY**:

- Subdirectory **SAM**:
  - Subdirectory **SAMPAR**
    (parametrization program)
  - **Main Program Files of SAM**
  - Subdirectory **SAMEND**
    (finishing program)
  - Subdirectory **SAMMANU**
    ("manual" programs)
  - Subdirectory **SAMSUB**
    (do not use it including "subroutines")
  - Subdirectory **MASH**:
    - Subdirectory **MASHPAR**
      (parametrization program)
    - **Main Program Files of MASH**
    - Subdirectory **MASHEND**
      (finishing program)
    - Subdirectory **MASHMANU**
      ("manual" programs)
    - Subdirectory **MASHSUB**
      (do not use it including "subroutines")

General Comments

Monthly, seasonal or annual time series can be homogenized by the aid of the program system.
The time series belonging to different stations are compared in the course of the procedure.
The maximal number of the stations: 500
The maximal length of the time series: 200

In case of having monthly series for all the 12 months, the monthly, seasonal and annual series can be homogenized together by the main program files of the subdirectory SAM (Seasonal Application of MASH; see page 27).

In case of having only annual series, or monthly series belonging to a given month, or seasonal series belonging to a given season, the series can be homogenized by the main program files of subdirectory MASH (see page 23).

Depending on the climatic elements, additive (e.g. temperature) or multiplicative (e.g. precipitation) models are applied. The second case can be transformed into the first one by logarithmization. The problem of values being near to zero can be solved by a Transformation Procedure which increases slightly the little values.

III. THE MASH SYSTEM

- Subdirectory **MASH**:
  - Subdirectory **MASHPAR** (parametrization program)
  - **Main Program Files of MASH**
  - Subdirectory **MASHAUTO** (automatic homogenization program)
  - Subdirectory **MASHEND** (finishing program)
  - Subdirectory **MASHMANU** ("manual" programs)
  - Subdirectory **MASHSUB** (don not use it including "subroutines")

MASH IN PRACTICE

I. Parametrization in Subdirectory MASH\MASHPAR

MASHPAR.BAT
Data File, Significance level (0.1, 0.05, 0.01), Table of Reference System OR Table of Filambda Station Coordinates, Table of META DATA

II. The Main Program Steps in Subdirectory MASH

1. Automatic filling of missing values (MASHMISS.BAT)
It is obligatory in case of missing values! It can be repeated!

2. The further steps can be used optionally

MASHVERI.BAT: To verify the actual or the final stage of homogenization.

MASHGAME.BAT: An intensive examination for correction of one of the examined series in a playful way.

MASHCOR.BAT: Possibility for manual correction of examined series.

MASHDRAW.BAT: Graphic series.

MASHLIER.BAT: For automatic correction of outliers.

AUTOMATIC, ITERATION application of MASHGAME.BAT (see Annex p. 64) i.e.:

Running two **Batch Files in Subdirectory MASH\MASHAUTO:**

i, MAUTOPAR.BAT: Parametrization; input: number of iteration steps

ii, MASHAUTO.BAT: Examination, homogenization

(The steps (1 -2) can be repeated optionally!!!!!)

III. Finishing in Subdirectory MASHEND

MASHEND.BAT

THE MAIN PROGRAM and I/O FILES of Subdirectory MASHPAR

1. Executive File

MASHPAR.BAT : Parametrization and a transformation procedure for the data which are near 0, in case of cumulative model.

2. Input Files and Input Data

Data File:

Format of Data File (maximal number of series: 500, maximal length of series: 200):
  row 1: names of series or stations (obligatory!)
  column 1: series of dates (I4)
  column i+1: series i.
Data Format:
  additive model (for example temperature): F6.2
  cumulative model: I6 (data must be nonnegative!)
  (for example precipitation, values multiplied by ten)
Mark of Missing Values:
  additive model:999.99 ; cumulative model:999999
(For example: HUNTEMP.DAT)

Significance level: 0.1 or 0.05 or 0.01

Table of Reference System:
Indexes of reference series belonging to the candidate series. For example: HUNTEMP.REF

OR: Table of Filambda Station Coordinates: For example: HUNCOORD.PAR

Table of META DATA: Probable dates of the Break Points. For example: HUNMETA.DAT

3. Result Files written in Subdirectory MASH

SEE: Data and Result Files of Subdirectory MASH:

MASHPAR.PAR, MASHPAR2.PAR, MASHMETA.DAT, MASHDAT.SER, MASHMISS.SER, MASHINH.SER, MASHHOM.SER

4. Parameter Files

MASHPAR1.PAR, MASHPAR2.PAR

THE MAIN PROGRAM and I/O FILES of Subdirectory MASHEND

1. Executive File

MASHEND.BAT : Finishing and a retransformation procedure in case of cumulative model.

2. Result Files

MASHMISS.SER : Original data series (with missing values).

MASHDAT.SER : Original data series (with filled missing values).

MASHHOM.SER : Homogenized data series.

MASHINH.SER : Inhomogeneity series.

3. Parameter File: MASHPAR2.PAR

THE MAIN PROGRAM and I/O FILES of Subdirectory MASH

1. Executive Files

MASHMISS.BAT : Automatic filling of missing values.

MASHHELP.BAT : For evaluation of homogeneity of the examined series; for selection of candidate series.

METAHELP.BAT : For evaluation of META DATA.

MASHLIER.BAT : For automatic correction of outliers.

MASHGAME.BAT:
An intensive examination for correction of one of the examined series in a playful way.

MASHGAUT.BAT:
An automatic version of MASHGAME.BAT for examination of all the series.
The examination is less intensive than the examination performed by MASHGAME.BAT.

MASHGAUH.BAT:
Combination of MASHGAUT.BAT with MASHHELP.BAT for Automation.

MASHCOR.BAT : Possibility for manual correction of examined series.

MASHDRAW.BAT: Graphic series.

MASHVERI.BAT : Verification of Homogenization.

2. Data and Result Files

MASHPAR.PAR : Parameters, Table of Reference System.

MASHMETA.DAT: Table of META DATA.

MASHMISS.SER : Original data series (with missing values).

MASHMISS.RES : Statistical results of filling missing values.

MASHDAT.SER : Original data series (with filled missing values).

MASHINH.SER : Inhomogeneity series.

MASHHOM.SER : Homogenized data series.

MASHHELP.RES : Table for evaluation of homogeneity of the examined series; for selection of candidate series.

METAHELP.RES : Table for evaluation of META DATA.

MASHEX1.RES : Statistical results: optimal difference series belonging to the candidate series and its detected inhomogeneities.

MASHEX1.SER : Result series: optimal difference series belonging to the candidate series and its inhomogeneity series.

MASHEX2.RES : Statistical results: optimal difference series system belonging to the candidate series and the detected inhomogeneities of the system elements.

MASHEX2.SER : Result series: optimal difference series system belonging to the candidate series and the inhomogeneity series of the system elements.

MASHGAUT.RES: Result of MASHGAUT.BAT.

MASHCOR.RES : Detected break points, outliers and shifts (additive model)
or ratios (cumulative model).

MASHSELR.RES : Table for selection of reference series.

MASHVERI.RES : Result of Verification file MASHVERI.BAT .

MASHVERO.RES : Result of Verification file MASHVERI.BAT . (ordered statistics)

3. Work and Parameter Files

MASHPAR2.PAR, MASHPRCR.PAR, MASHSTEP.PAR, MASHMETA.PAR, MASHEINH.SER,MASHAUTC.INP, MASHAUTC.IND, GAME1.PAR, GAME2.PAR, GAME3.PAR, GAME4.PAR, GAME5.PAR, GAME6.PAR

FILES of Subdirectory MASHMANU ("Manual" Program Files)

The „manual" program files (MASHSELR.BAT, MASHEX2.BAT, MASHAUTC.BAT) have been automatized. Their combined automatic version is the program file MASHGAME .BAT which is recommended to use instead of them.

MASHSELR.BAT: Help for selection of reference series.

MASHEX1.BAT : To examine the optimal series belonging to the candidate series.

MASHEX2.BAT : To examine the optimal series system belonging to the candidate series.

MASHAUTC.BAT: Automatic correction of candidate series .

FILES of Subdirectory MASHSUB ("Subroutines")

GAMEAUTA.EXE, GAMEAUTO.EXE, GAMESELA.EXE, GAMESELO.EXE, MASHAUTA.EXE, MASHAUTC.EXE, MASHAUTG.EXE, MASHAUTO.EXE, MASHCOR.EXE, MASHDRAW.EXE, MASHEX1.EXE, MASHEX2.EXE, MASHEX2A.EXE, MASHEX2G.EXE, MASHEX2O.EXE, MASHHELP.EXE, MASHHELX.EXE,MASHINV.EXE, MASHMISS.EXE, MASHPAR.EXE, MASHSELA.EXE, MASHSELG.EXE, MASHSELO.EXE, MASHSELR.EXE, MASHSETA.EXE, MASHSETG.EXE, METAHELP.EXE, MASHTRAN.EXE, MASHVERI.EXE, METAVERI.EXE

IV. THE SAM SYSTEM

The Suggested Step by Step Procedure:

I. Examination of the monthly series.
Homogenization of the monthly series.

II. Examination of the seasonal series for residual inhomogeneity.
Homogenization of the monthly series.

III. Examination of the annual series for residual inhomogeneity.
Homogenization of the monthly series.

THE STRUCTURE OF SAM SYSTEM

- Subdirectory **SAM**:
    - Subdirectory **SAMPAR** (parametrization program)
    - **Main Program Files of SAM**
    - Subdirectory **SAMMISS** (data complementing program)
    - Subdirectory **SAMVERI** (verification programs)
    - Subdirectory **SAMAUTO** (automatic homogenization program)
    - Subdirectory **SAMEND** (finishing program)
    - Subdirectory **SAMMANU** ("manual" programs)
    - Subdirectory **SAMSUB** (don not use it including "subroutines")

SAM IN PRACTICE

I. Parametrization in Subdirectory SAM\SAMPAR (SAMPAR.BAT)

Data Files, Significance level (0.1, 0.05, 0.01), Table of Reference System OR Table of Filambda Station Coordinates, Table of META DATA

II. The Main Program Steps in Directory SAM

DATA COMPLEMENTING for all the 12 Months together (see Annex p. 64):
(Automatic version of MASHMISS.BAT. It can be repeated!)
Running Batch File **SAMMISS.BAT in Subirectory SAM\SAMMISS.**
(It is obligatory in case of having missing values!)

VERIFICATION PROCEDURE for all Monthly,Seasonal,Annual Series (Annex p. 64):
(Automatic version of MASHVERI.BAT. It can be repeated!)
Running Batch File **SAMVERI.BAT in Subirectory SAM\SAMVERI.**

1. Taking the chosen monthly or seasonal series In (SAMIN.BAT)

2. The further steps can be used optionally

MASHMISS.BAT : Automatic filling of missing values.

MASHVERI.BAT : To verify the actual or the final stage of homogenization.

MASHGAME.BAT: An intensive examination for correction of one of the examined series in a playful way.

MASHCOR.BAT: Possibility for manual correction of examined series.

MASHDRAW.BAT: Graphic series.

MASHLIER.BAT: For automatic correction of outliers.

