Response to the Comments from Referee #1 on "Air temperature equation derived from sonic temperature and water vapor mixing ratio for air flow sampled through closed-path eddy-covariance flux systems"

X.H. Zhou, T. Gao, E.S. Takle, X.J. Zhen, A.E Suyker, T. Awada, J. Okalebo, J.J. Zhu

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The sentences in bold font are our responses to the underlined comments.

Air temperature is certainly a very important parameter for describing the state of the atmosphere from high-frequency turbulence to climatological means. There are very reliable and inexpensive measuring instruments for this purpose. It certainly makes sense to look for a measuring method that can accurately measure the air temperature without the influence of solar radiation (radiation error).

The purpose of the paper is not specifically to eliminate solar radiation contamination – it is to find an exact equation of air temperature in terms of sonic temperature and water vapor mixing ratio and to develop the methodologies from this equation for better measuring "turbulent *T*" for combining with concurrently measured turbulent 3D wind speeds to represent turbulent heat flux and related turbulent variables. The insensitivity of derived *T* to solar radiation is an expected additional merit of the derived *T*. For this purpose, ventilated thermometer screens are used for very accurate measurements. This is a good way to meet the World Meteorological Organisation's requirement of an accuracy of ± 0.2 K at 0 °C (WMO, 2018). **Our senior authors have worked on turbulence measurements over 30 years. To the best of our knowledge, we have not been aware that WMO has a standard for "high-frequency *T*". WMO (2018) requirements are for common low-frequency *T* of weather and climate network stations instead of "high-frequency *T*" in turbulent flux measurements. The Fine Wire Thermocouples (i.e. FW series. see https://www.campbellsci.com/fw05), which are most commonly used for the high-frequency *T* measurements in flux community, do not have specifications for accuracy and precision. Authors have used such an option over 20 years and programmatically implemented such measurements into EasyFlux series software for global use as optional measurements for users. However, this option cannot be used for long-term measurements because it is fragile as discussed in the manuscript. The experts on manufacturing FW sensors were consulted about unavailability for the specifications of accuracy and precision. Simple answers are a) the method to specify accuracy and precision for high-frequency *T* is not available and b) no standard for high-frequency *T* can be followed. Accordingly, this comment is not relevant to this study.** Even with naturally ventilated thermometer screens, this accuracy can be achieved in many cases (Harrison and Burt, 2021). **The reviewer misses the major point (Lines 60 to 65 in Introduction and lines 89 to 104 in Background) that accurate measurement of turbulent heat fluxes and related variables, which is the goal of the paper, cannot be done with a ventilated thermometer co-located with a sonic wind speed measurement. Furthermore,**

ventilated thermometers report only time-averaged (rather than at turbulence frequencies) temperature values.

It therefore seems somewhat absurd - if I have understood the authors correctly - to use device combinations of sonic anemometers and closed-path gas analysers to obtain an accurate temperature measurement, especially since operators of these systems often also use a simple temperature-humidity sensor for quality assurance. **Simple temperature-humidity measurements can provide quality assurance of mean, but not turbulent, *T*.** This request of the authors seems all the more doubtful, as the requirement of measuring accuracy for temperature measurements is not achieved. However, an accuracy of ± 1 K is quite sufficient to determine the temperature-dependent densities and specific heats for trace gas measurements. **But ±1K is not acceptable for turbulent fluxes at high frequency.** In most cases, the sonic temperature can be used directly, if necessary with a small correction. **Direct use of sonic temperature as *T* has a great uncertainty under warm and humid conditions and is not an acceptable approximation. What the sonic anemometer reports is sonic temperature, which requires knowledge of air humidity to calculate the actual air temperature (i.e., *T*). Actual air temperature and sonic temperature are quite different. Given *T* = 35 °C and RH = 100%, the difference is 5.6 °C. Under the same humidity, given *T* = 45 °C, this difference reaches 10 °C.** The authors start from the basic work on the conversion of sonic temperatures into air temperatures (Kaimal and Gaynor, 1991; Schotanus et al., 1983). At first sight, the calculation seems to be correct. However, due to the deviousness of the procedure, no examination in detail was carried out. **The reviewers should explain what they mean by the "deviousness of the procedure", which suggests a dishonest intent. The calculation is a bit complex, but in no way is it dishonest. Perhaps this was simply a poor choice of words. If so, the reviewers should find a more specific word so that more clarity of the procedure can be provided.**

