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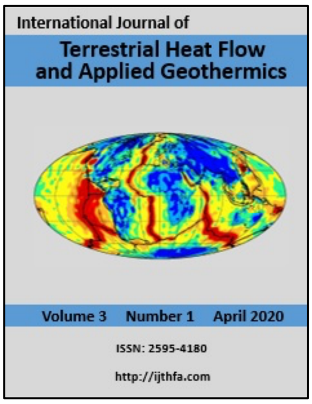

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# Daily temperature variations at the subsurface combined with water level records in Ajameti, Georgia

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## Abstract

High resolution temperatures at the subsurface down to 250 m and water level measurements were carried out in a borehole at Ajameti, Georgia. In both cases daily variations were analyzed for time periods of February/March 2018 and April 2018. Their frequency spectra demonstrate that the diurnal and semi-diurnal variations are generated by earth tides. The enhanced amplitude of the diurnal period at depth of 100 m coincides with the growth phase of vegetation. Frequent rainfall did not affect the temperature at 100 m or deeper but raises the water level. Daily surface temperature variations relate to the temperature variation at the subsurface during the growth phase of vegetation in April and down to 175 m. No relation is detected in records obtained during February/March and at 250 m in both cases. Vertical shift of the water column results from the prevailing temperature gradient and the temperature fluctuation. The estimated water flow yields an amplitude of 0.1 m at 250 m but increases continuously to 0.16 m at 100 m. However, the water level variation reaches only 0.03 m at the surface. It is likely that the free surface of the water level has an additional degree of freedom which causes the lower magnitude of fluctuation.

## Keywords

Water level,
Temperature variation,
Water movement,
Vegetation growth,
Borehole measurement
Precipitation,
Georgia.

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## 1. Introduction

A strong correlation was reported between volume strain measured by a strain-meter and groundwater temperature variation (Furuya and Shimamura, 1988; Shimamura and Furuya, 1999). Such variations are also affected by atmospheric pressure changes in many wells (Shimamura 1983, Shimamura & Furuya, 1999). Its impact differs by more than 100 times in different boreholes. According to Shimamura et al (1985) tectonic activities also have a remarkable effect on groundwater flow with con-temporal temperature changes.

Water level variations contain periodic components as well as aperiodic changes due to tidal forces, atmospheric pressure variations, precipitation and tectonically induced strain changes. The effect of periodic water level changes has been investigated in several previous works (e.g. Bredehoeft, 1967; Narasimhan, 1984; van Ruymbeke et al, 1991). All investigations demonstrate that the water level variations show, in general, main tidal periods generated by the sun-moon-earth gravitational system. This causes a periodic volume strain that can be documented with frequency analysis. Tectonically induced aperiodic water level changes were reported by Shimamura et al. (1985), Jimsheladze et al (2010). They also reported that strain variations in the subsurface and related to fluid flows.

The continuous conductive flow of heat from greater depths yields the prevailing temperature gradient. In cases where the flowing pore fluid has a vertical component the temperature varies at a fixed depth. Van Ruymbeke & Somerhausen (1991) reported con-temporal measurements of water level and temperature at the same borehole for a period of seven months. The main earth tide periods can be recognized at the water level record as well as in records at depths of 10 m below it. This can be seen in frequency spectra of the temperature records. These can also result from strain variations which cause fluid flow in the subsurface. In the present work, fluctuations of water level induced by earth tides are compared with those of temperature variations at depths of 100 m, 175 m and 250 m.

## 2. Methodology

### 2.1. Study area

The present work was carried out in a borehole at Ajameti, near Kutaisi in Western Georgia. It is 1339 m deep and has a diameter of 14.6cm. The seismicity is weak in the region so that the tectonic activity is low.

The study area in Western Georgia is characterized by mild, humid and warm climate, abundant atmospheric precipitation, favorable atmospheric humidity balance, high index of relative humidity and moderate temperature variations. The local climate is characterized by abundant annual precipitation up to 2500 mm (Elizbarashvili, 2007). The monthly mean temperature in January is 4°C and in July 22°C near the city of Kutaisi (Khatiashvili et al, 1989), so that the annual temperature variation at this location may be considered as having an average range of ca. 13°C. The nature of local precipitation was determined based on records at the meteorological station of Kutaisi which is ca. 20km distant from the study area.

