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Atmospheric Measurement Techniques
Discussions

Interactive comment on "Two fast temperature sensors for probing of the Atmospheric Boundary Layer using small Remotely Piloted Aircraft (RPA)" *by* N. Wildmann et al.

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Many thanks for the detailed review. In the following I will comment on each point. The referee comments will be repeated in italic before the answer.

1. *p. 3092, section beginning in line 4 from "Smaller..." Please provide references to the statements concerning radiosonde temperature sensors.*
   Nash et al. (2005) can be cited here as a reference that gives an overview of currently used sensors in radiosondes, their performance and errors. Additionally,

   a reference to Luers (1997) can be mentioned, which describes in detail the design of capacitive wire technology sensors and discusses the errors due to time response, radiation etc.

2. *p. 3096, Notice that Haman (1992) was using type E thermocouple as a temperature sensor on slowly flying powered glider.*
   The reference will be cited in a revised manuscript.

3. *p. 3099, last para, Test flight were performed in temperatures lower than the calibration range. I know that this is not an issue here, but should be commented.*
   In the experiment, temperatures slightly below the calibration range were experienced. However, subsequent calibrations of the same type of sensors to lower temperatures showed that the sensor output follows the calibration curve very well down to $10°C$ and further, staying well within the desired accuracy of 0.1 K.

4. *p. 3100 last para, Please comment on accuracy of humidity measurements and conversion to virtual temperature.*
   The measurement of relative humidity was done with a capacitive sensor which was found to be in good agreement with the reference instruments in this experiment. Deviations of up to $\pm 5\%RH$ can be observed, which, following the conversion to virtual temperature, can cause temperature errors of maximum $\pm 0.05K$ for the given situation.

5. *p. 3104, "From the spectra"... I do not take the argument that worse spectral resolution of PRWR sensor results from the wire diameter. In my opinion the effect is heat transfer between the support (of larger heat capacity) and the wire. Fig. 5 shows that there are at least 10 points of contact between the wire and support. For discussion of heat transport form support consult Payne et al, (1994) and Haman et. al. (1997) and references therein.*
   Subsequent tests showed that in fact the electronic circuit limits the frequency response for the FWPRT. The current to voltage converter also includes an active

low pass filter, which can be adjusted by the choice of the right capacitor. A more detailed simulation of the electronic circuit showed that the cut-off frequency with the given filter is at about 5 Hz, which coincides with the observations from the measurement. Increasing the cut-off frequency of the filter too much will degrade the signal to noise ratio. A careful redesign of the electronic circuit needed to be done to optimize measurement results. Figure 1 and 2 show variance spectrum and structure function of a flight with further developed filters and amplification factors. It can be seen that the spectral results of both sensors agree very well, especially in the higher frequency range. The flights were done in the residual layer at 375 m altitude on a summer day in June, just before noon, in Southern Germany. It is somewhat astonishing how close the results are. Figure 3 shows the time series of the complete racetrack pattern, including bends. On the other hand, very similar results have to be expected since the main physical influences to the time response are the wire diameter and the forced convection due to airspeed, which in this case are identical for both sensors. Additionally, the same data acquisition system and same operational amplifiers were used for both sensors, so that these influences are eliminated for the comparison. Remaining differences can mainly be assigned to imperfect calibration and the error sources that were discussed in the paper. Radiation, adiabatic heating and heat transfer might not contribute significantly to the absolute reading, but might still have some influence on the very small scales.

The variance spectrum and structure function still do not perfectly follow the Kolmogorov law of locally isotropic turbulence (inertial subrange) in this measurement. There are several possible reasons for this. Due to restrictions in the flight permission only rather short legs of about 1 km could be performed. Only four legs were used for the averaging of the spectral analysis because of the instationarity of the ABL. Thus, temporal variations of the spectral density can be expected. Also, in the residual layer, turbulence is weak and not necessarily isotropic. Eddies are compressed vertically.

