Bulletin of Geography. Physical Geography Series, No. 9 (2015): 67–79
http://dx.doi.org/10.1515/bgeo-2015-0017

An attempt to assess the results of air temperature measurements from automatic weather stations in comparison to glass thermometer measurements in the context of weather types

ISSN 2080-7686

Grzegorz Urban

Institute of Meteorology and Water Management – National Research Institute, Poland

Correspondence: Institute of Meteorology and Water Management – National Research Institute, Wrocław, Poland. E-mail: grzegorz.urban@imgw.pl

Abstract. In the article, an attempt was undertaken to compare the results of air temperature measurements made using automatic weather stations (AWS) to those of glass thermometers. The analysis considered the aspect of weather types. On the basis of simultaneous measurements carried out with the use of AWS and glass thermometers, the accuracy of measurements for 6 synoptic stations of IMGW-PIB was assessed. The stations represented the Lower and Opole Silesia regions. Mean differences in mean monthly and seasonal air temperature values (T) between AWS and glass results are not high. They are equal to ±0.1°C, only rarely reaching -0.2°C. In cold seasons and in particular months as well, they are negative. On an annual scale, differences hardly ever occur. No connection between mean difference for mean air temperature and weather types was found. The values of mean differences for mean monthly and seasonal maximum air temperature (T_x) are equal to ±0.1°C (except Śnieżka). The differences for T and T_x are of low significance, being within the normal range. Mean differences for mean monthly and seasonal minimum air temperature (T_n) are usually positive. In warm seasons they can reach 1.1°C. In the case of most of the stations under consideration, for positive differences for T_n, an increase in average (from +0.1°C to +0.5°C) and high (+0.5°C to +1.0°C) differences is noticed. The only exceptions are the Śnieżka and Opole stations. The differences for each category are not regular, therefore no universal corrections can be implemented.

Keywords:
air temperature,
automatic weather station,
glass thermometer,
weather type,
Lower and Opole Silesia,
methodology

Introduction

Technological progress has brought better measuring methods and devices to all scientific fields, including meteorology. However, it was the implementation of microelectronic systems that resulted in the automatization of meteorological stations in many countries. The public's increasing demand for information about the atmosphere and its processes has increased the number and frequency of measurements and, consequently, the number of data to be processed. For this reason, automatic weather stations (AWS) are constantly being improved and more frequently used. Consequently, the not-so-ancient prediction that automated measurements of meteorological elements would, in the near future, replace classical measurement methods has become a fact (Plummer et al. 2003; Rudel 2008). For this reason, the guarantee of high-quality measurements is one of the priorities of modern meteorology (Nash 2006). All automated, telemetric, remote sensing meteorological systems of measurement must provide reliable, real-time information, regardless of changeable external conditions and with no human interference or supervision (Różdżyński 2004).

The recent transfer of National Hydrological-Meteorological Service (PSHM) of many countries to automated measurement follows the obligation to accomplish one of the WMO goals expressed in WMO Convention, Article 2, i.e. "To promote standardization of meteorological and related observations and to ensure the uniform publication of observations and statistics". Moreover, the transfer was also dictated by technological and operational factors as well as socio-economic factors related to difficulties in recruiting new observers and the increasing cost of continual human monitoring. Furthermore, conducting simultaneous measurements using standard and new automated devices as they are introduced by the National Hydrological-Meteorological Service (PSHM) is in accordance with international action for series homogeneity (http://www.surfacetemperatures.org/databank/parallel_measurements).

Automatization of the technological (calibration, servicing, new sensors, etc.), meteorological and data quality aspects of the measurement-observation station network of the PSHM, (which is operated by the Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB)), is being implemented and perfected (Różdżyński 1995, 1996, 1999, 2004). IMGW-PIB, with the exception of publication by Lorec (2006), has no comparative study-related results for air temperature measurements using AWS and glass (standard) thermometers. A number of works on the subject was published earlier in other research centres, both in Poland (Kajewska, Rojek 2009; Kejna, Uscka-Kowalkowska 2006; Łabędzki et al. 2001; Rojek, Rojek 2000; Szwejkowski 1999), and around the world (Ying et al. 2006; Bil-Knozowá, Rožnovský 2006). The majority of them are focused on short periods, usually 1-3 years. A comprehensive estimate of results of measurements of many meteorological elements using both devices simultaneously was carried out in 2000-2009 in the Agro- and Hydrometeorological Observatory of the Natural Science University in Wrocław (Poland) by Kajewska (2011).

It seems sensible that air temperature measured at the exact same moment in the same conditions should render identical results. However, comparative studies indicate that they differ quite often, because of factors such as the inertia of devices and their accuracy (Szwejkowski 1999; Lorenc 2006). Still, air temperature is the most frequently compared element of all meteorological parameters and it has the least difference in values received from the analyzed devices (Kajewska 2011).

This paper attempts to estimate air temperature results using AWS and glass thermometers in IMGW-PIB synoptic stations located in the Lower and Opole Silesia in relation to weather types.

Sources and Method

The source material for this work consists of results of simultaneous air temperature measurements performed by automatic weather stations (AWS) and glass (standard) thermometers in the following synoptic stations of IMGW-PIB: Śnieżka (ŚN – 1603 m a.s.l.), Jelenia Góra (JG – 342 m a.s.l.), Kłodzko (KŁ – 360 m a.s.l.), Opole (OP – 165 m a.s.l.), Legnica (LG – 122 m a.s.l.) and Wrocław-Strachowice (WR – 120 m a.s.l.). Measurements were taken in a Stevenson screen placed 2 m a.g.l.. At the same time, hourly measurements were performed at the above-mentioned stations in 2004, with the exception of Śnieżka (13.07.2005-31.07.2006). Air temperature measurements were carried out using Vaisala QMT110 sensors. All sensors have a calibration certificate issued by the Central Laboratory of Measurement Equipment of IMGW-PIB, accredited by the Polish Accreditation Centre. The measurement uncertainty of the QMT110 sensor for different values of reference temperature was 0.050°C (internal IMGW-PIB documentation). At all locations, QMT110 sensors were inside standard, wooden meteorological boxes with the English type of openwork structure (Stevenson screen). The QMT110 sensors were placed beside the glass thermometers (Fig. 1). The meteorological box, which is still used in the weather station network of PSHM IMGW-PIB in Poland for protection of electronic sensors for air temperature and air humidity measurements against atmospheric elements, screened both types of devices from atmospheric factors. The same measurement devices (sensors and thermometers) were used throughout the entire period of measurement under discussion.