The Ajameti borehole is located in the central part of the West Georgian lithospheric plate. The upper part of the borehole consists of an alluvial layer of Quaternary age with gravels from the surface down to about 14m. From 14m to 300m, marl of Miocene age is encountered. Between 300m and 520m is a complex layer of clay, marl and limestone of Eocene age. At depths below 520m the borehole crosses a main regional water aquifer, which is classified as Lower Cretaceous limestone complex. It is composed of massive dolomitized fractured and karstic limestone (Jimshelidze et al. 2019).

### 2.2. Water level variation

The water level is measured with an absolute pressure sensor MPX5050. It is installed at 13 m below the earth surface. Its position is 3 m below the water level and data is recorded at a reading rate of 1 minute. The atmospheric pressure is recorded with the pressure sensor MPX4115, which also operates at the same reading rate. The raw water level data are processed by subtracting air pressure values in obtaining the response of earth tides (Kobzev and Melikadze, 2010). The influence of precipitation as well as possible tectonic settings are not considered.

### 2.3. Temperature records

The LogBox microtemperature recording equipment (www.geotec-instruments.com) was installed in Ajameti borehole. This is a high precision thermometer with resolution of 0.0002 K. During field measurements this instrument is protected by weatherproof casing and installed at the well head. The instrument consists of three individually calibrated temperature sensors protected in a waterproof stainless-steel housing. Environmental parameters such as surface temperature and precipitation are also recorded, and its influence taken into account. The temperature of the device is maintained close to the surface temperature. Rapid variations, however, undergo damping effects, so that the daily surface variations might be smoothed.

The temperatures were recorded at depths of 100, 175 and 250 m and at the surface close to the borehole head. The measurement frequency has been 3 per hour, resulting in 72 individual daily measurements.

## 3. Results

### 3.1. Water level fluctuations

The nature of water level variations that took place during the study period is illustrated in Figure 1. The upper panel of this figure indicates that a continuous rise of water level occurred during spring and summer 2018. In this record the effects of barometric pressure has been corrected (Kobzev, 2010), so that no relation between air pressure and water level fluctuation can be noticed. A data sequence of depth below water level recorded in April 2018 is illustrated in Figure 1b, while nature of daily fluctuations of water level from 1st April until 15th April 2018 is illustrated in Figure 1c. Note that on 1st April, which is only one day after full moon, a semi-diurnal and a diurnal period can be seen. The semi-diurnal period gradually decreases until the half-moon on 8th April and increases again until new moon on 16th April. The amplitude of diurnal variation is relatively high during the period when gravitational forces are maximum and low at its minimum.

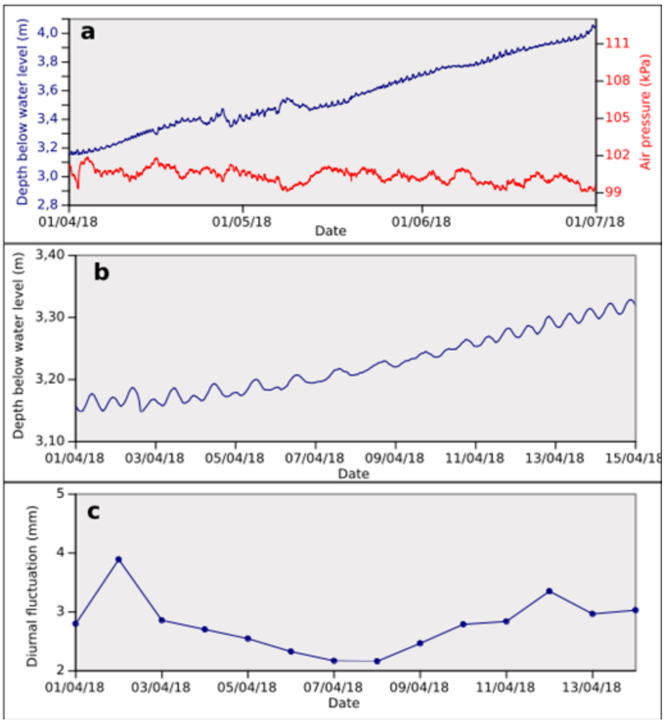

*Figure 1 - a) Water level data from April until July 2018 with air pressure at Ajameti, Georgia; b) detailed sequence of data from 1st April until 15th April 2018; c) daily fluctuation of the water level from 1st April until 15th April 2018.*

A summary of data acquired concerning daily fluctuations is given in Table 1. It includes maximum and minimum values, the difference and the average. Also included is a qualitative description of the precipitation.

