PRECIPITATION TOTALS AT TWO CZECH METEOROLOGICAL STATIONS AFTER CORRECTION OF SYSTEMATIC ERRORS IN MEASUREMENT

TOMÁŠ PTÁČEK

Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Czechia

ABSTRACT

This contribution presents the results of correcting the systematic errors that accompanied precipitation measurements at the Svratouch and Hradec Králové meteorological stations from 1961 to 1990. The selected stations are located in eastern Bohemia: the Svratouch station is situated 735 metres above sea level, the Hradec station at 270 metres above sea level. A slightly modified correction procedure constructed by R. Tihlárik was used in this study. After correction, the yearly precipitation totals recorded at the Svratouch and Hradec stations were greater by 32% and 17% of the original values, respectively. Undervaluation in Central European conditions is more significant in winter – between November and March, the average monthly undervaluation at Svratouch and Hradec reached 58–69% and 31–33%, respectively. From May to September, the average monthly undervaluation reached 7–17% at both stations. April and October were transitional months. Corrections in winter are generally indicative; corrections in the summer months are more reliable. According to the results and to literature, we can conclude that there is an undervaluation of at least 5% from May to September and an undervaluation of at least 25% from November to March at most stations in the Czech Republic. The year-to-year variability in annual and monthly corrected precipitation totals was also studied. The purpose of correcting such data is to provide more accurate precipitation totals, which subsequently provides a more accurate picture of trends in precipitation and of rainfall-runoff relationships.

Keywords: atmospheric precipitation, measurement errors, systematic errors, Czechia

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1. Introduction

Precipitation totals are among the most difficult meteorological variables to measure and predict, and may be significantly undervalued due to non-systematic and systematic errors. Neither manual or automatic gauges, nor measurements using radar adequately measure precipitation. Systematic errors undervalue precipitation totals by tens of percent depending on the conditions; therefore, there is a need to reduce the size of errors. Precipitation is inevitably a critical variable in any assessment of water resources. By correcting systematic errors, we strive to acquire accurate knowledge of rainfall-runoff relationships (Stisen et al. 2012). Without accurate measurements or estimates of precipitation, water balance studies and modelling become meaningless (Larson, Peck 1974). Corrections can also affect the calculation of trends in precipitation totals; in addition, it is possible that climate change could affect the size of systematic errors (Forland, Hanssen-Bauer 2000). Sevruk covered the problem of systematic errors in precipitation measurement in his book (Sevruk 2004). Other major contributions on this topic include: Goodison et al. 1998; Michelson 2004; Ye et al. 2004; Bogdanova et al. 2006; and Ye et al. 2012. Currently, the WMO experiment SPICE (Solid Precipitation Intercomparison Measurement) is being conducted (Nitu et al. 2014). This intercomparison is aimed at determining the systematic errors that arise during the measurement of solid precipitation.

The aim of this article is to present the results of correcting systematic errors in precipitation totals measured at two stations in the Czech Republic (Svratouch and Hradec Králové). The results should provide more accurate values for the precipitation totals measured at these stations during the period 1961–1990. During this period, Czechoslovak Metra manual gauges measured the precipitation (Ptáček 2012). It was decided to use this period because the Metra gauge was replaced by automatic gauges in 1997. The correction method suggested by Tihlárik (1995) was used, although many adjustments had to be made to input parameters. Earlier corrections of systematic errors in the Czech Republic were made by Brázdil (2007). Other corrections were made by Ptáček (2014) for several different stations.

2. Systematic errors in precipitation measurement

The undervaluation of precipitation totals measured by manual gauges is caused by the following three main systematic errors:

1. Wetting (water sticking to surfaces of the gauge and other surfaces during measurement).
2. Evaporation from the gauge.

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3. The diversion of precipitation from the receiving area of the gauge due to a strong wind above the receiving area (the aerodynamic effect of the gauge).