AUTOMATIC, ITERATION application of MASHGAME.BAT (see Annex p. 64) i.e.:

Running two **Batch Files in Subdirectory SAM\SAMAUTO:**

i, SAUTOPAR.BAT: Parametrization; input: number of iteration steps

ii, SAMAUTO.BAT: Examination, homogenization

3. The further step can be used in case of Seasonal Series

SAMTEST.BAT : Test for comparison of the inhomogeneities between the seasonal series and the appropriate monthly series, moreover procedure for selecting stations which have different inhomogeneities between the seasonal series and the appropriate monthly series.

4. Taking the chosen monthly or seasonal series Out (SAMOUT.BAT)

(The steps (1 - 4) can be repeated optionally!!!!!)

III. Finishing in Subdirectory SAMEND (SAMEND.BAT)

THE MAIN PROGRAM and I/O FILES of Subdirectory SAMPAR

1. Executive File

SAMPAR.BAT : Parametrization and a transformation procedure for the data which are near 0, in case of cumulative model.

2. Input Files and Input Data

12 Data Files:

m{j} (j=1,....,12): original monthly series

Format of Data Files (maximal number of stations: 500, maximal length of series: 200):
row 1: station names (obligatory!)
  column 1: series of dates (I4)
  column i+1: series i.
Data Format:
  additive model (for example temperature): F6.2
  cumulative model: I6 (data must be nonnegative!)
  (for example precipitation, values multiplied by ten)
Mark of Missing Values:
  additive model:999.99
  cumulative model:999999

Significance level: 0.1 or 0.05 or 0.01

Table of Reference System:
Indexes of reference series belonging to the candidate series.
For example: HUNTEMP.REF

OR: Table of Filambda Station Coordinates:
For example: HUNCOORD.PAR

Table of META DATA:
Probable dates of the Break Points. For example: HUNMETA.DAT

3. Result Files written in Subdirectory SAM

SEE Data and Result Files of Subdirectory SAM:

m{j}, **m{j}h**, **m{j}i**, **m{j}c** (j=1,....,12)

s{j}, **s{j}h**, **s{j}i**, **s{j}ei**, **s{j}c** (j=1, 2, 3, 4)

year, **yearh**, **yeari**, **yearei**, **yearc**

SAMPAR.PAR, MASHPAR.PAR, MASHMETA.DAT

4. Parameter Files

SAMPAR4.PAR, SAMPAR5.PAR, SAMPAR6.PAR

THE MAIN PROGRAM and I/O FILES of Subdirectory SAMEND

1. Executive File

SAMEND.BAT : Finishing and a retransformation procedure in case of cumulative model.

2. Result Files

m{j} (j=1,....,12): original monthly series (with filled missing values).

s{j} (j=1, 2, 3, 4) : original seasonal series (with filled missing values).
(winter = {1, 2, 12 }, spring = {3, 4, 5 }, summer = {6, 7, 8 }, autumn = {9, 10, 11 }).

year : original annual series (with filled missing values).

m{j}h (j=1,....,12): homogenized monthly series.

s{j}h (j=1, 2, 3, 4): homogenized seasonal series (based on homogenized monthly series).

yearh : homogenized annual series (based on homogenized monthly series).

m{j}i (j=1,....,12) : estimated inhomogeneity series for months.

s{j}i (j=1, 2, 3, 4) : estimated inhomogeneity series for seasons.

yeari : estimated inhomogeneity series for year.

s{j}ei (j=1, 2, 3, 4): estimated "expectation" of inhomogeneity series for seasons.

yearei : estimated "expectation" of inhomogeneity series for year.

m{j}c (j=1,....,12) : break points and shifts (add. m.) or ratios (cum. m.) for months.

s{j}c (j=1, 2, 3, 4) : break points and shifts (add. m.) or ratios (cum. m.) for seasons.

yearc : break points and shifts (add. m.) or ratios (cum. m.) for year.

3. Parameter File

SAMPAR5.PAR

THE MAIN PROGRAM and I/O FILES of Subdirectory SAM

1. Executive Files

1.1 Special Executive Files of SAM System

SAMIN.BAT : Taking the chosen monthly or seasonal series In.

SAMOUT.BAT : Taking the chosen monthly or seasonal series Out.

SAMTESTC.BAT: Test for comparison of the inhomogeneities between the seasonal series and the appropriate monthly series.

SAMTESTS.BAT : Test Procedure for selecting the different inhomogeneities between the seasonal series and the appropriate monthly series.

SAMTEST.BAT :
Combination of SAMTESTC.BAT and SAMTESTS.BAT for Automation.

1.2 Executive Files of MASH System

MASHMISS.BAT : Automatic filling of missing values.

MASHHELP.BAT : For evaluation of homogeneity of the examined series; for selection of candidate series.

METAHELP.BAT : For evaluation of META DATA.

MASHLIER.BAT : For automatic correction of outliers.

MASHGAME.BAT:
An intensive examination for correction of one of the examined series in a playful way.

MASHGAUT.BAT:
An automatic version of MASHGAME.BAT for examination of all the series.
The examination is less intensive than the examination performed by MASHGAME.BAT.

MASHGAUH.BAT:
Combination of MASHGAUT.BAT with MASHHELP.BAT for Automation.

MASHCOR.BAT : Possibility for manual correction of examined series.

MASHDRAW.BAT: Graphic series.

MASHVERI.BAT : Verification of Homogenization.

2. Data and Result Files

2.1 Special Data and Result Files of SAM System

m{j} (j=1,....,12): original monthly series

s{j} (j=1, 2, 3, 4) : original seasonal series
(winter = {1, 2, 12 }, spring = {3, 4, 5 }, summer = {6, 7, 8 }, autumn = {9, 10, 11 }).

year : original annual series.

m{j}h (j=1,....,12): homogenized monthly series.

s{j}h (j=1, 2, 3, 4): homogenized seasonal series (based on homogenized monthly series).

yearh : homogenized annual series (based on homogenized monthly series).

m{j}i (j=1,....,12) : estimated inhomogeneity series for months.

s{j}i (j=1, 2, 3, 4) : estimated inhomogeneity series for seasons.

yeari : estimated inhomogeneity series for year.

s{j}ei (j=1, 2, 3, 4): estimated "expectation" of inhomogeneity series for seasons.

yearei : estimated "expectation" of inhomogeneity series for year.

m{j}c (j=1,....,12) : break points and shifts (add. m.) or ratios (cum. m.) for months.

s{j}c (j=1, 2, 3, 4) : break points and shifts (add. m.) or ratios (cum. m.) for seasons.

yearc : break points and shifts (add. m.) or ratios (cum. m.) for year.

SAMPAR.PAR : Parameters, Table of Reference System.

SAMTESTC.RES: Output of SAMTESTC.BAT.

SAMTESTS.RES: Output of SAMTESTS.BAT.

SAMTEST.RES: Output of SAMTEST.BAT.

2.2 Data and Result Files of MASH System

MASHPAR.PAR : Parameters, Table of Reference System.

MASHMETA.DAT: Table of META DATA.

MASHMISS.SER : Original data series (with missing values).

MASHMISS.RES : Statistical results of filling missing values.

MASHDAT.SER : Original data series (with filled missing values).

MASHINH.SER : Inhomogeneity series**.**

MASHHOM.SER : Homogenized data series.

MASHHELP.RES : Table for evaluation of homogeneity of the examined series; for selection of candidate series.

METAHELP.RES : Table for evaluation of META DATA.

MASHEX1.RES : Statistical results: optimal difference series belonging to the candidate series and its detected inhomogeneities.

MASHEX1.SER : Result series: optimal difference series belonging to the candidate series and its inhomogeneity series.

MASHEX2.RES : Statistical results: optimal difference series system belonging to the candidate series and the detected inhomogeneities of the system elements.

MASHEX2.SER : Result series: optimal difference series system belonging to the candidate series and the inhomogeneity series of the system elements.

MASHGAUT.RES: Result of MASHGAUT.BAT.

MASHCOR.RES : Detected break points, outliers and shifts (additive model) or ratios (cumulative model).

MASHSELR.RES : Table for selection of reference series.

MASHVERI.RES : Result of Verification file MASHVERI.BAT .

MASHVERO.RES : Result of Verification file MASHVERI.BAT . (ordered statistics)

3. Work and Parameter Files

3.1 Special Work and Parameter Files of SAM System

SAMPAR2.PAR, SAMPAR3.PAR, SAMPAR4.PAR, SAMPAR5.PAR, SAMPRCR.PAR, SAMTEST.PAR, SAMORINH.SER, SAMTESTD.SER, SAMTESTI.SER,SAMTIMER.PAR

3.2 Work and Parameter Files of MASH System

MASHPAR2.PAR, MASHPRCR.PAR, MASHSTEP.PAR, MASHMETA.PAR, MASHEINH.SER,MASHAUTC.INP, MASHAUTC.IND, GAME1.PAR, GAME2.PAR, GAME3.PAR, GAME4.PAR, GAME5.PAR, GAME6.PAR

FILES of Subdirectory SAMMANU ("Manual" Program Files)

The „manual" program files (MASHSELR.BAT, MASHEX2.BAT, MASHAUTC.BAT) have been automatized. Their combined automatic version is the program file MASHGAME .BAT which is recommended to use instead of them.

MASHSELR.BAT: Help for selection of reference series.

MASHEX1.BAT : To examine the optimal series belonging to the candidate series.

MASHEX2.BAT : To examine the optimal series system belonging to the candidate series.

MASHAUTC.BAT: Automatic correction of candidate series .

FILES of Subdirectory SAMSUB ("Subroutines")

SAMHELP1.EXE, SAMHELP2.EXE, SAMHELP3.EXE, SAMIN1.EXE, SAMIN2.EXE, SAMINV.EXE, SAMMISS.EXE, SAMOUT1.EXE, SAMOUT2.EXE, SAMOUT3.EXE, SAMPAR.EXE, SAMTESTC.EXE, SAMTESTS.EXE, SAMTEST1.EXE, SAMTEST2.EXE, SAMTRAN.EXE

V. EXAMPLE FOR APPLICATION OF MASH SYSTEM

Data File: HUNTEMP.DAT

Examined Series: Hungarian annual mean temperature series (1901-1999).

