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Inhomogeneity introduced to the climate data series by instrumentation changes of the thermometer shields and rain gauges

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Abstract: Recently we can see the trend of introducing a new instrumentation and automatization in the field of information and monitoring systems for the meteorology, hydrology and crisis centers. Nowadays a great number of sensors are used in projects in many countries of various climates. Therefore it is crucial to deeply understand how the change of sensor types will affect the accuracy of measurements and how is accuracy of individual sensor type affected by different weather conditions.

We analyzed several screen/shields and rain gauges at the premises of faculty of Meteorology and Climatology of FMFI UK. On the basis of our results we can recommend as a most accurate and not depending on weather condition artificially ventilated screen although it is the most expensive. Our second choice would be a large naturally ventilated shield. In case of Stevenson screens we would recommend painting it with a high gloss coating. Our last choice would be a small naturally ventilated screen because of its high sensitivity to the global radiation.

Our first choice of the participating rain gauges would be the weighing rain gauge because of its best results in both cases, of rainfalls up to 2 mm and also over 2 mm. The tipping bucket rain gauge gave also agreeable result in both cases. The optical sensor gave very good results in rainfalls over 2 mm but it is unsuitable for rainfalls up to 2 mm. The radar sensor is also completely unsuitable for low intensity rainfalls and his performance for rainfalls over 2 mm was just average.

Key words: sensor intercomparison, thermometer shields, rain gauges

1. Introduction

For many human activities like agriculture, water or traffic management, it is very important to have accurate meteorological data. Much effort is put

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to the correct processing of all measured data to get required information (e.g. investment into long term databases or state of the art scientific research of results) but sometimes we are not even sure of accuracy of input measured data. Currently we can also see the trend to make great investments in replacing manual meteorological instruments by automatic. To choose suitable instruments for specific task it is crucial to know the accuracy of the instruments based on different principles depending on various weather conditions.

American National Weather Service has replaced over half of its liquid-in-glass thermometers in wooden Cotton Region Shelters (CRSs) with thermistor based Temperature Systems (MMTs) housed in smaller plastic shelters. Analyses of data from 424 MMTs and 675 CRSs showed a mean daily minimum temperature change of +0.30 °C and mean daily maximum temperature change −0.40 °C. These values are results of robust large dataset analyses of 10 years measured data in years 1980–1989 (*Quayle et al., 1991*). This type of analyses can help find corrections to produce more homogeneous time series for the various institutes for example to study climate change.

For exact measurements of the temperature, the shields and screens in which they are placed are crucial. Shields and screens must be constructed in a way that the temperature inside the shield or screen is always similar to the temperature outside of the screen or shield not depending on the weather conditions.

There were two notable WMO intercomparisons of the screens/shields. In years 2009–2010, WMO intercomparison of 18 models of screens/shields took place in Algerian desert (*Lacombe, 2010*). Another one took place in Japan during the same period comparing 10 models of screens/shields (*Aoshima et al., 2010*). We performed similar comparison in our climatic conditions and we focused more on the comparison of different types of construction of the shields/screens under different weather conditions than on the comparison of the specific models of the shields/screens.

There are several principles of operation of the rain gauges. In our experiment we tried to determine how accurately they can measure precipitations of different intensity. There were also WMO intercomparisons of the specific rain gauges in laboratory and field condition. In our experiment we compared the rain gauges based on different technologies in our climatic conditions.

2. Characteristics of measurement site

Our intercomparison took place at a meteorological station of Faculty of Mathematics, Physics and Informatics of Comenius University (FMFI UK) in Bratislava from 01. 04. 2011 to 31. 08. 2012. The meteorological station itself was established in 1986. It is situated on the FMFI UK grounds (Fig. 1) with dimensions of 60 × 40 m, according to the WMO directive. Its elevation is 182 m a.s.l. Its coordinates are $48°09'08''$ N and $17°04'13''$ E.

According to *Konček (1979)* and *Petrovič (1968)* Bratislava lies in the north hemisphere temperate zone and has a moderately continental climate with average temperature in its center of 20.9 °C in the warmest month July and −1.4 °C in the coldest month January (in 1931–1960), four distinct seasons and precipitation spread rather evenly throughout the year with

Fig. 1. Meteorological station of FMFI UK.