According to Sevruk (2004), the amount of wetting can be equivalent to between 2 and 10% of the measured total for most gauges. Wetting appears before precipitation is measured and, later, while pouring the collected water from the gauge into a volumetric vessel. Evaporation is usually small; Sevruk (2004) reported values of up to 2%. The Metra gauge has a higher evaporation rate due to its construction (Ptáček 2014). The aerodynamic effect of a gauge leads to rain precipitation being undervalued by 2–15% and snowfall by 10–50% or more (Sevruk 2004); therefore, this error is very important. Wind has different effects on precipitation particles depending on their mass, size, and shape. Light particles (snowflakes and small rain drops) can be blown away from the receiving area of the gauge more easily than heavier particles. For this reason, correction equations are performed separately for solid, liquid, and sometimes also for mixed precipitations. Wetting and evaporation are determined by experimental measurements, and the error caused by the aerodynamic effect is determined by intercomparison measurements with reference gauges (Goodison et al. 1998). Systematic errors are usually not included during procedures for checking the measured precipitation (procedures for testing homogeneity).

3. Correction method used in this study

Currently, in the Czech Republic and Slovakia, it is only possible to correct precipitation data that was measured by a Metra manual gauge. This gauge was used in this region from the 1950s. Proper experimental measurements and comparison measurements with reference gauges were conducted in the 1970s and 1980s. Bratislava-Koliba became the main experimental station. On the basis of these experiments, Lapin et al. (1990) developed correction equations determining all of the three main systematic errors (Lapin, Priadka 1989; Lapin 1993). Then, these equations were applied to data from Slovak stations (Lapin et al. 1990). Tihlárik (1995) adopted the correction equations for evaporation and wetting from Lapin et al. (1990), but developed his own equations for errors caused by the aerodynamic effect. His study was primarily focused on the region of the High Tatra Mountains. Tihlárik's approach appears to be more reliable – his results are comparable with intercomparison measurements (Ptáček 2014). For this reason, it was decided to use Tihlárik's equations in this research; however, many modifications had to be made to input parameters. Brázdil also used Tihlárik's procedure (in modified form) to correct data from Milešovka, Lysá Hora, and Brno Tuřany (Brázdil 2007).

To calculate rain losses caused by the aerodynamic effect, Tihlárik (1995) used intercomparison measurements from Bratislava-Koliba. Some data had to be re-calculated because they were no longer available. Subsequently, Tihlárik derived this equation (1):

$$\boldsymbol{k_{lq}} = 0.03146\ (\boldsymbol{N} \cdot \boldsymbol{u_{hpg}})^2 + 0.07398\ (\boldsymbol{N} \cdot \boldsymbol{u_{hpg}}) + 1 \quad (1)$$

where $\boldsymbol{k_{lq}}$ is a conversion factor for liquid precipitation, $\boldsymbol{N}$ is a rain structure parameter, and $\boldsymbol{u_{hpg}}$ is the wind speed at the level of the gauge orifice during precipitation [m s^{-1}]. The procedure constructed by Lapin et al. (1990) does not include parameter $\boldsymbol{N}$. This parameter determines the proportion of liquid precipitation falling out with an intensity of less than 0.03 mm min^{-1}. This threshold was found experimentally (Sevruk 2004). Under this threshold, liquid particles are usually smaller and lighter and the influence of wind is stronger on the trajectory of particles (Tihlárik 1995). This experimental observation confirms the results of mathematical and physical simulations (Nespor, Sevruk 1999).

The procedure constructed by Lapin et al. (1990) distinguishes mixed precipitation, unlike that the procedure constructed by Tihlárik (1995). For solid and mixed precipitation, Tihlárik derived the following regression equation from the intercomparison measurements taken at the Harzgerode in Germany from 1986 to 1993 (Günther 1993):

$$\boldsymbol{k_{s+m}} = -0.004878\ (\boldsymbol{u_{hpg}})^3 + 0.02206\ (\boldsymbol{u_{hpg}})^2 + 0.1821\ \boldsymbol{u_{hpg}} + 1, \quad (2)$$

where $\boldsymbol{k_{s+m}}$ is a conversion factor for solid and mixed precipitation and $\boldsymbol{u_{hpg}}$ is the wind speed at the level of the gauge orifice during precipitation [m s^{-1}]. The unification of mixed and solid precipitation is debatable because snowfall is carried away more easily than mixed precipitation and not all stations can have the same proportion of mixed and solid precipitation as the station Harzgerode had. There could also be different methods of differentiating mixed precipitation from rain and snow in different countries.

