Author comments to the reviewers:

Potsdam (Germany), the 20th of September 2021

Dear colleague,

Thank you for your time and effort in reviewing our publication. Your input and suggestions are valuable to us. Below, you find our replies (in grey) to your comments (in black).

Best regards,

Martin Lipus

Reviewer 2:

This manuscript reports interesting observations in a borehole with DTS and DAS, which includes sucker rod contraction and sudden contraction events. The sudden contraction events on the DAS records during the first 72 minutes of cold-water fluid injection are reported. A friction force model was proposed to explain the mechanism of vibration events instead of the microseismic event. General speaking, it provides very useful information. The following is my comments.

Section 2.

Eq 1 should be in "2.1 derivation of strain from Distributed Temperature Sensing" rather than "2.3 Deformation balance …".

Agreed. The explanation of the method and the related equation are placed in succession to improve readability. We added the equation closer to the DTS description.

"2.2 Direct measurement of strain via DAS". iDAS measures the strain rate instead of strain. Was any high pass filtered applied to the raw data?

No high pass filtering was applied to the raw data. We have added a sentence to clarify. At the end of 2.2 Direct measurement of strain via DAS now reads:

"No additional filtering was applied in post-processing (no high pass and no low pass filtering)."

"2.3 Deformation balance from DTS and DAS measurements". This section includes how to compute strain from DTS and obtain strain from strain rate records, which is not strongly related to the "balance". It may be better to merge with section 2.1 & 2.2.

To improve the readability of the method section, we restructured the method part. The subchapter 2.3 Deformation balance from DTS and DAS Measurements" was removed from the manuscript. Instead, it was merged with section 2.1 and section 2.2.

Eq. 5, the applied force Fapp is used in this study instead of the stress.

Thank you for pointing this out. You are correct, it makes more sense to introduce the applied force Fapp instead of the stress. The text is changed accordingly.

"2.4 Event detection and picking" looks not related to the other sections.

We have changed the title of the subchapter to anticipate the significance of this additional tool for the analysis of the fiber-optic recording. It now reads:

"Stick-slip event detection and picking"

Section 3.

Line 290-295, the difference between strain_DTS and strain_DAS looks relative to the inclination angle. It may be worth to make a figure showing this difference and inclination angle. Adding some discussions about this phenomenon is also useful. Another interesting observation is that difference at 01:18 is larger than the one at 02:08, especially between ~700m and 2800m.

That is an interesting observation. Thank you for pointing this out. Below, we computed the difference for strain_DTS and strain_DAS of Figure 4 (see Figure 4_review). The most prominent apparent relation between strain and borehole inclination is located at the top of the liner, where the inclination strongly increases in a downward direction from an angle of 42° at 2852 m MD to a value above 50° below 2950 m. This is already discussed in the manuscript. To make this point clearer to the reader, we have added the borehole inclination to the close-up plot in figure 4.

For the remaining differences in the fiber optic strain readings along the well path, we do not see a strong correlation to the borehole inclination.

However, we might make a statement about the strain differences of Figure 4_review with respect to time. The strain difference above 2800 m MD is higher at 01:18, because the cable is stretched to a maximum before the sucker rod events occur. Within the next 50 minutes (until 02:08), the sucker rod events lead to a relaxation of the cable and therefore the strain difference reduces.

For the depth interval below 3100 m, please see the following comment.

