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Interactive comment on "Does temperature affect the accuracy of vented pressure transducer in fine-scale water level measurement?" *by* Z. Liu and C. W. Higgins

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Reviewer's Comments in General

1. Overall the paper is concisely prepared and makes a good case for error analysis of pressure sensor data in the context of precision water level measurement. However by the end of a detailed reading it seems to this reader that as good as this error analysis is, it could be describing an error source that may be relatively insignificant when taking into account the entire detection/estimation system. One need delve into the relevant literature to be certain but it seems to me that the flow calibration of the weir needs to

be related to the pressure sensor errors and then placed in context of what are all the significant measurement errors. Also, and this may be a show-stopper, the variation of water viscosity with temperature would introduce flow rate errors possibly much greater than those created by pressure measurement imperfections. I do not know what is standard practice with respect to the calibration of weir flow vs temperature. I must leave that to the practicing hydrologist.

*Response: The authors would like to thank the reviewer for providing us with such a detailed feedback for this manuscript. For the reviewer's concern about the relationship between flow calibration and the sensor accuracy in the above comment, the authors agree that the pressure transducer error or accuracy has an impact on the calculation of the weir flow in the device presented in this paper. We have another paper cited in the reference (Stewart et al, 2014) which addresses this part. The error in the flow calibration is associated with our sensor accuracy and using a sensor with better accuracy will improve the performance of the flow measurement device. We didn't include that part in this paper for we only want to look at the effect of temperature on the strain gauge reading. However we agree with the reviewer that the variation of water viscosity with temperature should be investigated in our future work since it could introduce error in flow rate calculation, especially for small flow rate.

2. Here are some 'back of the envelope' estimates.

Over a 20K [10-30C] temperature swing the dimensions of the weir container will change about 0.1% due to thermal expansion of the materials. For a 0.5m water head that introduces 0.5mm pressure error.

Over a 20K [10-30C] temperature swing water density changes about 0.5%. For a 0.5m water head that introduces 2.5mm pressure error – similar in magnitude to the transducer errors. [Note that this error and the previous one tend to cancel each other. One might get lucky and find an ideal flow container material that results in a really good cancellation.]

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Over a 20K [10-30C] temperature swing water viscosity changes about 35%. This must cause massive changes in flow rate.

I did delve somewhat into the literature looking for 'state of the art', so to speak, and into the reference list. I did find two papers by Constantz from 1994 and 1998:

"Influence of diurnal variations in stream temperature on streamflow loss and groundwater recharge", Jim Constantz, Carole L. Thomas, Gary Zellweger. WATER RESOURCES RESEARCH, VOL.30, NO.12, PAGES3253-3264 DECEMBER 1994.

"Interaction between stream temperature, streamflow, and groundwater exchanges in alpine streams", Jim Constantz, WATER RESOURCES RESEARCH, VOL. 34, NO. 7, PAGES 1609-1615, JULY 1998.

Both these paper address the issue of viscosity change with temperature and what then happens to stream channel flow rates. These may shed light on the issues most of concern to me here.

*Response: We agree with the reviewer that the thermal expansion of the container material as well as the variation of water density with temperature will introduce error in the the flow calculation. The change of viscosity with temperature will have a great impact on stream flow. In our field experiment. surface runoff was collected into a channel and then flowed out of the v-notch on the flow container, the flow path is about 6.5 meters. So we think for such a short distance and relatively smaller flow rate (compare to stream flow) in this case, the effect of viscosity change is negligible.

We examined the paper the reviewer listed which looked at the interaction between stream temperature, flow rate, and groundwater recharge. And in the 1994 paper it mentioned that the pressure transducer used in the flume stage measurement has a temperature compensation range from -2 to 30 Celsius degree, plus the tape measure, this should be pretty reliable for recording the water level. However the thermal compensation from the manufacture may be done under a controlled laboratory envi-

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ronment. If the diurnal pattern of the stream temperature has an effect on the strain gauge (even small), the error in the resulted flow calculation could be large through the propagation of the rating curve. It is the best if the pressure transducer was tested in a tank with constant water level but still experiencing same diurnal temperature change.