*Table 1 - Daily water level fluctuation.*

| Amplitude of variation (m) | February/ March 2018 | April 2018 |
|---|---|---|
| maximum | 0.050 | 0.042 |
| minimum | 0.023 | 0.023 |
| difference | 0.027 | 0.019 |
| average | 0.032 | 0.030 |
| Precipitation | frequent | scarce |

The volume strain was calculated for the first half of April and plotted in Figure 2a. Its Fourier spectrum with respect to the time period is illustrated in Figure 2b with the diurnal and semi-diurnal periods. The frequency spectrum has been analyzed with the data series from February until July 2018 and shows well the semi-diurnal and the diurnal period (Figure 2c). The resolution is not high as to split the diurnal period ($S_1$) into the lunisolar ($K_1$), the larger lunar ($O_1$) and the larger solar ($P_1$) periods which are close to the daily period. The semi-diurnal period shows the principal lunar ($M_2$) and the principal solar ($S_2$) contribution.

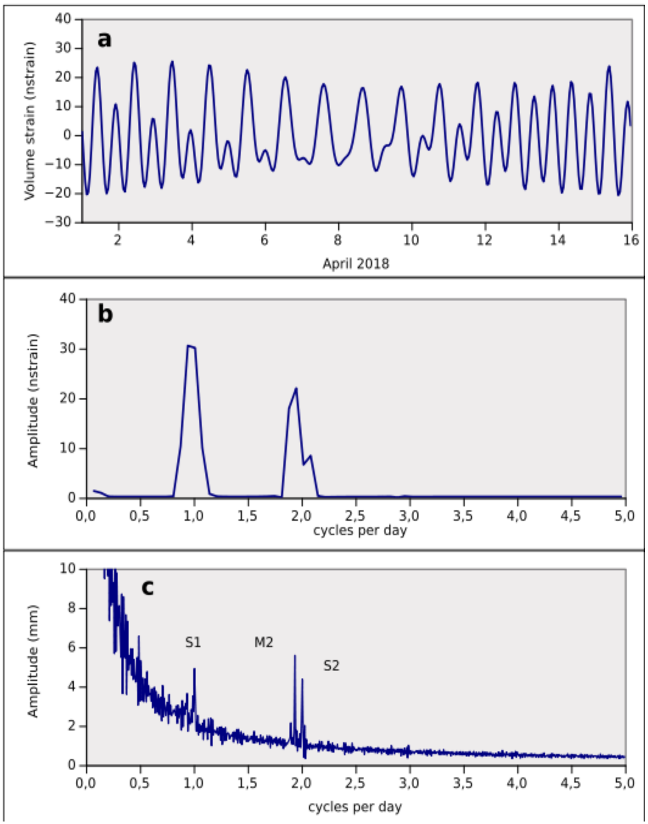

*Figure 2 - a) the volume strain from 1st April to 15th April 2018 (T. Jahr, personal communication); b) its Fourier spectrum; c) the Fourier spectrum of water level record from February 2018 until July 2018.*

### 3.2. Temperature records

Temperatures were recorded continuously since July 2017 at Ajameti, Georgia and data series for depth levels of 100m, 175m and 250m are reported by Jimsheladze et al (2019). Records for time periods from February 2018 until July 2018 and from December 2019 until January 2020 have been selected in order to demonstrate temperature variations from winter until summer. Buntebarth et al (2019) reported that the subsurface temperature is affected not only by the seasonal surface temperature variations but also by the earth tides and the water abstraction of vegetation. Taking these findings into consideration, two time periods were studied in detail, i.e. February/March which is represented by the dormancy period of vegetation and April during its growth phase. The nature of temperatures is shown in Figure 3 for the latter time period. The surface temperature is added to diagrams of subsurface variations at 100, 175 and 250m. The similarity between both records is evident at all depths. The average temperatures as well as the water level demonstrate a trend in both time periods. Figure 3 shows the similar features of the period, amplitude and phase.