The analyzed stations provide comparative data for contrasting conditions such as altitude and relief. Śnieżka is an isolated mountain peak in the

Karkonosze Mountains where conditions are close to those in free atmosphere; Jelenia Góra is located in the foothills of the Karkonosze Mts and at the bottom of a large intermontane valley which tends to host cold air and with a large daily temperature amplitude; Kłodzko is analogical to Jelenia Góra, and in the Central Sudetes; Legnica station is located on the large Western Sudetes Foreland; and finally, Wrocław-Starachowice and Opole are two lowland stations.

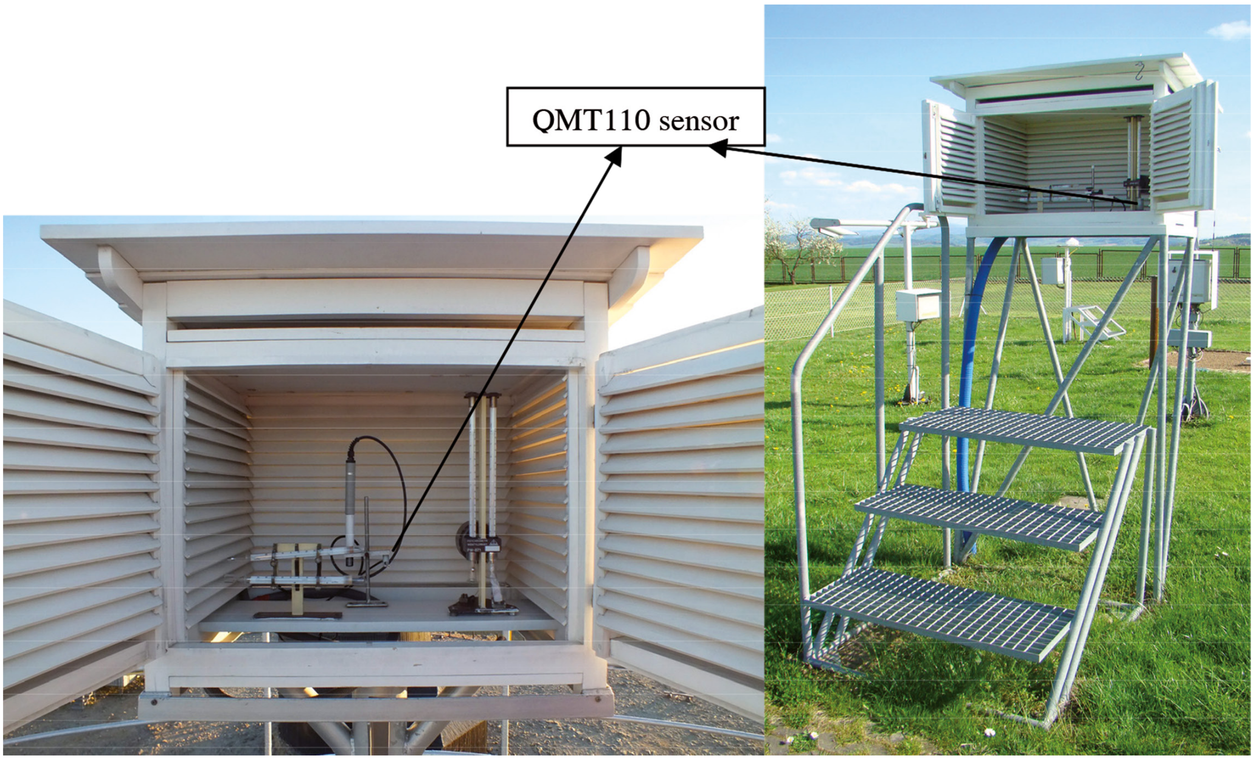

Fig. 1. Glass thermometers and automatic sensors (QMT110 (thin sensor) for air temperature measurements, and large sensor for air humidity measurements) in meteorological box, as used at the IMGW-PIB Śnieżka weather station (left) (photograph by G.Urban) and Kłodzko (right) (photograph by I. Zając)

The study compares the difference in value between daily mean air temperature (T) and daily minimum (T_n) and maximum (T_x) air temperatures as measured using AWS and glass thermometers. T was calculated as the arithmetic average of 8 principal synoptic times using the following formula: $T = (T_{00} + T_{03} + T_{06} + \ldots + T_{21}) / 8$ in UTC time. Additionally, the values of mean T differences between AWS and glass thermometer, calculated as the arithmetic average of daily extremes, i.e.: $T = (T_x + T_n) / 2$, were compared. The difference in value was calculated using the sample equation: $dT = T_a - T_{sz,}$ where T_a is the AWS air temperature reading and T_{sz} is the glass thermometer air temperature value. A negative value of the difference indicates that a given category of temperature from AWS is lower than that from glass thermometer while a positive value indicates a higher AWS temperature reading.

Furthermore, values of differences and their frequency were identified for each temperature category (T_x, T_n, T). For the purposes of this study, the following grouping of differences was adopted:

1. small: values from -0.1°C to +0.1°C resulting from accuracy of air temperature reading, differences of 0.0°C (no difference) omitted,
2. medium: values ±0.1°C to ±0.5°C resulting from accuracy of air temperature; reading from extreme glass thermometer,
3. high: intervals from ±0.5°C to ±1.0°C,
4. very high: values higher/lower than ±1.0°C.

366 days in 2004 were analyzed for the studied weather stations, with the exception of Śnieżka, where the number of complete daily measurements was 378 in the period 13.07.2005-31.07.2006.

In each case of difference in medium or extreme daily air temperature in the analyzed period, the weather types (a – anticyclone; c – cyclone; 0 – transitional) were identified according to Lityński's classification (1969) (regardless the direction of air mass advection). The calendar of types of atmospheric circulation and weather types according to Lityński for the period 2004-2005 was obtained from unpublished materials from IMGW-PIB. The analysis included the calendar year (J-D), the warm season (May-October), the cold season (January-April and November-December) and temperate seasons, i.e.: winter (December-February), spring (March-May), summer (June-August) and autumn (September-November), as well as individual months (J, F, M, ..., D). The relationship of difference values and weather types was analyzed for a single 12-month period, and then for its warm and cold seasons only, due to the fact that the frequency of occurrence of any given weather type in separate months or even temperate seasons is insufficient to draw valid conclusions.

