https://doi.org/10.1038/s41567-024-02428-w

The air temperature conundrum

Check for updates

Measuring air temperature is far from a trivial task, as Andrea Merlone, Graziano Coppa and Chiara Musacchio explain.

If you happen to have a thermometer within reach, try measuring the air temperature. As you will discover, this is much more difficult than it seems.

The results will be affected by radiative heat, so the thermometer needs to be protected from sunlight. If you are indoors, you will have to consider how to define room temperature and where to measure it. Or if you are outdoors, you will need to ask how representative the measurement will be. Pictured is a setup used to study the effect of meteorological thermometers' distances from the ground.

Indoors, you will experience temperature gradients – from the floor to the ceiling – or see the effects of windows, air conditioning or heating systems. Outdoors, obstacles such as buildings, rivers, trees and roads will affect your measurement[1]. Raindrops can cool your thermometer and snow on the ground reflects sunlight, adding extra heat to the sensor with errors of up to 3 °C[2]. You will also have to deal with effects of wind, self-heating[3] and all the complex thermodynamics of using non-perfect sensors to measure non-ideal gases.

You might feel reassured by the fact that at least the thermometer is well calibrated by the manufacturer. Not to rain on your parade, but this is yet another open issue: there is no official procedure – normative or prescriptive – for how to calibrate temperature sensors in air. In the range of atmospheric temperatures, calibration methods are based on liquids.

Calibrations are carried out in temperature-stabilized, quasi-adiabatic liquid baths with almost no radiation effects and only minimal convective and conductive effects and are corrected for self-heating. Such calibrated thermometers are then used to measure air temperature in conditions that are far from adiabatic. This poses serious problems in assessing the metrological traceability of the result, which is the only way to establish comparability among different measurements.

Traceability also requires a full evaluation of uncertainty. Let's face it, we are currently not able to do that for air temperature measurements. Despite the World Metrology Organization's Observing Systems Capability And Review tool or the Guide to Instruments and Methods of Observations requiring pre-determined expressions of uncertainties in order to classify instruments, sites and observations, it is impossible to coherently, technically and scientifically evaluate them, thus precluding the comparison of data quality with prescriptions.

If this has not already made you shake your head in disbelief, there is not even an agreed definition of air temperature. There is no consensus on whether measurements should refer to steady air or should instead be conducted at a relative airspeed, and likewise no consensus on the levels of humidity and radiation at which measurements should be performed. Air density varies with altitude, changing the heat equilibrium between radiative and convective effects. Thus, radiosondes flying up to 30 km and ground-based systems measure temperatures of a different gas in different conditions.

Temperature is a key quantity in climatology and the main observable we have for assessing whether climate change mitigation efforts will be efficient. The Intergovernmental Panel on Climate Change requires a careful consideration of the impacts associated with a global temperature increase of over 1.5 °C above pre-industrial levels. Thus air temperature needs to be measured and compared with historical records in locations where the effects of climate change are amplified, such as in the Arctic.

With both those needs and challenges in mind, the metrology and meteorology communities have started to work in close and intense cooperation, for example in a Task Group focusing on air temperature with three main goals: providing a definition of air temperature, assessing the corresponding measurement uncertainty, and publishing an international guideline for the calibration of thermometers in air.

In 2023, the Global Climate Observing System launched the pilot phase of its Surface Reference Network[4], which aims to produce top-quality air temperature values. At the European level, a project by an association of National Metrology Institutes concluded a large inter-laboratory comparison in 2022 on the calibration of thermometers in air – each participating institute following their internal best practices. This information will be used to prepare a European guideline on air temperature measurements, which will also contribute to a global initiative led by the International Bureau of Weights and Measures, tackling a problem we were not even supposed to have.

Andrea Merlone ✉, **Graziano Coppa** & **Chiara Musacchio**
Istituto Nazionale di Ricerca Metrologica INRiM, Torino, Italy.
✉e-mail: a.merlone@inrim.it

Published online: 14 March 2024

References

1. Coppa, G., Quarello, A., Steeneveld, G., Jandrić, N. & Merlone, A. *Int. J. Climatol.* **41**, 3705–3724 (2021).
2. Musacchio, C. et al. *Atmos. Meas. Tech.* **14**, 6195–6212 (2021).
3. Pavlasek, P. et al. *Meteorol. Appl.* **27**, e1844 (2020).
4. Thorne, P. W. et al. *Int. J. Climatol.* **38**, 2760–2774 (2018).

CREDIT: ANDREA MERLONE