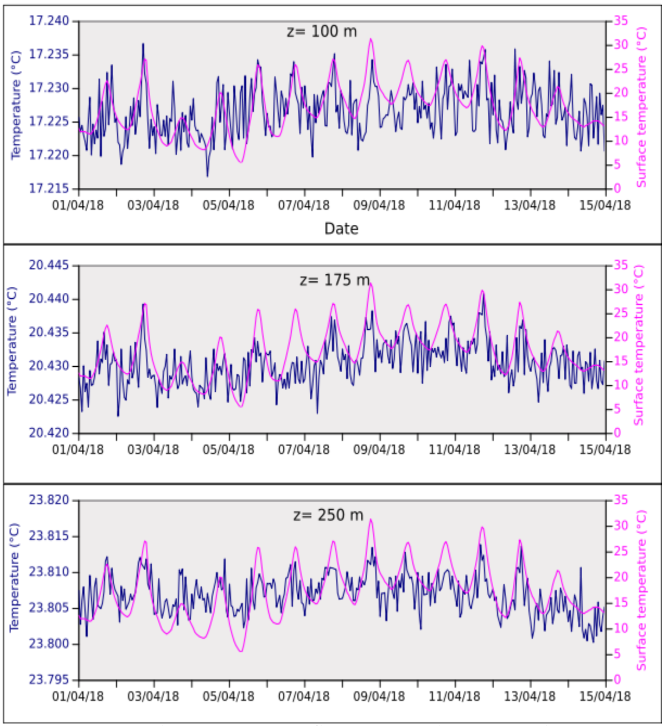

*Figure - 3 The temperature fluctuations during April 2018 at different depths and at the surface.*

A summary of the linearized trend for the periods of several weeks is given in Table 2. The mean temperature gradient for the depth interval of 100 m to 175 m is 0.0427 K/m and 0.0451 K/m for the depth interval of 175 m to 250 m. In order to analyze relationships between the characteristics of the records the standard deviations of the daily temperature averages at a given depth were calculated. It demonstrates that the variation depends on the depth. The largest average value occurs at depth levels of 100 and 175 m with maximum related to the amplitude of the daily surface temperature changes. The standard deviation is selected to avoid weights of single spikes.

*Table 2 - Linear trends for selected time periods.*

| **Description** | **February/ March 2018** | **April 2018** |
|---|---|---|
| Surface temperature ΔT (°C) | 1.5 | 5 |
| Water level changes (m)<br>19/02/18 - 6/03/18<br>7/03/18 - 11/03/18 | 0.2<br>-0.2 | 0.15 |
| ΔT (°C) at 100 m<br>Equivalent water rise (m) | 4.5<br>0.11 | 3<br>0.07 |
| ΔT (°C) at 175 m<br>Equivalent water rise (m) | 4.5<br>0.11 | 3.5<br>0.08 |
| ΔT (°C) at 250 m<br>Equivalent water rise (m) | -0.8<br>-0.02 | -1.5<br>-0.03 |

The variation of daily standard deviation with respect to the time of measurement is illustrated in Figure 4a. It demonstrates that the variation depends on depth. The fluctuations have larger magnitudes at 100m but relatively less at 175m. Even smaller variations are recorded at 250m. The surface temperature variation is plotted with respect to the daily standard deviation in Figure 4b. As deduced from Figure 3, the surface temperature affects the measured values directly. The slope of the regression line is largest at 100m, relatively smaller at 175m and practically no effect at 250m. Figure 4c indicates that scarce rain occurred at the beginning of April only.