Examined Stations:
1. Budapest (bp), 2. Debrecen (de), 3. Kecskemét (ke), 4. Miskolc (mi), 5. Mosonmagyaróvár (mo), 6. Nyíregyháza (ny), 7. Pécs (pe), 8. Sopron (sr), 9. Szeged (se), 10. Szombathely (so)

Table of Reference System: HUNTEMP.REF

```
TABLE OF REFERENCE SYSTEM (two rows belong to each examined series)
row 1: index of candidate series(I3); number of reference series(I3)
row 2: indexes of reference series(I3)
  1  9
  2  3  4  5  6  7  8  9 10
  2  6
  1  3  4  6  7  9
  3  9
  1  2  4  5  6  7  8  9 10
  4  9
  1  2  3  5  6  7  8  9 10
  5  7
  1  3  4  7  8  9 10
  6  6
  1  2  3  4  7  9
  7  9
  1  2  3  4  5  6  8  9 10
  8  7
  1  3  4  5  7  9 10
  9  9
  1  2  3  4  5  6  7  8 10
 10  7
  1  3  4  5  7  8  9
```

Table of META DATA: HUNMETA.DAT

```
TABLE OF META DATA (one or two rows belong to each examined series)
row 1: index of examined series(I3); number of meta data(I5)
row 2: meta data(I5), if they exist
  1    8
 1909 1960 1986 1987 1988 1991 1992 1993
  2    3
 1950 1954 1955
  3    7
 1943 1944 1945 1946 1947 1969 1970
  4    6
 1922 1930 1938 1950 1964 1965
  5    5
 1950 1960 1966 1969 1970
  6    8
 1950 1951 1960 1965 1966 1967 1991 1992
  7    4
 1950 1957 1958 1960
  8    1
 1973
  9    2
 1950 1951
 10    1
 1950
```

Table of Filambda Station Coordinates: HUNCOORD.PAR

```
index    lambda(x)         fi(y)
1       19.02499960   47.50833510   Budapest
2       21.60833360   47.49166490   Debrecen
.
.
9       20.09166720   46.25833510   Szeged
10      16.63333320   47.26666640   Szombathely
```

```
99 1021.60a12.00 8.08  .05
Name of Data File: huntemp.dat           MISSING VALUES!
Model: additive
Number of series:  10
Length of series:  99
Significance level:   .05
Critical value for break points: 21.60
Critical value for correction: 12.00
Critical value for outliers:  8.08

EXAMINED SERIES AND INDEXES

     bp: 1       de: 2       ke: 3       mi: 4       mo: 5       ny: 6
     pe: 7       sr: 8       se: 9       so:10

TABLE OF REFERENCE SYSTEM (two rows belong to each examined series)
row 1: index of candidate series(I3); number of reference series(I3)
row 2: indexes of reference series(I3)
  1  9
  2  3  4  5  6  7  8  9 10
  2  6
  1  3  4  6  7  9
  3  9
  1  2  4  5  6  7  8  9 10
  4  9
  1  2  3  5  6  7  8  9 10
  5  7
  1  3  4  7  8  9 10
  6  6
  1  2  3  4  7  9
  7  9
  1  2  3  4  5  6  8  9 10
  8  7
  1  3  4  5  7  9 10
  9  9
  1  2  3  4  5  6  7  8 10
 10  7
  1  3  4  5  7  8  9

File of Meta Data: MASHMETA.DAT
Original series (with missing values): MASHMISS.SER
Original series (without missing values): MASHDAT.SER
Homogenized series: MASHHOM.SER
Inhomogeneity series: MASHINH.SER
Automatic filling of missing values: MASHMISS.BAT
Help for selection of candidate series: MASHHELP.BAT
Evaluation of meta data: METAHELP.BAT
Automatic correction of outliers: MASHLIER.BAT
GAME of MASH: MASHGAME.BAT
Automatic version of GAME of MASH: MASHGAUT.BAT
Non-automatic correction: MASHCOR.BAT
Graphics: MASHDRAW.BAT
```

Figure 1. Output of Parametrization (MASHPAR.PAR)

```
                   CANDIDATE SERIES:     bp

VARIANCE & DEVIATION:   .4865   .6975
DATE OF MISSING VALUE:  1916
EXCLUDED REFERENCE SERIES:     de
OPTIMAL POSITIVE WEIGHTING
REFERENCE SERIES, WEIGHTING FACTORS, ERRORS

             ke      ny      sr      so      Variance      std.error
    bp    .16281  .24556  .54768  .04396        .06357        .25214

INTERCEPT:    1.34
ESTIMATED VALUE:   11.73


                   CANDIDATE SERIES:     de

VARIANCE & DEVIATION:   .5411   .7356
DATE OF MISSING VALUE:  1916
EXCLUDED REFERENCE SERIES:     bp
OPTIMAL POSITIVE WEIGHTING
REFERENCE SERIES, WEIGHTING FACTORS, ERRORS

             ke      ny      Variance      std.error
    de    .28617  .71383        .06031        .24559

INTERCEPT:    -.04
ESTIMATED VALUE:   10.46


                   CANDIDATE SERIES:     de

VARIANCE & DEVIATION:   .5411   .7356
DATE OF MISSING VALUE:  1928
THERE IS NO EXCLUDED REFERENCE SERIES
OPTIMAL POSITIVE WEIGHTING
REFERENCE SERIES, WEIGHTING FACTORS, ERRORS

             bp      ke      mi      ny      Variance      std.error
    de    .35121  .12020  .02383  .50476        .04568        .21374

INTERCEPT:    -.41
ESTIMATED VALUE:    9.73


                   CANDIDATE SERIES:     de

VARIANCE & DEVIATION:   .5411   .7356
DATE OF MISSING VALUE:  1996
EXCLUDED REFERENCE SERIES:     pe
OPTIMAL POSITIVE WEIGHTING
REFERENCE SERIES, WEIGHTING FACTORS, ERRORS

             bp      ke      mi      ny      Variance      std.error
    de    .35121  .12020  .02383  .50476        .04568        .21374

INTERCEPT:    -.41
ESTIMATED VALUE:    9.42
```

Figure 2. Part of Statistical Results of Filling Missing Values (MASHMISS.RES)

```
STAGE FIRST
HELP: TABLE FOR SELECTION OF CANDIDATE SERIES
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  21.60
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1     719.39          de    2     151.68          ke    3     599.99
    mi    4    1180.70          mo    5     160.65          ny    6     137.37
    pe    7     457.81          sr    8     111.60          se    9     828.81
    so   10     100.97
```

Figure 3. First Output of Test Program MASHHELP.BAT (MASHHELP.RES)

```
STAGE FIRST
HELP: EVALUATION OF META DATA
Null hypothesis: the inhomogeneities can be explained by the Meta Data.
Critical value (significance level .05):  21.60
Test statistics (TSM) can be compared to the critical value.
The larger TSM values are more suspicious!

Series  Index     TSM       Series  Index     TSM       Series  Index     TSM
    bp    1      53.09          de    2      41.63          ke    3      96.93
    mi    4    1180.70          mo    5      88.35          ny    6     120.16
    pe    7     228.76          sr    8      41.62          se    9      92.58
    so   10      77.92
```

Figure 4. First Output of Test Program METAHELP.BAT (METAHELP.RES)

Application of Program MASHGAME.BAT (one step)

```
HELP: TABLE FOR SELECTION OF REFERENCE SERIES AND/OR CANDIDATE SERIES
Null hypothesis 1: the examined series are homogeneous.
Test Statistics belonging to the null hypothesis 1: TS
Null hypothesis 2: the inhomogeneities can be explained by the Meta Data.
Test Statistics belonging to the null hypothesis 2: TSM
Critical value (significance level .05):  21.60
Test Statistics (both TS and TSM) can be compared to the critical value.
The larger Test Statistics are more suspicious!
Series marked with asterisk(*) are not used for reference series.

Candidate series:     mi   Index:  4     TS: 1155.78*     TSM: 1155.78
Reference series:     bp   Index:  1     TS:  279.07*     TSM:   57.92
Reference series:     de   Index:  2     TS:   68.20      TSM:   49.58
Reference series:     ke   Index:  3     TS:   96.73      TSM:   35.91
Reference series:     mo   Index:  5     TS:   82.01      TSM:   62.51
Reference series:     ny   Index:  6     TS:  177.52*     TSM:   56.82
Reference series:     pe   Index:  7     TS:  512.79*     TSM:  185.26
Reference series:     sr   Index:  8     TS:  104.88      TSM:   56.83
Reference series:     se   Index:  9     TS:  934.22*     TSM:   83.67
Reference series:     so   Index: 10     TS:  162.95*     TSM:  116.41
```

Figure 5. Partial Output of Program MASHGAME.BAT (On the Screen)

```
                    CANDIDATE SERIES:     mi      (Index:   4)

NUMBER OF DIFFERENCE SERIES: 2
REFERENCE SERIES, WEIGHTING FACTORS, VARIANCE OF DIFFERENCE SERIES

             ke      mo      Variance       Deviation
    mi    .66227  .33773        .06984        .26427

             de      sr      Variance       Deviation
    mi    .77541  .22459        .04675        .21621

NO FORMER ESTIMATED BREAKS

EXAMINATION OF DIFFERENCE SERIES

1. DIFFERENCE SERIES
BREAK POINTS ( critical value:  21.60 )
Test statistic before homogenization of diff. s.:  420.27
             Date    Conf. Int.    Stat.   Shift      Conf. Int.
                                    8.46       +
        1    1908    [1908,1908]  420.27   -2.03    [ -2.38, -1.69]
                                   19.54       -
        2    1921    [1919,1922]   80.06     .82    [   .52,  1.19]
                                    4.38       +
        3    1931    [1929,1932]   59.00    -.80    [ -1.19,  -.45]
                                    2.11       +
        4    1939    [1937,1940]   38.34     .84    [   .37,  1.30]
                                    5.74       +
        5    1943    [1941,1949]   22.07    -.61    [ -1.24,  -.19]
                                    1.04       -
        6    1950    [1945,1959]   22.73     .47    [   .14,   .88]
                                    4.71       -
        7    1964    [1962,1967]   33.55     .67    [   .27,  1.06]
                                    3.36       +
        8    1969    [1968,1971]   39.69    -.67    [ -1.04,  -.30]
                                   10.64       -
Test statistic after homogenization of diff. s.:   19.54

2. DIFFERENCE SERIES
BREAK POINTS ( critical value:  21.60 )
Test statistic before homogenization of diff. s.:  895.43
             Date    Conf. Int.    Stat.   Shift      Conf. Int.
                                    2.21       -
        1    1904    [1902,1906]   26.92     .48    [   .22,  1.08]
                                    6.82       -
        2    1908    [1908,1908]  498.17   -2.09    [ -2.42, -1.77]
                                    1.76       +
        3    1916    [1915,1916]   35.92    -.52    [  -.83,  -.22]
                                    2.65       +
        4    1921    [1921,1922]  158.75    1.06    [   .77,  1.35]
                                   12.16       +
        5    1931    [1929,1932]   44.86    -.41    [  -.87,  -.28]
                                    3.74       +
        6    1939    [1933,1940]   25.43     .38    [   .16,   .88]
                                    7.68       -
        7    1944    [1942,1944]   37.20    -.50    [ -1.22,  -.34]
                                   12.18       +
        8    1950    [1950,1950]  194.56     .92    [   .70,  1.16]
                                   13.91       +
Test statistic after homogenization of diff. s.:   17.64
```

Figure 6. Statistical Partial Results of Program MASHGAME.BAT (MASHEX2.RES)

