INFLUENCE OF THE AVERAGING PERIOD IN AIR TEMPERATURE MEASUREMENT

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ABSTRACT

With the introduction of a range of automatic weather stations (AWSs), questions concerning the comparability of data from "traditional" measurements with mercury thermometers and these with AWSs arise. The issues related to the influence of different periods of averaging of meteorological elements on the measured values play important role. In this paper, the dependence of the air temperature value from the period of averaging is shown. The respective dependences are obtained on the basis of theoretical estimates about the influence of averaging period of the thermometer on the temperature value which changes in linear or harmonic law. A four-years experiment is carried out to verify the theoretical conclusions. One and the same measurement system (sensor, radiation shield and location of measurement) and a differential method of testing are used to eliminate the errors of measurement. This allows to determine the difference in measuring the air temperature related only to the use of different averaging periods. The results obtained for the region of Sofia, Bulgaria, are presented.

INTRODUCTION

Air temperature measurements with mercury thermometers have been carried out for many years in the National Institute of Meteorology and Hydrology of Bulgaria (NIMH) and in most of the National Meteorological Services worldwide. With the penetration of automatic weather stations (AWSs) on a mass scale, the air temperature is measured with different in design and characteristics sensors. For this reason, a number of questions concerning the comparability of data from "traditional" measurements and these with AWSs arise. Before starting comparative measurements and search of any regression relationships, it is needed to settle a series of important questions.

The first ones are issues related to the influence of different averaging periods of meteorological elements on the measured values, the second – issues related to the influence of measurement errors of various instruments and sensors on the resulting value, and the third - issues related to the influence of the conditions under which the measurement takes place. For example, in the case of temperature and relative humidity measurements, the type, the design and the material of sunshine and rainfall shield – i.e., a classic meteorological cage, radiation shield with possibility for passive or active ventilation, play role. The fourth issues relate to the algorithms for processing of data from the AWSs and for data quality control. Many more details may compromise the measurement as well. The present paper is devoted to a study on the first issues.

THEORETICAL JUSTIFICATION

From general physical considerations (Kachurin, 1985), it follows that the change of air temperature with time and the period of averaging should affect the measured value. The time of thermal inertia of the thermometer $\boldsymbol{\lambda}$ is to have influence, too:

(1) $$\lambda = \frac{mc}{\alpha S}$$

where m is the mass of the thermometer, c - specific heat capacity, α - total thermal conductivity, S - total area of the thermometer.

Let Θ_0 is the air temperature at the initial moment; T_0 - temperature of the thermometer at the initial moment; Θ is the air temperature, T - temperature of the thermometer; δt - averaging period of the temperature.

For the rate of change of the temperature of thermometer it can be written:

(2) $$dT/(T-\Theta) = -dt/\lambda$$

Let us consider the case where the air temperature changes in a linear law:

(3) $$\Theta = \Theta_0 + \gamma t \qquad \text{where} \quad \gamma = d\Theta/dt$$

Integrating for the time of averaging **δt** from ***0*** to ***t*** and for air temperature change from ***(T_0-Θ_0)*** to ***(T-Θ)*** we get:

(4) $$T-\Theta = (T_0 - \Theta_0 + \gamma\lambda)e^{-t/\lambda} - \gamma\lambda$$

And when the period of averaging **(δt =t)>>λ,** it is seen that:

(5) $$T-\Theta = -\gamma\lambda$$

Or, the values obtained for the air temperature will differ from the true value by the quantity ***–γλ***.

If we consider the case where the temperature changes in harmonic law with amplitude ***A*** and period of oscillation ***p***:

(6) $$\Theta = \Theta_0 + A\sin(2\pi t/p)$$

then the solution is

(7) $$T-\Theta = (T_0-\Theta_0)e^{-t/\lambda} + \frac{A}{\sqrt{1+(\frac{2\pi}{p}\lambda)^2}}.\sin(\frac{2\pi}{p}t - arctg\frac{2\pi\lambda}{p})$$

Again, it can be seen that after period of averaging much greater than the time of thermal inertia of the thermometer **(δt = t) >> λ**, the first term in (7) tends to zero and the fluctuations in the temperature of the thermometer are sinusoidal with the same period ***p*** as the air temperature but with lower amplitude ***A*** and phase lags. Similarly to the above findings, it can be shown that the same results will be obtained in the case of asymmetric law of the air temperature change.