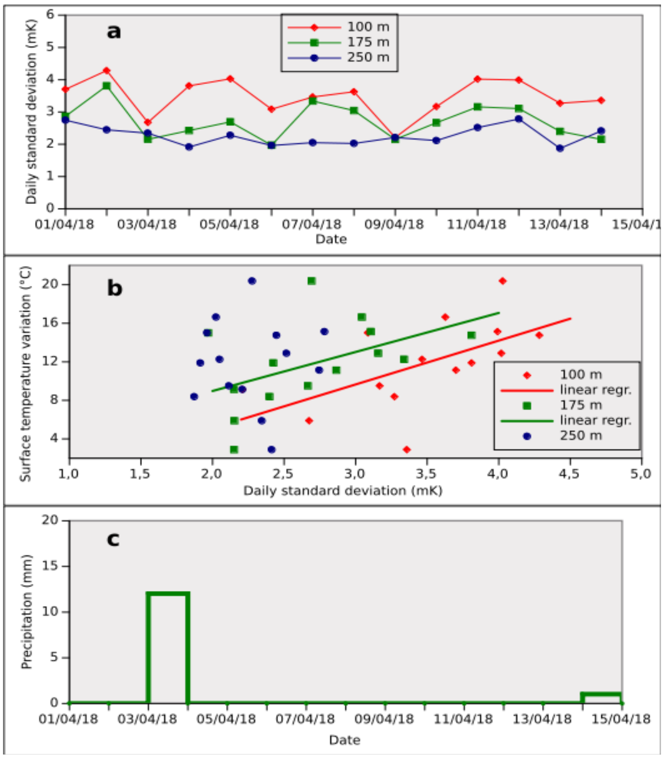

*Figure 4 - a) Daily temperature variation in April 2018; b) with respect to the surface temperature and c) the precipitation in April 2018.*

Records of further time periods were analyzed for getting additional information as to the impact of the surface temperature. The periods chosen are from February to March 2018 and from December 2019 to January 2020.

Figure 5a illustrates the results of analysis of the first time period. The scatter of the daily standard deviation is small and the features that the average daily standard deviation is high at 100 m, moderate at 175 m and small at 250 m are confirmed. However, no effect of the surface temperature at larger depths could be detected during this period (Figure 5b). Frequent rainfalls occurred in March whereas only occasional ones were recorded in February (Figure 5c).

Figure 6 illustrates the results of analysis of records obtained approximately two years later. The temperature series at the depth of 100 m were analyzed to yield the daily variations from December 2019 until January 2020 (Figure 6a). The mean value is 3.1mK ±0.5mK, which is the same as that obtained two years ago. In spite of the remarkable impact of the surface temperature during April, no evidence of the down going surface temperature signal was found in recorded data for winter, as Figure 6b demonstrates. Figure (6c) reveals that strong rainy events that occurred during the period of registration had very little impacts in the temperature records.

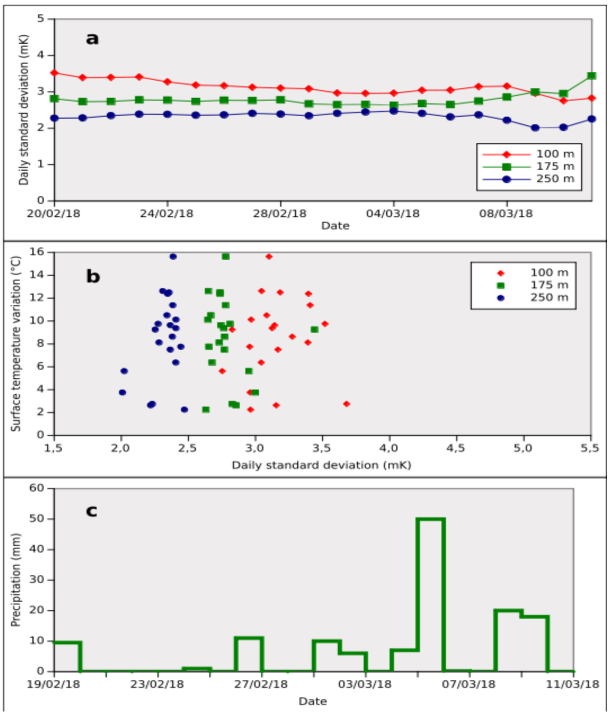

*Figure 5 - a) Daily temperature variation in February/March 2018; b) with respect to the surface temperature and c) the precipitation in February/March 2018.*