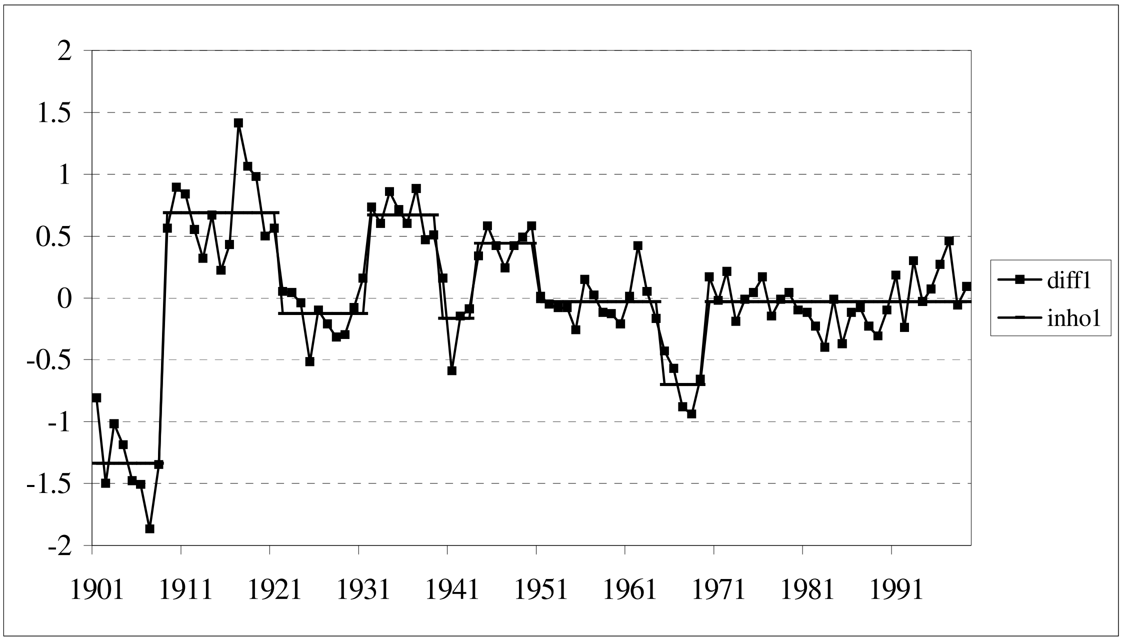


Figure 7. Graphic Partial Results of Program MASHGAME.BAT: Difference series 1 with its estimated Inhomogeneity series (MASHEX2.SER, MASHDRAW.BAT)

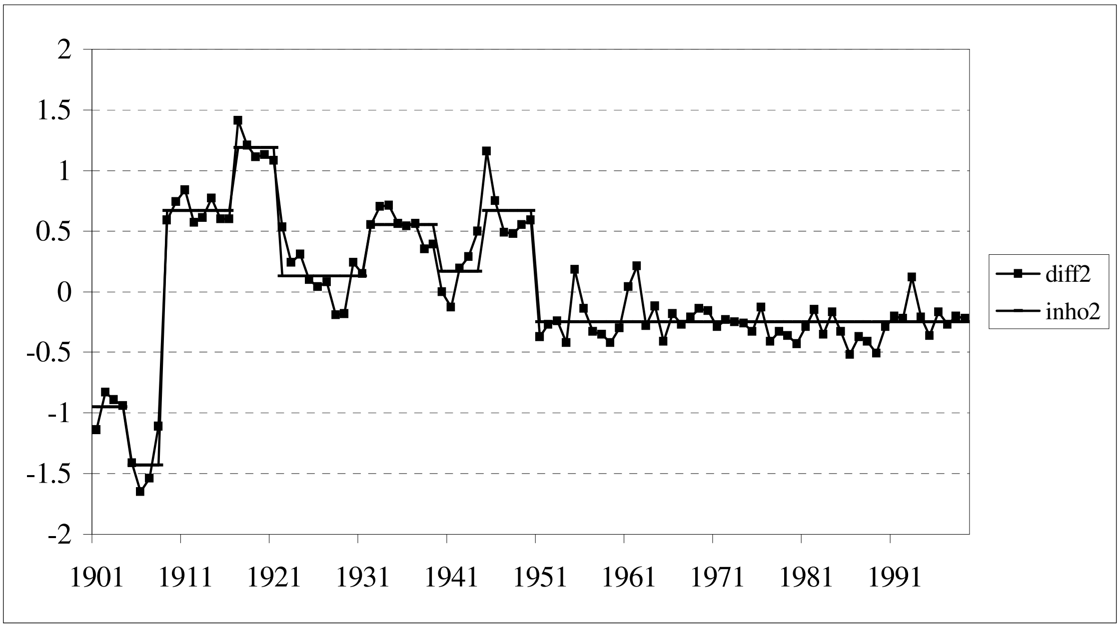


Figure 8. Graphic Partial Results of Program MASHGAME.BAT: Difference series 2 with its estimated Inhomogeneity series (MASHEX2.SER, MASHDRAW.BAT)

```
ESTIMATED BREAK POINTS AND SHIFTS
 (Mark M: META DATA)

   bp:
 No Break Points

   de:
 No Break Points

   ke:
 No Break Points

   mi:
  1908: -1.78/  M1922:   .78/  M1930:  -.41/  M1938:   .38/   1944:  -.35/
 M1950:   .47

   mo:
 No Break Points

   ny:
 No Break Points

   pe:
 No Break Points

   sr:
 No Break Points

   se:
 No Break Points

   so:
 No Break Points
```

Figure 9. Result of Examination made by Program MASHGAME.BAT (MASCOR.RES)

```
HELP: TABLE FOR SELECTION OF REFERENCE SERIES AND/OR CANDIDATE SERIES
Null hypothesis 1: the examined series are homogeneous.
Test Statistics belonging to the null hypothesis 1: TS
Null hypothesis 2: the inhomogeneities can be explained by the Meta Data.
Test Statistics belonging to the null hypothesis 2: TSM
Critical value (significance level .05):  21.60
Test Statistics (both TS and TSM) can be compared to the critical value.
The larger Test Statistics are more suspicious!
Series marked with asterisk(*) are not used for reference series.

Candidate series:     mi   Index:  4     TS:   76.28*     TSM:   57.04
Reference series:     bp   Index:  1     TS:  279.07*     TSM:   57.92
Reference series:     de   Index:  2     TS:   68.20      TSM:   49.58
Reference series:     ke   Index:  3     TS:   96.73      TSM:   35.91
Reference series:     mo   Index:  5     TS:   82.01      TSM:   62.51
Reference series:     ny   Index:  6     TS:  177.52*     TSM:   56.82
Reference series:     pe   Index:  7     TS:  512.79*     TSM:  185.26
Reference series:     sr   Index:  8     TS:  104.88      TSM:   56.83
Reference series:     se   Index:  9     TS:  934.22*     TSM:   83.67
Reference series:     so   Index: 10     TS:  162.95*     TSM:  116.41
```

Figure 10. Last Output of Program MASHGAME.BAT after Automatic Correction (On the Screen)

Verification of Homogenization (MASHVERI.BAT)

```
   I. TEST STATISTICS FOR SERIES INHOMOGENEITY
 Null hypothesis: the examined series are homogeneous.
 Critical value (significance level .05):  21.60
 Test statistics (TS) can be compared to the critical value.
 The larger TS values are more suspicious!

 1. Test Statistics After Homogenization
Series  Index     TSA       Series  Index    TSA        Series  Index    TSA
    bp     1     26.51         de     2     18.01          ke     3     29.93
    mi     4     22.64         mo     5     16.94          ny     6     22.20
    pe     7     26.99         sr     8     30.01          se     9     26.11
    so    10     13.89
 AVERAGE:     23.32
 2. Test Statistics Before Homogenization
Series  Index     TSB       Series  Index    TSB        Series  Index    TSB
    bp     1    719.39         de     2    151.68          ke     3    599.99
    mi     4   1180.70         mo     5    160.65          ny     6    137.37
    pe     7    457.81         sr     8    111.60          se     9    828.81
    so    10    100.97
 AVERAGE:    444.90
 3. Statistics for Estimated Inhomogeneities
(IS statistics can be compared with the TSB ones)
Series  Index      IS      Series  Index     IS       Series  Index     IS
    bp     1    570.28         de     2    212.85          ke     3    296.11
    mi     4   1121.99         mo     5     77.62          ny     6     37.03
    pe     7    438.62         sr     8     54.16          se     9    627.87
    so    10     90.94
 AVERAGE:    352.75

  II. CHARACTERIZATION OF INFHOMOGENEITY

 1. Relative Estimated Inhomogeneities
Series  Index     RI1      Series  Index     RI1      Series  Index     RI1
    bp     1       .36         de     2       .29          ke     3       .32
    mi     4       .52         mo     5       .22          ny     6       .12
    pe     7       .43         sr     8       .14          se     9       .45
    so    10       .21
 AVERAGE:       .30
 2. Relative Modification of Series
Series  Index     RI2      Series  Index     RI2      Series  Index     RI2
    bp     1       .49         de     2       .41          ke     3       .43
    mi     4       .53         mo     5       .26          ny     6       .12
    pe     7       .60         sr     8       .27          se     9       .76
    so    10       .21
 AVERAGE:       .41
 3. Lower Confidence Limit for Relative Residual Inhomogeneities
   (confidence level:  .95)
Series  Index     RI3      Series  Index     RI3      Series  Index     RI3
    bp     1       .01         de     2       .00          ke     3       .03
    mi     4       .00         mo     5       .00          ny     6       .00
    pe     7       .02         sr     8       .02          se     9       .03
    so    10       .00
 AVERAGE:       .01

 III. REPRESENTATIVITY OF STATION NETWORK
(1-relative interpolation error)
Series  Index      RS      Series  Index      RS      Series  Index      RS
    bp     1       .84         de     2       .82          ke     3       .82
    mi     4       .80         mo     5       .82          ny     6       .81
    pe     7       .78         sr     8       .80          se     9       .81
    so    10       .82
 AVERAGE:       .81
```

Figure 11.a, Verification Results after Finishing the Homogenization Procedure (MASHVERI.RES)

EVALUATION OF META DATA

IV. TEST STATISTICS
Null hypothesis: the inhomogeneities can be explained by the Meta Data.
Critical value (significance level .05): 21.60
Test statistics (TSM) can be compared to the critical value.
The larger TSM values are more suspicious!

Series	Index	TSM	Series	Index	TSM	Series	Index	TSM
bp	1	53.09	de	2	41.63	ke	3	96.93
mi	4	1180.70	mo	5	88.35	ny	6	120.16
pe	7	228.76	sr	8	41.62	se	9	92.58
so	10	77.92						

AVERAGE: 202.17

V. REPRESENTATIVITY OF META DATA
(Relative part of estimated inhomogeneity can be explained by the Meta Data)

Series	Index	RM	Series	Index	RM	Series	Index	RM
bp	1	.55	de	2	1.00	ke	3	.33
mi	4	.04	mo	5	.20	ny	6	.05
pe	7	.49	sr	8	1.00	se	9	.52
so	10	.05						

AVERAGE: .42

Figure 11.b, Verification Results for Meta Data after Finishing the Homogenization Procedure (MASHVERI.RES)

VI. EXAMPLE FOR APPLICATION OF SAM SYSTEM

Data Files (monthly series)**: m{j}** (j=1,....,12)

Examined Series: Hungarian monthly mean temperature series (1901-1930).