Additionally, in order to determine the behaviour of both types of device in conditions of large daily air temperature changes, daily amplitude (A) differences between AWS amplitude (A_a) and the amplitude of extreme results of glass thermometers (A_{sz}) were calculated and analyzed. Daily amplitudes were calculated for results of glass thermometers (A_{sz}) and AWS (A_a) using the following formulas: $A_{sz} = T_{xsz} - T_{nsz}$ and $A_a = T_{xa} - T_{na}$. Negative values of $A = A_a - A_{sz}$ reflect a smaller sensitivity to large and fast temperature changes in the AWS sensor compared to the glass thermometer. For all analyzed stations (except Śnieżka), large changes of temperature are defined as $A_{sz} \geq 16$°C. In the case of Śnieżka, due to its high elevation and localization, this value is defined as $A_{sz} \geq 8$°C. Selected daily air temperature amplitudes above the defined threshold values constitute on average circa 10% of data in all stations.

Results and Discussion

Monthly mean differences between T_a and T_{sz}, calculated from mean daily values, fluctuate between -0.2°C in January in Legnica and +0.1°C in May-October in Wrocław-Starachowice and in October and December in Opole. Generally, mean differences of T at the majority of the analyzed stations are 0.0°C during the warm season, and also in each month in the season. In Wrocław-Starachowice, the mean monthly difference is +0.1°C while in Legnica, during a 12-month period, T shows a negative value of -0.1°C, with a mean minimum of -0.2°C in January. In the majority of stations, on the other hand, the months of the cold season show a prevalence of mean T differences of -0.1°C (Table 1). This, however, has no significant effect on differences in longer time periods (6 months, a year) where they are absent or have a value of -0.1°C (Table 1). These results are similar to those in IMGW-PIB stations in Łeba, Płock and Katowice in 2003 where 90% of daily mean temperature differences were ±0.2°C (Lorenc 2006). The standard deviation (of daily mean) for particular stations is ca. 0.1°C. The extreme differences between daily T values varied from -1.0 to +1.0°C throughout the year (Table 1).

Analysis of the monthly scale indicates small mean differences of T_x (ca. ±0.1°C) between AWS and glass thermometer. In the majority of cases, no differences are noted in lowlands stations. Jelenia Góra station saw a negative deviation of -0.1°C from January to April and a deviation of +0.1°C from August to October. Śnieżka is the only station with a positive mean deviation of 0.1-0.2°C, (with a maximum of +0.3°C in July), which, consequently, results in a deviation of +0.1°C in consecutive seasons and the entire year.

Hence, as concluded by Lorenc (2006), T_x deviations occur in both positive and negative directions, which indicates that the AWS sensor shows temperature values higher and lower than values read from an analogue maximum thermometer.

Still, on average, no differences of T_x in the analyzed stations – except Śnieżka – can be found in consecutive temperate seasons and an entire year (Table 2). The extreme positive differences between T_x daily values vary within a range of +0.4°C to +1.7°C while the extreme negative values within a range of +0.4°C to -1.3°C. The standard deviation is 0.1-0.3°C (Table 2).

The data on mean T_n deviations between AWS and glass thermometer present a different perspective. In each station, a deviation (usually positive) is identified in the majority of months. Its mean val-

Table 1. Mean and extreme differences between T_a and T_{sz} (°C) and standard deviation (σ) of daily mean temperatures for the whole year

Months/Season	ŚN	JG	KŁ	OP	LG	WR
Jan	-0.1	-0.1	-0.1	-0.1	-0.2	0.0
Feb	0.0	-0.1	-0.1	-0.1	-0.1	0.0
Mar	0.0	-0.1	-0.1	-0.1	-0.1	0.0
Apr	0.0	-0.1	-0.1	-0.1	-0.1	0.0
May	0.0	0.0	0.0	0.0	-0.1	0.1
Jun	0.0	0.0	0.0	0.0	-0.1	0.1
Jul	0.0	0.0	0.0	0.0	-0.1	0.1
Aug	0.0	0.0	0.0	0.0	-0.1	0.1
Sep	0.0	0.0	0.0	0.0	-0.1	0.1
Oct	0.0	-0.1	0.0	0.1	-0.1	0.1
Nov	-0.1	-0.1	0.0	0.0	-0.1	0.0
Dec	-0.1	-0.1	0.0	0.1	-0.1	0.0
May-Oct	0.0	0.0	0.0	0.0	-0.1	0.1
Jan-Apr and Nov-Dec	0.0	-0.1	-0.1	0.0	-0.1	0.0
Jan-Dec	0.0	-0.1	0.0	0.0	-0.1	0.0
Max. (Jan-Dec)	0.4	0.4	0.2	0.9	0.6	0.5
Min. (Jan-Dec)	-0.3	-0.3	-0.5	-0.8	-0.9	-0.6
σ	0.09	0.08	0.10	0.12	0.10	0.10

Table 2. Mean and extreme differences between Txa a Txsz (°C) and standard deviation (σ) of maximum temperatures for the whole year

Months/Season	ŚN	JG	KŁ	OP	LG	WR
Jan	0.1	-0.1	-0.1	0.0	0.0	0.0
Feb	0.0	-0.1	0.0	-0.1	0.0	0.0
Mar	0.1	-0.1	0.0	-0.1	0.0	0.0
Apr	0.1	-0.1	0.0	0.0	0.1	0.1
May	0.2	0.0	0.0	0.0	0.0	0.0
Jun	0.1	0.0	0.0	0.0	0.0	0.0
Jul	0.3	0.0	-0.1	0.0	0.0	0.0
Aug	0.2	0.1	0.0	0.1	0.0	0.0
Sep	0.1	0.1	0.0	0.0	0.1	0.0
Oct	0.0	0.1	0.0	0.0	0.0	0.1
Nov	0.1	0.0	0.1	0.0	-0.1	0.0
Dec	0.1	0.0	0.0	0.0	0.0	0.0
May-Oct	0.1	0.0	0.0	0.0	0.0	0.0
Jan-Apr and Nov-Dec	0.1	0.0	0.0	0.0	0.0	0.0
Jan-Dec	0.1	0.0	0.0	0.0	0.0	0.0
Max. Jan-Dec	1.7	0.4	0.5	1.2	1.0	0.5
Min. Jan-Dec	-0.8	-0.4	-1.3	-0.9	-0.5	-0.5
σ	0.27	0.15	0.23	0.22	0.16	0.12

ues fluctuate from -0.2°C to 1.1°C (Table 3). Surprisingly high positive monthly deviations, from 0.4°C in January to 1.1°C in September were registered in the IMGW-PIB station in Kłodzko. Only in the case of Śnieżka were negative differences (of 0.1°C to -0.2°C) identified (in all months except August and September, when no deviations were noted) (Table 3).