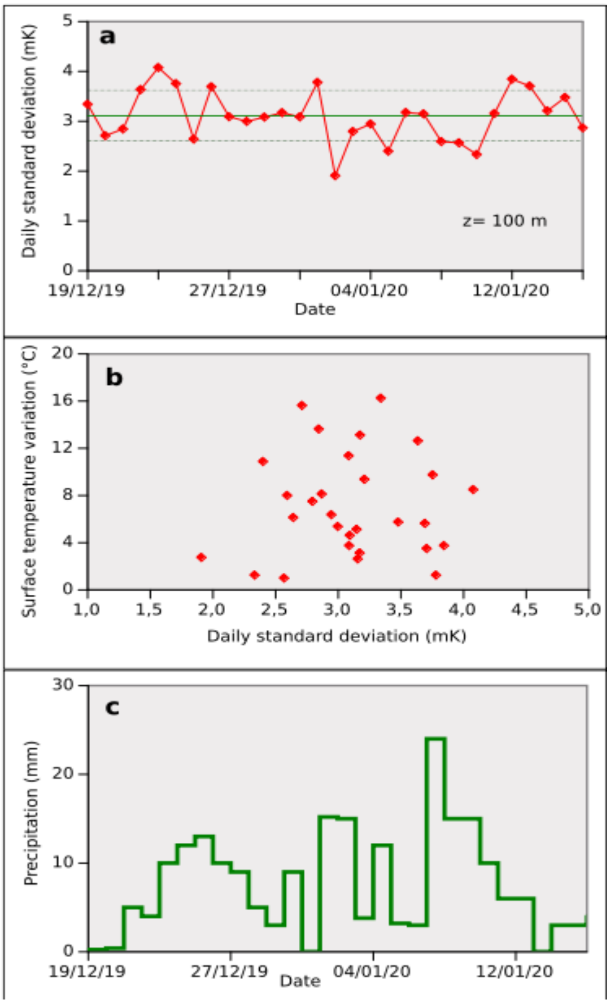

*Figure 6 - a) Daily temperature variation in December 2019 and January 2020; b) with respect to the surface temperature and c) the precipitation in December 2019 and January 2020.*

A Fourier analysis was carried out of the results of the data series for the period of February/March and April. The results presented in Figure (7) revealed for the first time the presence of a remarkable diurnal signal in records at depths of 250m, but it is weak at 100m and 175m.

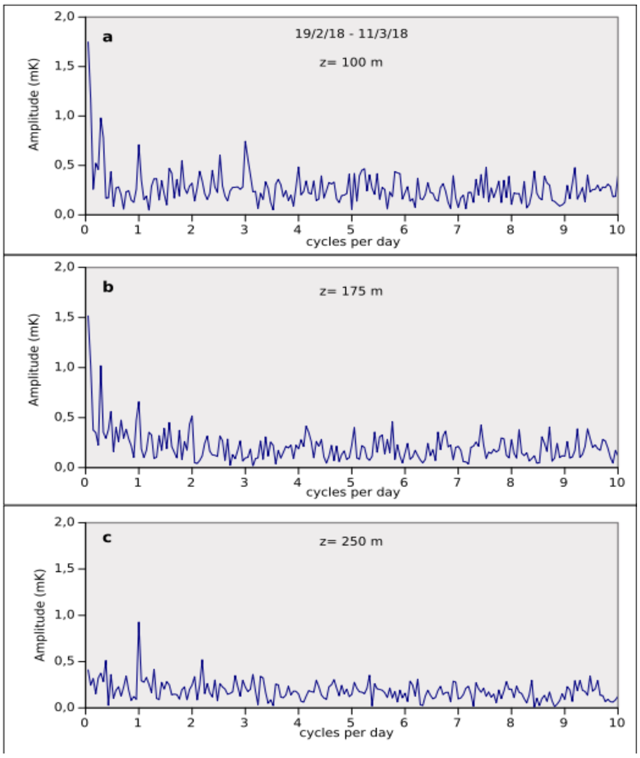

*Figure 7 - Fourier spectrum of temperature record in February/March 2018 at the depth: a) 100m, b) 175m and c) 250m.*

The diurnal signal is significant at all depths in April, but the semi-diurnal one is visible at 100m and 250m only. It is not visible at 175m (Figure 8).