666 mm of average precipitation total per year and maximum in July (in 1931–1960). It is often windy with a marked variation between hot summers and cold, humid winters. Increase of mean annual temperature by about 1.0 °C and no significant change in mean annual precipitation total was registered in the last 30-years in the period 1981–2010 (compared to 1931–1960) (*Lapin and Melo, 2012*).

3. Participating instruments

Various thermometers are offered with screen/shields by their manufacturers. In our experiment we choose identical standard thermometers with Pt 100 Ω resistance sensing element to allow evaluation of screen/shields performance, free of influence from differences between thermometers themselves. All participating instruments were calibrated in calibration laboratory of Slovak Hydrometeorological Institute before beginning of our experiment. We regularly checked the correct acquisition of all sensors. The basic properties of instruments are summarized in Table 1, while the sensors themselves can be seen in Fig. 2.

Table 1. Basic description of participating instruments

Participating rain gauges	**Type**	**Participating screen/shields**	**Type**
Meteoservis MR3H	tipping bucket mechanism	Stevenson screen (screen)	naturally ventilated wooden Stevenson screen
MPS system TRWS 500	weighting mechanism	Rotronic AC1004 (small)	small round-shape multi-plate naturally ventilated shield
Luft R2S	radar rain sensor	Meteoservis MetCover3 (large)	large round-shape multi-plate naturally ventilated shield
Biral S WS-200	optical sensor	RS12T (vent)	artificially ventilated shield

Fig. 2. Participating rain gauges and screen/shields. Top from left side: tipping bucket MR3H, weighting TRWS, radar R2S, optical SWS-200. Bottom from left: small shield, ventilated shield, large Meteoservis shield and wooden Stevenson screen.

4. Results – data analysis

4.1. Screens/shields

At first we had to establish a reference. According to standard *ISO 17714: 2007*, screens "that are cooler during the day and warmer during the night are likely to be giving measurements that are closest to the truth". The reference screen should ideally have a fast response which is generally the case for artificially ventilated shields. In our case the artificially ventilated Rotronic RS12T met this condition. The basic data measuring interval was 10 minutes (the average of six 10-second samples formed one measurement for a minute; such measurement was recorded every 10 minutes). The air temperature difference between the test screen/shields and the reference is called the deviation of temperature.

Figure 3 presents air temperature measurements during whole measured period. There are clearly notable differences, even though we used identical thermometers and all of them professionally calibrated. Further in this section, starting with Fig. 4, we present deviations from the reference rather than absolute values of air temperature, in order to study the differences in more detail. Temperature measurement accuracy depends heavily on the global solar radiation as shown on Fig. 4, Fig. 5 and Fig. 6. For surface global radiation balance Equation (1) applies:

$$B = I_k(1 - A_k) - (E_z - E_a(1 - A_d)), \qquad (1)$$

where

I_k – incoming shortwave solar radiation,

E_z and E_a – long wave radiation of surface and atmosphere,

I_k – global radiation comprising of direct and diffuse solar radiation, it is a function with significant periods 24 hours, 12 hours and 0.5 year,

A_k and A_d – albedo of surface and atmosphere, respectively depends on type of surface/aerosol, on wave length, on angle of incidence of radiation.

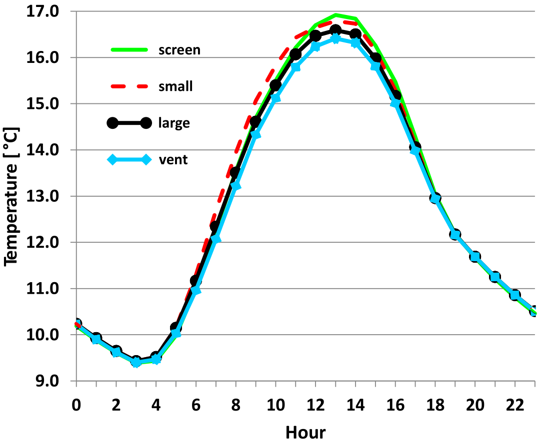


Fig. 3. Daily regime in UTC of mean air temperature during whole measured period for all screen/shields.