The authors used a sonic anemometer, which allows a fairly accurate measurement of the sonic temperature. Since the measurement depends strongly on the mechanical stability of the device, there are also devices with much worse values (Mauder and Zeeman, 2018) with deviations up to several kelvin, so that the proposed method is only applicable for selected types of sonic anemometers. **Of course, there may be some sonic instruments that have large errors in sonic temperature measurement. The authors test only one state-of-the-art sonic instrument which is designed with both hardware configuration and instrument-specific software developed from turbulence theory based on fundamental principles. Their reported detailed tests show high accuracy can be achieved for measuring *T* at high frequency. Due to different grade of accuracies from different brands of sonic anemometers (e.g., CAST, Gill, and Young), one of our major objectives is to avoid the direct error of turbulent *T* from theoretical equation side. The indirect error from sonic anemometers for sonic temperature and from gas analyzer for air moisture goes beyond the scope of this paper. For the objectives of this study, there is no need to test this equation by more sonic instruments in the field.**

The reviewer strongly doubts that there is a reader of AMT who would find this method interesting for application. **This doubt is subjective instead of objective. The following three points disagree with reviewer's doubt.**

1. This study has been driven by applications of sonic temperature and water vapor mixing ratio for sensible heat flux. When the first author started his EasyFlux_CR6CP for close-path eddy-covariance (CPEC) systems in Campbell Scientific Inc., he needed an equation for sensible heat flux from sonic temperature and water vapor mixing ratio. Definitely, Schotanus et al. (1983), Kaimal and Gaynor (1991), and van Dijk (2002) were under consideration, but the problem was found as addressed in Introduction and Background. We thoroughly studied the relationship of sonic temperature and air moisture to *T* and derived the exact equation of *T* in terms of sonic temperature and water vapor mixing ratio. For field applications of this equation to CPEC systems, we also developed algorithms as addressed in the manuscript. As well known, Schotanus et al. (1983), Kaimal and Gaynor (1991), and van Dijk (2002), all of which did not have uncertainty specifications and field tests for high-frequency *T*, have wide applications in flux community. Our exact equation avoids the uncertainty/controversies from their equations with additional field tests. It is better developed, tested, and documented as in the manuscript.

As always, exact equations are pursued tirelessly by scientists, so replacing the approximate equations with an exact equation represents a scientific advance for field measurement (this assertion is validated by reviewer #2). Now, after verification against sensible heat flux measurements from a fine wire thermocouple configured in a CPEC system, this equation has been used in the open-source software EasyFlux-DL-CR6CP (https://www.campbellsci.com/revisions/626-1506#revisions). This software is being used globally for hundreds of Campbell Scientific CPEC systems deployed in the field (e.g., 30 in New York Mesonet and 36 new orders to China). China alone has over 100 CPEC systems in the field. CPEC systems are recommended systems, due to better data continuity and reliability, now as demonstrated in a China national field laboratory (Zhu et al. 2021). For their customized use of EasyFlux-DL-CR6CP, the users of hundreds of field CPEC systems deserve to fully understand the equations used in the software from a formal journal like AMT. If the reviewer can show where the theory and derivation of our paper is invalid, he/she should point out the flaw so that the field implementation of the algorithm is changed for more accurate measurements.

2. Manufacturers of sonic anemometers need the exact equation, instead of approximation ones, to improve the manufacturing process. For precision measurements of sonic temperature along with 3D wind, the lengths of three sonic anemometer paths are precisely measured physically by Coordinate Measurement Machine (CMM) in manufacturing process. CMM has some limitations in the length measurements to achieve the accuracy of sonic temperature to high accuracy (e.g. $< \pm 1.00$ K). From the measurements of *T* and water vapor mixing ratio, sonic temperature can be accurately determined if an

exact equation to describe the relationship among the three variables is available. Using this accurate sonic temperature, the sonic path lengths can be theoretically acquired better than CMM. See Zhou et al (2018) for the relationship of sonic temperature to the path lengths. This technology is under development. The exact equation, which has been pursued since 1932 (Ishii 1932, Barrett and Suomi 1949, Schotanus et al. 1983, Kaimal and Gaynor 1991, Swiatek 2018), is fundamental, prerequisite, and valuable, in particular, for this technology. For commercial rules, it is inappropriate for authors to disclose more details of this technology here. Our brief disclosure can say the exact equation is "exactly valuable" for the advancement of sciences and technology, which is a common sense in scientific community.

3. From June 21 this year until now (less than two months), as recorded by AMT editorial website, this manuscript has received 273 views, and 58 XML and PDF download actions from the limited number of viewers of five countries. These metrics provided by AMT indicate the interest of this manuscript to AMT readers. If formally published, more readers can access this information. This topic would be of interest to AMT readers in the same way as this topic is often asked by the audience in international training courses (e.g. Annual ChinaFlux training courses) by the first author.

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