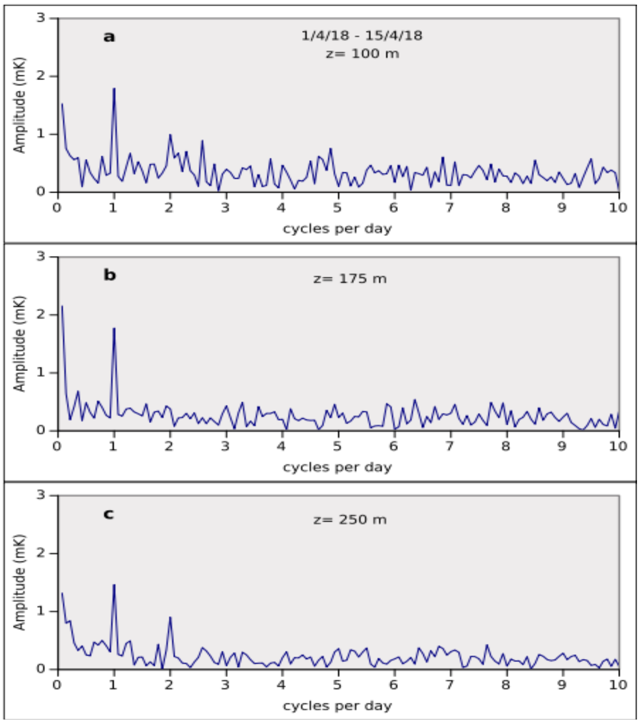

*Figure 8 - Fourier spectrum of temperature record in April 2018 at the depth: a) 100 m, b) 175 m and c) 250 m.*

## 4. Discussion

The sun-moon-earth gravitational forces are often considered as responsible for water level changes at the subsurface. Buntebarth et al (2019) reported associated temperature fluctuations generated by earth tides. The temperature variations at the subsurface are believed to be related to the changes in volume strain. The volume strain at the borehole location is displayed in Figure 2a. It shows that the strain has a minimal value on 8th April at half-moon and highest value occurs at full or new moon. It also shows the variation of the semi-diurnal period of the strain which varies from weak to nearly the same strength as the diurnal period. This feature is also expressed in the frequency spectrum of Figure 2b. The water level changes (Figure 1b) relates to the strain changes, but the variation of amplitudes is different. The ratio of the amplitude of the diurnal to the semi-diurnal period of the water level is smaller than expected (Figure 2a, c). The height of the daily water level variation has a mean value of 0.03 m at both time intervals (Table 1). The temperature variation may be differentiated between both time periods. The division is based on the dependence of variations with respect to the surface temperature. The daily temperature fluctuation varies with the surface temperature at the time when the growth phase of vegetation starts (Buntebarth et al. 2019). The increasing demand of water by vegetation seems to cause water movement from greater depths. The transmissivity of subsurface layers seems to allow water flow from depths greater than 100 m. No effect of the surface temperature variation on the subsurface temperature can be noticed at 250 m depth.

The effect of water flow related to earth tides-based variations can be detected in the Fourier spectrum (Figures 7, 8). The diurnal period becomes more important in relation to semi-diurnal one in April than for the period of February/March. It is possible that the radiation of the sun causes an additional need of water and increases the amplitude of the diurnal period. These evidences support the hypothesis that at the start of the growth phase, which is initiated by the radiation of the sun and which results in transpiration of vegetation, water is abstracted from greater depths. The height of the diurnal temperature variation can be translated into a vertical variation of the water in the well by applying the measured temperature gradient. The height of the water fluctuations can be read from Figure 5. Temperature gradients of 0.0426K/m at 175 m and 0.045K/m at 250 m were applied. The annual mean surface temperature is ca. 13°C and the temperature is 17.2°C at 100 m, so that the mean temperature gradient is 0.042K/m down to 100 m. The resulting fluctuation of the water movement is estimated in Table 3. A general decrease of the daily water level fluctuation is recorded from 100 m to 250 m below the subsurface during February until April 2018. Whereas the daily fluctuation ranges from 20 % to 30% in February/March, it rises from 40% to 70% in April (Table 3).

This behavior reassures the assumption that the radiation of the sun becomes more importance for the fluid flow during the growth phase of vegetation. The season independent decrease of the estimated vertical water fluctuation between 100m and 250m can be explained with a possible increase of transmissivity with depth in partially non-cased borehole. The well properties need to be checked in future works. The water level fluctuation has lower amplitudes than the estimated values from the temperature variation. The water level has a free movable surface, i.e. an additional degree of freedom which underlies different hydrological conditions. This free surface is also sensitive to frequent precipitation as Figure 9 demonstrates.

