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Technical Note

Does the accuracy of fine-scale water level measurements by vented pressure transducers permit for diurnal evapotranspiration estimation?

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ABSTRACT

Evapotranspiration (ET) estimation methods based on diurnal water level (surface or groundwater) fluctuations are sensitive to measurement accuracy (McLaughlin and Cohen, 2011; Cuevas et al., 2010). Water level fluctuations are often measured by pressure transducers of varying design and precision. Available total pressure transducers require a compensation for barometric pressure change supplied by barometric pressure transducers. Recently McLaughlin and Cohen (2011) as well as Cuevas et al. (2010) analyzed the 'thermal artifacts' of such transducer-pair data questioning the applicability of sub-daily water level measurements in non-buffered thermal mode for diurnal ET estimation. Similar problems should not, in principle, occur for so-called vented pressure transducers. With the help of ancillary manual measurements, this study verifies the accuracy of vented pressure transducer obtained ultra-fine scale (temporal resolution of 1–10 min) stream- and groundwater level data. Thermal effects were examined by a statistical analysis of concurrent water level and temperature data. The results support the thermal artifact-free nature of vented pressure transducers and therefore their suitability for diurnal ET estimation purposes when proper maintenance and periodic calibrations are provided. In the lack of such measures, diurnal temperature changes can induce errors in vented pressure transducer readings as well.

1. Introduction

Diurnal fluctuations in shallow groundwater and surface water levels can typically be detected in the growing season, due predominantly to transpiration of the vegetation. Several methods exist (most based on the original work of White (1932)) that estimate ET (for a review, see Gribovszki et al. (2010)) by exploiting certain characteristics of these fluctuations.

The magnitude of the fluctuations in groundwater levels is typically much larger than in surface water levels, since the gravitational pore space (i.e., specific yield) of the soil is significantly smaller than 100%. For example, a 6–7 $\mathrm{mm\,d^{-1}}$ summer ET rate can induce a groundwater level fluctuation of 10–12 cm in amplitude, but only about 2 cm in stream stages (Fig. 1). Therefore methods, based on surface water level fluctuations, require particularly accurate stage level readings, in comparison to those based on groundwater level fluctuations which, of course, will also benefit from accurate readings. Some diurnal fluctuation based ET estimation methods work with temporal differences of the recorded water levels (Gribovszki et al., 2008; Loheide, 2008) in which cases accuracy of the readings becomes even more important.

Other issues, like the determination of appropriate specific yield value (Loheide et al., 2005) and/or artificially-induced fluctuations in water levels (Zhu et al., 2011) that can cause considerable uncertainty in diurnal-fluctuation based ET estimations, will not be dealt in this study having a focus on the thermal artifacts induced errors in the measurement of fine-scale water level variations.

Starting in the 1960s, water level measurements have gradually been performed by pressure transducers of differing engineering design and corresponding accuracy (Freeman et al., 2004). In case of total pressure transducers, it is important to keep both sensors (underwater and atmospheric) in similar (buffered) thermal conditions for obtaining the water level as the difference in pressure measured by the two sensors. Recent articles (e.g., Cuevas et al., 2010; McLaughlin and Cohen, 2011) pointed out thermal artifacts in total pressure transducer readings and questioned the reliability of the resulting ET rates derived by transducer pairs without a temperature correction. Since the data of Gribovszki et al. (2008) have been referenced among others (Constantz, 1998; Wondzell et al., 2007), the authors would like to shed better light on how their water-level measurements were performed and fill an existing gap in providing an analysis of accuracy for vented pressure

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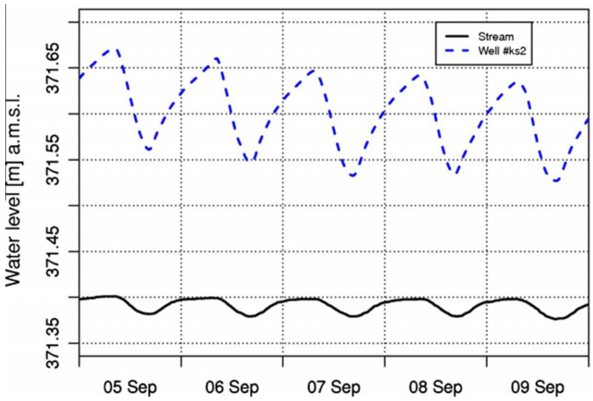

Fig. 1. Typical diurnal fluctuations in groundwater (well #ks2) and stream levels in the summer of 2005, Hidegvíz Valley catchment, Hungary.

transducer readings under a range of diurnal water level fluctuations typical of a small, pre-alpine forested catchment of temperate climate.