The obtained findings show that due to non-stationary nature of the air temperature, the period of averaging in its measurement affects the resulting value. As far as the time of thermal inertia of the thermometer is known quantity, the real temporal variations of air temperature are random process. For this reason, analytical numerical estimations of these differences based on the obtained dependencies are not of practical interest.

EXPERIMENTAL VERIFICATION AND RESULTS

A field experiment within four years has been conducted to define quantitative estimates of the influence of averaging period on the air temperature value. Data from measurements by the AWS model MS&E-4 (MS&E, 2012) is used. A platinum sensor for air temperature measurement with absolute measurement error of ± 0.2º for the range from -25 to +60 ºC is applied in this model of AWS. The time of thermal inertia of the sensor is less than 10 seconds. Averaging regime of 60 seconds is set as 10 measurements are made during this period. The choice of averaging period of

60 seconds is made because it is less than the time of thermal inertia for all the mercury thermometers used in the network of the National Institute of Meteorology and Hydrology of Bulgaria (NIMH), as well as it is less than the time of averaging in measurements by AWS (10 minutes) recommended by WMO (WMO No 8). The AWS is situated in the experimental ground of the Consortium "Meteorological Systems and Equipment" in the region of Sofia city, Bulgaria, and it makes record of the measured within 60 seconds average air temperature for every 60 seconds.

Because of using one and the same measuring system (sensor, radiation shield and location of measurement) and of determining differences (differential test method), the measurement error is practically eliminated. This allows to make the assumption that all the effects which will be examined later are solely due to the different periods of averaging in determing the air temperature.

With instrumental error of ±0.2ºC and wind 0.5-2.0 m/s, the mercury thermometers used in the network of NIMH measure average value of the air temperature within interval in the range of 90 to 130 seconds due to their design (this is the time of thermal inertia **λ**). That is why the differences in air temperature values will be considered if it is measured as an average of 120 seconds (2 minutes) or 600 seconds (10 minutes). In this way, the measurement by classic mercury thermometer can be "replaced" with two-minutes average measurement by the AWS.

The time course of air temperature for a typical winter day is shown in Figure 1.

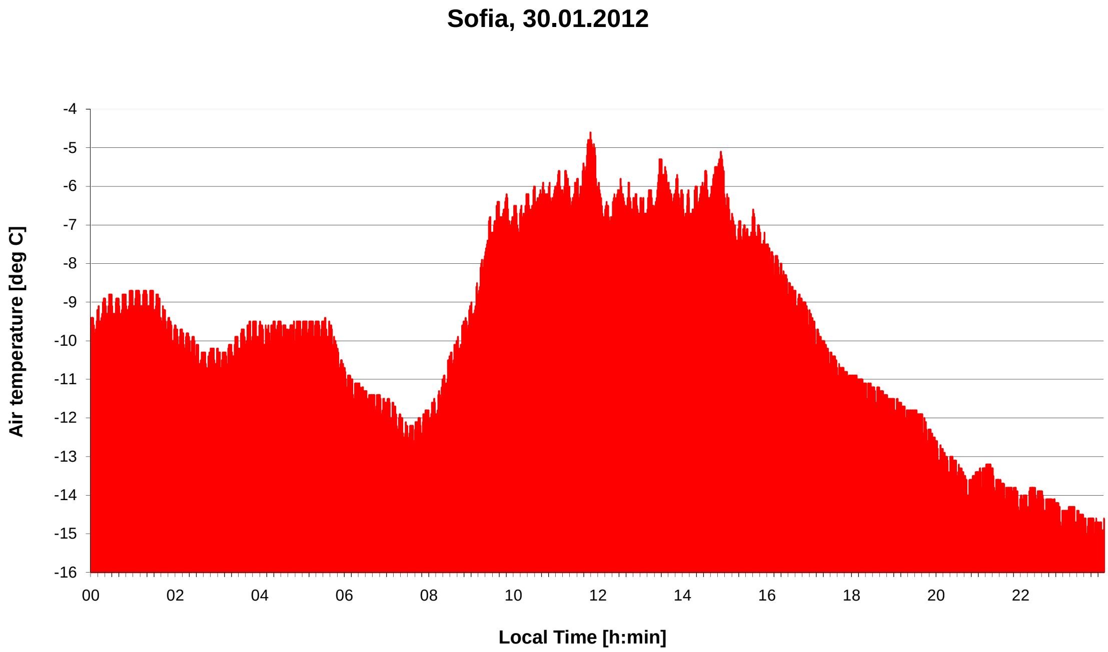


Fig.1. Time course of the one-minute average air temperature in Sofia on 30.01.2012.