Examined Stations:
1. Budapest (bp), 2. Debrecen (de), 3. Kecskemét (ke), 4. Miskolc (mi), 5. Mosonmagyaróvár (mo), 6. Nyíregyháza (ny), 7. Pécs (pe), 8. Sopron (sr), 9. Szeged (se), 10. Szombathely (so)

Table of Reference System: HUNTEMP.REF

```
TABLE OF REFERENCE SYSTEM (two rows belong to each examined series)
row 1: index of candidate series(I3); number of reference series(I3)
row 2: indexes of reference series(I3)
  1  9
  2  3  4  5  6  7  8  9 10
  2  6
  1  3  4  6  7  9
  3  9
  1  2  4  5  6  7  8  9 10
  4  9
  1  2  3  5  6  7  8  9 10
  5  7
  1  3  4  7  8  9 10
  6  6
  1  2  3  4  7  9
  7  9
  1  2  3  4  5  6  8  9 10
  8  7
  1  3  4  5  7  9 10
  9  9
  1  2  3  4  5  6  7  8 10
 10  7
  1  3  4  5  7  8  9
```

Table of Filambda Station Coordinates: HUNCOORD.PAR

```
index     lambda(x)        fi(y)
1        19.02499960   47.50833510   Budapest
2        21.60833360   47.49166490   Debrecen
.
.
9        20.09166720   46.25833510   Szeged
10       16.63333320   47.26666640   Szombathely
```

Table of META DATA: HUNMETA.DAT (for the given period)

```
TABLE OF META DATA (one or two rows belong to each examined series)
row 1: index of examined series(I3); number of meta data(I5)
row 2: meta data(I5), if they exist
  1    1
 1909
  2    0
  3    0
  4    1
 1922
  5    0
  6    0
  7    0
  8    0
  9    0
 10    0
```

```
30 1020.53a12.00 7.44  .05
 Model: additive
 Number of stations:  10
 Length of series:  30
 Significance level:   .05
 Critical value for break points: 20.53
 Critical value for correction: 12.00
 Critical value for outliers:  7.44
 EXAMINED STATIONS AND INDEXES

      bp: 1       de: 2       ke: 3       mi: 4       mo: 5       ny: 6
      pe: 7       sr: 8       se: 9       so:10

 TABLE OF REFERENCE SYSTEM (two rows belong to each examined station)
 row 1: index of candidate station(I3); number of reference stations(I3)
 row 2: indexes of reference stations(I3)

  1  9
  2  3  4  5  6  7  8  9 10
  2  6
  1  3  4  6  7  9
  3  9
  1  2  4  5  6  7  8  9 10
  4  9
  1  2  3  5  6  7  8  9 10
  5  7
  1  3  4  7  8  9 10
  6  6
  1  2  3  4  7  9
  7  9
  1  2  3  4  5  6  8  9 10
  8  7
  1  3  4  5  7  9 10
  9  9
  1  2  3  4  5  6  7  8 10
 10  7
  1  3  4  5  7  8  9

 File of Meta Data: MESHMETA.DAT
 Original monthly series: M{J}, (J=1,..,12)
 Original seasonal series: S{J}, (J=1,2,3,4)
 (winter,spring,summer,autumn)
 Original annual series: YEAR
 Homogenized monthly series: M{J}H, (J=1,..,12)
 Homogenized seasonal series: S{J}H, (J=1,2,3,4)
 (winter,spring,summer,autumn)
 Homogenized annual series: YEARH
 Inhomogeneity series for months: M{J}I, (J=1,..,12)
 Inhomogeneity series for seasons: S{J}I, (J=1,2,3,4)
 (winter,spring,summer,autumn)
 Inhomogeneity series for year: YEARI
 Break Points and Shifts for months: M{J}C, (J=1,..,12)
 Break Points and Shifts for seasons: S{J}C, (J=1,2,3,4)
 (winter,spring,summer,autumn)
 Break Points and Shifts for year: YEARC
 Taking the chosen monthly or seasonal series In: SAMIN.BAT
 Taking the chosen monthly or seasonal series Out: SAMOUT.BAT

 MONTHS with MISSING VALUES:  7  8
```

Figure 1. Output of Parametrization (SAMPAR.PAR)

1. Taking Month August In (SAMIN.BAT)

```
TAKING SERIES IN

SEASONAL INDEXES
MONTHS: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
WINTER: 13  SPRING: 14  SUMMER: 15  AUTUMN: 16  YEAR: 17

MONTHS with MISSING VALUES:   7  8
MONTHS without FILLING    :   7  8

Index?
```

8 (for example)

```
EXAMINED STATIONS AND INDEXES

     bp: 1       de: 2       ke: 3       mi: 4       mo: 5       ny: 6
     pe: 7       sr: 8       se: 9       so:10


Information, Parameters: SAMPAR.PAR, MASHPAR.PAR
File of Meta Data: MASHMETA.DAT
Original series (with missing values): MASHMISS.SER
Original series (without missing values): MASHDAT.SER
Homogenized series: MASHHOM.SER
Inhomogeneity series: MASHINH.SER
Break Points and Shifts: MASHCOR.RES
Automatic filling of missing values: MASHMISS.BAT
Help for selection of candidate series: MASHHELP.BAT
Evaluation of Meta Data: METAHELP.BAT
Automatic correction of outliers: MASHLIER.BAT
GAME of MASH: MASHGAME.BAT
Automatic version of GAME of MASH: MASHGAUT.BAT
Comparing Test for seasonal series: SAMTESTC.BAT
Selecting Test Procedure for seasonal series: SAMTESTS.BAT
Non-automatic correction: MASHCOR.BAT
Graphics: MASHDRAW.BAT

MISSING VALUES!
THE FIRST STEP: MASHMISS.BAT
```

Figure 2. Partial Output of Program SAMIN.BAT on the Screen

2.The Further Steps

Filling of missing values (MASHMISS.BAT); Correction of outliers (MASHLIER.BAT); Taking month AUGUST Out (SAMOUT.BAT).

Taking month JULY In (SAMIN.BAT); Filling of missing values (MASHMISS.BAT); Correction of outliers (MASHLIER.BAT); Taking month JULY Out (SAMOUT.BAT).

Taking month JUNE In (SAMIN.BAT); Correction of outliers (MASHLIER.BAT); Taking month JUNE Out (SAMOUT.BAT).

3.The Next Steps: Examination of Season SUMMER

There is a possibility for examination of the seasonal series instead of the monthly series.
The monthly inhomogeneities can be corrected by usage of the detected seasonal inhomogeneities, if the monthly inhomogeneities are identical within the given season.

3.1 Taking Season SUMMER In (SAMIN.BAT), Application of Program SAMTESTC.BAT

```
HELP: TEST TABLE
COMPARISON  between   June      and  Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Station  Index     TS       Station  Index     TS       Station  Index     TS
    bp     1      10.20         de     2      11.14         ke     3       9.79
    mi     4      18.65         mo     5      19.96         ny     6      15.74
    pe     7       4.56         sr     8      20.84         se     9      15.90
    so    10       9.78
```

```
HELP: TEST TABLE
COMPARISON  between   July      and  Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Station  Index     TS       Station  Index     TS       Station  Index     TS
    bp     1      15.87         de     2      24.45         ke     3      47.06
    mi     4      12.33         mo     5      22.01         ny     6       8.07
    pe     7      10.68         sr     8      11.75         se     9       7.75
    so    10      12.32
```

```
HELP: TEST TABLE
COMPARISON  between   August    and  Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Station  Index     TS       Station  Index     TS       Station  Index     TS
    bp     1      20.19         de     2       8.62         ke     3      10.28
    mi     4      15.02         mo     5      21.56         ny     6       8.36
    pe     7      21.42         sr     8       4.99         se     9      25.89
    so    10      19.83
```

Figure 3. Output of Test Program SAMTESTC.BAT (SAMTESTC.RES)

It can be seen that the null hypothesis can not be accepted for all the stations. The examination can be continued with a Test Procedure for excluding stations having different inhomogeneities between the seasonal series and the appropriate monthly series (SAMTESTS.BAT).

3.2 Application of Program SAMTESTS.BAT

```
HELP: TEST TABLE FOR EXCLUDING STATIONS
COMPARISON between  June      and Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!
Stations marked with asterisk(*) are not used for reference stations. Reference
stations marked with asterisk(*) are excluded,i.e. null hypothesis is rejected.
Candidate station:     ke   Index:  3  Test Statistic:   16.03*
Reference station:     bp   Index:  1  Test Statistic:    3.87
Reference station:     de   Index:  2  Test Statistic:    7.38
Reference station:     mi   Index:  4  Test Statistic:   18.65
Reference station:     mo   Index:  5  Test Statistic:   19.96*
Reference station:     ny   Index:  6  Test Statistic:   15.74
Reference station:     pe   Index:  7  Test Statistic:    7.04
Reference station:     sr   Index:  8  Test Statistic:   18.63
Reference station:     se   Index:  9  Test Statistic:   15.90*
Reference station:     so   Index: 10  Test Statistic:    4.67

COMPARISON between  July      and Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!
Stations marked with asterisk(*) are not used for reference stations. Reference
stations marked with asterisk(*) are excluded,i.e. null hypothesis is rejected.
Candidate station:     ke   Index:  3  Test Statistic:   32.68*
Reference station:     bp   Index:  1  Test Statistic:   10.71
Reference station:     de   Index:  2  Test Statistic:   16.43
Reference station:     mi   Index:  4  Test Statistic:   12.33
Reference station:     mo   Index:  5  Test Statistic:   22.01*
Reference station:     ny   Index:  6  Test Statistic:    8.07
Reference station:     pe   Index:  7  Test Statistic:    5.15
Reference station:     sr   Index:  8  Test Statistic:   12.26
Reference station:     se   Index:  9  Test Statistic:   10.38*
Reference station:     so   Index: 10  Test Statistic:    3.76

COMPARISON between  August    and Summer
Null hypothesis: the monthly and the seasonal inhomogeneities are identical.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!
Stations marked with asterisk(*) are not used for reference stations. Reference
stations marked with asterisk(*) are excluded,i.e. null hypothesis is rejected.
Candidate station:     ke   Index:  3  Test Statistic:   10.28*
Reference station:     bp   Index:  1  Test Statistic:   12.49
Reference station:     de   Index:  2  Test Statistic:    8.91
Reference station:     mi   Index:  4  Test Statistic:   15.02
Reference station:     mo   Index:  5  Test Statistic:   21.56*
Reference station:     ny   Index:  6  Test Statistic:    8.36
Reference station:     pe   Index:  7  Test Statistic:    8.95
Reference station:     sr   Index:  8  Test Statistic:   15.59
Reference station:     se   Index:  9  Test Statistic:   25.89*
Reference station:     so   Index: 10  Test Statistic:    9.42

Indexes of excluded stations:  3,  5,  9
```

Figure 4. Result Output of Test Program SAMTESTS.BAT (SAMTESTS.RES)

3.3 Homogenization of the SUMMER Series (MASHGAME.BAT, MASHGAUT.BAT etc.)

```
ESTIMATED BREAK POINTS AND SHIFTS
  (Mark M: META DATA)
    bp:
  M1909:   .26
    de:
  No Break Points
    ke:
   1927:   .39/   1928:  -.39
    mi:
   1908: -3.74
    mo:
  No Break Points
    ny:
   1901:   .93
    pe:
   1918:   .52/   1921: -1.18
    sr:
  No Break Points
    se:
   1918:  -.76
    so:
   1917:   .25
```

Figure 5. Detected SUMMER Inhomogeneities (MASHCOR.RES)

3.4 Evaluation of the Homogenization of SUMMER Series

```
 STAGE FIRST
 Null hypothesis: the examined series are homogeneous.
 Critical value (significance level .05):  20.53
 Test statistics (TS) can be compared to the critical value.
 The larger TS values are more suspicious!
 Series  Index     TS        Series  Index     TS        Series  Index     TS
     bp    1      87.15          de    2      22.40          ke    3      36.23
     mi    4    1012.34          mo    5      27.64          ny    6      39.53
     pe    7      82.45          sr    8       8.01          se    9      68.63
     so   10      84.04

 STAGE LAST
 Null hypothesis: the examined series are homogeneous.
 Critical value (significance level .05):  20.53
 Test statistics (TS) can be compared to the critical value.
 The larger TS values are more suspicious!
 Series  Index     TS        Series  Index     TS        Series  Index     TS
     bp    1      10.46          de    2       7.49          ke    3      18.98
     mi    4      27.96          mo    5      19.10          ny    6      10.23
     pe    7      22.70          sr    8       4.91          se    9      16.21
     so   10      12.21
```