Vented pressure transducers (also called gauge pressure sensors), in principle, do not need additional barometric pressure measurements, thus seemingly obviating a thermal correction. However Cain et al. (2004) analysed thermal effects on gauge pressure sensors and found that direct insolation of long and thin venting cables can cause significant errors in measurements, up to 2–3 cm. Another potential problem can be that vent tubes may accumulate moisture or become crimped, impeding pressure transfer to the transducer (Freeman et al., 2004). Until now there has been no field verification of the accuracy of vented pressure transducer measurements of diurnal water level fluctuations under buffered thermal conditions.

2. Methods

A short field campaign was launched from September 16 to 17 of 2011 to evaluate the accuracy of vented pressure transducer readings in a small research catchment (called Hidegvíz Valley) of western Hungary near the Austrian border. A detailed description of the research catchment and the measurement site can be found in Gribovszki et al. (2006, 2008).

Water levels in the stream (drainage area of 6 km^2) and in two groundwater wells (#ks1 at a distance of 1.5 m to the stream and #ks3 at 18 m) were measured by vented pressure transducers [in every 1 min (stream) and 10 min (wells), respectively] and verified by manual measurements [DA-OP type optical instrument (www.dataqua.hu)] in almost every hour (Fig. 2). The accuracy of the manual measurements was ±2 mm (the scale of the tape measure). The transducers were inserted in the groundwater wells and in the vertical pipe of the stream gage. The wells were dug with an 80-mm drill. The casings of the PVC wells have a diameter of 63 mm, screened at the bottom 1 m (#ks1) and 1.2 m (#ks3), respectively, starting 0.3 m below the surface. The space between the casing and the wall of the borehole is filled with space between the casing and the wall of the borehole is filled with coarse sand. The wells were open to the atmosphere by a 5 mm slot on the top. The stream gage house is a 2 m deep concrete well of radius 0.5 m (open to the atmosphere with two small slots) with a horizontal pipe connection to the streambed attached to a vertical pipe for the transducer placing (the radii of both pipes are 5 cm). The vent-cable lengths of the transducers were 1.1 m (#ks1), 1.2 m (#ks3) and 1.5 m (stream gage), respectively.

The vented pressure transducers employed in the campaign are manufactured by Dataqua Ltd. (absolute precision of the transducer is ±2 mm with a sensitivity of ±0.1 mm are valid up to a