Periodically changing values of the global radiation (because of I_k member in Eq. (1)) induce varying temperature deviations for all screen/shields. Temperature deviations are larger in August (the summer month with high average global radiation) than in December (the winter month with low average global radiation), see Fig. 6a and Fig. 6b. This dependence of the temperature deviation on the global radiation is also well illustrated in figures for two days in the same month (daily average temperature is similar) with significantly different amount of the global radiation (the bright day and the cloudy day), see Fig. 5a and Fig. 5b. There are significant differences of temperature deviation noticeable between the screen/shields. The global radiation had largest influence on the small shield. We assume this is because of its small dimensions and limited circulation of the air. Small shield was closely followed by Stevenson screen. In addition to overheating of the screen we can also see the shift of heating and cooling of the screen towards later hours in Fig. 4. We believe it is caused by high heat capacity of the Stevenson screen. We also assume that there was insufficient albedo of the paint on the screen that contributed to the heating of the screen (see first member in the Eq. (1)). The Stevenson screen also showed negative deviation during the nights (Fig. 4) which can be attributed to its high ra-

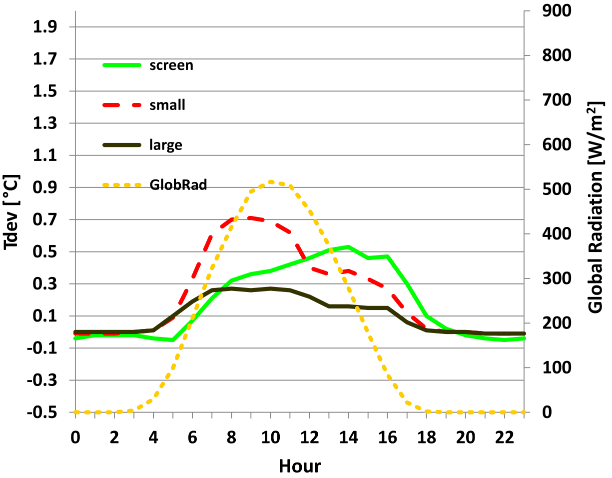


Fig. 4. Daily regime in UTC of mean air temperature deviation during the whole measurement period for all screen/shields depending on solar radiation.

diation cooling (second member in the Eq. (1)). We suppose that high heat capacity of the screen prevents the heat exchange with the surrounding air to quickly compensate for radiation loss. The global radiation had smallest impact on the large shield. We reason it is because of its larger dimensions in comparison to the small shield and better circulation of the air and the better paint in comparison to the Stevenson screen.

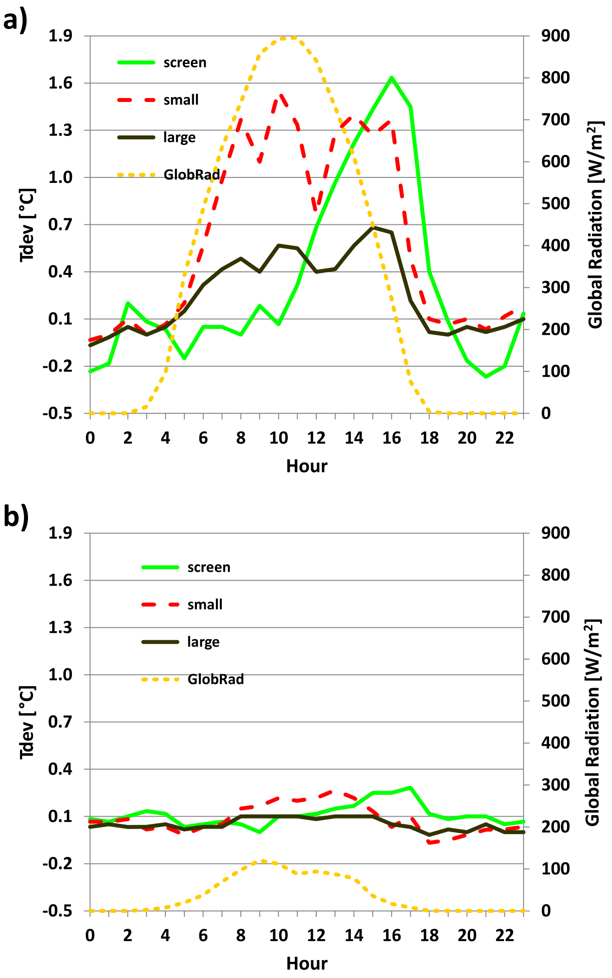


Fig. 5. Daily regime in UTC of air temperature deviation during the a) bright day 2011-07-10 b) cloudy day 2011-07-25 for all screen/shields depending on solar radiation.