As the chart shows, the differences in temperature measured in a ten-minutes interval have amplitude of up to 1.5 ºC. At night, the amplitude has lower, and in daytime – bigger values (especially in the moments of sunrise and sunset).

Let us consider the most frequently realized in practice case: measurement of air temperature in meteorological cage by meteorological observer before the synoptic term and automatic transfer of data from AWS at the synoptic term. The "classic thermometer" makes average of the temperature in two-minutes interval (from the 10th to the 8th minute before the term) and AWS - in ten-minutes interval (from the 10th minute to the round hour of synoptic term). The diurnal course of minute-by-minute differences in the average values of temperature by two- and ten-minutes averaging ($\mathbf{t_{10}\text{-}t_2}$) within one and the same ten-minutes interval is shown in Figure 2.

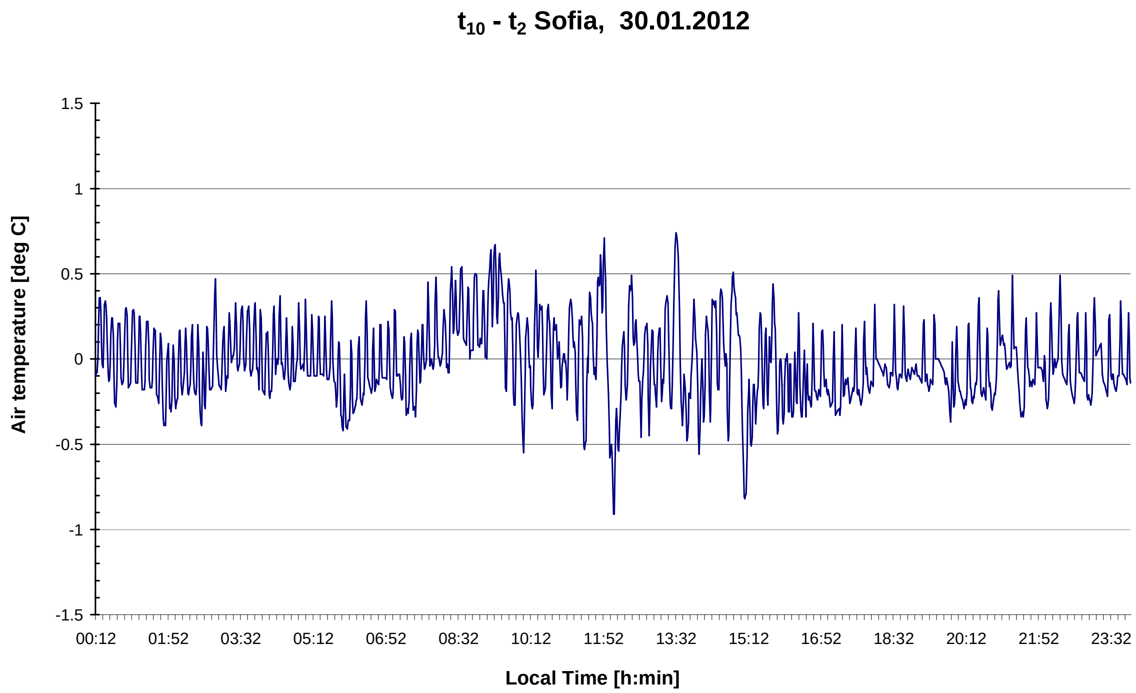


Fig.2. Difference between the values of air temperature measured by averaging of 10 and 2 minutes (**t_{10}-t_2**) for winter day.

As it is seen in Figure 3 and Figure 4, the experimental results for transition seasons - spring and autumn, are similar.