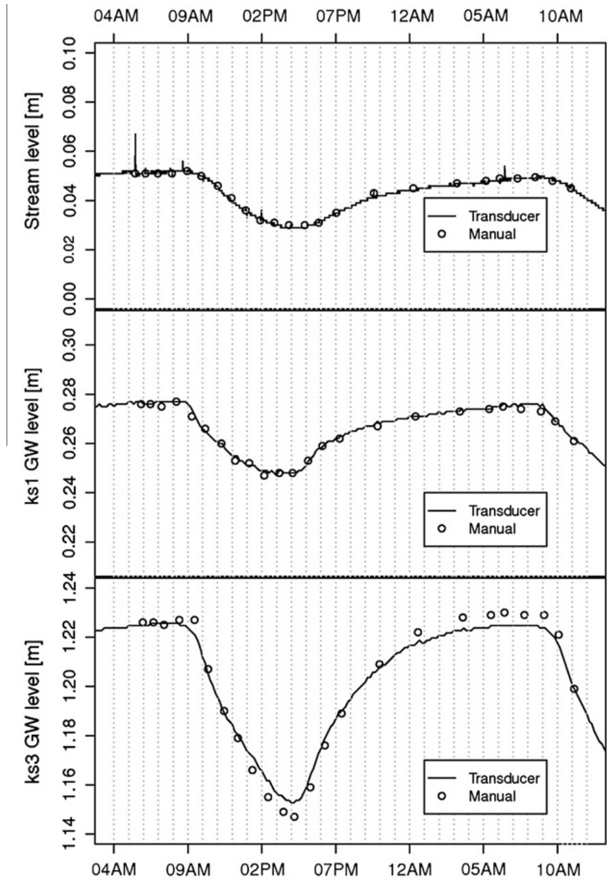

Fig. 2. Water level time series measured manually and by a vented pressure transducer. Top panel: stream gage; middle panel: transducer (#ks1) close to the stream; bottom panel: transducer (#ks3) farther away from the stream.

water-depth of 1.5 m, www.dataqua.hu). The sensor physically compensates the absolute pressure measured by a platinum membrane with atmospheric pressure (directed onto the back-side of the membrane by a vent tube) to yield hydraulic pressure relative to atmospheric (which then is converted into a depth value).

Air temperature inside the wells and the vertical pipe of the stream gage-house (10 cm above water table) were also recorded manually with a Multi 3420 device (accuracy of 0.1 K, www.wtw.de) every hour. Since the stream gage was located in a forest clearing while groundwater wells about a hundred meter away under the canopy of alder trees, additional air temperature measurements were taken automatically (in every 10 min) in both locations at a height of 2 m from the ground in a standard meteorological housing in order to obtain information of any temperature change of the broader environment. During the 24-h measurement period no precipitation occurred.

Data analysis started with selecting concurrent, manually and transducer-obtained, water level values (when necessary, a linear interpolation was applied for the transducer readings to find the value at the exact time of the manual readings). Then, the manually-measured hourly water levels were subtracted from the corresponding transducer values, followed by a linear regression analysis of the air temperature and the water level differences. For the detection of possible non-linear effects, a scatter-plot smoother (loess, Cleveland et al., 1992) was also applied.

3. Results

The temperature record (Fig. 3) indicates that open air temperature in the forest clearing where the stream-gage is located, dis-

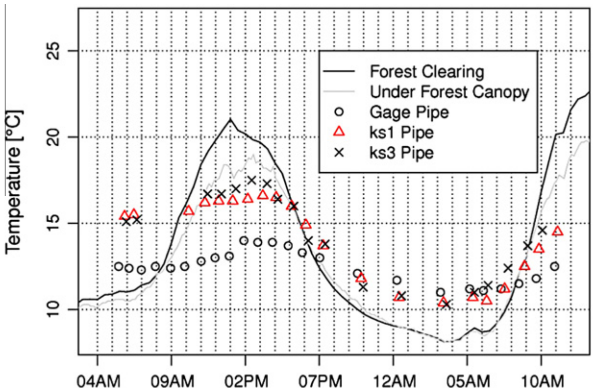

Fig. 3. Air temperature time series at the study site.

play a diurnal range of 12.9 °C which is 2 °C larger than what is found under the tree canopy for the same minimum temperature value. The same air temperature range is higher in well #ks3 (7.2 °C) than in well #ks1 by one degree, most likely due to differences in measurement depth. The smallest diurnal temperature range (3 °C) can be detected in the vertical pipe of the stream gage house measured at the largest depth from the surface there.

The diurnal amplitude of water levels (Fig. 2) is the smallest (2.0 cm) for the stream, a somewhat larger amplitude can be detected at the stream-side well, #ks1 (2.8 cm), and the largest at well #ks3 (8.3 cm). Differences between the manual and transducer-detected water levels are within the range of the accuracy of manual measurements for the stream gage and well #ks1, but for well #ks3 these differences were larger, up to ±6 mm (Fig. 2). For this latter site overestimation typically occurs in the afternoon (when air temperature is highest), and underestimation in the morning (when air temperature is the lowest). This pattern is just the opposite of what Cuevas et al. (2010) and McLaughlin and Cohen (2011) describe. This is not surprising because the source of the error is different in the present case as well: maintenance work has not been performed on the sensor for several years, nor was it re-calibrated (the manufacturer suggests the latter in every 3-year period).

