Field intercomparison of candidates for measuring the reference surface air temperature

Akira Yamamoto
Meteorological Research Institute, ayamamot@mri-jma.go.jp
Hiroshi Ishimoto
Meteorological Research Institute
Shinichi Miyatake
Meteorological Instrument Centre, Japan Meteorological Agency

Summary
We have begun a field intercomparison of a shielded thermometer and other candidates for measuring the reference surface air temperature, including a very thin handmade thermocouple, an ultrasonic anemometer and thermometer, and two types of instruments using the brightness temperature of atmospheric radiation. Our preliminary analysis indicates results that differ with those of previous studies. It is necessary to analyze more data over a longer period of time with a wider range of temperature, solar irradiance, and wind speed.

1. Introduction

The impact of radiation is unavoidable in surface air temperature measurement using a conventional thermometer. Although thermometer screens and shields are used to reduce these effect, inaccurate measurements associated with the effects of radiation are common, including the influence of radiation on the screens/shields themselves. The characteristics of these devices are different for each type of screen/shield. It is considered that the reference surface air temperature measurement which has little effect of radiation in principle is effective to evaluate these characteristics.

2. Candidates for the reference surface air temperature measurement

International Organization for Standardization (ISO) (2007) stated that there is no recognized reference system for measuring the true air temperature. Some potential candidates for measuring the reference air temperature have been suggested.

2.1 Very thin thermometer

ISO (2007) suggests a very thin resistive wire (thickness <15 μm) as a potential candidate for measuring the reference air temperature. If it is very thin, the wire may be exposed to the open air without a radiation screen. There are certain technical issues that must be solved for the practical use of this technique to be successful, including the design of a sensor with stable characteristic that is capable of surviving outside for long periods in all weather conditions. This is somewhat rare, and they are not widely available.

Very thin thermocouples also may have a potential for this application and are more commonly available. Sahashi (1973) estimated the theoretical influence of solar radiation on very thin thermocouples, and Kurzeja (2010) also estimated error by solar radiation on thermocouples. While certain cost issues must be resolved, we proposed very thin "handmade" thermocouples after Moriwaki et al. (2003) that are a less expensive and readily available.

2.2 Sonic sensor

An ultrasonic anemometer and thermometer (UAT) have also been proposed as candidates for this type of temperature measurement (Lacombe et al. 2011). Sonic anemometers measure the acoustic virtual temperature (no influence from solar radiation) using a sonic sensor. This makes it possible to calculate the estimated air temperature using additional relative humidity and pressure information. Lacombe et al. (2011) reported some issues with this approach, including calibration difficulties and the unaccounted dependency between temperature and solar radiation based on the experiments that used two THIES CLIMA Ultrasonic anemometers 2D in a World Meteorological Organization (WMO) field intercomparison of thermometer screens/shields and humidity measuring instruments, which was conducted in Ghardaia, Algeria, November 2008–October 2009. They recommended that further investigation be conducted on the potential use of UAT as temperature reference systems. Accordingly, two types of UAT have been compared in this study.

2.3 Radiometer

The atmosphere is almost transparent to electromagnetic waves, but they were absorbed and emitted at some absorption bands by atmospheric molecules, and the brightness (power of electromagnetic waves) is proportional to the temperature of the atmosphere. This method has already been put into practical use in microwave radiometers to measure temperature profiles, but not the surface temperature. Yamamoto (2016) suggested the brightness temperature of atmospheric radiation in the horizontal direction may make it possible to estimate the mean surface air temperature to some interval. If it is not affected by solar radiation, it might be another candidate for measuring the reference surface temperature. However, it is difficult to use a radiometer directly for surface temperature measurement because of aperture angles and antenna siderobes. Yamamoto (2016) estimated three low-elevation data extrapolated to an angle of zero and compared those results with temperature sensor data from inside the radiometer inlet, which obtained reasonably comparable results (Figure 1).

This approach might present certain advantages if sensors with stronger absorption bands and a high degree of directionality are used. We have proposed the use of far infrared cameras with a band path filter configured with a 15 µm carbon dioxide absorption band. Figure 2 shows the weighting functions at 59 GHz channel for the oxygen band and 15 µm carbon dioxide absorption band calculated by Line-By-Line Radiative Transfer Model (LBLRTM) (Clough et al. 2005). A weighting function for the 15 µm band has as much weight at a much shorter distance of the order of 10 m.