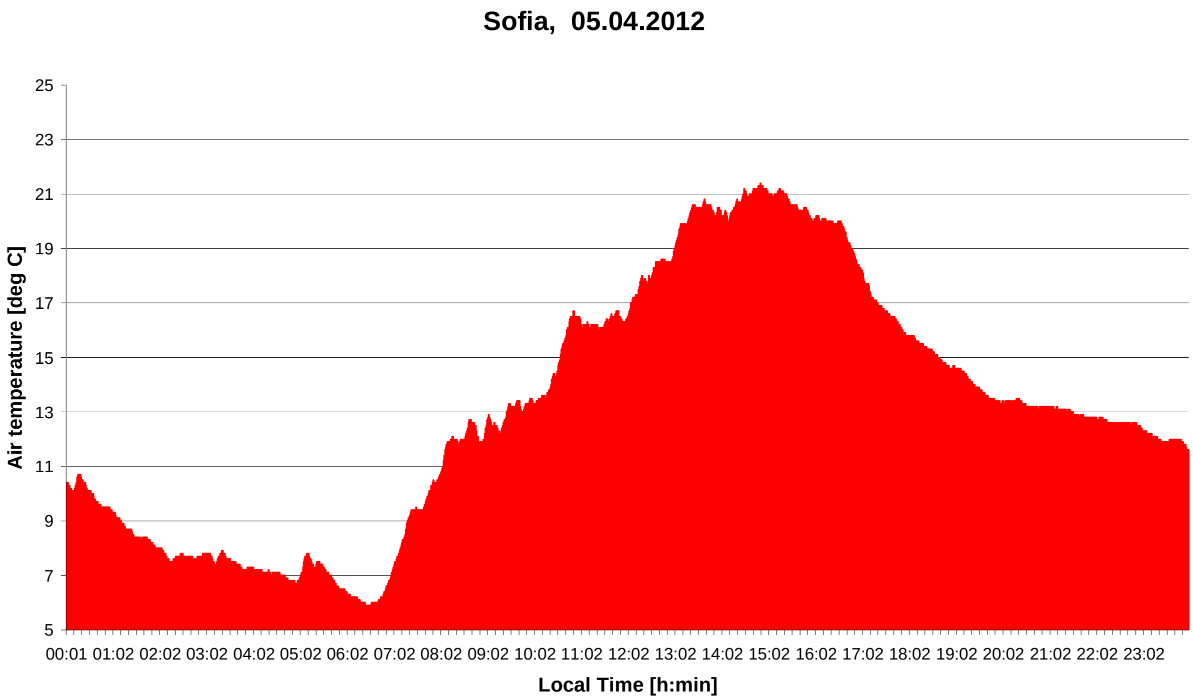


Fig. 3. Time course of the one-minute average air temperature in Sofia on 05.04.2012.

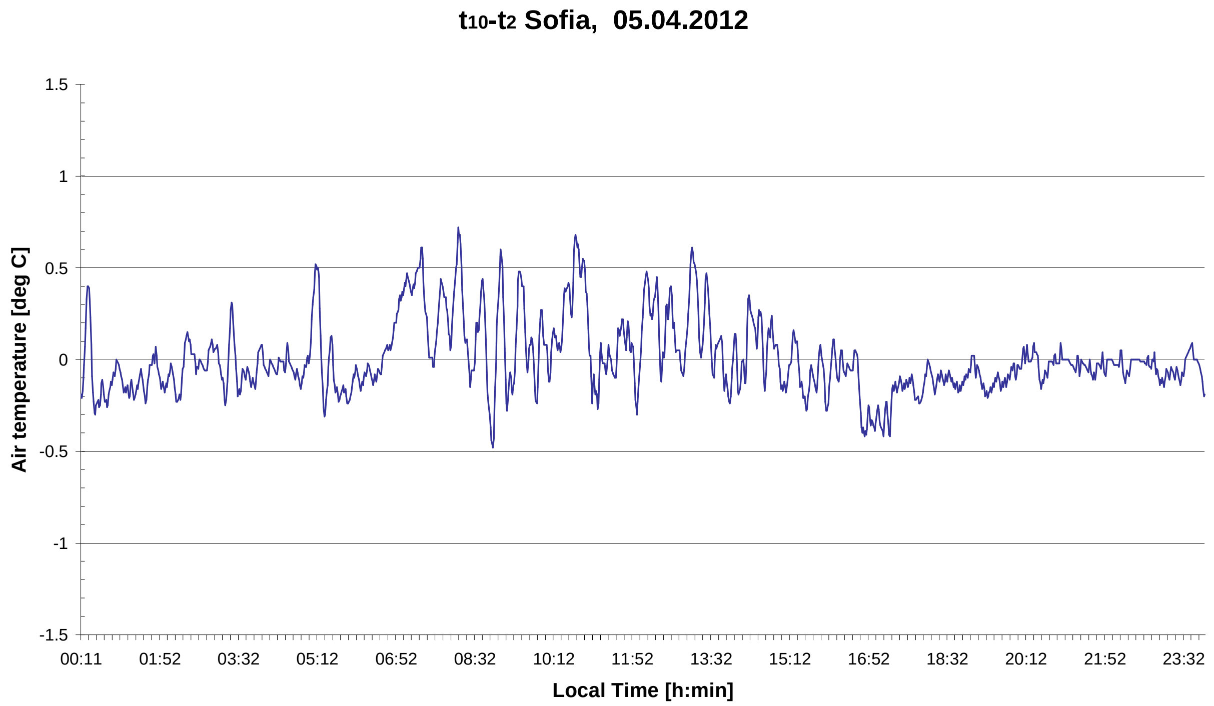


Fig. 4. Difference between the values of air temperature measured by averaging of 10 and 2 minutes (**t_{10}-t_2)** for spring day.