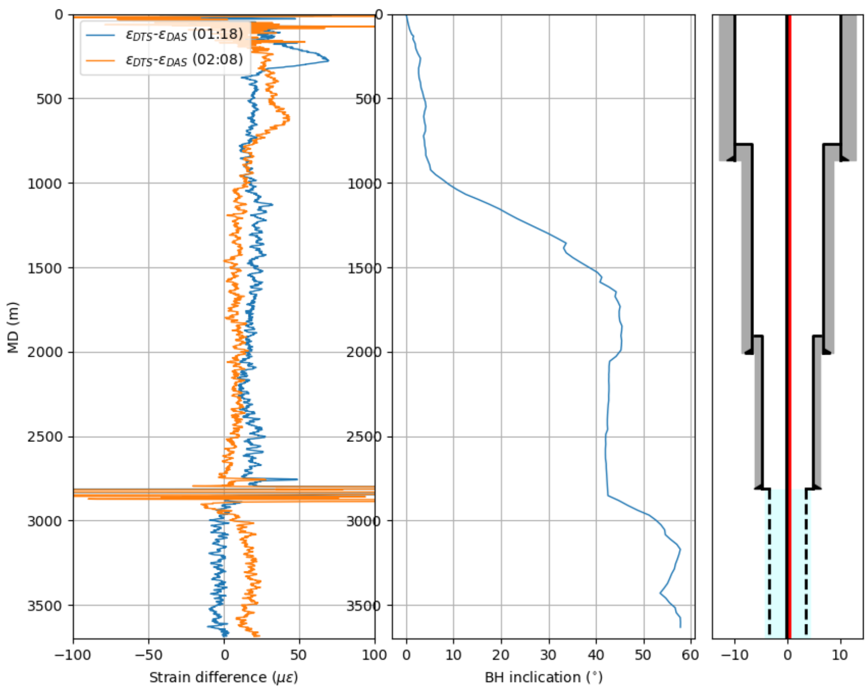

Figure 4_review: Strain differences between DTS and DAS

On the 2nd subplot of the Figure 4, the differences between strain_DTS and strain_DAS below the 3100m MD are quite different at 01:18 and 02:08. At 02:08, the strain_DTS is positive while the strain_DAS is close to zero. Such difference is not observed on the data at 01:48. Any clue?

Thank you for spotting this. We overlooked this phenomenon in this depth interval. We carefully checked the DTS data and found that for the deeper part of the well (deeper than 3100 m MD), a constant offset in the DTS profiles by about one degree Celsius in subsequent measurements is present. Such offset is not observed in the shallower part of the well. Also, no anomaly is observed in the P/T gauge data from 2750 m MD and no anomaly is observed in the DAS data. We speculate that the temperature anomaly is related to the processing of the DTS data. DTS temperature was measured in a double-ended configuration. A temperature profile is created by overlaying the DTS signal from both directions which are measured consecutively for both fiber branches. Close to the folding location (at the bottom of the well), an asymmetry in the temperature reading was observed between both fiber branches, which does not seem to be caused by any fluid motion. Averaging this difference between both branches led to a temperature offset. This offset was only visible if strong temperature changes were observed in the upper part of the well.

Was:

"Between 2900-3100 m MD, the temperature difference between the two DTS profiles rapidly decreases (see Figure 4, 1st and 2nd subplot). Hence, in this lowest depth region of the well, no thermal contraction is expected."

Now reads:

"Between 2900-3100 m MD, the temperature difference between the two DTS profiles rapidly decreases (see Figure 4, 1st and 2nd subplot). At 02:08, the DTS profile shows slightly increased temperatures (+1 °C) with a constant offset from 3100 m to the end of the cable compared to the DTS profile at 01:18. This leads to a constant offset of a positive expected strain ε_{DTS}. The measured strain ε_{DAS} shows no offset in this depth interval."

A paragraph was added to the discussion:

"The constant temperature offset by +1 °C in the DTS profiles from 02:08 (relative to 01:18) in the depth interval from 3100 m MD to the end of the cable is unlikely to be caused by any fluid movement. While DTS temperature measurements did show a variation, no additional offset was recorded from the measured strain εDAS. This could mean that the rod builds up thermal extensional stresses without actual movement taking place (εDTS > 0 εDAS = 0). However, we speculate that the temperature anomaly is related to the processing of the DTS. DTS temperature was measured in a double-ended configuration. A temperature profile is created by overlaying the DTS signal from both directions which are measured consecutively for both fiber branches. Close to the folding location (at the bottom of the well), an asymmetry in the temperature reading was observed between both fiber branches, which does not seem to be caused by any fluid motion. Averaging this difference between both branches led to a temperature offset. This offset was only visible if strong temperature changes were observed."

Since both section 3.2 and 3.3 reported sudden contraction events, it is possible to merge together.

That is true. We have merged section 3.2 and section 3.3. Because these chapter are already quite extensive, we have added two sub headers in the new section 3.2 "Event description" and "Event detection over time".

Line 320. It is not easy to see precursors and successors on the Figure 6. Add marks on the Figure 6?

The statement that precursors and successors are also present in the events in Figure 6 is somewhat misleading and inaccurate. It is only clearly visible in the subplot Figure 6 B. The text was changed accordingly to clarify.

Now reads:

“Precursors and successors can also be observed in the examples in Figure 6 (in particular in Figure 6 B), yet the events shown here are distinguished by the fact that their upwards propagation extends beyond the noisy reservoir section.”

As shown in Figure 8, some STA/LTA detections are outliers. How to determinate the origin time of each event and the origin depth? Another interesting parameter is the strength of event. Does the stronger event have stronger spatial extend?