The commonly-used Stevenson screen has a high thermal inertia and its capacity deteriorates over time (Budzik, Marszał 2006; Nagy 2006). As observed, the temperature measured inside a Stevenson screen can be higher than the temperature of its surroundings during the day and lower at night by 0.2°C (Kejna, Uscka-Kowalkowska 2006 after Parker 1994). However, if radiation screens are applied in AWS located outside a Stevenson screen, the differences of air temperature values can be even higher than those in a Stevenson screen, reaching 0.5-1.4°C (Bartoszek, Skiba 2006) and as high as 0.5-2.5°C, depending on time of day and year (Amudha et al. 2008 after Lin et al. 2001). For this reason, in order to minimize disparities in comparative studies, it is good practice in a Stevenson screen to place AWS sensors alongside glass thermometers (Bartoszek, Skiba 2006; Beinde 2006), as was the case of this research.

Table 3. Mean and extreme differences between Tna a Tnsz (°C) and standard deviation (σ) of daily minmum temperatures for the whole year

Months/Season	ŚN	JG	KŁ	OP	LG	WR
Jan	-0.2	0.1	0.4	0.1	-0.1	0.1
Feb	-0.1	0.1	0.5	0.0	0.0	0.2
Mar	-0.1	0.1	0.8	0.1	-0.1	0.2
Apr	-0.1	0.2	0.7	0.0	-0.1	0.2
May	-0.1	0.1	0.8	0.0	0.1	0.2
Jun	-0.1	0.2	0.9	-0.1	0.2	0.3
Jul	-0.2	0.3	0.9	-0.1	0.2	0.2
Aug	0.0	0.3	0.9	-0.1	0.3	0.2
Sep	0.0	0.3	1.1	0.0	0.3	0.4
Oct	-0.1	0.2	1.0	0.1	0.2	0.1
Nov	-0.2	0.2	0.9	0.1	0.2	0.2
Dec	-0.2	0.2	0.9	-0.1	0.2	0.1
May-Oct	-0.1	0.2	0.9	-0.1	0.2	0.2
Jan-Apr and Nov–Dec	-0.1	0.1	0.7	0.0	0.0	0.2
Jan-Dec	-0.1	0.2	0.8	0.0	0.1	0.2
Max. Jan-Dec	1.8	0.4	1.5	1.2	0.6	0.9
Min. Jan-Dec	-1.1	-0.4	-0.9	-1.0	-0.8	-0.3
σ	0.25	0.15	0.41	0.28	0.21	0.18

The difference distribution in consecutive groups shows very interesting features. In case of T_x and T, the majority of deviations (64-84% and 77-93%) fall into the -0.1 to +0.1°C interval (Table 4). They are, therefore, of little significance and can be interpreted as falling within the normal range of readings.

However, the interpretation of T_n differences is much more intriguing. Small differences vary from only ca. 7% in Kłodzko to ca. 63% on Śnieżka. The frequency of medium and high differences, especially positive differences (positive asymmetry of distribution), which predominate in several instances, increases considerably as seen in the examples of the Jelenia Góra, Kłodzko, Legnica and Wrocław weather stations. The prevalence of negative differences of T_n, on the other hand, is apparent on Śnieżka and in Opole (Table 4). High errors, of over 1.0°C, are incidental or not present. The only exception is the Kłodzko station where such errors constitute 30% of the total, and combined with medium error, amount to the high total count of 80% (Table 4). This phenomenon is difficult to explain. One possibility is imperfection of the T_n sensor in the AWS.

The distribution of daily differences within each of the temperature categories (T_x, T_n, T) in selected mountain and lowland stations is presented in Figures 2 and 3. T differences show little scattering. However, the scattering of T_x and T_n it is much higher and asymmetrically distributed, particularly in the case of T_n (Figs 2 and 3).

Although AWS and glass thermometer annual T calculated for 8 synoptic terms shows no differences or insignificant differences, T values calculated from the extreme values indicate visible differences reaching +0.2°C for mean annual value and, in case of Kłodzko, even +0.4°C (Table 5). Hence, the overestimation of daily T_n by AWS sensor results in T overestimation (calculated from extreme values) even in annual average, regardless of location.

Table 4. Differences (dT) and their frequency (%) in air temperature records between AWS and and glass thermometer for each category of air temperature

dT	Śnieżka			Jelenia Góra			Kłodzko			Opole			Legnica			Wrocław-Str.		
	T_x	T_n	T	T_x	T_n	T	T_x	T_n	T	T_x	T_n	T	T_x	T_n	T	T_x	T_n	T
>1.0	0.8	0.5	0.0	0.0	0.0	0.0	0.0	31.4	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
(0.5; 1.0]	6.3	0.5	0.0	0.0	0.0	0.0	0.0	48.9	0.0	1.9	4.9	0.5	0.8	0.5	0.3	0.0	3.0	0.0
(0.1; 0.5]	22.2	3.2	2.9	10.4	59.6	0.8	18.3	10.4	2.2	9.8	11.7	1.6	13.7	51.1	0.3	12.0	54.9	6.3
(0.0; 0.1]	18.8	5.6	15.9	24.0	19.9	3.8	23.8	2.5	13.7	22.7	11.7	16.4	21.9	15.3	1.1	24.0	13.9	40.7
0.0	38.9	33.3	50.0	35.2	16.4	40.7	29.5	2.2	38.5	28.4	19.9	39.3	28.7	13.7	19.4	47.0	25.1	44.8
[-0.1; 0.0)	6.3	23.8	24.9	14.2	2.5	46.7	12.6	1.9	36.1	18.9	22.4	33.1	22.4	9.6	56.3	12.8	1.9	7.1
[-0.5; -0.1)	5.6	29.4	6.3	16.1	1.6	7.9	12.3	1.9	9.6	16.4	26.8	8.5	12.6	9.3	22.1	4.1	1.1	0.8
[-1.0; -0.5)	1.1	3.4	0.0	0.0	0.0	0.0	3.0	0.8	0.0	1.6	2.2	0.5	0.0	0.5	0.5	0.0	0.0	0.3
<-1.0	0.0	0.3	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[-0.1; 0.1]	64.0	62.7	90.8	73.4	38.8	91.2	65.9	6.6	88.3	70.0	54.0	88.8	73.0	38.6	76.8	83.8	40.9	92.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