The experimental results for summer season are shown in Figure 5, Figure 6 and Figure 7.

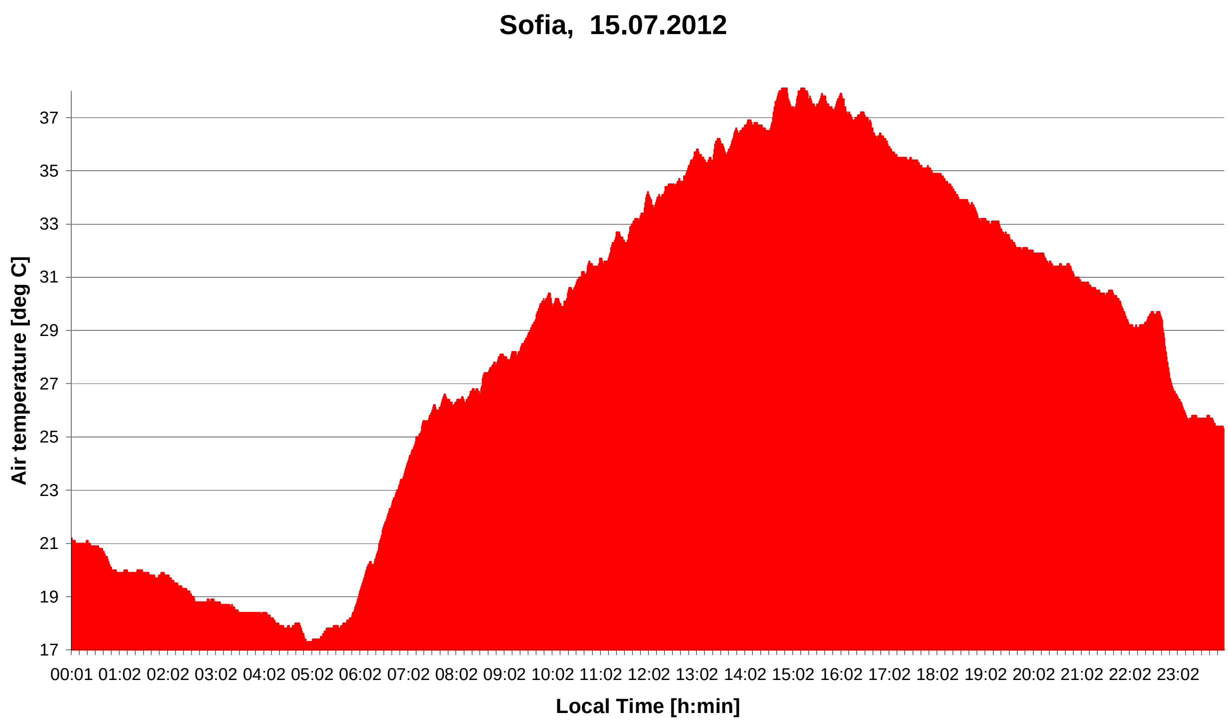
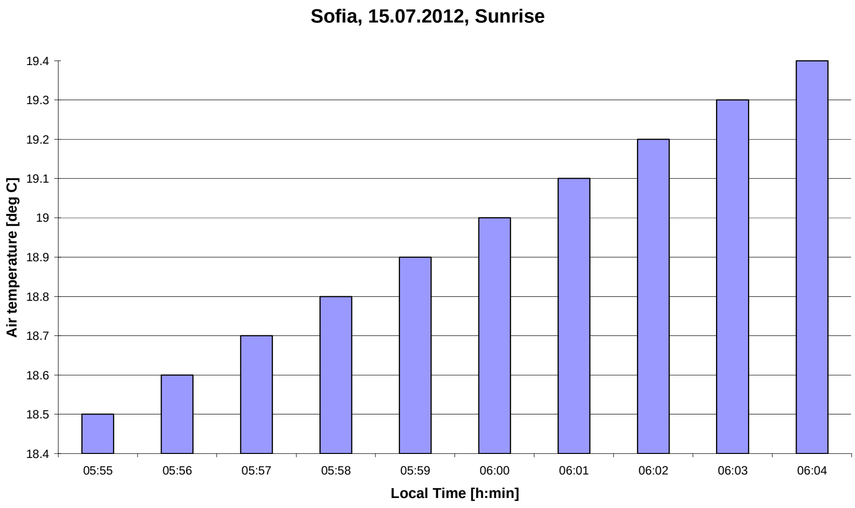