The cause of the error probably lies in a partial plugging of the vent tube by condensed water in it which leads to underestimation of the water level in the cooler morning hours when water levels are the highest. Due to the plugging, the diurnal thermal fluctuation is reduced inside the tube which means higher than ambient pressure (since tube air temperature is higher than ambient) on the back side of the membrane in the cool mornings, therefore suppressing the measured hydraulic pressure. In the warmer afternoon hours the opposite happens, the cooler than ambient tube air temperature causes lower tube pressure, which leads to an overestimation of the, by then lowered, true water levels. The two effects combined yields a diminished diurnal amplitude in the readings.

To eliminate the above problem, vent tubes should be inspected at least once in every three-year and have the instrument recalibrated in a lab. A period of vegetation dormancy (in the winter) is the best time of the year for such maintenance, since evapotranspiration is minimal then and a weekly manual water level measurement is generally sufficient for tracking the slowly changing water levels.

Fig. 4 displays the temperature dependence of the water level differences. There is no significant linear trend for well #ks1 ($p = 0.9879$) and the stream gage ($p = 0.3456$), nor any non-linear one, detectable by the scatterplot smoother (loess). Water level differences for well #ks3, however, display a strong temperature

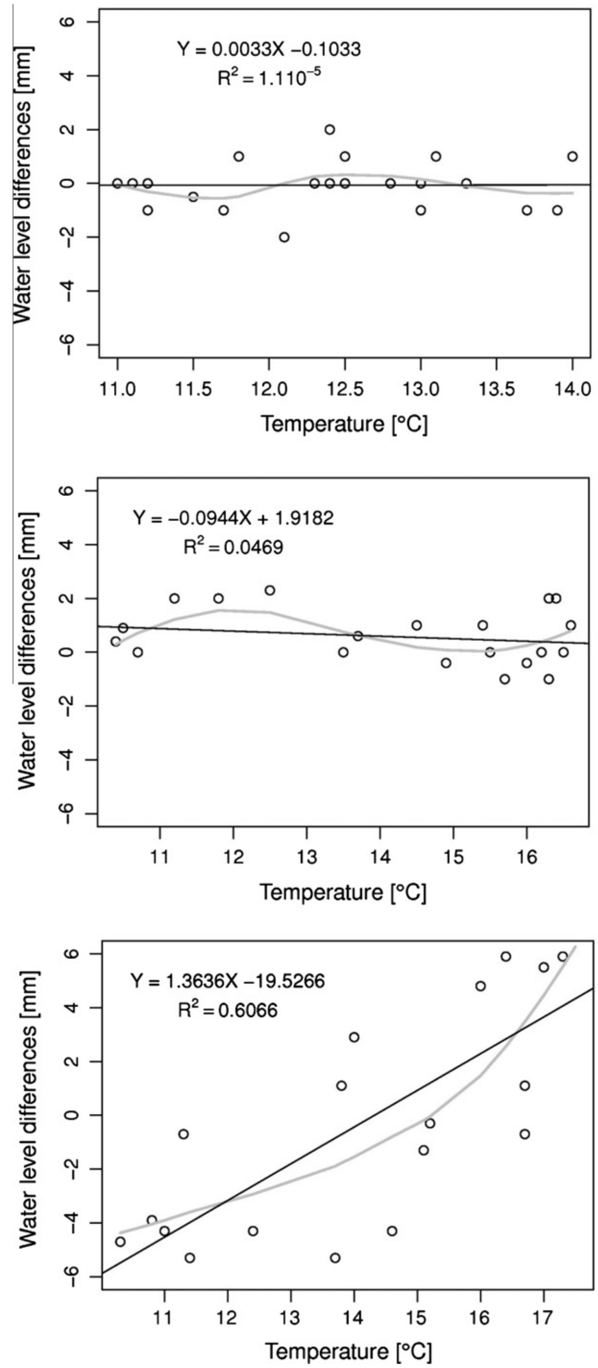

Fig. 4. Differences in manual and transducer-obtained water-level readings as a function of air temperature inside the pipe. Top panel: stream gage; middle panel: well #ks1; bottom panel: well #ks3. Linear regression line is black and scatterplot smoother is gray.

dependence (1.4 mm K^{-1}, $p = 8.54 \times 10^{-5}$) due to the above mentioned condensation effect.