It is necessary to take into account the fact that a different version of the Metra gauge (with all internal parts removed) is used in winter, approximately from November to April. Errors caused by evaporation and wetting are usually larger under winter operation and the corrections take this into account. Wetting is accounted for by adding 0.1 or 0.2 mm to the daily amount of measured precipitation (Lapin et al. 1990). Evaporation losses are determined by temperature; the evaporation equations derived by Lapin et al. (1990) are extensive and, for this reason, are not presented in this paper.

In this study, the procedure derived by Lapin et al. (1990) was used for wetting and evaporation, and the equations derived by Tihlárik (1995) were used for the aerodynamic effect. The correction calculation used in this study is described schematically as

$$\boldsymbol{P_c} = \boldsymbol{k} \cdot (\boldsymbol{P_g} + \Delta \boldsymbol{P_{1+2}} + \Delta \boldsymbol{P_3}), \quad (3)$$

where P_c is the amount of corrected daily precipitation [mm], P_g is the measured amount of daily precipitation [mm], ΔP_{1+2} is the daily loss by wetting [mm], ΔP_3 is the daily loss due to evaporation [mm], and k is a conversion factor – formula (1) in the case of rain; formula (2) in the case of solid and mixed precipitation. Corrected values of precipitation were determined for each day; for more details, see: (Ptáček 2012).

All of the equations included many parameters which had to be calculated. In order to calculate the corrected precipitation, it is necessary to know the wind speed at the level of the gauge orifice, the weather conditions at climatological observation times or an estimate of the proportion of solid and mixed precipitation, the times of usage of summer and winter versions of the gauge, and air temperature (to determine the amount of evaporation). It is also necessary to know the time which elapses between the end of precipitation and measurement (Lapin et al. 1990).

During intercomparison measurements, the wind speed is measured at the level of gauge orifices. Most stations do not measure at this level, so it is necessary to calculate wind speed at the level of the gauge orifice (commonly 1 m). This is usually done using the following logarithmic equation (Sevruk 2004):

$$u_{hp} = u_{Hp} \cdot (\ln(h) - \ln(z_0))/(\ln(H) - \ln(z_0)), \quad (4)$$

where u_{hp} is the wind speed at height h during precipitation (the height of the gauge orifice), u_{Hp} is the wind speed at height H during precipitation (the height of the station anemometer), and z_0 is a terrain roughness coefficient. WMO (2008) recommends the coefficient from 0.01 to 0.03 for the case when snow cover occurs and 0.03 for summer conditions. Thus, 0.02 was chosen for the winter and 0.03 for the summer period. This conversion is one of the most questionable parts of the correction procedure, as wind speed values significantly influence the corrected precipitation totals.

The daily average wind speed was taken to be the wind speed at the time of precipitation. Corrections were based on observations at 7 AM, 2 PM, and 9 PM local time. In the Czech Republic, precipitation is measured at approximately 7 AM. Thus, a precipitation day was taken to be the period from 7 AM to 7 AM of the following day. It was not possible to determine the form of precipitation (solid, mixed, or liquid) directly from the data because weather observations were incomplete. The form of precipitation was therefore determined from the temperature. The temperature at 2 PM seemed to be the best for determining the form of precipitation. Solid and mixed precipitation theoretically appeared at temperatures below 2.0 °C, rain at above 2.1 °C. Detailed information may be found in: (Ptáček 2012; 2014).

4. Description of the stations used in the study

The Svratouch and Hradec Králové meteorological stations fall under the administrative branch of the Czech Hydrometeorological Institute. The Svratouch station is situated on Otava Hill (735 m), near the town of Hlinsko. The hill is treeless and has a slightly sloping gradient (Figure 1). The station in Hradec Králové is located in a suburb of the city of Hradec Králové (Figure 2). The gauge and anemometer are situated at an observatory complex at an altitude of 270 m. The anemometers at the Svratouch and Hradec stations are elevated 16 m and 25 m above the ground, respectively. Svratouch is a very windy station; the average wind speed during the period 1961–1990 was 5.6 m s^{-1}, calculated from three observations per day. At Hradec, it was only 2.9 m s^{-1}. The maximum monthly average wind speed at Svratouch was 6.9 m s^{-1} in January and the minimum was 4.1 m s^{-1} in July. The maximum monthly average wind speed at Hradec was 3.5 m s^{-1} in March, and the minimum was 2.4 m s^{-1}, also in July. The mean annual temperature was 5.7 °C at Svratouch and 8.5 °C at Hradec. The data were not interrupted.