Fig. 5. Time course of the one-minute average air temperature in Sofia on 15.07.2012.



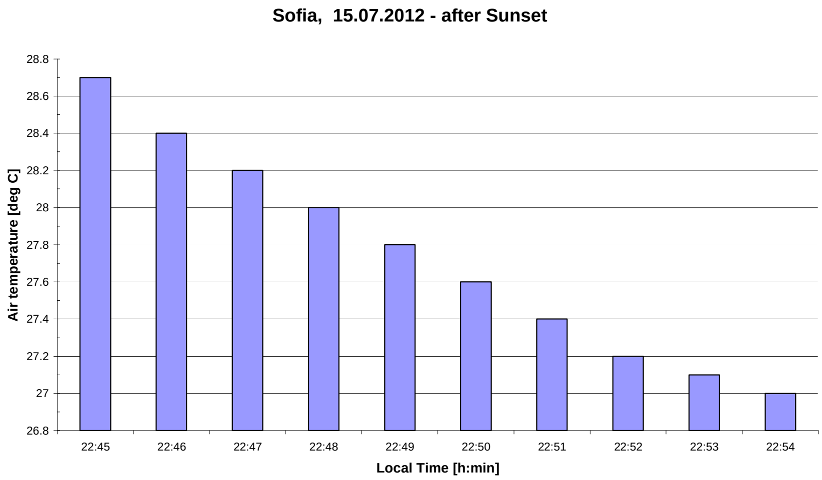


Fig. 6. Time course of the temperature in a ten-minutes interval for a summer day at the sunrise and sunset.

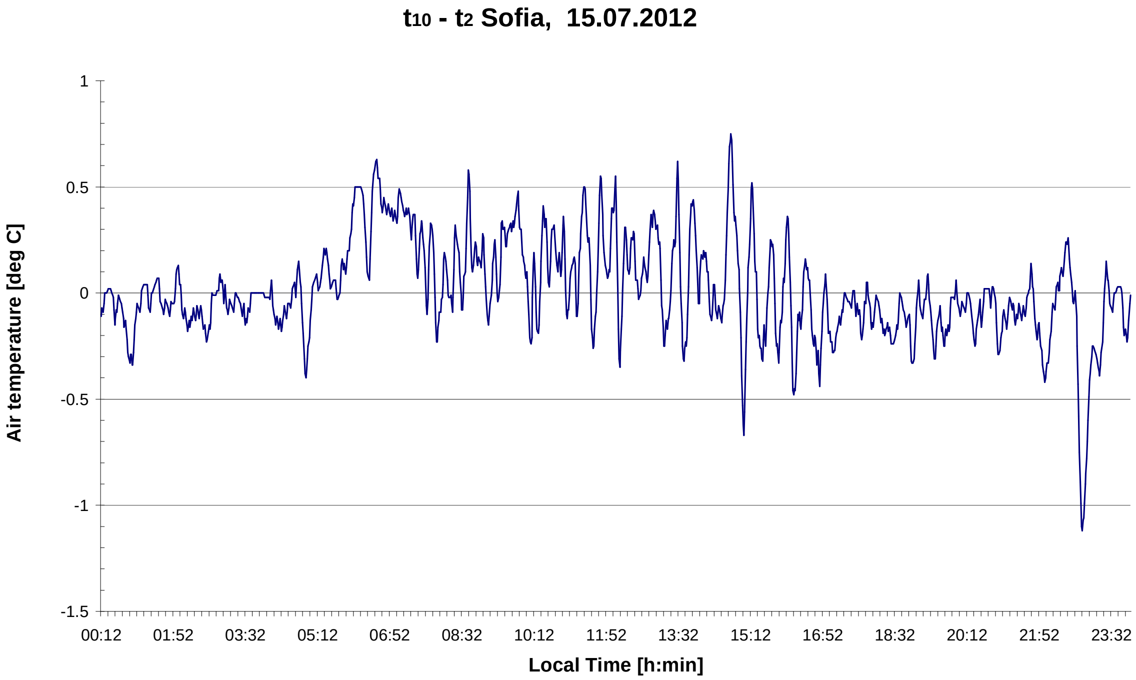


Fig. 7. Difference between the values of air temperature measured by averaging of 10 and 2 minutes (**t_{10}-t_2)** for summer day.