6. *Fig.1. Some acronyms are not described and their meaning is not straightforward.*
   The acronym TC stands for thermocouple, μC is short for microcontroller and GPS is the acronym for Global Positioning System. ADS1258, STM32 and XBee are product names. All other acronym descriptions are already in the text. In a revised manuscript the missing acronym explanations will be included in the paragraph.

7. *It seems that thermocouple measurement error has a trend. Any comments?*
   It is true that the figure visually suggests a trend. A regression analysis yields an increase in error of 0.06 K per 1 K decrease of environmental temperature. This could be due to less accuracy at the edges of the calibration range, but a lot more flights over the whole calibration range would be needed to verify this.

8. *Figs. 10. and 11. Symbols (Tower, Profiler, Sodar) are hard to distinguish.*
   The symbols were changed to symbols that are easier to distinguish, see figure 4. All figures will be adapted to this style in a revised manuscript.

9. *Fig. 12. No description of solid/dashed lines. Their meaning can be deduced from the text, but the description should be added.*
   New caption: Averaged thermocouple temperature measurement over legs in all geographic directions with and without radiation shield of the PCAP sensor. Dashed lines are for legs with irradiated sensors, solid lines are for legs with sensors in the shadow of the fuselage.

References

Haman, K. E.: A New Thermometric Instrument for Airborne Measurements in Clouds, J. Atmos. Oceanic Technol., 9, 86–90, 1992.

Luers, J. K.: Temperature Error of the Vaisala RS90 Radiosonde, Journal of Atmospheric and Oceanic Technology, 14, 1520–1532, 1997.

Nash, J., Smout, R., Oakley, T., Pathack, B., and Kurnosenko, S.: WMO Intercomparison of High Quality Radiosonde Systems, Vacoas, Mauritius, 2–25 February 2005, Tech. rep., WMO Report. Available from CIMO, 2005.

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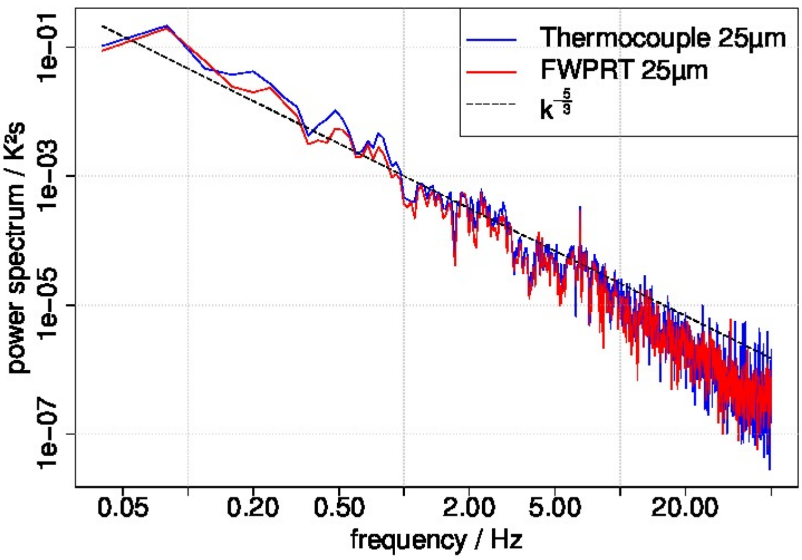

Fig. 1. Variance spectra of both sensors, compared to Kolmogorov law of turbulence, the spectra that are shown are averaged over 4 single spectra of 25 s time series each.