Fig. 1 The Svratouch meteorological station.
Source: http://www.ok2af.nagano.cz/omne.htm

Fig. 2 The Hradec Králové meteorological station.
Source: http://www.astro.cz/clanky/multimedia/v-lete-se-zacne-v-hradci-kralove-stavet-digitalni-planetarium.html

5. Results

The corrections led to significant changes in precipitation totals. In Figure 3 (Svratouch) and Figure 4 (Hradec Králové), it is evident that all three systematic errors were more substantial in the winter months. Wetting was more significant in winter because there were relatively more days with precipitation and the winter version of the gauge was used. The wetting loss reached comparable values at both stations. Evaporation losses were also usually higher under the winter version. The highest evaporation losses were in transitional months (March or April and October or November), when the winter version was already in use but temperatures were relatively high. The most significant error was caused by the wind, especially in the winter months due to the frequent occurrence of solid precipitation. This error was far more pronounced at the windy Svratouch station than at Hradec Králové. After correction, the annual course of precipitation at Svratouch changed significantly: the winter subsidiary maximum increased and the climate assumed a more oceanic character. Overall, the average annual precipitation at Svratouch increased by 32% due to correction (from 762 mm to 1007 mm); at Hradec, it increased by 17% (from 617 mm to 723 mm). At Svratouch (Figure 3), the greatest systematic errors occurred, on average, in January (69% of the measured total) and the smallest in August (12% of the measured total). At Hradec Králové (Figure 4), the highest undervaluation was in January and December (33%) and the lowest undervaluation was also in August (7%).

The systematic errors at the studied stations differed from year to year (Figure 5 and Figure 6): at Svratouch, they ranged from 25% of the measured total in 1985 to 43% in 1974; at Hradec they ranged from 14% in 1964 to 23% in 1990; standard deviations were 4.6% (Svratouch) and 2.4% (Hradec). The year-to-year variability in systematic errors for January and July was also investigated. In January, the variability was relatively large: at Svratouch, corrections ranged from 31% in 1972 to 108% in 1970; at Hradec Králové, corrections ranged from 17% in 1969 to 62% in 1964. The variability in systematic errors results mainly from the fact that the proportions of snowfall and wind speeds differ year after year. In the summer months, the variability in systematic errors is considerably lower. In July, corrections at Svratouch ranged from 8% in 1967 to 21% in 1969; at Hradec, they ranged from 5% in 1975 to 13% in 1983. Even in this case, the variability was caused by differences in wind speed; however, evaporation was also found to have a significant influence on measurement at the Hradec Králové station. Wetting and evaporation, in general, have a slightly greater variability in winter. In July 1990, an outlier undervaluation occurred at Hradec (24%); this outlier was caused by that particular month's low rainfall (12 mm). In general, when the total for a month is low, the undervaluation can deviate far from its average value.

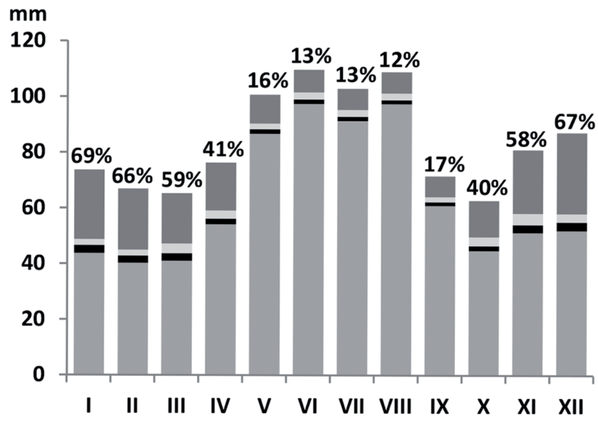

Fig. 3 Precipitation totals at the Svratouch meteorological station (1961–1990) after the correction of systematic errors in measurement. Each column shows (from the bottom up): 1) measured precipitation – light gray colour; 2) wetting losses – black colour; 3) evaporation losses – very light gray colour; 4) losses due to the aerodynamic gauge effect – gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