Looking at all sucker rod events as a whole within the first hour of fluid injection, their appearance and shape is highly variable. As accurate automated picking was out of scope for this study, the picking of the depth and shape was done manually by displaying each 30 seconds of raw DAS data recording overlaid by the trigger start and end marker as shown in Figure 8. The onset time/depth location was picked at the based on the moveout of the signal towards top and bottom. The upper and lower boundaries are picked when the Sta/Lta stops to trigger.

Section 2 rework:

2. Data Analysis

The analysis in this study is based on the comparison of strain derived from fiber-optic distributed temperature sensing (DTS) on the one hand and distributed acoustic sensing (DAS) on the other.

2.1 Derivation of strain from Distributed Temperature SensingDTS

DTS uses each location of a glass fiber as a sensor for temperature (*Hartog, 1983, Hartog and Gamble, 1991*). This is achieved by coupling laser-light pulses into a glass fiber and analyzing the Raman spectrum of the backscattered light whose origin along the fiber is determined by the two-way travel time of the light. In this study, we use a system based on Raman backscatter. Temperature profiles were acquired every 10 minutes with a spatial sampling of 0.25 m. Detailed information about the performance of the fiber-optic system and the calibration procedure are presented in *Schölderle et al., 2021*.

We calculate the change in temperature from DTS at the start of fluid injection and the profile later during fluid injection. From the temperature change ΔT, a theoretical thermal contraction of the rod is calculated by multiplying ΔT with the thermal expansion coefficient α_{rod} of the rod. We compare this theoretical thermal contraction with strain information inferred from DAS measurements along the rod. We then use the DTS data to compute stresses along the rod which occur due to cooling.

2.3 Deformation balance from DTS and DAS measurements

From DTS measurements we may predict themothermo-mechanical deformation according to

$$\varepsilon_{DTS}(x) = \alpha_{rod} \cdot \Delta T(x) \qquad (1)$$

where α_{rod} is the thermal expansion coefficient and ΔT(x) is the temperature difference at two subsequent points in time at some location x of the fiber. The rod construction as a whole consists of many different materials with different thermal expansion coefficients, such as the sensing fibers, gel filling, metal tubes, polypropylene mantle, steel rod and nylon centralizers. However, the steel of the sucker rod and the steel of the fiber--optic mantle are the dominant material by weight and the most relevant for any thermal stresses. The sucker rod consists of 4332 SRX Nickel Chromium Molybdenum steel with a thermal expansion coefficient of 10 - 13 µϵ/K (*Hidnert, 1931*) and a modulus of elasticity of 200 GPa (*T.E. Toolbox, 2012*). The second most dominant material is the polypropylene cable mantle with a modulus of elasticity of 1.5-2 GPa (*T.E. Toolbox, 2012*). The proportion of steel on the thermal stresses in the rod construction are 99.8%. For simplicity, we assume that thermal expansion coefficient α_{rod} = 13 µϵ/K for the sucker rod / fiber-optic cable construction and neglect the other materials. In our study, DAS data is acquired at 10000 Hz and down-sampled to 1000 Hz

2.2 Direct measurement of strain via DAS

Similar to DTS, DAS also analyzes the back scatter of light coupled into a fiber from one end. Upon contraction or dilatation, the strain-rate of the fiber, i.e. the temporal derivative of relative change of length, can be derived from the temporal change of the interference pattern of coherent light elastically scattered (Rayleigh scattering) from adjacent points within a certain interval of fiber called the gauge length (*Masoudi et al., 2013)*. The centroid of the gauge length is defined as a sensor node. The location (x) of a sensor node along the fiber is again determined by the two-way travel time of light from its source to the node and back. In our study, DAS data is acquired at 10000 Hz and down-sampled to 1000 Hz. The gauge length and spatial samping are 10 m and 1 m, respectively. No additional filtering was applied in post-processing (no high pass and no low pass filtering).

In contrast to DTS, DAS directly yields the temporal derivative of strain. In order to convert the measured strain rate $\dot{\varepsilon}$(x,t) data to strain $\varepsilon_{DAS}(x)$ at each location, we integrate in time:

$$\varepsilon_{DAS}(x) = \int_{t1}^{t2} \dot{\varepsilon}(x,t)dt \qquad (2)$$

where t1 and t2 delineate the time window and $\dot{\varepsilon}$(x,t) the recorded strain rate at position x. In the following we speak of “measured strain” ε_{DAS} in contrast to “predicted or expected” strain -ε_{DTS}.

We compare ε_{DTS} with ε_{DAS} measurements. We then use the ε_{DTS} data to compute the contractional forces along the rod which occur due to cooling. We compare the result with a static friction curve that was estimated from the sucker rod tally and borehole inclination.