Figure 6. Output of MASHHELP.BAT before and after Homogenization (MASHHELP.RES)

```
STAGE FIRST
Null hypothesis: the inhomogeneities can be explained by the Meta Data.
Critical value (significance level .05):  20.53
Test statistics (TSM) can be compared to the critical value.
The larger TSM values are more suspicious!
Series  Index     TSM       Series  Index     TSM       Series  Index     TSM
    bp    1       9.18          de    2      20.45          ke    3      38.11
    mi    4     971.28          mo    5      17.86          ny    6      39.53
    pe    7      82.45          sr    8       8.01          se    9      71.13
    so   10      68.18

STAGE LAST
Null hypothesis: the inhomogeneities can be explained by the Meta Data.
Critical value (significance level .05):  20.53
Test statistics (TSM) can be compared to the critical value.
The larger TSM values are more suspicious!
Series  Index     TSM       Series  Index     TSM       Series  Index     TSM
    bp    1       7.93          de    2       7.85          ke    3      17.27
    mi    4      18.34          mo    5      17.22          ny    6      10.23
    pe    7      22.70          sr    8       4.91          se    9      19.79
    so   10      14.84
```

Figure 7. Output of METAHELP.BAT before and after Homogenization (METAHELP.RES)

3.5 Taking Season SUMMER Out (SAMOUT.BAT)

Homogenization of summer (June, July, August) monthly series on the basis of the detected summer inhomogeneities with exception of stations ke (index:3), mo (index:5), se (index:9), as a result of the Test Program SAMTESTS.BAT (see Figure 4.)

4. Evaluation of the Homogenization of Monthly Series

4.1 Taking month JUNE In (SAMIN.BAT); Application of MASHHELP.BAT

```
STAGE FIRST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!
Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1      24.42          de    2       7.78          ke    3     193.86
    mi    4     633.59          mo    5      43.84          ny    6      27.35
    pe    7      28.89          sr    8      14.92          se    9      88.49
    so   10      53.76

STAGE LAST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!
Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1       9.71          de    2       9.38          ke    3      54.18
    mi    4      43.60          mo    5      46.04          ny    6      10.28
    pe    7      22.98          sr    8      18.63          se    9      98.85
    so   10      11.97
```

Figure 8. Output of MASHHELP.BAT before and after Homogenization (MASHHELP.RES)

4.2 Taking Month JULY In (SAMIN.BAT); Application of MASHHELP.BAT

```
STAGE FIRST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1      55.11          de    2       9.72          ke    3      58.27
    mi    4     764.40          mo    5      45.49          ny    6      53.30
    pe    7      54.73          sr    8       5.99          se    9      78.28
    so   10      50.69

STAGE LAST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1      12.83          de    2      19.69          ke    3      19.98
    mi    4      18.29          mo    5      28.06          ny    6      12.60
    pe    7      41.91          sr    8       6.01          se    9     168.83
    so   10      12.09
```

Figure 9. Output of MASHHELP.BAT before and after Homogenization (MASHHELP.RES)

4.3 Taking Month AUGUST In (SAMIN.BAT); Application of MASHHELP.BAT

```
STAGE FIRST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1     140.41          de    2      39.04          ke    3       8.82
    mi    4    1935.64          mo    5      14.22          ny    6      23.56
    pe    7      53.83          sr    8      18.30          se    9      26.14
    so   10      32.30

STAGE LAST
Null hypothesis: the examined series are homogeneous.
Critical value (significance level .05):  20.53
Test statistics (TS) can be compared to the critical value.
The larger TS values are more suspicious!

Series  Index     TS        Series  Index     TS        Series  Index     TS
    bp    1       8.10          de    2      18.16          ke    3      10.21
    mi    4      33.45          mo    5       9.02          ny    6       8.57
    pe    7      18.05          sr    8      14.93          se    9      84.55
    so   10      15.46
```

Figure 10. Output of MASHHELP.BAT before and after Homogenization (MASHHELP.RES)

5. Verification of Homogenization for SUMMER series (MASHVERI.BAT)

```
 I. TEST STATISTICS FOR SERIES INHOMOGENEITY
 Null hypothesis: the examined series are homogeneous.
 Critical value (significance level .05):  20.53
 Test statistics (TS) can be compared to the critical value.
 The larger TS values are more suspicious!

 1. Test Statistics After Homogenization
Series  Index     TSA       Series  Index    TSA       Series  Index    TSA
    bp     1     10.46         de     2      7.49         ke     3     39.51
    mi     4     36.10         mo     5     19.10         ny     6     10.23
    pe     7     40.89         sr     8      4.91         se     9    107.80
    so    10     12.21
 AVERAGE:     28.87
 2. Test Statistics Before Homogenization
Series  Index     TSB       Series  Index    TSB       Series  Index    TSB
    bp     1     97.39         de     2     17.04         ke     3     39.72
    mi     4   1012.34         mo     5     27.64         ny     6     39.53
    pe     7     82.45         sr     8      8.01         se     9     68.75
    so    10     84.04
 AVERAGE:    147.69
 3. Statistics for Estimated Inhomogeneities
(IS statistics can be compared with the TSB ones)
Series  Index     IS       Series  Index     IS       Series  Index     IS
    bp     1     19.29        de     2       .00        ke     3      3.27
    mi     4    889.88        mo     5       .00        ny     6     17.29
    pe     7     42.41        sr     8       .00        se     9       .00
    so    10      9.29
 AVERAGE:     98.14

  II. CHARACTERIZATION OF INFHOMOGENEITY

 1. Relative Estimated Inhomogeneities
Series  Index     RI1      Series  Index     RI1      Series  Index     RI1
    bp     1       .13        de     2       .00        ke     3       .08
    mi     4       .98        mo     5       .00        ny     6       .18
    pe     7       .31        sr     8       .00        se     9       .00
    so    10       .15
 AVERAGE:       .18
 2. Relative Modification of Series
Series  Index     RI2      Series  Index     RI2      Series  Index     RI2
    bp     1       .15        de     2       .00        ke     3       .08
    mi     4      1.14        mo     5       .00        ny     6       .18
    pe     7       .54        sr     8       .00        se     9       .00
    so    10       .22
 AVERAGE:       .23
 3. Lower Confidence Limit for Relative Residual Inhomogeneities
   (confidence level:  .95)
Series  Index     RI3      Series  Index     RI3      Series  Index     RI3
    bp     1       .00        de     2       .00        ke     3       .08
    mi     4       .06        mo     5       .00        ny     6       .00
    pe     7       .09        sr     8       .00        se     9       .24
    so    10       .00
 AVERAGE:       .05

 III. REPRESENTATIVITY OF STATION NETWORK
(1-relative interpolation error)
Series  Index      RS      Series  Index      RS      Series  Index      RS
    bp     1       .84        de     2       .79        ke     3       .70
    mi     4       .65        mo     5       .79        ny     6       .74
    pe     7       .73        sr     8       .64        se     9       .80
    so    10       .75
 AVERAGE:       .74
```

Figure 11.a, Verification Results at the actual stage of Homogenization (MASHVERI.RES)

EVALUATION OF META DATA

IV. TEST STATISTICS
Null hypothesis: the inhomogeneities can be explained by the Meta Data.
Critical value (significance level .05): 20.53
Test statistics (TSM) can be compared to the critical value.
The larger TSM values are more suspicious!

Series	Index	TSM	Series	Index	TSM	Series	Index	TSM
bp	1	10.42	de	2	16.54	ke	3	39.72
mi	4	971.28	mo	5	17.86	ny	6	39.53
pe	7	82.45	sr	8	8.01	se	9	71.23
so	10	68.18						

AVERAGE: 132.52

V. REPRESENTATIVITY OF META DATA
(Relative part of estimated inhomogeneity can be explained by the Meta Data)

Series	Index	RM	Series	Index	RM	Series	Index	RM
bp	1	1.00	de	2	1.00	ke	3	.00
mi	4	.07	mo	5	1.00	ny	6	.00
pe	7	.00	sr	8	1.00	se	9	1.00
so	10	.00						

AVERAGE: .51

Figure 11.b, Verification Results for Meta Data at the actual stage of Homogenization (MASHVERI.RES)

VII. HOMOGENIZATION OF DAILY DATA

MATHEMATICAL BASIS (draft version)

Only the additive model is presented that is appropriate for temperature, pressure etc. elements.

Relation of daily and monthly homogenization

Alternative possibilities
– To use the detected monthly inhomogeneities directly for daily data homogenization
– Direct methods for daily data homogenization
Problems
– The direct use of the detected monthly inhomogeneities is probably not sufficient.
– Direct methods for daily data homogenization is probably not enough efficient thinking of the larger variability (less signal to noise ratio).
The Question
How can we use the valuable information of detected monthly inhomogeneities for daily data homogenization?

Additive model for daily values (e.g. temperature)

$$X^{st}(y,m,d) = \mu(y,m,d) + \mu_0^{st}(m,d) + IH^{st}(y,m,d) + \varepsilon^{st}(y,m,d)$$

μ : climate change signal, μ_0: spatial expected value,

IH : inhomogeneity , ε : normal noise

st : station, m : month, y : year, d : day

Additive model for monthly means

$$X_m^{st}(y) = \mu_m(y) + \mu_{0m}^{st} + IH_m^{st}(y) + \varepsilon_m^{st}(y)$$

$IH_m^{st}(y) = \overline{IH^{st}}(y,m)$: inhomogeneity (break points and shifts)

We have: estimated monthly inhomogeneities: $I\hat{H}_m^{st}(y)$

Valuable information! : $\overline{IH^{st}}(y,m) = IH_m^{st}(y)$

But maybe a problem of direct use: the smoothness

Question:

Smooth estimation $I\hat{H}^{st}(y,m,d)$ for daily inhomogeneities

by using the estimated monthly inhomogeneities $I\hat{H}_m^{st}(y)$?

Possible condition for daily estimation $I\hat{H}^{st}(y,m,d)$:

Smoothness and condition for mean: $\overline{I\hat{H}^{st}}(y,m) = I\hat{H}_m^{st}(y)$

Maybe a problem: too strong inhomogeneities can be obtained.

Other train of thought

Not to forget: the monthly values $I\hat{H}_m^{st}(y)$ are only estimations, stochastic variables. To know the real $IH_m^{st}(y)$ is impossible. Consequently the monthly estimations $I\hat{H}_m^{st}(y)$ may be modified. But the modification must be controlled.