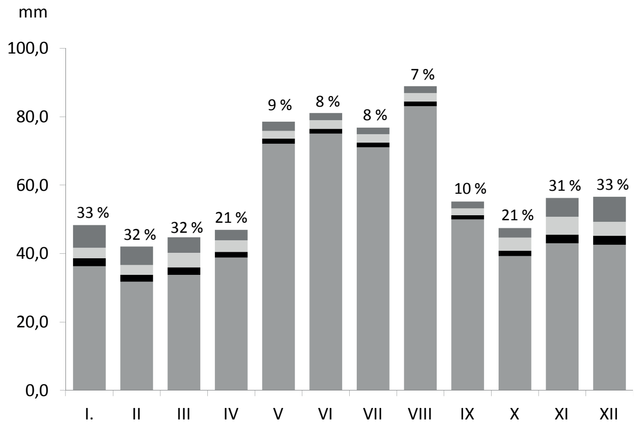

Fig. 4 Precipitation totals at the Hradec Králové meteorological station (1961–1990) after the correction of systematic errors in measurement. Each column shows (from the bottom up): 1) measured precipitation – light gray colour; 2) wetting losses – black colour; 3) evaporation losses – very light gray colour; 4) losses due to the aerodynamic gauge effect – gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

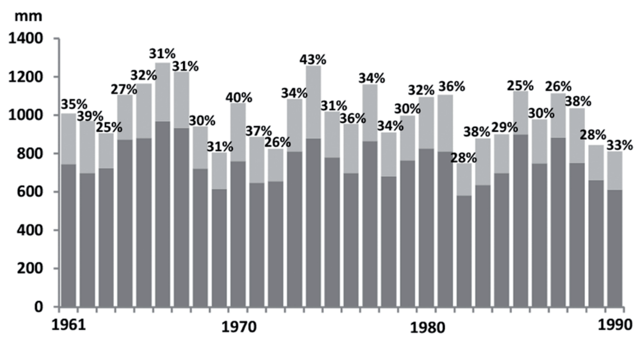

Fig. 5 The year-to-year variability in precipitation totals at the Svratouch meteorological station (1961–1990). Columns show (from the bottom up): 1) measured precipitation – gray colour, and 2) losses resulting from all three systematic errors – light gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

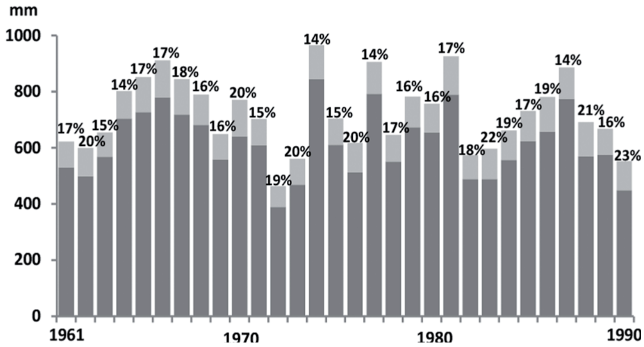

Fig. 6 The year-to-year variability in precipitation totals at the Hradec Králové meteorological station (1961–1990). Columns show (from the bottom up): 1) measured precipitation – gray colour, and 2) losses resulting from all three systematic errors – light gray colour. Percentages above the columns express the size of all three systematic errors (relative to the measured total).

4. Discussion and Conclusion

The corrections of precipitation data from the Svratouch and Hradec Králové stations suggest that the true annual precipitation at Svratouch and Hradec was greater by some 32% and 17%, respectively. The errors in winter were far more significant. The corrections also change the annual course of precipitation, mainly at Svratouch. The results presented here are comparable with those of previous corrections in the territories of the Czech Republic and Slovakia (Tihlárik 1995; Brázdil 2007; Ptáček 2012) and with the results of intercomparison measurement in Harzgerode (Günther 1993). For the winter months, undervaluation usually varies between 25% and 100% of the measured precipitation total; for the summer months, undervaluation is around 10%. This is generally valid for conditions in Central Europe, although there could be higher levels of undervaluation in mountainous areas. Spring and autumn are transitional periods for systematic errors. Regarding the Metra gauge, it is necessary to take into account the significant changes in undervaluation which occur when the winter and summer versions are exchanged for each other. This is because the winter version of the Metra gauge suffers higher losses from evaporation and wetting.