Temperature measurement accuracy also depends on the wind speed as shown in Fig. 7. There is a significantly smaller temperature deviation during the windy days for all screen/shields. On the other hand for the small shield and Stevenson screen on a calm day it is almost 2 °C. These results document how air circulation in the shield affects the measurement accuracy of the screen/shields.

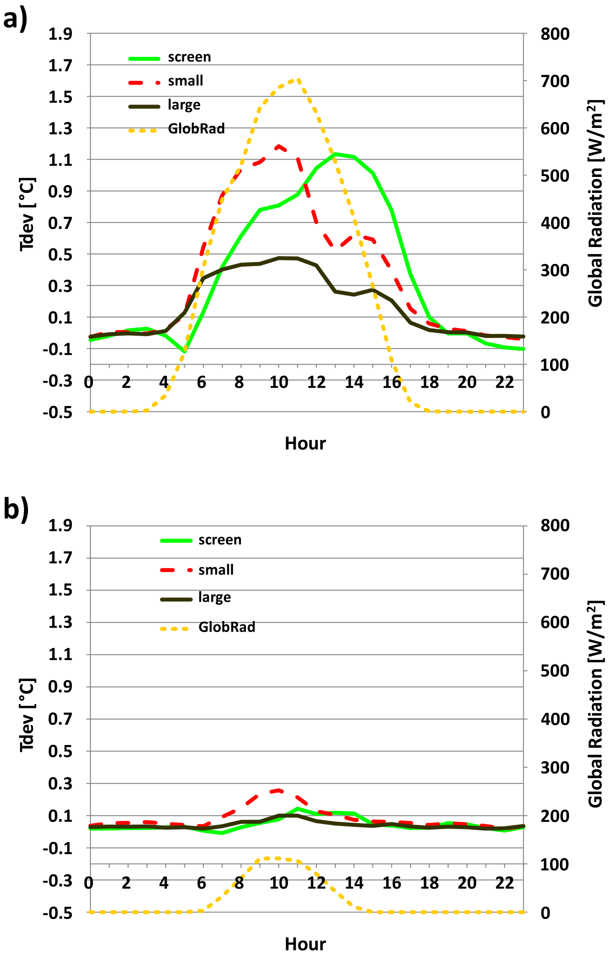


Fig. 6. Daily regime in UTC of mean air temperature deviation during a) August 2011 b) December 2011 for all screen/shields depending on solar radiation.