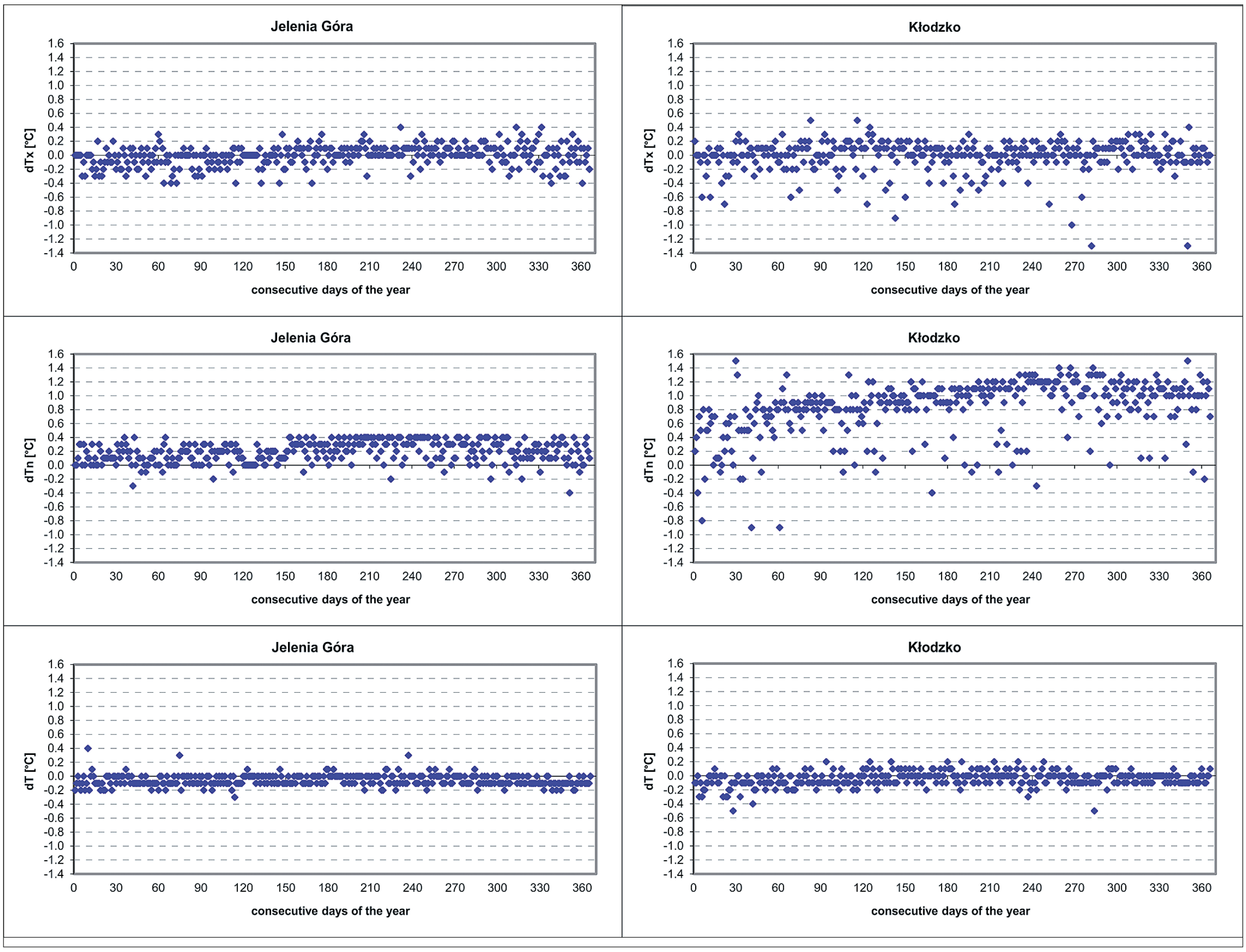

Fig. 2. The course of differences (dT) for daily T_x, T_n and T in Jelenia Góra and Kłodzko stations in 2004

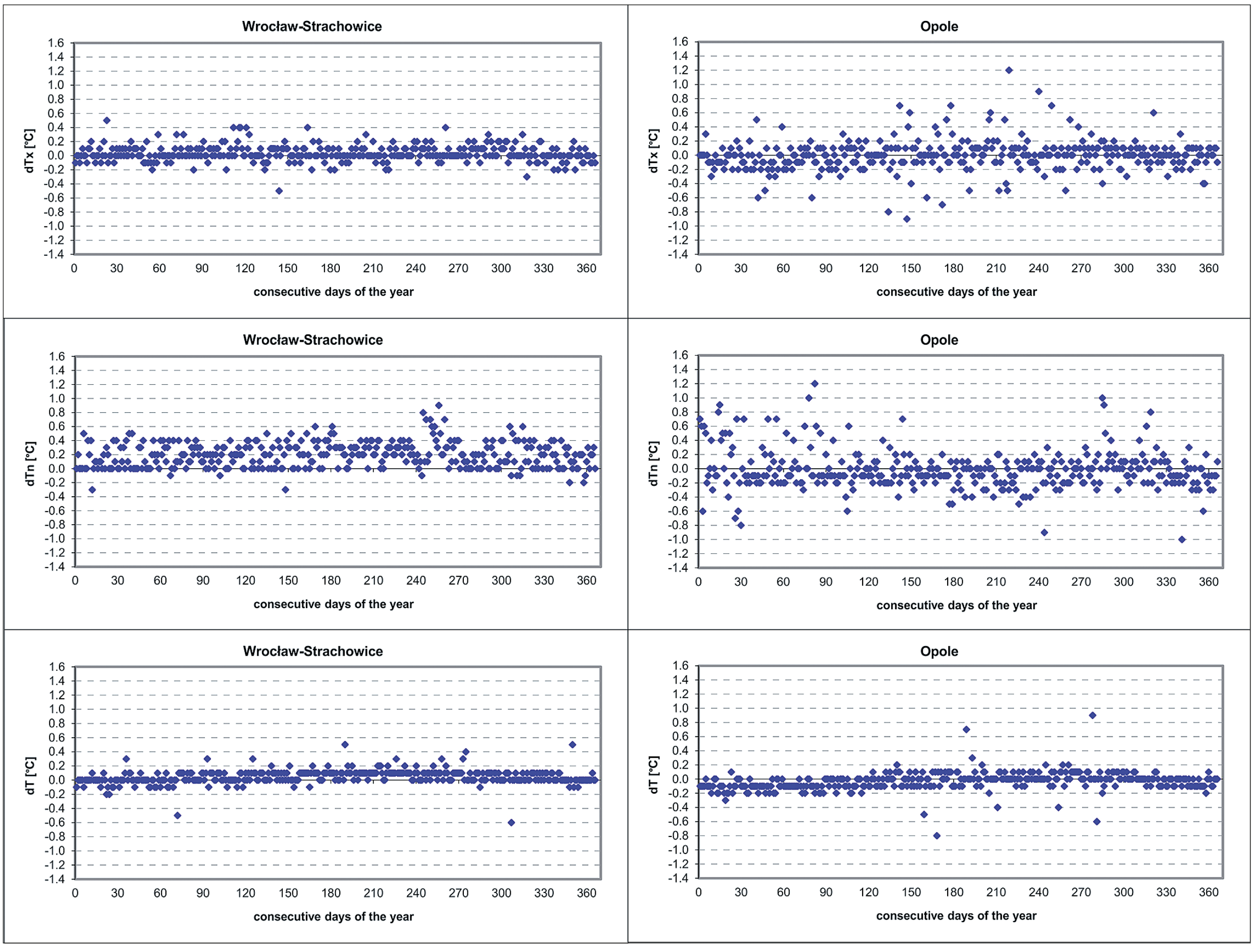

Fig. 3. The course of differences (dT) for daily T_x, T_n and T in Wrocław and Opole stations in 2004

