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Atmospheric Measurement Techniques Discussions

Interactive comment on "Fast-response high-resolution temperature sonde aimed at contamination-free profile observations" *by* K. Shimizu and F. Hasebe

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Comment: This reviewer has had the opportunity to read reviews of two other referees and one short comment. I find that I agree with the nearly all of these comments. There are several anomalies in the measurements that are not explained in the manuscript, especially the large spikes that do not correspond with the pendulum swing in Fig. 4. The authors need to provide adequate explanations to the comments and questions raised by the other referees and the by the short comment. I strongly suggest that the authors eliminate claims that the new sonde should be used universally. The

manuscript needs to present this work as an approach that shows potential to improve temperature measurements in the UTLS, and that additional testing and evaluation is needed to confirm the preliminary findings presented in the paper.

Reply: We believe that we have reasonably resolved all uncertainties on the cause of the temperature perturbations and that the results are worth being published at this stage. We hope our revisions described in the following have eliminated all the concern expressed by the reviewer.

Spikes in Fig. 4: We believe we have reached reasonable understanding on all spikes we found in the sonde record. As the reviewer mentioned, there found large spikes that do not correspond to the swing motion in Fig. 4. That's why the test flight using a paired tungsten sondes (Fig. 5) is attempted. The evidences obtained from the flight (Fig. 6) lead us to the following interpretation on the spikes seen in Fig. 4. They appear as the result of the sensor's spin combined with the pendulum motion; large temperature perturbation will be observed when the sensor is swinging behind the sonde box while no such spike will be generated when it moves ahead of the box. As the period of the spin rotation is different from that of the pendulum motion, there is no synchronization between the sensor's encounter with the perturbed air and the swing motion. What we should learn from Fig. 4 is that the perturbations do occur when the sensor is apparently out of the reach of the balloon wake (page 3300, lines 8 to 10). Corresponding part in Section 3.2 (page 3300, lines 19 to 26) has been rewritten as follows:

Under this configuration, the spin motion of individual sonde will disappear and one can expect that the swing motion is aerodynamically constrained in a manner in which one of the two sondes alternately follows the other (switchback motion) due to the plate. The observed temperature records are shown in the left panel of Fig. 6. Groups of pulses appear alternately in the two records with the time interval of about 12 s, which roughly corresponds to the period of the pendulum motion. The horizontal projection of the sonde trajectories are shown in the right panel of Fig. 6. We can see the alternate appearances of the temperature pulses in the left panel are synchronized with the swing direction seen in the right panel. Although the differential position of the two sondes cannot be resolved by current GPS system, we can interpret that those temperatures observed by the follower are contaminated by the sonde box swinging ahead, while those on the front are free from perturbations.

Universal use of tungsten sonde: We are not necessarily developing a sonde for universal use. Current design might be an over-specification for operational use. What is important from our findings is that the temperature data from the conventional radiosondes may have been contaminated without being recognized. It will be a difficult and laborious task, but such a possibility should be carefully examined for each make from each manufacturer in the near future for climate studies. One of the opportunities are given by an international inter comparison of radiosondes, which we have participated in this July 2010. The analysis are under way in WMO, and we believe the tungsten sondes have shown good performance among those participated.

"may not be recommended for universal use, but" is inserted between "It" and "is ideal for" in page 3304, line 6. The sentence "It has participated in the international intercomparison of radiosondes organized by WMO and the results will be published elsewhere." has been added after "procedures." in page 3304, lines 8-9.

Comment: I am not convinced of the 0.4 K accuracy claim. There is simply insufficient evidence to support this figure. First, there is no description of the signal conditioner, and there is no documentation showing tests of its performance specifications. Electronic conditioning of the signal from a tungsten wire over an environmental temperature range of +50 to –90 C is not trivial. For example, research aircraft, military aircraft and commercial airliners have relied on the Rosemount 0510BH (or GH) sig-

nal conditioners for the past 50 years, and these units currently cost about $20,000 USD. They have proven performance over extreme environmental conditions. The manuscript should describe the signal conditioner used and how it was tested. Was its performance tested in an environmental chamber down to –90 C? For a future test one could deploy the new fast-response instrument along with a Minco wire-wound (25 micron diameter) platinum element and a Rosemount signal conditioner in the dual-sensor configuration shown in Fig. 7. The combination of the Minco platinum element and Rosemount signal conditioner has been used in reverse-flow housings on research aircraft for several years and its performance is well documented. However, I realize that this suggestion is not within the scope of the current paper.

Reply: Let me be clear by replying one by one.