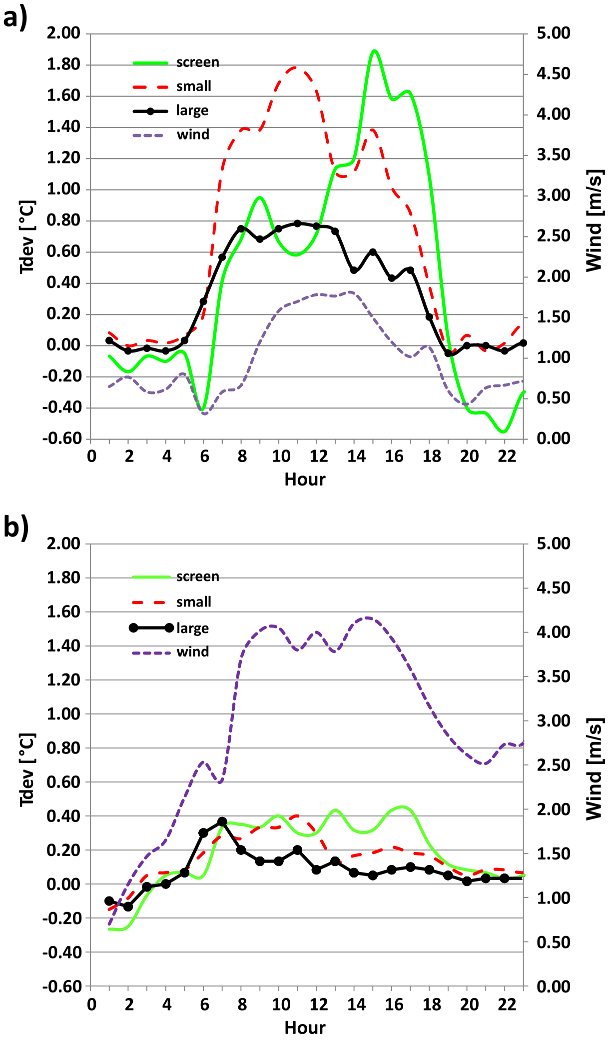
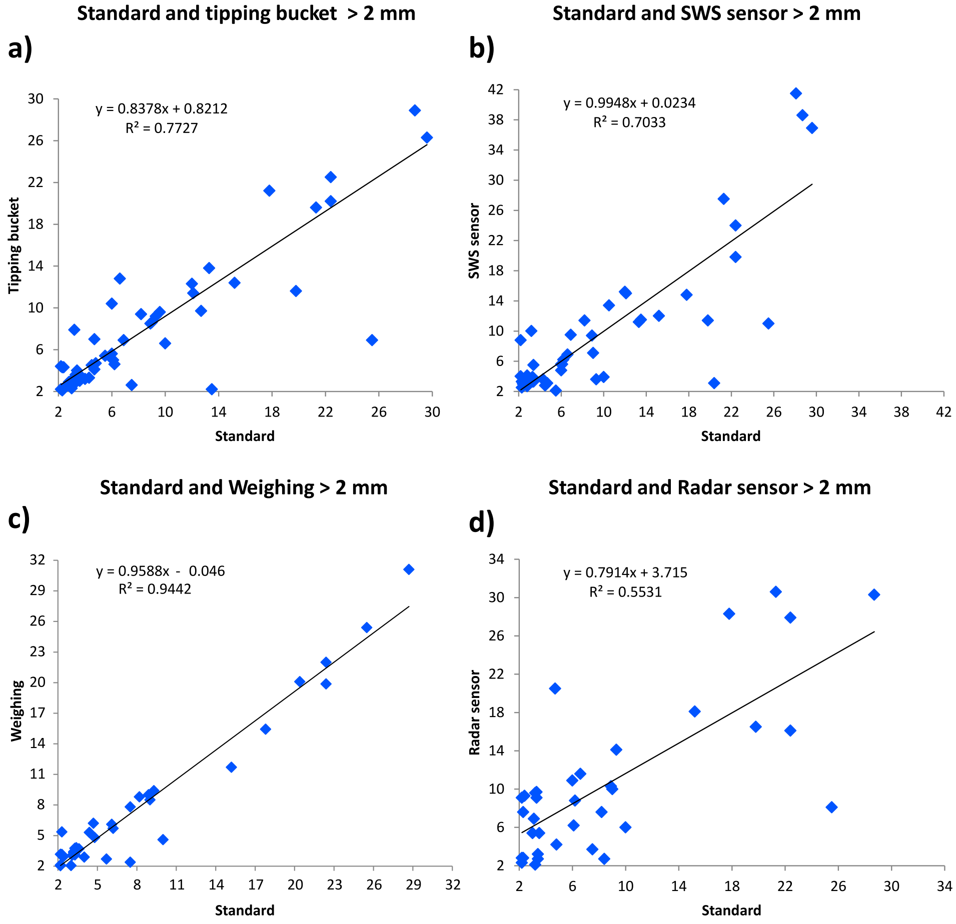


Fig. 7. Daily regime in UTC of air temperature deviation for pair of days with similar global radiation and a) low wind speeds b) high wind speeds.

4.2. Rain gauges

In the comparison of the rain gauges we choose for the reference the standard manual rain gauge which is used by SHMU network for many years.

We focused on measurement accuracy of the rain gauges depending on the rainfall amount. Our result is shown in the following scatter plot diagrams. The first quartet of scatter plots (Fig. 8) shows measurement accuracy of the participating rain gauges for rainfalls over 2 mm and second quartet (Fig. 9) for rainfalls up to 2 mm. At first sight we can see that all rain gauges gave much better results for rainfalls over 2 mm. The best result for rainfalls over 2 mm shows the weighing rain gauge, it is followed by the tipping bucket rain gauge and the SWS sensor and the worst result came


Standard and tipping bucket > 2 mm

Standard and SWS sensor > 2 mm

Standard and Weighing > 2 mm

Standard and Radar sensor > 2 mm

Fig. 8. Scatter plot diagrams for rainfall amounts over 2 mm per day.

from the radar sensor. In general all rain gauges underestimated the rainfalls over 2 mm compared to the standard rain gauge although situations where individual rain gauge overestimated precipitation occurred.