Table 5. Mean annual air temperature Tx, Tn, T calculated from 8 synoptic terms and from the extremes, obtained from automatic weather stations (AWS) and glass thermometers (S)

Station	T_x		T_n		T (from 8 term)		T $(T_x+T_n)/2$	
	AWS	S	AWS	S	AWS	S	AWS	S
Śnieżka	4.5	4.1	-0.5	-0.6	1.8	1.7	2.0	1.8
Jelenia Góra	12.7	12.7	2.8	2.6	7.7	7.8	7.8	7.7
Kłodzko	12.1	12.1	3.2	2.3	7.6	7.6	7.6	7.2
Opole	13.6	13.6	4.9	5.0	9.1	9.1	9.3	9.3
Legnica	14.1	14.1	4.9	4.8	9.4	9.5	9.5	9.4
Wrocław-Str.	14.0	13.9	4.6	4.4	9.3	9.3	9.3	9.2

Before the relationship between differences and weather types was examined, a calculation of frequency of occurrence of weather types in the analyzed period was carried out. It showed that year 2004 and its warm and cold seasons had a relatively even distribution of weather types. However, in the period July 2005 to July 2006 anticyclonic weather predominated, at over 50% (Table 6). Anticyclonic weather is usually characterized by a low horizontal gradient of atmospheric pressure and little cloudiness, resulting in strong insolation during the day. Cloudless nights are characterized by heat radiation off the ground in the infra-red band, causing thermal inversions. During anticyclonic weather, high daily amplitudes of air temperature are noted. On the other hand, cyclonic weather is characterized by high cloudiness and air humidity, significant air turbulence limiting radiation thermal inversions, and low daily amplitudes of air temperature. The transitional weather type (zero, undetermined) occurs when no advection of air masses can be determined over Poland, and occurs between anticyclonic and cyclonic weather.

Table 6. Frequency (%) of occurrence of particular circulation types

Circulation type	Year		Warm season		Cold season	
	2004	2005/6	2004	2005/6	2004	2005/6
0 – transition	27.9	22.0	13.1	10.6	14.8	11.4
a – anticyclonic	37.9	51.0	18.6	30.4	19.3	20.6
c – cyclonic	34.2	27.0	18.6	11.1	15.6	15.9
Total	100.0	100.0	50.3	52.1	49.7	47.9

Analysis of the relationship between mean differences in each air temperature category as measured by AWS and glass thermometer and weather types showed almost no differences for T_x for the 12-month period and both seasons. They occurred only on Śnieżka, reaching values of +0.1°C in the cold season and the 12-month period, and up to +0.2°C in the warm season (Table 7).

Table 7. Mean differences (dT) between daily Txa and Txsz (°C) during particular weather types (0 – transitional, a – anticyclonic, c – cyclonic)

season	ŚN			JG			KŁ			OP			LG			WR		
	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c
May-Oct	0.1	0.2	0.2	0.0	0.1	0.0	-0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Jan-Apr, Nov-Dec	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jan-Dec	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Mean T_n differences, on the other hand, both for the year and for the warm and cold seasons, were positive (with the exception of Śnieżka, where they were slightly negative, and Opole where almost no differences were registered) and vary from +0.1°C to -1.0°C. The highest differences occurred in the warm season during anticyclonic weather and ranged from 0.3°C in Wrocław-Strachowice and Jelenia Góra to 1.0°C in Kłodzko (Table 8).

Table 8. Mean differences (dT) between daily Tna and Tnsz (°C) during particular weather types (0 – transitional, a – anticyclonic, c – cyclonic)

season	ŚN			JG			KŁ			OP			LG			WR		
	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c
May-Oct	-0.1	-0.1	-0.1	0.2	0.3	0.2	1.0	1.0	0.8	-0.1	0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.2
Jan-Apr, Nov-Dec	-0.1	-0.1	-0.1	0.2	0.2	0.2	0.8	0.9	0.8	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2
Jan-Dec	-0.1	-0.1	-0.1	0.2	0.2	0.2	0.8	0.9	0.8	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2

In the case of the mean differences of T, it is difficult to find any regularities. The differences, if they occur, are small and not higher than ±0.1°C (Table 9). Similarly, there is no seasonality in daily differences in all three air temperature categories (Kajewska 2011).

The analysis of large daily air temperature changes expressed by threshold values of daily amplitude (≥ 16.0°C for all stations and ≥ 8.0°C for Śnieżka) indicates that the mean difference between AWS amplitude and glass thermometers is from 0.0°C in Opole to -1.0°C in Kłodzko. Only in the case of Śnieżka is the difference positive, reaching 0.2°C. The maximum differences fluctuate from -0.1°C in Kłodzko to +1.6° on Śnieżka. The minimum differences range from -0.3°C on Śnieżka to -1.7°C in Kłodzko (Fig. 4). In general, it can be stated that, in the majority of cases, differences in daily amplitude are negative. Moreover, with the exception of Śnieżka, absolute values of extreme negative differences are higher than extreme positive differences. Therefore, with large daily air temperature changes, AWS usually shows lower amplitude values than glass thermometers. AWS air temperature sensors react more slowly to high daily temperature changes than glass thermometers, thus indicating higher inertia.

Furthermore, the discussed high daily air temperature changes occurred in anticyclonal weather type in most cases (from 66% in Wrocław to 73% in Kłodzko). High daily air temperature changes occurred during transitional and cyclonic weather types 13-24% and 8-17%, respectively. In the majority of cases, large amplitude differences could be noted on days in the warm season. On Śnieżka, however, large amplitude differences occurred mostly on days in the cold season.