3. Intercomparison

We have begun a field intercomparison of some candidates for measuring the reference surface air temperature at the Meteorological Instrument Centre (MIC) of Japan Meteorological Agency (JMA), Tsukuba, Japan, which has been underway since April 2018. Temperature and humidity are also measured with equipment identical to the system at the JMA operated by MIC, using a Pt 100 ohm resistive thermometer (with 3.2 mm diameter protect tube) and a capacitive humidity sensor with an artificially ventilated screen. Table 1 and Figures 3 show the instruments in the intercomparison.

4. Preliminary results

Some preliminary results from ultrasonic sensors and a very thin thermocouple with a shield thermometer as a working reference obtained from June 22 to July 1, 2018 are shown in Figures 4 and 5. The SAT600 sensor has relatively large bias that must not be ignored despite the prior calibration in a thermostatic and hygrostatic chamber by the manufacturer. Differences between the Ultrasonic SAT600 sensor and the shielded thermometer decrease as global irradiance increases. This result is the same as that reported by Lacombe et al. (2011). Thermocouples shows weaker but similar tendencies, and differences between the SAT600 and the shielded thermometer decrease when wind speed increases both in the daytime and at night. A thermocouple shows no dependency with respect to wind speed, whereas the Ultrasonic WMT701 sensor demonstrated the same qualitative results as the SAT600.

Lacombe et al. (2011) suggested that the ultrasonic sensor is not affected directly by solar radiation, so it may be an effect of the radiation on the shielded temperature itself. However, these results suggest more complex dependency relationships. More data must be obtained and analyzed for a longer period under a wider range of temperature and wind speed conditions.

The data of radiative sensors are also being analyzed. Far infrared cameras have calibration issues that are inherent in the manufacturing process, and we are considering additional procedures to the camera keep its temperature constant and more accurate calibration.

5. Conclusions

We have begun a field intercomparison of a shielded thermometer and some candidates for measuring the reference surface air temperature, including very thin handmade thermocouples, two UATs, and two types of instruments using the brightness temperature of atmospheric radiation.

Preliminary analysis shows different results with previously conducted studies, such as Lacombe et al. (2011). We are in the process of developing experiments to analyze more data over longer periods with a wider range of temperature, solar irradiance, and wind speed.

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References

Clough, S. A., M. W. Shephard, E. J. Mlawer, J. S. Delamere, M. J. Iacono, K. Cady-Pereira, of the AER codes. J. Quant. Spectrosc. Radiat. Transf., 91, 233–244.

International Organization for Standardization, 2007: ISO 17714:2007 Meteorology - Air temperature measurements - Test methods for comparing the performance of thermometer shields/screens and defining important characteristics. 19 pp.

Kurzeja, R., 2010: Accurate temperature measurements in a naturally-aspirated radiation shield. Boundary-Layer Meteorol., 134, 181–193.

Lacombe, M., D. Bousri, M. Leroy, and M. Mezred, 2011: WMO field intercomparison of thermometer screens/shields and humidity measuring instruments: Ghardaia, Algeria, November 2008-October 2009. Instruments and Observing Methods Report No. 106 , World Meteorological Organization, 101 pp.

Moriwaki, R., M. Kanda, and Y. Kimoto, 2003: Dependencies of Profiles of Turbulent Fluxes on Atmospheric Stability in an Urban Surface Layer (in Japanese). Proc. Hydraul. Eng., 47, 1–6.

Sahashi, K. 1973: Effects of the Insolation on Thermocouple Psychrometer, Bulletin of School of Education of Okayama University, No.37, 123-130.

Yamamoto, A. 2016: Evaluation of radiative effect on the measurement of the surface air temperature by thermometers using the ground-based microwave radiometer. Instruments and Observing Methods Report No. 125, World Meteorological Organization.

Table 1. List of instruments in the intercomparison.