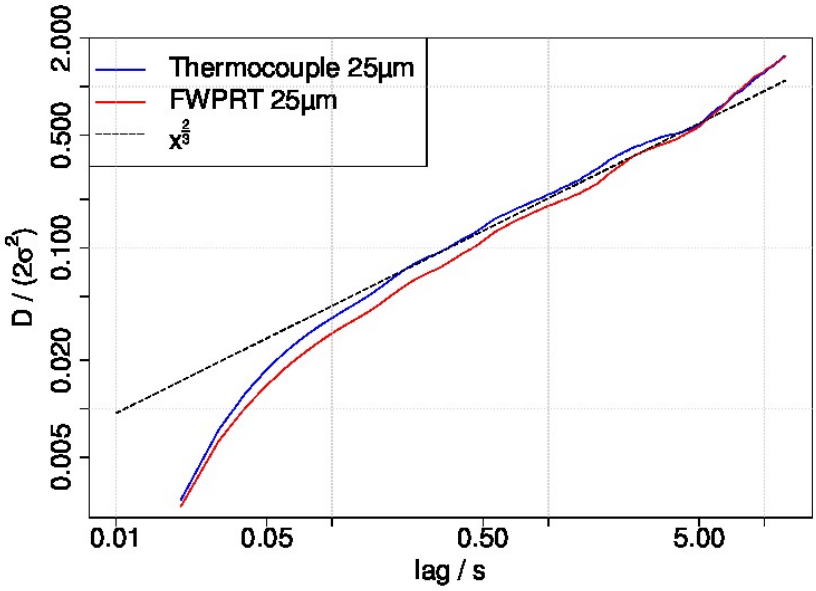

Fig. 2. Structure function of both sensors, compared to Kolmogorov law of turbulence. The structure function is normalized 2 by 2σ .

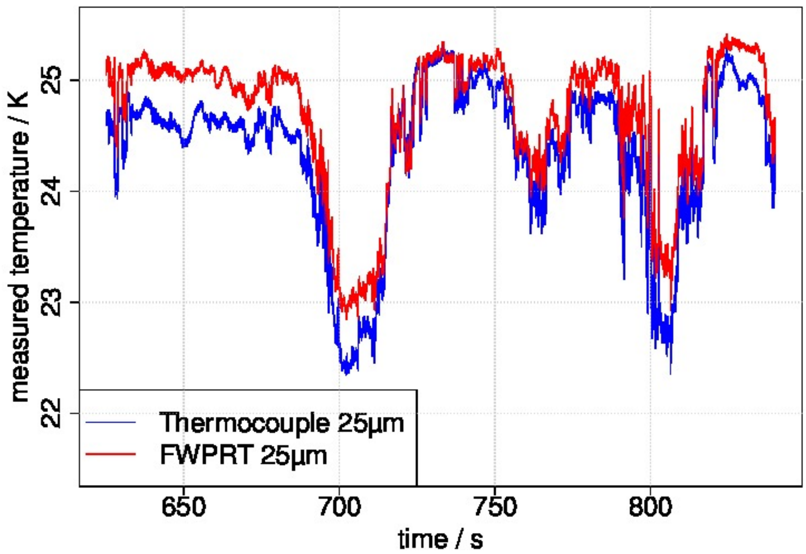

Fig. 3. Time series of temperature measurements in racetrack pattern

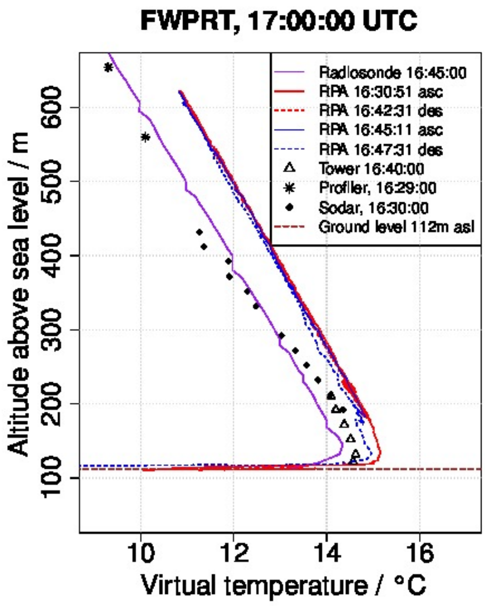

Fig. 4. Comparison of FWPRT on the RPA with remote sensing and tower data for vertical profile flights.