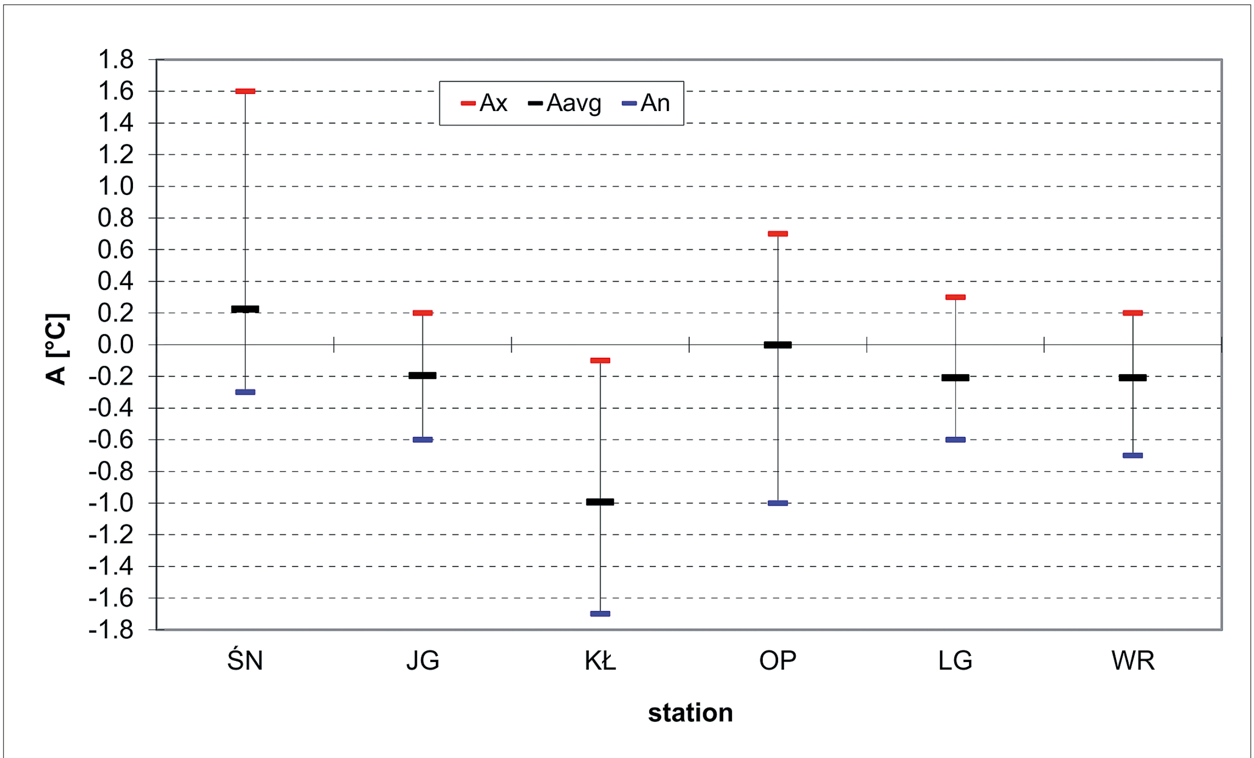

Fig. 4. Values of differences in daily air temperature amplitude between AWS and glass thermometer for average (A_{avg}), maximum (A_x) and minimum (A_n)

Table 9. Mean differences (dT) between daily Ta and Tsz (°C) during particular weather types (0 – transitional, a – anticyclonic, c – cyclonic)

season	ŚN			JG			KŁ			OP			LG			WR		
	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c	0	a	c
May-Oct	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.1	0.1	0.1
Jan-Apr, Nov-Dec	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0	0.1
Jan-Dec	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	-0.1	0.0	0.0	0.1

In the 6 analyzed weather stations located in the Lower and Opole Silesia, mean differences of mean monthly air temperature (T) between AWS and glass thermometer are not high, reaching only ±0.1°C and incidentally (for example, in Legnica in January) up to -0.2°C. In months during the cold season (except for Wrocław) they are negative, which results in the negative deviation for cold seasons. However, on the annual scale, there are almost no differences in readings between AWS and glass thermometer. Moreover, no relationship was found between mean deviation of T and weather types.

Mean monthly maximum air temperatures (T_x) show sporadic differences of ±0.1°C. Deviations in T and T_x are of little significance, fitting in the normal range of readings. The only exception is Śnieżka where, in almost all months throughout the year AWS shows positive mean differences compared to glass thermometer: from 0.1°C in the cold season to 0.3°C in the warm season.

Furthermore, based on annual data and cold season data, no apparent relationship between the T_x deviation value and weather type could be found. Only during the warm season in anticyclonic weather were there small positive deviations from 0.1°C at JG, OP, LG stations to 0.2°C on Śnieżka.

In the case of mean monthly minimum values of air temperature (T_n), AWS usually renders positive mean deviations compared to glass thermometer. The highest deviations (of up to 1.1°C) occur in the warm season. The only exception is Śnieżka, where the difference is permanently negative in relation to glass thermometers.

Mean differences of T_n over the 12-month period and over both seasons are mostly positive (with the exception of Śnieżka, where they are negative, and Opole, where almost no differences were noted) varying between 0.1°C and 0.9°C. The highest deviations, reaching as much as 1.0°C in Kłodzko, occur in the warm season in anticyclonic weather conditions.

In general, deviations in each air temperature category (T, T_x, T_n) do not show any regularities, which excludes the possibility of permanent correction.

The majority of the frequency of deviations of T_x and T fluctuates between -0.1°C and +0.1°C, 64-84% and 77-93% respectively. They can therefore be considered of little significance, falling within the normal range of error. The frequency of medium and high deviations of T_n, on the other hand, is higher, and deviations are positive and prominently dominate over negative deviations in the majority of stations. High deviations of over 1.0°C are extremely rare or absent. The one exception is Kłodzko, where they occur in over 30% of cases and, combined with medium deviations, constitute as much as 80% of all errors. The only occurrence of dominance of negative T_n deviations over positive ones is noted on Śnieżka.

Mean difference in daily amplitude between AWS and glass thermometers is from 0.0°C in Opole to -1.0°C in Kłodzko. It is positive only in the case of Śnieżka, where it is +0.2°C. Usually, in the case of high daily air temperature changes, AWS shows lower amplitude values than glass thermometer. AWS sensor reaction to high daily changes of air temperature is slower than that of glass thermometers.

The discussed high daily air temperature changes occurred mostly during anticyclonal weather type (from 66% in Wrocław to 73% in Kłodzko). The majority of large amplitude differences were noted in days of the warm season. The exception was Śnieżka, where large amplitude differences occurred mostly in days of the cold season.

Deviations caused by different factors are inherent to all measurement instruments and need to be dealt with in all countries. Although the irregularity in mean differences between AWS readings of air temperature categories and those of glass thermometers makes it impossible to implement appropriate corrections, the differences are relatively small. Moreover, the natural dynamic changeability of atmospheric conditions necessitates averaging of reading in order to reduce measurement uncertainty (Durło, Kajewska 2009).