<u>The Essence of Procedure</u>

i, Smooth estimation for daily inhomogeneities with a not too strong condition e.g.: $\exists d_0 : I\hat{H}^{st}(y,m,d_0) = I\hat{H}_m^{st}(y)$

ii, Test of hypothesis to control the new monthly estimations: $I\tilde{H}_m^{st}(y) := \overline{I\hat{H}^{st}(y,m)}$

The MASH Procedure for Daily Data

1. Monthly means $X_m^{st}(y)$ from daily data $X^{st}(y,m,d)$.
2. MASH homogenization procedure for monthly series $X_m^{st}(y)$, estimation of monthly inhomogeneities: $I\hat{H}_m^{st}(y)$
3. On the basis of estimated monthly inhomogeneities $I\hat{H}_m^{st}(y)$, smooth estimation for daily inhomogeneities: $I\hat{H}^{st}(y,m,d)$.
4. Homogenization of daily data:

   $\tilde{X}^{st}(y,m,d) = X^{st}(y,m,d) - I\hat{H}^{st}(y,m,d)$.
5. Qulity Control for homogenized daily data $\tilde{X}^{st}(y,m,d)$.
6. Missing daily data complementing.
7. Monthly means $\tilde{X}_m^{st}(y)$ from homogenized, controlled, complemented daily data $\tilde{X}^{st}(y,m,d)$.
8. Test of homogeneity for the new monthly series $\tilde{X}_m^{st}(y)$ by MASH. Repeating steps 2-8 with $\tilde{X}_m^{st}(y)$, $\tilde{X}^{st}(y,m,d)$ if it is necessary.

Interpolation technique for QC and Data Complementing

<u>Daily data for a given month:</u>

$X_j(t) \in N(E_j(t), D_j(t))$ ($j = 1,..,M$ station; $t = 1,...,30$)

<u>Candidate data:</u> $X_j(t)$ <u>Reference data:</u> $X_i(t)$ ($i \neq j$)

Interpolation: $\hat{X}_j(t) = w_{j0}(t) + \sum_{i \neq j} w_{ji}(t) X_i(t)$ where $\sum_{i \neq j} w_{ji}(t) = 1$.

RMS Error and Representativity: $RMSE_j(t)$, $REP_j(t) = 1 - \frac{RMSE_j(t)}{D_j(t)}$

The Optimum Interpolation Parameters $w_{j0}^{opt}(t)$, $w_{ji}^{opt}(t)\,(i \neq j; t = 1,..,30)$ minimizing $RMSE_j(t)$, are uniquely determined by the expectations, st. deviations and the correlations.

Problem: Estimation of daily statistical parameters.

Assumptions:

i, $E_j(t) - E_i(t) = e_{ji}$, $D_j(t)/D_i(t) = d_{ji}$, $(i \neq j; t = 1,..,30)$

ii, $\text{corr}(X_{j_1}(t_1), X_{j_2}(t_2)) = r_{j_1 j_2}^S \cdot r_{t_1 t_2}^T$ $(j_1, j_2 = 1,..M; t_1, t_2 = 1,..,30)$

$r_{j_1 j_2}^S$: correlation structure in space, $r_{t_1 t_2}^T$: correlation structure in time

$\Leftrightarrow$ Partial corr.: $\text{corr}_{X_{j_1}(t_2)}(X_{j_1}(t_1), X_{j_2}(t_2)) = \text{corr}_{X_{j_2}(t_1)}(X_{j_1}(t_1), X_{j_2}(t_2)) = 0$

Statement: If the assumptions i, ii, are fulfilled then

$w_{j0}^{opt}(t) \equiv w_{j0}^{opt}$, $w_{ji}^{opt}(t) \equiv w_{ji}^{opt}$, $REP_j^{opt}(t) \equiv REP_j^{opt}$ $(t = 1,..,30)$,

where w_{j0}^{opt}, w_{ji}^{opt}, REP_j^{opt} are the optimal parameters of monthly interpolation: $\hat{\bar{X}}_j(t) = w_{j0} + \sum_{i \neq j} w_{ji} \bar{X}_i$ where $\sum_{i \neq j} w_{ji} = 1$.

Consequence

The monthly statistical parameters can be used for daily interpolation.

i, Data Complementing: $\hat{X}_j(t) = w_{j0}^{opt} + \sum_{i \neq j} w_{ji}^{opt} X_i(t)$

ii, Quality Cotrol can be based on the standardized error:

$$Z_j(t) = \frac{X_j(t) - \hat{X}_j(t)}{D_j(t)(1 - REP_j^{opt})} \in N(0,1)$$

where w_{j0}^{opt}, w_{ji}^{opt}, REP_j^{opt} are the optimal parameters of monthly interpolation, and $D_j(t)$ is the daily standard deviation.

Test of Hypothesis of the standardized error series $Z(t)\ (t=1,..,n)$

If the data have good quality then $Z(t) \in N(0,1) \quad (t=1,..,n)$.

But Problem: $\mathrm{P}\left(\max_t |Z(t)| < z \right)$ depends on the autocorrelation.

Statement:

i, If $Z(t)\ (t=1,..,n)$ is a Markov process, furthemore

ii, and $\mathrm{P}\left(|Z(t)| < z \mid |Z(t-1)| < z \right) \geq \mathrm{P}\left(|Z(t)| < z \right) \qquad (t=2,..,n)$,

then $\mathrm{P}\left(\max_t |Z(t)| < z \right) \geq \prod_{t=1}^{n} \mathrm{P}\left(|Z(t)| < z \right)$.

Example:

If $Z(t)\ (t=1,..,n)$ is a normal AR(1) process then i, ii, are fulfilled.

Decision according to test of hypothesis

We have wrong data:

If $|Z(t)| > z_p$ where critical value z_p is defined by

the significance level p (e.g.: p=0.01) as,

$$\mathrm{P}\left(\max_t |Z(t)| < z_p \right) \geq \left(2\Phi(z_p) - 1 \right)^n = 1 - p \quad ,$$

$\Phi(z)$: standard normal distribution function.

Multiple QC for daily data

More standardized error series are examined without common reference series to separate the wrong data for the candidate station. Correction of the wrong data is based on confidence intervals.

THE STRUCTURE OF MASHDAILY PROGRAM SYSTEM

Main Directory **MASHv3.02**:

Directory **MASHDAILY:**

- Subdirectory **MASHDAMO**
    - MASHDAMO.BAT
    - Subdirectory **MASHFORMAT**
    - Subdirectory **MASHDAMOSUB** (do not use it including "subroutines")
- Subdirectory **MASHDAILY:**
    - Subdirectory **MASHDPAR**
        - Parametrization program: MASHDPAR.BAT
    - Main Program: MASHD.BAT
    - Subdirectory **MASHDSUB** (do not use it including "subroutines")

Directory **MASHMONTHLY** (See Page 21)

MASHDAILY IN PRACTICE

I. Monthly Data from Daily Data in Subdirectory MASHDAILY\ MASHDAMO

MASHDAMO.BAT (see page 58)

II. Homogenization of Monthly Series in Directory MASHMONTHLY\SAM

MASH homogenization procedure for monthly series, estimation of monthly inhomogeneities.
Input Files from **MASHDAMO\MASHFORMAT: M{j} (j=1,....,12), FILASTAT.PAR**
(see p. 58; Copy batch File in Subdirectory MASHFORMAT: COPYSAMPAR.BAT)

III. Homogenization of Daily Data in Subdirectory MASHDAILY\ MASHDAILY

1. Parametrization in Subdirectory MASHDAILY\ MASHDAILY\MASHDPAR:
MASHDPAR.BAT (see pages 58-59)

2. Homogenization of Daily Data, Qulity Control for Homogenized Daily Data, Missing Daily Data Complementing in Subdirectory MASHDAILY\ MASHDAILY:
MASHD.BAT (see pages 59-60)

THE MAIN PROGRAM and I/O FILES in Subdirectory MASHDAMO

EXECUTIVE FILE: MASHDAMO.BAT

INPUT:
Original Daily Data: **DAILY.DAT**
Maximal number of stations: 500
Maximal number of years: 200
Format of Data File:
  row 1: names of stations (obligatory!), Format: (2x,character*6)?
  column 1: date of year (I4)
  column 2: month (I2)
  column 3: day (I2)
  column i+3: series i.
  Data Format: F8.2
  Mark of Missing Values: 9999.99

File of Filambda Station Coordinates: **FILASTAT.PAR** (see page 61)

Model: additive or multiplicative

RESULT OUTPUT FILES in MASHDAMO\MASHFORMAT:
(Input Files of MASHMONTHLY\SAM)
Files of Monthly Series: **M{J} (J=1,..,12)**
File of Filambda Station Coordinates: **FILASTAT.PAR**

RESULT OUTPUT FILES in MASHDAILY\MASHDPAR:
Original Daily Data: **DAILY.DAT**
Files of Monthly Series: **M{J} (J=1,..,12)**
File of Filambda Station Coordinates: **FILASTAT.PAR**
Parameter File: **MASHDPAR.PAR**

THE MAIN PROGRAM and I/O FILES of Subdirectory MASHDAILY\ MASHDAILY\MASHDPAR

EXECUTIVE BATCH FILE: MASHDPAR.BAT

THE STEPS OF MASHDPAR.BAT:
MASHDTRAN.EXE & MASHDTOP.EXE& MASHDTEXT.EXE

INPUT DATA FILES:
Result Files from **MASHMONTHLY\SAM\SAMEND**:
  Homogenized Monthly Series **M{j}h (j=1,....,12)**
  Monthly Inhomogeneities **M{j}i (j=1,....,12)**
(Copy batch File in Subdirectory SAMEND: COPYMASHDPAR)

INPUT DATA FILES DAILY.DAT, M{J} (J=1,..,12), MASHDPAR.PAR, FILASTAT.PAR are written in by MASHDAMO.BAT

OUTPUT FILES written in Directory MASHDAILY\MASHDAILY:
MASHDPAR.PAR, FILASTAT.PAR, REFERENCE.PAR, DAILY.DAT, M{j} (j=1,....,12), M{j}h (j=1,....,12), M{j}i (j=1,....,12)
Work and Parameter Files: DMP{j}.PAR (j=1,....,6), M{j}h.tr (j=1,....,12)

THE MAIN PROGRAM and I/O FILES of Subdirectory MASHDAILY\ MASHDAILY

EXECUTIVE BATCH FILE: MASHD.BAT

INPUT DATA FILES are written in by MASHDPAR.BAT

RESULT OUTPUT FILES:

Homogenized, Controlled and Complemented daily Data: **DAILYHOMQC.DAT**

Homogenized and Complemented daily Data (without QC): **DAILYHOM.DAT**

Daily Inhomogeneities: **DAILYINHOM.DAT**

Result of Quality Control: **ERROR.RES**

THE STEPS OF MASHD.BAT:

1. STAT1.EXE:
Input: MASHDPAR.PAR, M{j}h (j=1,....,12), FILASTAT.PAR
Output: STAT1{j}.PAR (j=1,....,12)

2. DMINHOM1.EXE:
Input: MASHDPAR.PAR, M{j} (j=1,....,12), M{j}i (j=1,....,12)
Output: DMSTAT.RES, DM{j}i.PAR (j=1,....,12)

3. DMINHOM2.EXE:
Input: MASHDPAR.PAR, M{j} (j=1,....,12), M{j}i (j=1,....,12)
Output: DM{j}i (j=1,....,12)

4. DMINHOM3.EXE:
Input: MASHDPAR.PAR, DM{j}i (j=1,....,12)
Output: DM{j}i (j=1,....,12) (Daily inhomogeneities in 12 files)