Performance for the rainfalls up to 2 mm was poor for all rain gauges, when as a measure of performance the correlation with manual gauge is considered. There were many cases of unregistered precipitation for all of them though there was difference in correlation when precipitation was registered. We can see at least some correlation for tipping bucket and weighing rain

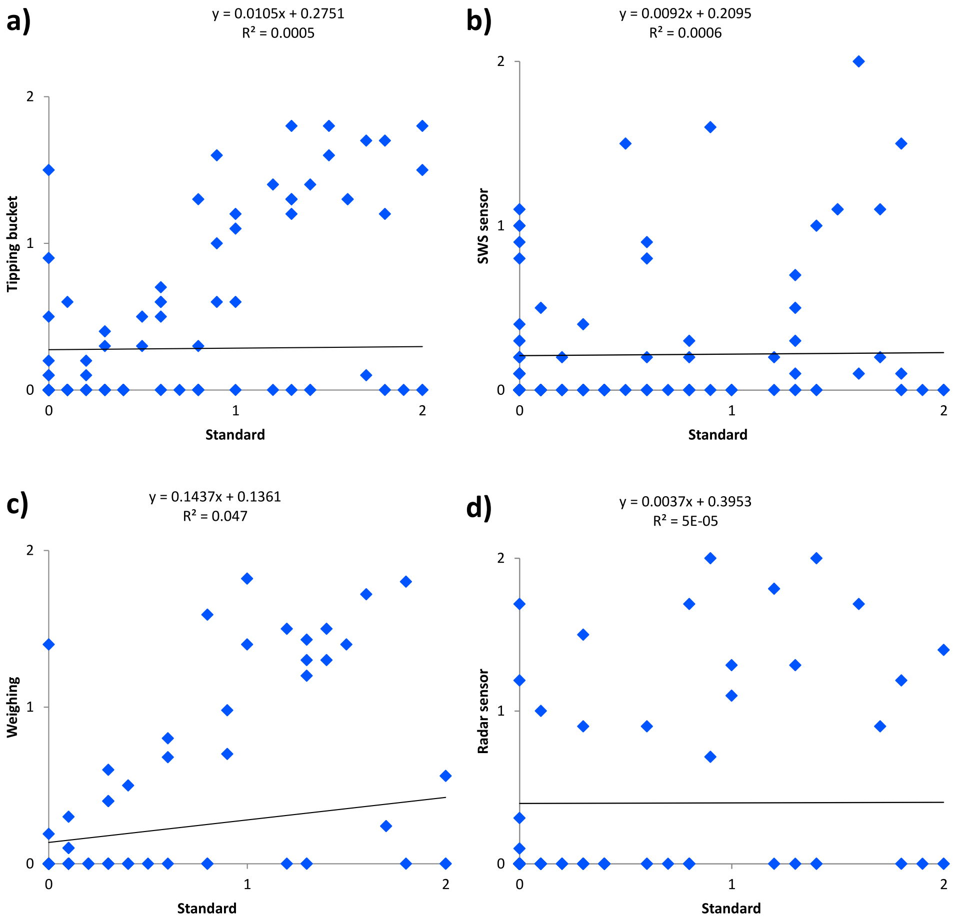


Fig. 9. Scatter plot diagrams for rainfall amounts up to 2 mm.

gauges when we neglect the unregistered precipitation events in Fig. 9. (the points residing on the x-axis). There is no visible correlation for SWS sensor and radar sensor in case of light precipitation events up to 2 mm. The high number of unregistered events is quite interesting, because for highly sensitive sensors like weighting rain gauge or optical sensor we have expected quite the opposite – high number of false precipitation alarms.