4. Conclusions

From the analysis of our field campaign data it was found that properly maintained vented pressure transducers can satisfactorily measure diurnal fluctuations in both surface and groundwater levels provided the vent tube is not directly exposed to the sun. Therefore this type of transducers can provide appropriate data for diurnal-signal based evapotranspiration estimation methods (e.g., Gribovszki et al., 2008) at least with vent-cable length and climate similar to what was specified in the present study. In arid climate where diurnal temperature fluctuations may exceed 20 °C and with the application of longer vent cables, thermal effects should be further tested. Similar to the findings of others, it should be stressed that a proper barometric pressure installation (total and barometric pressure transducer pairs) and periodic maintenance of the vent tube (vented pressure transducer) are necessary to minimize temperature induced errors in the readings.

Acknowledgments

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References

Cain III, S.F., Davis, G.A., Loheide II, S.P., Butler, J.J., 2004. Noise in pressure transducer readings produced by variations in solar radiation. Ground Water 42, 939–944.

Cleveland, W.S., Grosse, E., Shyu, W.M., 1992. Local regression models. In: Chambers, J., Hastie, T. (Eds.), Statistical Models in S. CRC, pp. 309–376 (Chapter 8).

Constantz, J., 1998. Interaction between stream temperature, streamflow, and groundwater exchanges in alpine streams. Water Resources Research 34, 1609–1615.

Cuevas, J., Calvo, M., Little, C., Pino, M., Dassori, P., 2010. Are diurnal fluctuations in streamflow real? Journal of Hydrology and Hydromechanics 58, 149–162.

Freeman, L., Carpenter, M.C., Rosenberry, D.O., Rousseau, J.P., Unger, R., McLean, J.S., 2004. Use of submersible pressure transducers in water-resources investigations. In: U.S. Geol. Surv. Tech. Water Resour. Invest. U.S. Department of the Interior, U.S. Geological Survey, vol. 8-A3.

Gribovszki, Z., Kalicz, P., Kucsara, M., 2006. Streamflow characteristics of two forested catchments in Sopron Hills. Acta Silvatica et Lignaria Hungarica 2, 81–92.

Gribovszki, Z., Kalicz, P., Szilágyi, J., Kucsara, M., 2008. Riparian zone evapotranspiration estimation from diurnal groundwater level fluctuations. Journal of Hydrology 349, 6–17.

Gribovszki, Z., Szilágyi, J., Kalicz, P., 2010. Diurnal fluctuations in shallow groundwater levels and streamflow rates and their interpretation a review. Journal of Hydrology 385, 371–383.

Loheide II, S.P., 2008. A method for estimating subdaily evapotranspiration of shallow groundwater using diurnal water table fluctuations. Ecohydrology 1, 59–66.

Loheide II, S.P., Butler Jr., J.J., Gorelick, S.M., 2005. Use of diurnal water table fluctuations to estimate groundwater consumption by phreatophytes: a saturated–unsaturated flow assessment. Water Resources Research 41.

McLaughlin, D.L., Cohen, M.J., 2011. Thermal artifacts in measurements of fine-scale water level variation. Water Resources Research 47.

White, W.N., 1932. Method of estimating groundwater supplies based on discharge by plants and evaporation from soil – results of investigation in Escalante Valley, Utah – U.S. Geological Survey. Water Supply Paper 659-A, 1–105.

Wondzell, S.M., Gooseff, M.N., McGlynn, B.L., 2007. Flow velocity and the hydrologic behavior of streams during baseflow. Geophysical Research Letters 34, L24404.

Zhu, J., Young, M., Healey, J., Jasoni, R., Osterberg, J., 2011. Interference of river level changes on riparian zone evapotranspiration estimates from diurnal groundwater level fluctuations. Journal of Hydrology 403, 381–389.