*Table 3 - Double standard deviation of daily temperature fluctuations (in milli Kelvin).*

| Period | 100 | 175 | 250 | depth (m) |
|---|---|---|---|---|
| February/March 2018 | 7.4 | 6.9 | 4.9 | maximum |
| | 5.5 | 5.3 | 4.0 | minimum |
| | 6.3 | 5.6 | 4.6 | average |
| | 30 | 29 | 20 | scatter (%) |
| April 2018 | 8.6 | 7.6 | 5.6 | maximum |
| | 4.4 | 3.9 | 3.9 | minimum |
| | 7.0 | 5.4 | 4.5 | average |
| | 60 | 69 | 38 | scatter (%) |

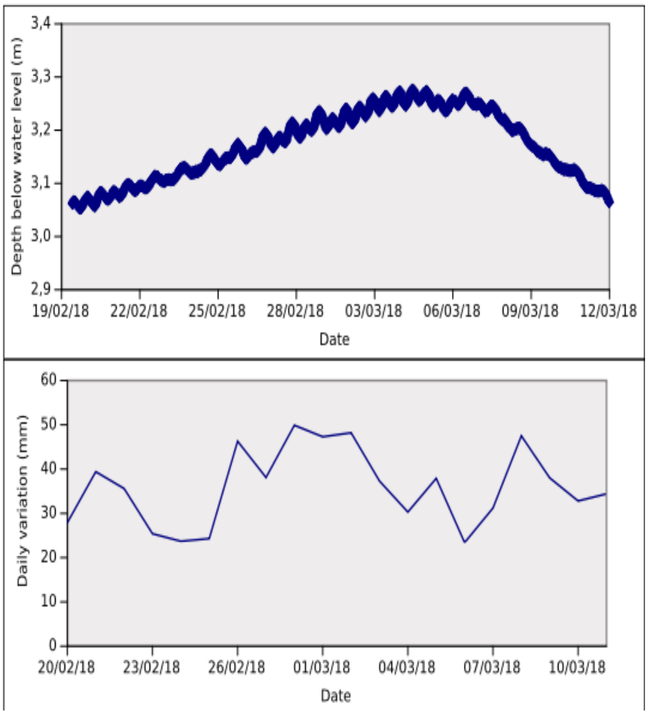

*Figure 9 - Water level variation during February/March with its daily amplitude.*

The casing efficiency of the well must also be incomplete as the presence of impacts at very strong rainfalls indicate. The meteoric water may be flowing into the borehole between the surface and the depth of 100 m (Jimsheladze et al. 2019). Individual temperature measurements show a high scattering (Figure 3) which decrease from 100 m to 250 m and reaches peak to peak amplitudes of 6mK. The scattering seems to be specific for each well and depth interval. As reported by Buntebarth et al. (2019), the scatter can reach amplitudes of 0.3mK during winter and rises to 2mK in summer at the subsurface. Some scatter might be caused by instruments. However, high amplitudes are generated by other processes. A likely effect is the vortex build-up of ascending gas bubbles in the well. The bubbles grow during ascension due to decreasing pressure and cause an increasing vortex build-up.

## 5. Conclusions

The subsurface temperatures are sensitive to earth tides at depths down to 250 m. These have amplitudes of a few milli-Kelvin as ascertained with results of analysis of the frequency spectrum. It demonstrates the diurnal as well as the semi-diurnal period of the volume strain caused by the variation of gravitational forces. The radiation of the sun contributes to an additional diurnal water fluctuation during the growth phase of vegetation which can be detected down to 100 m, but it is missing at 250 m. Applying the known temperature gradient, the temperature variation can be translated into a vertical water movement which reaches 0.1 m at the depth of 250 m. It rises to 0.13 m at 175 m and 0.16 m at 100 m. The increase is higher during April than in February/March, but the general characteristics remain. The effect of transmissivity needs to be explored in further detail. The water level variation indicates the lower average variation of 0.03 m. The discrepancy is due to the free surface of the water level and varies with the location. Frequent precipitation changes the depth of the water level but does not affect the temperature at greater depth which supports an independent movability.

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