Due to the dominant position of the IMGW-PIB in this field, and the fact that it carries out data processing in an operational system while implementing continual improvement of measurement methods and data verification, it may be concluded that the application of AWS in air temperature measurements is fully justified. However, in climatological analyses of, for example, climate change and variability, AWS air temperature results may cause a lack of homogeneity in data series and, consequently, erroneous interpretations.

Successive transition to full automatization of IMGW-PIB's weather station network will make it possible to calculate daily mean air temperature using the same method in all weather and climate stations.

Due to the relatively short research period and limited area (Lower and Opole Silesia), the presented results are of rather demonstrative value and require further study based on parallel measurement series. Nonetheless, they can be considered as a starting point for the development of a methodology of meteorological measurements using AWS.

References

AMUDHA B. et al., 2008, Effect of non-wooden radiation shield on measurements of air temperature and humidity in Automatic Weather Stations at climatologically different Indian stations Pune and Mumbai. WMO Technical Conference on Instruments and Methods of Observations, St. Petersburg. Russian Federation, 27-29 November 2008.

BARTOSZEK K., SKIBA K., 2006, Wpływ rodzaju termometru i osłony na pomiary temperatury powietrza. Annales UMCS, 61: 34–38.

BEINDE B., 2006, Comparsion of Classical Instruments and Automatic Hydrometeorological Systems. WMO Technical Conference on Instruments and Methods of Observations, Geneva, Switzerland, 4-6 December 2006.

BIL-KNOZOVÁ G., ROŽNOVSKÝ J., 2006, Comparsion of a series of air temperature and relative air humidity measured using HOBO and AMS sensors and conventional methods. Annales UMCS, Lublin, 61: 72–81.

BUDZIK T., MARSZAŁ M., 2006, Porównanie temperatury powietrza w klatce meteorologicznej i osłonie antyradiacyjnej na przykładzie pomiarów w Sosnowcu w 2003 roku. Annales UMCS, 61: 107–115.

DURŁO G. B., KAJEWSKA J., 2009, Czynnik technologiczny w automatycznych stacjach meteorologicznych. Acta Agrophysica, 13: 49–66.

KAJEWSKA J., 2011, Ocena wybranych parametrów agrometeorologicznych mierzonych przyrządami klasycznymi i za pomocą stacji automatycznej. PhD Thesis, UP, Wrocław.

KAJEWSKA J., ROJEK M., 2009, Porównanie temperatury powietrza mierzonej przy wykorzystaniu klasycznej i automatycznej stacji meteorologicznej w Obserwatorium Wrocław-Swojec. Acta Agrophysica, 13: 713–723.

KEJNA M., USCKA-KOWALKOWSKA J., 2006, Porównanie wyników pomiarów meteorologicznych w stacji ZMŚP w Koniczynce (Pojezierze Chełmińskie) wykonanych metodą tradycyjną i automatyczną w roku hydrologicznym 2002. Annales UMCS, 61: 208–217.

LIN X. et. al., 2001, Some perspectives on recent insitu air temperature observations: Modeling the microclimate inside the radiation shields. Journal of Atmospheric and Oceanic Technology, 18: 1470–1484.

LITYŃSKI J., 1969, Liczbowa klasyfikacja typów cyrkulacji i typów pogody dla Polski. Prace PIHM, 97: 3–15.

LORENC H., 2006, Ocena jakości danych meteorologicznych po wprowadzeniu automatycznych przyrządów rejestrujących do sieci IMGW. Annales UMCS, 61: 256–266.

ŁABĘDZKI L., ROGUSKI W., KASPERSKA W., 2001, Ocena pomiarów meteorologicznych prowadzonych stacją automatyczną. Przegląd Naukowy Wydziału Inżynierii i Kształtowania Środowiska SGGW, 21: 195–201.

NASH J., 2006, Challenges posed by the WMO Integrated Observing System. WMO Technical Conference on Instruments and Methods of Observations, Geneva, Switzerland, 4–6 December 2006.

NAGY Z., 2006, Effect of thermometer screens on accuracy of temperature measurements. WMO Technical Conference on Instruments and Methods of Observations, Geneva, Switzerland, 4–6 December 2006.

PARKER D. E., 1994, Effects of changing exposure of thermometers at land stations. International Journal of Climatology, 14: 1–31.

PLUMMER N., COLLINS D., DELLA-MARTA P., ALLSOP T., DUROCHER Y., YUCYK T., HELM R., HELFERT M., HEINO R., RUDEL E., STASNEY P., ZAHUMENSKY I., AND ZHOU S., 2003, Progress of Automatic Weather Stations in Meeting the Needs of Climate. 3a Conferencia Internacional sobre Experiencias con Estaciones Meteorológicas Automáticas, Instituto Nacional de Meteorologia, Torremolinos (Málaga), 19-21 February 2003.

ROJEK M, ROJEK M. S., 2000, Porównanie temperatury i wilgotności powietrza mierzonych przy wykorzystaniu klasycznej i automatycznej stacji meteorologicznej. Roczniki Naukowe AR Poznań, Melioracje, 239/21: 59–67.

RÓŻDŻYŃSKI K., 1995, Miernictwo meteorologiczne. 1, IMGW, Warszawa.

RÓŻDŻYŃSKI K., 1996, O znaczeniu rzetelności pomiarów w miernictwie meteorologicznym, hydrologicznym i oceanograficznym. Wiadomości IMGW, 40.

RÓŻDŻYŃSKI K., 1999, Metodyka pomiarów wielkości meteorologicznych i hydrologicznych w systemie SMOK. Gdynia (opracowanie niepublikowane).

RÓŻDŻYŃSKI K., 2004, Podstawy telemetrycznego miernictwa meteorologicznego. IMGW, Warszawa.

RUDEL E., 2008, Design of the new Austrian Surface Meteorological Network. WMO Technical Conference on Instruments and Methods of Observations, St. Petersburg, Russian Federation, 27-29 November 2008.

SZWEJKOWSKI Z., 1999, Porównanie wyników pomiarów dokonywanych za pomocą klasycznej i automatycznej stacji meteorologicznej. Folia Universitatis Agriculturae Stetinensis, 201, Agricultura, 89: 199–202.

YING W., XIAONING L., XIAOHUI J., 2006, Differences between Automatic and Manual Meteorological Observation. WMO Technical Conference on Instruments and Methods of Observations, Geneva, Switzerland, 4-6 December 2006.

Manuscript received 23 February 2015, revised 13 May 2015 and accepted 19 May 2015.