Kind	Type	Spec	Interval	Duration and remarks,
Very thin thermocouple	Handmade	13 μm diameter E-type: Cromel-Constantan	0.01 sec	April 2018-
Ultrasonic sensor	Sonic SAT600 Vaisala WMT701		0.1 sec 0.25 sec	April 2018- June 2018-
Brightness Temperature	Ground-based microwave radiometer Radiometrics MP-3000A	51-58 GHz Digital	Several mins	August 2018-Elevation angles: (temtative)1.3, 2.3, 4.7, 9.4, 14.3, 19.3, 30.1, 41.8, 90
Far Infrared camera	Vision Sensing VIM-384G2UL VIM-640G2ULC	Bandpass filter Northumbria Optical Coatings SBP-15036-000330 14-16 μm	1 min	April 2018-
Thermometer and Hygrometer with artificial ventilated screen	Thermometer: Yokogawa K5639AJ Hygrometer: Vaisala HMT333 Shield: Ogasawara JV-280	Pt 100Ω, Protect Tube 3.2 mm diameter	1 min	April 2018- JMA operational instruments

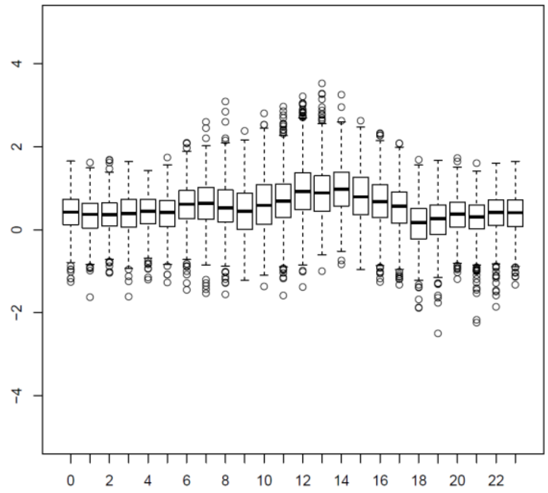

Figure 1. The boxplot variation of the difference between the temperature by a Rotronic S3 Sensor in the inlet of a MP-3000A and the 59 GHz brightness temperature by MP-3000A (Yamamoto, 2016). The box edges and the line in the middle of the box represent three quartiles.

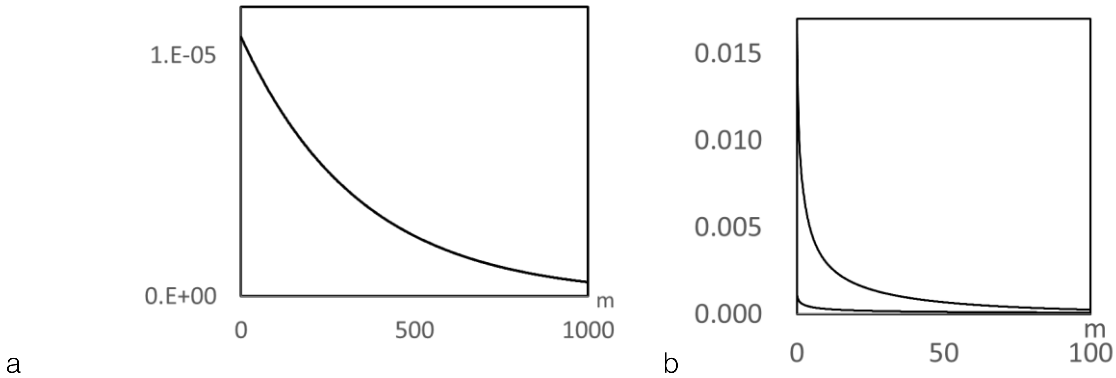

Figure 2. (a) Weighting functions calculated by LBLRTM (Clough et al. 2005) for (a) 59 GHz channel of MP-3000A and (b) 15 µm Bandpass filter SBP-15036-000330.

Figure 3. Instruments in the intercomparison study at the Meteorological Instrument Centre of Japan Meteorological Agency, Tsukuba, Japan. (a) Very thin thermocouples, (b) Ultrasonic SAT600, (c) Ultrasonic WMT701, (d) Radiometer MP-3000A, (e) Infrared camera VIM-384G2UL, (f) thermometer K5639AJ and hygrometer HMT333 within a JV-280 shield, and (g) a full view.