The correction of systematic errors in precipitation measurement could be subject to uncertainty. Precipitation is most accurately measured by means of intercomparison measurements, as, for example, in Harzgerode. The further determination of precipitation undervaluation could be uncertain. Uncertainty is caused by many variables (wind speed conversion; precipitation time; the amount of solid, mixed, and liquid precipitation; the parameter ***N***, etc.). Also, Tihlárik's correction equations have some imperfections, such as the combining mixed and solid precipitation. A procedure for the determination of wetting and evaporation losses was constructed by Lapin et al. (1990). These authors note that corrected values for daily or monthly precipitation have little relevance; extremes, however, are equalized over longer periods of correction and the results of correction are admissible. Results are more credible for the summer period and, in general, are more accurate for occurrences of rain precipitation. Also, the correction of summer precipitation is more credible due to lower levels of year-to-year variability during this period. Even in summer, however, undervaluation could be considerable in the case of rain of weak intensity subject to high wind speeds.

After correcting the total precipitation, we should expect higher values of evaporation from the landscape (Ye et al. 2012). Corrections can give us a better idea of hydrological balance, especially in regions where there is not permanent snow cover in the winter. Finally, the correction of precipitation may have an influence on long-term changes in precipitation totals. The correction could have an impact on the perceived trends with respect to climate change conditions. In particular, the trends of winter precipitation could be affected by climate change (Forland, Hanssen-Bauer 2000). The undervaluation of precipitation due to the aerodynamic effect concerns all types of gauges including the automatic gauges currently used in the Czech network (from the Meteoservis company). Comparison measurements of Metra and automatic gauges have already been made; it appears that automation has not significantly affected the homogeneity of the precipitation data (Gajdušková 2009).

In brief, this contribution presents the results of correcting precipitation totals at two meteorological stations in the Czech Republic. The Svratouch station is situated in a mountainous area and the Hradec Králové station is situated in the lowlands. The method of correction was adopted from R. Tihlárik (1995), but many adjustments were made to input parameters. The special merit of this contribution is a description of the variability in systematic errors. According to this and previous research: (Brázdil 2007; Gajdušková 2009; Ptáček 2014), we should expect that there is at least a 5% undervaluation of precipitation from May to September and at least a 25% undervaluation from November to March in most stations in the Czech Republic. At the present time, attention should be paid to systematic errors associated with automatic gauges from Meteoservis (Lanza et al. 2005; Nitu 2014). Attention should also be focused on how corrections influence perceived trends in precipitation and also on the question of how climate change influences the trends of corrected precipitation.

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RESUMÉ

Příspěvek přináší výsledek korigování systematických chyb doprovázejících měření srážek na meteorologických stanicích Svratouch a Hradec Králové. Stanice Svratouch je položena ve výšce 735 m n. m., stanice Hradec Králové ve výšce 270 m n. m. Korigována byla srážková data za období 1961–1990. Ke korigování byl použit již dříve osvědčený postup a rovnice R. Tihlárika. Pro určení některých vstupních parametrů bylo potřeba vlastních metod. Po korigování došlo na Svratouchu k navýšení ročního úhrnu srážek o 32 % a na Hradci o 17 % naměřeného úhrnu. Podhodnocení je v podmínkách střední Evropy významnější v zimě, na použitých stanicích dosahuje v zimních měsících i více než 50 % naměřeného úhrnu. V letních měsících dosahuje podhodnocení na obou stanicích kolem 10 %. Je nutné počítat s tím, že korigování může být hlavně v zimních měsících zatíženo nejistotou. S přihlédnutím ke stávajícím výsledkům korigovaných srážkových úhrnů v Česku lze konstatovat, že v období od května do září je nutné na většině stanic v Česku počítat minimálně s 5% podhodnocením a od listopadu do března minimálně s 25% podhodnocením. Studována byla taktéž časová variabilita systematických chyb na daných stanicích. Důsledkem korigování je například změna ročního chodu srážek a změna srážko-odtokových vztahů.

Tomáš Ptáček
Charles University in Prague, Faculty of Science
Department of Physical Geography and Geoecology
Albertov 6
128 00 Prague
Czechia
E-mail: tommaes@seznam.cz