In the conclusion about change of the temperature in linear law (5), it was obtained that if air is cooling and warming, there is "lag" proportional to the rate of change of temperature and the period of averaging. Comparisons of the measured average temperature for 10 minutes interval in relation to the one for two-minutes interval - Figures 2, 4 and 7, show that in cases of air cooling, the ten-minutes value is lower than the two-minutes one and vice versa – it is higher in cases of air warming, i.e., the experimental data supports the theoretic conclusions.

The presented typical seasonal cases show that due to non-stationary nature of the air temperature, even for intervals of 10 minutes, there are always differences in the measured values. Based on the experimental results, it can be concluded that even if the metrological characteristics of the classic thermometer and the sensor of AWS are exactly the same, only due to different averaging periods, there can be differences in the measured air temperatures of ±0.4 ºC in average. These differences are higher in the moments of sunrise and sunset (about ±1.0 ºC) and lower - for the rest of the day. During transition seasons, the differences are lower compared to the summer and winter. Overall, during the night hours, the AWS will measure lower values than the "classic thermometer", while in the daytime – higher ones.
Whereas in the measurements at synoptic terms it can be assumed that for the time range within 2 ÷ 10 minutes, the air temperature changes in linear law, this is not the case of the determination of average temperatures for longer periods of time. In the case of the daily, monthly and annual average temperatures, it can be assumed that the air temperature changes in a periodic law. Then, the findings (7) are effective and the result has to be different.

To assess the influence of the averaging period in measurements of air temperature on the value of the monthly and annual average temperature, data from the same experiment carried out in the experimental polygon of Consortium "MS&E" in the region of Sofia city is used. Mean differences between ten- and two-minutes averaging period ΔT [℃] in the temperature measurement for each month within the four years of measurements are calculated. Air temperature data only for the synoptic terms – measured in the interval from 10 minutes prior to the exact term, is used. The data for cases when precipitation starts in this 10 minute interval to the synoptic term is removed. On Table 1, the average values of ΔT during the experiment as well as Max and Min – the respective maximum and minimum values, are presented.

Table 1. Average monthly, maximum and minimum values of ΔT for the Sofia region for each of the synoptic terms of measurement.

Months		Local Time (UTS +2)							
		02	05	08	11	14	17	20	23
January ΔT [℃]	Average	-0.1	0.0	0.0	0.1	0.1	-0.2	0.0	0.0
	Max.	1.1	0.8	1.1	1.1	2.2	0.8	3.6	1.2
	Min.	-1.0	-0.9	-0.9	-0.9	-1.0	-1.5	-1.0	-0.9
February ΔT [℃]	Average	0.0	0.0	0.1	0.2	0.0	-0.1	-0.1	0.0
	Max.	0.6	0.8	1.1	1.2	1.8	0.5	0.5	2.0
	Min.	-0.8	-0.7	-2.1	-0.9	-2.2	-1.1	-0.6	-0.6
March ΔT [℃]	Average	0.0	0.0	0.2	0.2	0.1	-0.1	-0.1	-0.1
	Max.	0.4	0.5	1.7	1.1	1.2	0.5	1.3	0.5
	Min.	-0.4	-0.9	-0.5	-1.0	-1.2	-0.6	-0.7	-1.6
April ΔT [℃]	Average	-0.1	-0.1	0.3	0.1	0.0	-0.1	-0.1	-0.1
	Max.	0.6	0.5	1.7	1.3	1.8	0.4	0.2	0.2
	Min.	-0.5	-0.7	-0.5	-1.2	-1.7	-1.0	-0.9	-0.7
May ΔT [℃]	Average	0.0	-0.1	0.2	0.2	0.0	-0.4	-0.2	-0.1
	Max.	0.6	0.9	1.6	1.5	2.3	0.7	0.2	0.4
	Min.	-0.9	-0.6	-0.7	-1.1	-2.1	-17.2	-0.8	-0.6
June ΔT [℃]	Average	-0.1	0.0	0.3	0.2	0.0	-0.2	-0.2	-0.1
	Max.	1.1	0.3	1.4	1.5	1.3	0.8	1.7	0.5
	Min.	-1.5	-0.8	-1.5	-1.2	-2.0	-1.2	-2.0	-1.2