5. DMDATA.EXE:
Input: MASHDPAR.PAR, DAILY.DAT
Output: DM{j} (j=1,....,12) (Original daily data in 12 files)

6. DMINHCORR.EXE:
Input: MASHDPAR.PAR, DM{j}i.PAR (j=1,....,12), DM{j}i (j=1,....,12),
DM{j} (j=1,....,12)
Output: DM{j}h (j=1,....,12) (Homogenized daily data in 12 files),
DM{j}d (j=1,....,12) (Daily st. deviations in 12 files)

7. QC.EXE
Input: MASHDPAR.PAR, REFERENCE.PAR, STAT1{j}.PAR (j=1,....,12),
DM{j}i (j=1,....,12), DM{j}h (j=1,....,12), DM{j}d (j=1,....,12),
DM{j} (j=1,....,12), M{j}i (j=1,....,12)
Output: DM{j}hc (j=1,....,12) (Homogenized, controlled daily data in 12 files)
ERROR.RES
Work and Parameter Files: QC1.PAR, QC2.PAR, ERR{j} (j=1,....,12), ERROR.PAR

8. MISSING.EXE:
Input: MASHDPAR.PAR, FILASTAT.PAR,
DM{j}hc (j=1,....,12), STAT1{j}.PAR (i=1,..12)
Output: DM{j}hcm (j=1,....,12) (Homog., controlled, complemented daily data in 12 files)
Work and Parameter Files: MISSING1.PAR, MISSING2.PAR

9. DAILYEND.EXE:
Input: MASHDPAR.PAR, DM{j}hcm (j=1,....,12), DM{j}i (j=1,....,12)
Output: **DAILYHOMQC.DAT, DAILYHOM.DAT, DAILYINHOM.DAT**

EXAMPLE FOR APPLICATION OF MASHDAILY SYSTEM

Examined Data: DAILY.DAT

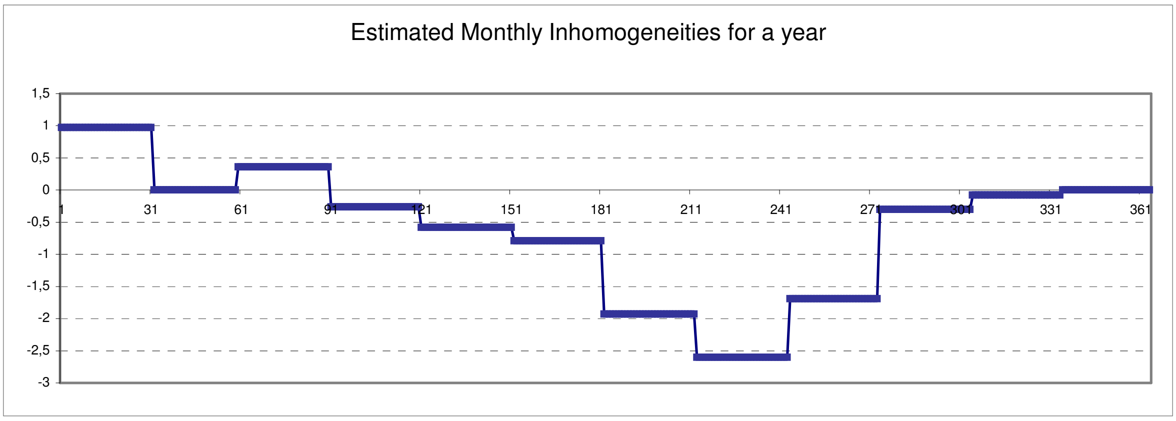
Daily temperature series (1901-1930), 10 Stations in Hungary.

Temperature element: (max+min)/2

Model: additive

File of Filambda Station Coordinates: FILASTAT.PAR

```
index    lambda(x)       fi(y)
   1    18.65308760   47.18486400
   2    20.62684630   46.57159040
   3    17.09815790   47.05921170
   4    20.14969640   47.21730420
   5    17.39957430   47.90058140
   6    20.80181500   46.85120390
   7    16.83021930   47.91734310
   8    19.18956180   45.94506840
   9    16.73989490   47.59620290
  10    19.86032100   46.45614240
```



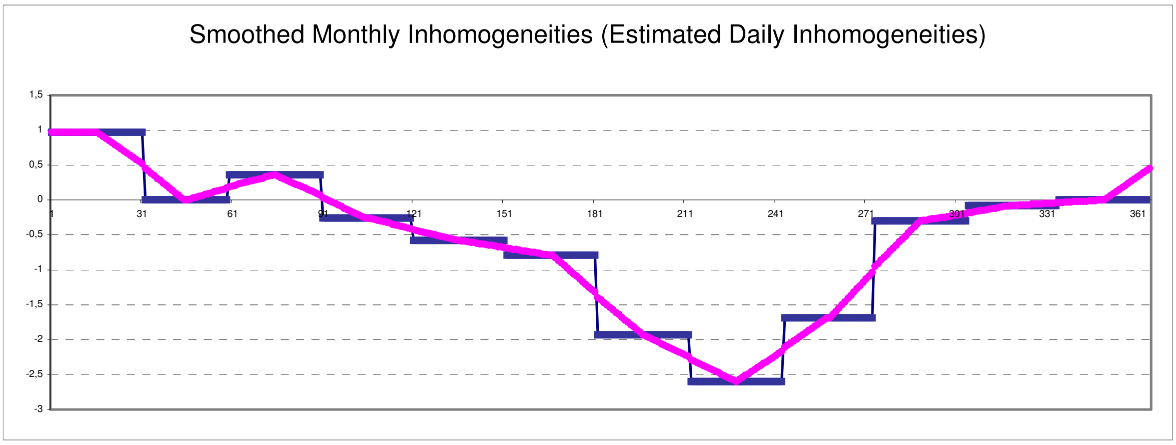


Figure 1. Example for smoothing of Monthly Ihomogeneities

Detected errors in September 1903 at Station 10 (ERROR.RES)

	st1	st2	st3	st4	st5	st6	st7	st8	st9	st10
1903 9 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.4
1903 9 2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.2
1903 9 3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-3.1
1903 9 4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-5.0
1903 9 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.6
1903 9 6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.7
1903 9 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-4.9
1903 9 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-2.9
1903 910	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8
1903 911	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-5.5
Original Data										
1903 9 1	20.5	17.1	20.0	17.5	21.0	18.1	18.7	19.5	19.3	12.3
1903 9 2	19.8	17.9	20.8	15.5	21.5	14.9	18.4	19.3	20.2	13.2
1903 9 3	19.1	17.3	20.8	15.5	21.3	15.8	18.5	17.2	17.5	11.3
1903 9 4	19.7	17.5	19.8	15.3	19.0	15.8	18.8	19.2	17.2	10.4
1903 9 5	20.3	17.8	20.5	16.0	21.0	17.4	19.3	20.4	17.8	13.2
1903 9 6	20.9	18.7	21.3	17.3	20.0	18.6	19.9	21.4	18.8	13.8
1903 9 7	22.9	21.5	22.5	17.8	22.0	19.5	18.9	23.6	19.0	13.9
1903 9 8	22.5	20.9	25.0	19.0	23.0	19.8	19.1	23.5	19.5	15.5
1903 910	17.7	18.4	17.0	13.8	13.6	19.0	14.3	18.9	13.7	12.7
1903 911	16.5	13.7	18.3	11.8	14.5	13.5	13.1	18.8	14.1	6.2
Longterm means in September										
	16.7	15.9	16.2	14.9	15.9	15.5	14.6	17.0	14.7	16.6

Figure 2. Part Results of Quality Control

TEST STATISTICS for ANNUAL SERIES (OUTPUT of MASH)
Critical value (significance level 0.05): 20.53

1. Test Statistics Before Monthly Homogenization

Station	TSBM	Station	TSBM	Station	TSBM
4	317.85	6	241.41	2	155.04
9	127.66	7	91.66	10	68.36
1	62.55	8	61.84	5	42.06
3	15.82	AVERAGE:	118.42		

2. Test Statistics After Monthly Homogenization

Station	TSAM	Station	TSAM	Station	TSAM
7	28.64	5	25.11	9	22.73
4	18.52	1	18.12	8	15.26
6	14.96	2	14.82	10	12.41
3	10.26	AVERAGE:	18.08		

3. Test Statistics After Monthly&Daily Homogenization

Station	TSAMD	Station	TSAMD	Station	TSAMD
7	28.89	5	25.40	2	25.06
9	21.98	1	17.60	4	16.52
8	15.23	6	14.66	3	9.69
10	9.00	AVERAGE:	18.40		

Figure 3. Verification Results for the Annual Series (MASHVERI.RES)

AVERAGED TEST STATISTICS FOR MONTHLY SERIES (10 Stations)

Average of Test Statistics Before Monthly Homogenization: **TSBM**

Average of Test Statistics After Monthly Homogenization: **TSAM**

Average of Test Statistics After Monthly&Daily Homogenization: **TSAMD**

MONTH	TSBM	TSAM	TSAMD
1	28.5	12.0	12.1
2	21.1	16.6	17.0
3	41.2	24.0	22.4
4	73.7	17.5	17.8
5	82.1	15.7	13.4
6	100.7	14.7	12.5
7	84.5	16.1	14.2
8	61.7	16.0	14.3
9	131.4	12.9	13.1
10	56.3	14.6	16.0
11	38.9	10.4	11.2
12	34.5	18.7	20.4
SP	90.6	19.9	20.2
SU	92.6	18.7	17.2
AU	101.3	17.1	19.6
WI	32.1	18.3	16.6
Y	118.4	18.1	18.4

Critical value (significance level 0.05): **20.53**
Test statistics (TS) can be compared to the critical value.

Figure 4. Average of Verification Results for the Monthly Series

ANNEX: SOME NEW DEVELOPMENTS FOR AUTOMATION
('User friendly' procedures)

1. In Directory MASHMONTHLY\SAM\MASH

1.1. Automatic, iteration application of MASHGAME.BAT
(Iteration Examination of all the station series)

Directory: MASHMONTHLY\SAM\MASH\MASHAUTO

Batch Files:

i, MAUTOPAR.BAT: Parametrization
Input: Number of Iteration Steps

ii, MASHAUTO.BAT: Examination, homogenization

2. In Directory MASHMONTHLY\SAM

2.1. Automatic, iteration application of MASHGAME.BAT
(Iteration Examination of all the station series)

Directory: MASHMONTHLY\SAM\SAMAUTO

Batch Files:

i, SAUTOPAR.BAT: Parametrization
Input: Number of Iteration Steps

ii, SAMAUTO.BAT: Examination, homogenization

2.2. Data Complementing for all the 12 Months together
(Automatic version of MASHMISS.BAT)

Directory: MASHMONTHLY\SAM\SAMMISS

Batch File: **SAMMISS.BAT**

2.3. Verification Procedure for all Monthly, Seasonal and Annual Series together
(Automatic version of MASHVERI.BAT)

Directory: MASHMONTHLY\SAM\SAMVERI

Batch File: **SAMVERI.BAT**

Output Files in Directory SAM: **V{j}.** (j=1,….,17)

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Szentimrey, T., 2007: „Manual of interpolation software MISHv1.02", Hungarian Meteorological Service, p. 32

Here are some APN (Asia-Pacific Network) web sites connected with the MASH method:
„Software Used by the APN Network for Climate Extremes"
http://www.bom.gov.au/bmrc/csr/apn/software.html
„A Guide to Programs for Calculating Indices of Extremes"
http://www.bom.gov.au/bmrc/csr/apn/papers/apn_manual.pdf