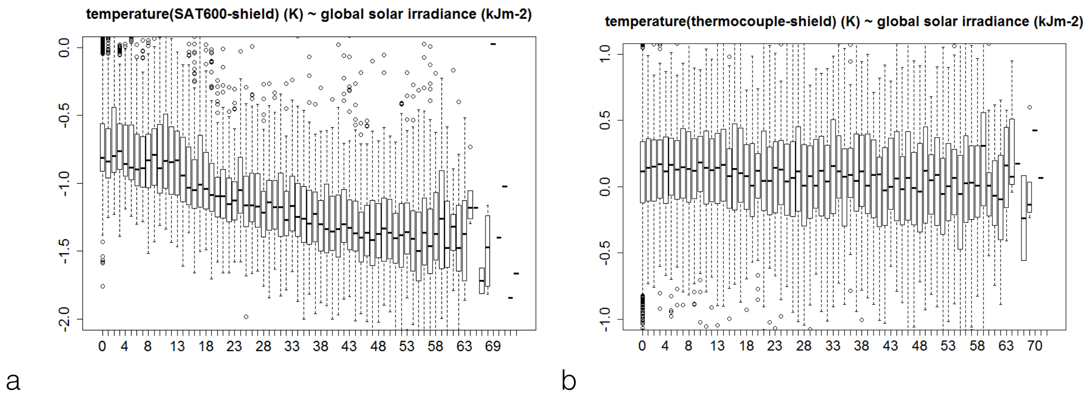

Figure 4. Examples of differences between sensors and the shielded thermometer for global solar irradiance. (a) Ultrasonic SAT600. (b) A very thin thermocouple.

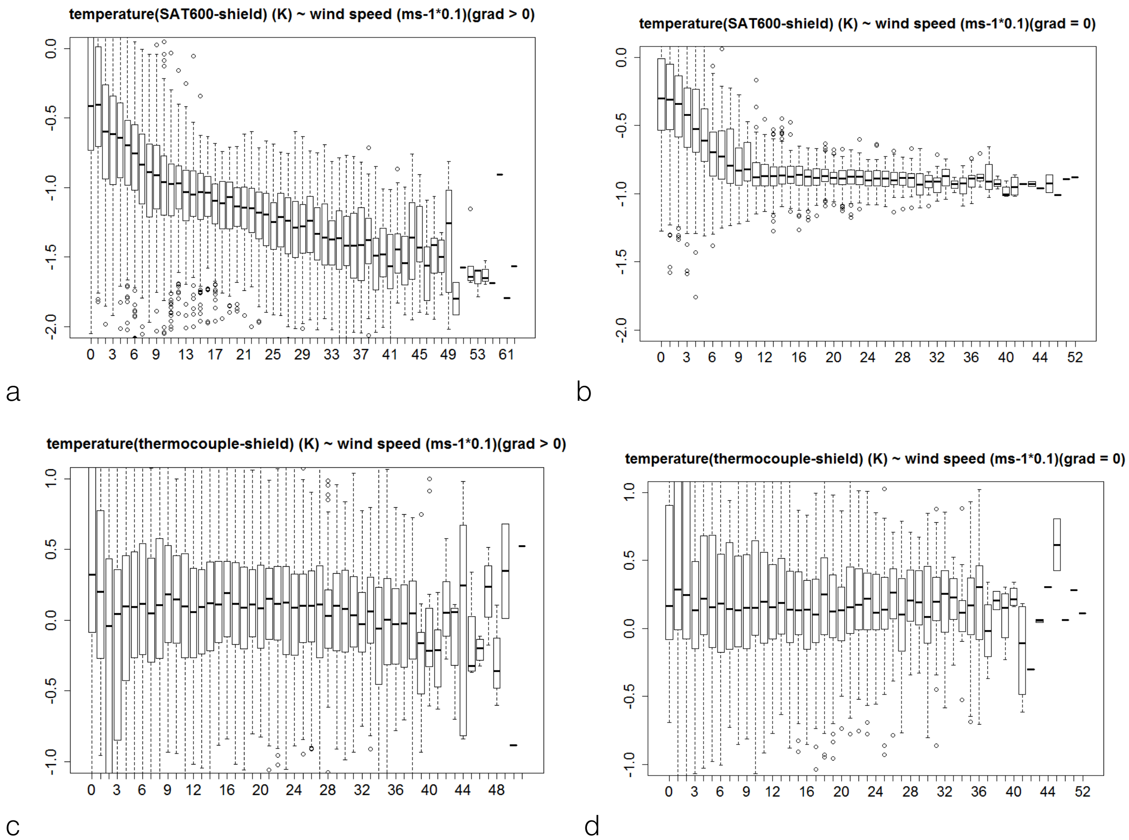

Figure 5. Same as Figure 4 but for wind speed at 1.5 m height. (a) Ultrasonic SAT600 and a global solar irradiance greater than zero. (b) Same as (a), but a global solar irradiance equal to zero. (c) A very thin thermocouple and a global solar irradiance greater than zero. (d) Same as (a), but a global solar irradiance equal to zero.