July ΔT [℃]	Aver.	-0.1	0.0	0.3	0.2	0.0	-0.3	-0.3	-0.1
	Max.	0.4	0.6	1.6	1.4	1.4	0.9	0.3	0.9
	Min.	-1.3	-0.8	-1.2	-1.4	-2.4	-1.2	-2.1	-1.9
August ΔT [℃]	Average	-0.1	-0.1	0.3	0.3	0.1	-0.3	-0.3	-0.1
	Max.	0.7	0.3	1.1	1.7	1.5	0.5	0.8	0.2
	Min.	-0.6	-0.4	-0.4	-0.8	-0.9	-2.6	-2.9	-0.7
September ΔT [℃]	Average	-0.1	-0.1	0.3	0.2	0.0	-0.1	-0.2	-0.1
	Max.	0.3	0.3	1.3	1.3	1.5	1.2	0.8	0.3
	Min.	-0.5	-0.4	-0.9	-0.7	-1.9	-0.5	-0.9	-0.6
October ΔT [℃]	Average	0.0	0.0	0.3	0.2	0.0	-0.2	-0.1	0.0
	Max.	0.6	0.9	1.3	1.0	0.9	0.2	0.7	1.2
	Min.	-0.5	-0.8	-0.5	-0.5	-1.1	-0.9	-0.7	-0.8
November ΔT [℃]	Average	0.0	-0.1	0.3	0.2	0.1	-0.3	-0.1	-0.1
	Max.	1.3	0.5	1.2	0.8	1.0	0.1	0.4	0.9
	Min.	-0.9	-0.6	-0.6	-0.6	-0.7	-0.9	-0.6	-1.4
December ΔT [℃]	Average	0.0	0.0	0.0	0.1	0.0	-0.2	0.0	-0.1
	Max.	2.4	0.9	0.5	1.2	1.0	0.3	1.2	0.5
	Min.	-2.4	-0.9	-0.9	-2.2	-0.8	-0.8	-0.6	-0.8

As seen from the obtained results, the difference between air temperature values from the "classic" two-minutes averaging measurement and the ten-minutes averaging measurement by the AWS is influenced by the daily course of temperature change and by the trend of this change, i.e., the conclusions made in obtaining (7) are confirmed by the experimental data. The phase shift is expressed by the fact that in the hours of sunrise, the ten-minutes average is higher than the two-minutes average while in the hours of sunset it is lower. In order to assess the change in the amplitude of fluctuation, the averaged in terms and months differences ΔT_a in the air temperature value due to the averaging period are used. These differences are shown on Table 2.

Table 2. ΔT_a – averaged in terms and months differences in the air temperature value due to the averaging period

Months	1	2	3	4	5	6	7	8	9	10	11	12	Average
ΔT_a [℃]	**-0.01**	**0.00**	**0.01**	**-0.01**	**-0.04**	**-0.03**	**-0.06**	**-0.02**	**0.00**	**0.01**	**-0.01**	**-0.01**	**-0.014**

Generally, a decrease of the mean annual air temperature is obtained, i.e., the expected decrease in the amplitude of fluctuations associated with the increased averaging period of measurements by AWS is observed.

CONCLUSIONS

What conclusions can be drawn on the basis of the obtained results for differences in the measured air temperature values due to the averaging period of 2 or 10 minutes? Practically, these differences appear in the process of switching from measurements of air temperature with classical mercury thermometer to measurements by AWSS, and the following conclusions are to be considered in these cases:

• differences larger than 1.0 ℃ can be obtained for individual measurements in the terms of observation. The differences are positive at the sunrise and negative - at the sunset;

• during transition seasons, the differences are lower compared to the ones in the summer and winter. Overall, the "classic thermometer" measures higher values of the air temperature during the night hours than the AWS, and lower - in the daytime;

• as seen from the obtained results, the periodic character of the time course of air temperature is able to "compensate" significantly the differences due to different averaging period. For the each month, these differences are below 0.1 ℃ and it should not be expected that they affect the estimate of the climatic variations in air temperature.

Final Remarks

When use the above results, it should be taken into account that they are relevant to the area of middle latitudes of the Northern Hemisphere and are based on relatively limited experimental material.

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