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Interactive comment on "Recent trends of groundwater temperatures in Austria" *by* Susanne A. Benz et al.

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Thank you for the opportunity to review "Recent trends of groundwater temperatures in Austria" by Benz, Bayer, Winkler, and Blum. I enjoyed reading the manuscript and appreciate the work it represents. I have outlined my specific primary suggestions for improvement below. I've also included minor comments, along with typographical suggestions as requested by the Journal. Only the primary comments rise to the level of serious consideration and response. The authors should feel free to contact me if anything is unclear at rjhunt@usgs.gov.

Specific/Primary Comments:

1) Overall manuscript: It strikes me that a focus on annual air temperature misses a

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fundamental process important for this discussion. The temperature of the groundwater system reflects the temperature of groundwater recharge. Groundwater recharge, however, is variable over time, thus annual temperature changes are likely too coarse to capture the temperature effects of inter-annual recharge process. That is: snowmelt recharge will be near 0 degrees C; rain-derived recharge will be warmer. Perhaps there is a shift in recharge from less snowmelt to warmer rain sources that is driven by air temperatures. A groundwater recharge approach means that the simple relation of air temperature to groundwater temperature is more indirect, and this additional "noise" to the signal is perhaps why the correlations are not higher.

2) Section Groundwater Temperature/Figure S1: Similar to comment #1, groundwater basins have a residence time, with multiple ages and potential lags. There is an assumption that all groundwater reflects current air temperatures (e.g., line 269) but this may not be the case. Given the importance of other factors such as residence time, and the unsaturated zone buffering that dampens the climatic drivers, it seems worthwhile to include well statistics relating to:

- Depth to water table

- Well open interval

- Distance the well's open interval is below land surface

- Distance the well's open interval is below the water table

- Estimated position in the groundwater flow system (e.g., uppermost, middle, discharge; near groundwater divide versus near flow system end; urban versus rural agriculture versus forest; high elevation versus low elevation)

3) Lines 104-106: It seems that only focusing on annual averages may limit the applicability of the insights. For example, for cold water fisheries it is usually the temperatures in the late summer – late fall that are important.

4) Figure 2: The shaded area and short-duration blue line dipping below y=0.0 is in-

teresting – can you say something about what conditions would cause the GWT to be inversely correlated with SATs?

5) Figure 3: It appears that the annual averaging is hiding important relations. That is, if surface air temperature (SAT) is the driver of groundwater temperature, it does not follow that the summary groundwater system temperatures would be warmer than the SATs at every location. Is it not likely winter periods skew the annual SAT, but the groundwater system is buffered from these colder temperatures? Therefore, might it be more insightful to look at SATs during non-winter conditions?

6) Lines 176-177: For this sentence: "This indicates that GWTs are often influenced by local causes and not necessarily solely by surface temperatures.", the correlation is between the weather station that is measuring surface temperatures correct? Then wouldn't it follow that the correlation is between groundwater temperatures and local SATs?

7) Lines 220-225: Can you provide reasons (and citations for the interested reader) for why there are different levels of change with land use?

8) Line 248: Did the hot spring suddenly appear or was it always there and something else changed? It was not apparent to me in Figure 5 what is the hot spring effect that I should be seeing in IIb and IIc in Figure 5. It does seem these outlier wells that have known atypical perturbations make the narrative hard to follow because they pop up every time a point is being made, and cause two sets of statistics to be reported – one with them and one without them (e.g., Villach wells, lines 265-359, wells near the Drau River). Because you know they are not representative of the larger scale climate driver would it not be clearer to just state this in the beginning and say you are not going to include them when reporting the subsequent statistics?

9) Please describe briefly the technique of Menberg et al. (2014) and define "regime shift index" used to save the reader from having to find it.

10) Lines 296-297 and 313-314: There are other statistical tests that beyond linear and regime shift methods (such as autoregressive integrated moving average techniques). Were any of these tried? The difference in RMSE is reported here is so small that it seems a stretch to say one performs superior than the other, and maybe other methods would perform better.

11) Is there something we can learn about the fact that nationwide correlation is higher than any of the individual weather station / well combinations? Would it be worth including a sentence in the manuscript pointing out that if researchers simply used the nationwide relation they could potentially hurt their ability to solve their more local problem?

Minor Comments / Technical Corrections

Line 19: It would be nice to relate the locations to features transferable to other parts of the world (e.g., high topographic relief/mountainous versus less topographic relief/less mountainous).

Lines 47-67: Bill Selbig used a regression of historical groundwater and air temperatures for the purpose of forecasting what future groundwater temperatures would be given expected changes calculated by GCMs. Not sure if your work would benefit from an application of how groundwater temperature trends influences societally relevant endpoints such as trout. There are others as well, but this work can be found in: Hunt, R.J., Walker, J.F., Selbig, W.R., Westenbroek, S.M, and Regan, R.S., 2013, Simulation of Climate-Change Effects on Streamflow, Lake Water Budgets, and Stream Temperature Using GSFLOW and SNTEMP, Trout Lake Watershed, Wisconsin: U.S. Geological Survey Scientific-Investigations Report 2013-5159, 118 p., http://pubs.usgs.gov/sir/2013/5159/.

Figure 1: the dashed line is not defined in the figure or in the caption.

Lines 158-159: It would be clearer to state exactly what is meant when stating

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"...the distance in the north-south direction of two wells has more influence on the correlation..." As written the influence can be augmenting (more correlation) or degrading (less correlation).

Line 176: I don't think figure 3 shows "pairs of wells" but wells within 5 km of a weather station.

Lines 205-206: It seems Vienna may not be the best example to state as it only has one well included in its calculation of correlation.

Line 240-241: I am not sure I followed the sentence construction – what is meant by "...but in one sudden drop or rather rise in temperatures."?

Lines 222-224: In the beginning of this paragraph the topic is rate of change and then in these lines it is absolute change over a period, then the next paragraph goes back to rate of change. Perhaps better to start out with the differences in absolute temperatures then stay with changes in temperature. Also, the period 1990-2012 stated in these lines is not the same as reported in the caption of Figure S2 (01/1994 – 12/2013).

Line 239: Here is perhaps an opportunity to reinforce the importance of including groundwater flow when trying to interpret groundwater temperature (as opposed to dry borehole temperatures mentioned in the introduction). Same with line 304 in the Conclusions.

Line 240: Are there other cases of extreme changes not discussed in the text?

Line 243: The word "extend" should be "extent".

Line 236-249: The discussion starts with the <5% cases then includes the >95% then concludes again with <5%.

Line 261: My PDF had an odd "extend" tacked onto the end of the line.

Line 265-266: I think this sentence is less clear than it could be. I think the point is that if SATs are the driver of GWTs the former cannot lag behind the latter. The fact

that GWT changes precede the SAT driver suggests this method does not have the resolution to determine short lags between SATs and GWTs.

Line 303: “instalment” should be “installment”, or even better, “installation”

Figure 6: I am not sure what to make of the checkerboard bar around 2006.

Figure S5: Perhaps add a vertical line to the figure to help the reader identify the exact date of the July 2007 flood.

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