3. With respect to the paper's references I took the time to examine in particular both Grant and Dawson, and Sweet et al. The former is a basic handbook regarding weirs, flumes and the like. The 1995 version I could access makes no mention anywhere of either temperature or viscosity variation with temperature. Sweet et al is a paper which discusses measurement of essentially standing water in boreholes where viscosity variation with temperature is also not discussed, but in that environment it is irrelevant with respect to measurement error. I feel the way they the two have been cited by this paper is at the very least confusing. In the context of viscosity induced error they add nothing. Why they have been cited needs clarification.

*Response: We cited these two papers not as a reference for variation of viscosity with temperature. They are cited here to emphasize that in flume or weir flow, small error or uncertainty can lead to large uncertainties in the calculated flow rate, sometimes up to 100%.

4. With some thought additional error sources might be identified. In the context of the present paper all these errors could be significant. Neither this paper nor the cited references take these error types into their discussions. For the GI Journal which must be considered a general audience such a discussion is needed in this paper. Thus I recommend the authors revise and resubmit, placing the present results in the wider context of temperature induced errors in the entire measurement system.

*Response: In this paper we only focused on the effect of temperature on the performance of the vented strain gauge pressure transducer. If we consider the whole flow device (the flow container plus the water level sensor), then there are indeed some additional error sources such as the size of the v-notch, etc. These were discussed in

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another paper also submitted to GI journal (Stewart et al, 2014), and this was cited in the current paper.

5. What follows is a large list of minor English errors, mixed with comments on the paper's content.

*Response: We corrected all the places the reviewer indicated and we deeply appreciate the reviewer for providing us with such a thorough lists. We added the changes into the manuscript and here we won't list every correction in terms of English errors. Some points which need extra expalnation to the reviewer are below.

6. p5, l10 “The water level is at the bottom of the weir” I was a bit confused here. To help readers such as I it would be helpful to identify the weir as being precisely the v-notch which is cut into the side of the flow container, either here or a paragraph earlier in the paper. Also in Fig 1 I think I do not see any collection pipes. Are they buried?

*Response: We clarified this in the text as the reviewer suggested. The collection pipes are indeed buried in the ground so they are not seen in the picture.

7. p5. l13 “bucket” Is this the same as “container”? If so it could be restated as “The water level inside the container will rise and water will flow out through the weir.” It may be useful to expand the device description here a bit further. Without access to Stewart et al (2014) the reader is left to rely entirely on what is presented here.

*Response: For the test done in the laboratory we just used a bucket and in the field experiment it is a flow device. We kept "bucket" wherever refers to the laboratory experiment and we now use "flow container" for all the field experiment part. The Stewart et al (2014) paper is now on the GI discussion forum.

8. p7, l5 “Figure 4 shows a schematic of the derivation” I believe this model makes the assumption that the two ends of the vent tube are at a common elevation. In principle the thermal effect of expansion should include that caused by the gravitational potential caused by differential air densities inside and outside the vent tube. I did the calculation

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for myself and satisfied myself that it is a small effect, but in the interest of thoroughness the authors may wish to address this detail. There is also a similarly small effect which will reduce the cable's temperature sensitivity due to thermal expansion of the cable, which must occur simultaneously with that of the air inside the vent tube. The volumetric thermal coefficient of air will be the order of 3000 ppm/deg, while that of the cable materials will likely be in the range 150-300. Thus the proposed cable thermal effect will be reduced from that predicted by about 5%, worst case 10%. This is not significant. It does however bring to mind an expression: "Everything is a thermometer, but some are better than others".