The accuracy of 0.4 K: It is not clear which sentence the Referee is mentioning. The figure 0.4 appears in the following:

- p. 3294, l. 5: "the radiation correction of less than 0.4 K"
- p. 3294, l. 13: "small fluctuations (less than 0.4 K)"
- p. 3298, l. 2: "0.4 K after an upgrade"
- p. 3301, l. 9: "(0.4 K after upgrade)"
- p. 3302, l. 12: "the temperature reduction by 0.4 K"
- p. 3302, l. 20: "small perturbations with the magnitude of ≤ 0.4 K"
- p. 3303, l. 2: "less than 0.4 K"
- p. 3303, l. 11: "the magnitude of less than 0.4 K"

None of the above sentences states the accuracy. The radiation correction is the magnitude of perturbations arising from solar illumination against the sensor. It depends on the solar zenith angle and cloud amount, as well as the solid angle for our tungsten sonde. Such fluctuations are related to the precision in this sense.

The mean bias denoted by T_b has been introduced on the right hand side of Eq. (1) to avoid confusion. The numbers “0.4 K” in the above list are reached by the following procedures.

- p. 3294, l. 5: It was obtained from laboratory measurements shown in Table 1. 0.4 K has been written by rounding up the maximum number 0.429 for short-wave radiation at 30 km. So “less than 0.4 K” is not correct. The sentence is modified by changing “less than 0.4 K” to “less than 0.5 K”.
- p. 3294, l. 13: It comes from the fluctuations that still remain in the profile shown in the inset of Fig. 10 (Fig. 11 after revision).
- p. 3298, l. 2: The same as the top.
- p. 3301, l. 9: The same as the top.
- p. 3302, l. 12: It is the magnitude of the negative temperature pulse that can be seen in Fig. 8.
- p. 3302, l. 20: The same as the second one in this list.
- p. 3303, l. 2: The same as the top.
- p. 3303, l. 11: The same as the second one in this list.

The signal conditioner: Our laboratory experiments show that the signal conditioner has a calibration error of 0.04 K (1 σ) with the repeatability of 0.02 K (1 σ). A new paragraph (see below at the bottom of this reply) has been written to describe the accuracy of the sensor. The information on the signal conditioner has been given in this new paragraph.

Electronic conditioning: Every tungsten sensor has been calibrated in the temperature range between $-90°$C to $+50°$C. The calibration error is within 0.05 K (1 σ). Any sensor that fails this criterion has been discarded. The signal conversion circuit on radiosonde is kept warm so that it never reaches below $-20°$C even if the

outside temperature is $-90°$C during normal ascending condition. The signal conversion circuit has been tested in laboratory chamber. The temperature drift of the circuit was within 0.07 K in the temperature range from $-30°$C to $+50°$C. The description on the electronic conditioning and temperature drift has been given in the new paragraph mentioned above.

Comment: I do suggest that the manuscript show a complete propagation of measurement uncertainties, starting with a bath calibration of the sensor, an environmental calibration of the signal conditioner, evaluation of the data recording system, and then propagation of these errors into evaluation of the dynamic performance discussed in the text. The bias and random error components need to be computed separately, propagated through the entire measurement chain of events, and combined in quadrature (see Abernethy, R.B. and R.P. Benedict, 1984: Measurement uncertainty: a standard methodology. ISA Transactions, 24, 75-79). The bias error is the major concern in this case, because the temperature measurement has not been compared during the balloon ascent with a well documented “standard” (not the radiosonde standard, which is known to have significant errors). Thus, currently there is no way to actually quantify the bias error in temperature measurement of the new temperature sonde, and this is the critical component of temperature measurement that needs to be quantified if the new sonde is to be used in the UTLS.

Reply: As has been written above in this reply, all the numbers associated with the uncertainty in the current manuscript describe the precision. We agree to the Referee that “there is no way to actually quantify the bias error in temperature measurement” under the field condition. We believe, however, it is worth mentioning the accuracy and biases estimated from laboratory tests. In short, the overall bias will be less than 0.14 K considering the calibration error of tungsten sensor, repeatability and calibration error of signal conditioner and temperature drift of electric circuit. Note that it does not include errors in pre-launch calibration. The above information has been given in the new paragraph after “(World Meteorological Organization, 2008).” line 25 of page 3297.

It reads as follows:

The sensor bias T_b is estimated from the following laboratory experiments. The electric resistance of the tungsten sensor is converted to the frequency of an alternative current, which is counted to digital values by a signal conditioner. The errors (1 standard deviation) associated with the frequency conversion are less than 0.05 K, while those in the signal conditioner correspond to 0.04 K. Our signal conditioner has a repeatability of 0.02 K. T_b is thus expected to be less than 0.07 K if we assume the errors listed above are mutually independent and that the law of propagation of errors (e.g., Abernethy and Benedict, 1985) is applicable. T_b is also subject to systematic drift associated with the temperature change of the thermally protected circuit board in the radiosonde. The estimated drift is 0.07 K in the operational range from $-30°$C to $+50°$C. All these considered, the maximum value of T_b at the time of delivery will not exceed 0.14 K, although the errors in pre-launch calibration should be added for those of field observations.