5. Discussion and conclusion

5.1. Screens/shields

On the basis of our results we can recommend artificially ventilated screen although it is most expensive choice and the maintenance is most difficult. Our second choice would be a large naturally ventilated shield. It gave surprisingly good results even in situations with high global radiation and during the night it did not show signs of radiation cooling. In case of Stevenson screens we would recommend painting it with a coating with high gloss. Our last choice would be a small naturally ventilated screen because of its high sensitivity on the global radiation. Our results are fairly agreeable with the results of WMO intercomparisons in Algerian Desert and also in Japan (*Lacombe et al., 2011; Aoshima et al., 2010*) mentioned in the introduction. The only significant difference is better performance of their Stevenson screens. We assume this was because of their better paint on the screens.

5.2. Rain gauges

Our first choice of the participating rain gauges would be the weighing rain gauge because of its best results in both cases, of rainfalls up to 2mm and mainly over 2 mm (linear correlation coefficient R2 = 0.94). The tipping bucket rain gauge gave also agreeable result in both cases. The SWS sensor gave a very good result in rainfalls over 2 mm but it is unsuitable for rainfalls up to 2 mm. The Radar sensor seems also unsuitable for low intensity rainfalls and his performance for rainfalls over 2mm was just average. These results are also in agreement with the results of WMO field comparison of rain gauges. Following the request of users and the recommendation of CIMO-XIV, the WMO Expert Team on Surface-Based Instrument Intercomparison and Calibration Methods (ET on SBII&CM) and the International Organizing Committee (IOC) on Surface-Based Instrument Intercomparisons performed the WMO Field Intercomparison of Rainfall Intensity (RI) Gauges from October 2007 to April 2009 (*Lanza and Vuerich, 2009*). The campaign was held at the Centre of Meteorological Experimentations (ReSMA) of the Italian Meteorological Service located in Vigna di Valle, Italy. This intercomparison has shown that suitably post-processed weighing gauges and tipping-bucket rain gauges had acceptable performance, while none of the non-catching rain gauges agreed well with the reference (*Lanza et al., 2010*). Of non-catching sensors in our comparison the optical sensor is different type than they used in WMO intercomparison and radar sensor they didn't use at all. But worse results of both non-catching sensors than catching ones in our comparison follow the trend of WMO intercomparison.

5.3. Homogeneity issues

As far as a long term series of meteorological data has to be maintained in order to study the climate change and variability, as well as its impact on hydrological cycle, changes in temperature regime resulting in shift of inhabitable zones for biological species and dozens of other impacts, it is of quite a concern that the series are homogeneous. In other words, the long term changes in data should be a result of climate shift itself and not caused by artificial changes (station relocation, change of surrounding environment, change of instrumentation etc.). As the artificial changes are not always avoidable (e.g. new construction in station neighborhood) and sometimes are result of actions we do to gain other advantages (e.g. automated stations can sample the environment with far higher frequency than traditional measurement and can be distributed in more distant locations), we have to apply methods to minimize the impact of introducting inhomogeneities. As noted in the WMO WCMDP 53 (*Aguilar et al., 2003*) the gradual changes of surrounding environment (e.g. growth of a city) are harder to substract from the natural changes than sharp shifts like station relocation or instrumentation change. In case of the instrumentation change, the mathematical homogenization methods (like Alexandersson's test etc.) can reveal a breakpoint in the past and also provide means for applying correction to the original data series to make them homogeneous. But the most recommended method is a direct intercomparison of new sensor and the sensor planned to be discontinued for some overlapping period, whose length depends on the natural variability of the measured phenomenon (shorter periods are needed for temperature than for precipitation).

From our work, we can conclude that the temperature shift a average is of magnitude 0 °C to +0.7 °C when considering change in radiation shield type. This interval of values is apparent from Fig. 4 which represents daily regime in UTC of mean air temperature deviation during the whole measurement period for all screen/shields depending on global radiation. In case of temperature maximums, the shift can be up to +1.6 °C in days with high global radiation as can be seen in Fig. 5a which represents daily regime in UTC of air temperature deviation in the day with the maximum of air temperature deviation during whole measurement period. In case of the rain gauges, we can expect a correction factor of +1% for SWS, +4% for weighting and +16% for the tipping bucket gauge (see the slope of the linear fits in Fig. 8) to be applied to yearly totals when using them as a replacement of the traditional rain gauge used in our experiment. But to conclude more on the precipitation measurement, longer intercomparison is advisable and our experiment is in progress.

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