*Response: In the derivation we do just consider the two end of the venting tube are at a common elevation. Like the reviewer said, the gravitational potential caused by differential air density should be small effect in this case. The air exchange between the inside and outside of the venting tube is via a port (made of porous teflon). In general it should be a very fast process unless the port is blocked in someway. We agree with the reviewer that this issue deserves some detailed discussion although then we need to also consider the permeability of the venting port material and most importantly, we need to design an experiment to measure the actual temperature of the cable during the test. This is a little beyond the scope of this paper however we will consider to write a technical note to address this problem in the future.

9. p7, l10 "ML/T2" It took me a short while to see that this and other similar expressions are dimensional notations. A note to that effect would be helpful. The journal may have some preference regarding best or preferred practice. For certain negative exponents are preferred over "/" characters.

*Response: We will consult with the editorial office to see if they want to keep the notation this way or they prefer to use negative exponents over "/". If it is the latter then we will change correspondingly.

10. Eq 14 Starting from (13) I don't get to (14). Should not the exponent on alpha

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be one? Should not there be an “L” in the numerator? This needs to be rechecked carefully. Just on the basis of “look and feel” it makes sense that higher viscosity will lead to higher pressure errors. Also larger cross sections lead to lower errors. Longer tubes would also imply a need for larger pressures or longer time lags.

*Response: This is a typo we overlooked in the proof reading. There is a L^2 in the numerator. We apologize for the confusion.

11.One can do a thought experiment. An instantaneous change in air temperature would lead to an equally instantaneous change in pressure, mediated by the coefficient alpha. That pressure jump would then decay to ambient with something like a time constant. An equally instantaneous change in ambient air pressure would have the identical effect, same time constant. In both cases a longer tube will slow things down.

Using alpha to adjust temperature to pressure [a corrected] Eq (14) provides a system time constant. At this point it would be useful to obtain actual numbers for the various parameters and to work out an actual value for the vent tube system time constant. Not for the present study, but perhaps it would be possible to actually measure the vent tube time constant, say by placing an inflated balloon over the vent tube open end, suddenly deflating the balloon, then monitoring the sensor error transient?

*Response: This is a wonderful idea to test the system time constant, actually for both vented and absolute strain gauge pressure transducer. We can place the venting port in a chamber starting with one atmospheric pressure then gradually increase the pressure over certain time interval and monitor the pressure transducer reading on the other end. Such information would be valuable for designing better vented water level sensor.

12. Taking into account the paper as a whole, particularly the recommendations at the end, particularly recommendation 5, it occurs to me that the data in Fig 5, both 5a and 5b, could be used immediately to demonstrate what is achievable in terms of correcting for thermal errors. Using both the regression results a new, corrected plot should be

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possible, taking into account both error types, and plotting water level vs time. Also one significant thing that is missing from Fig 5a is a definition as to what is meant by “Temperature Gradient”. Are these values all first differences, or are the deltaT’s taken over longer intervals than the minimum possible?

*Response: The data for Fig 5a is from pressure transducer 1 and for Fig 5b the data is from pressure transducer 2 which shows the strongest relationship between error and absolute temperature (that 40 mm swing). In Fig 5a, the definition of temperature gradient is a delta T taken over a 10 min interval. We clarified this in the Figure 5 caption.

13. p12, l3 “Poor or nonexistent ... as the water density is normally effected by the temperature” Is this relevant? Yes, poor strain gauge temperature compensation causes measurement errors. But are you trying to measure water mass quantities or water volume quantities or what? Thermal variation of water viscosity will cause flow rate errors at the weir, will it not? Doesn’t the large variation in its dynamic viscosity over the same temperature range cause havoc with trying to calculate actual flow rates? Are these compensated somehow? Same for the dimension stability properties of the flow container itself though such errors aught to be relatively small. If the water temperature is varying what else are its error paths? How do these relate to the present discussion?

*Response: We agree with the reviewer that the discussion of water density here seems a little irrelevant here so we removed this part from the text.

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., 4, 533, 2014.

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