Field Results from New Tensor Borehole Optical Fiber Strainmeter Installations in Oklahoma and Utah

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ABSTRACT

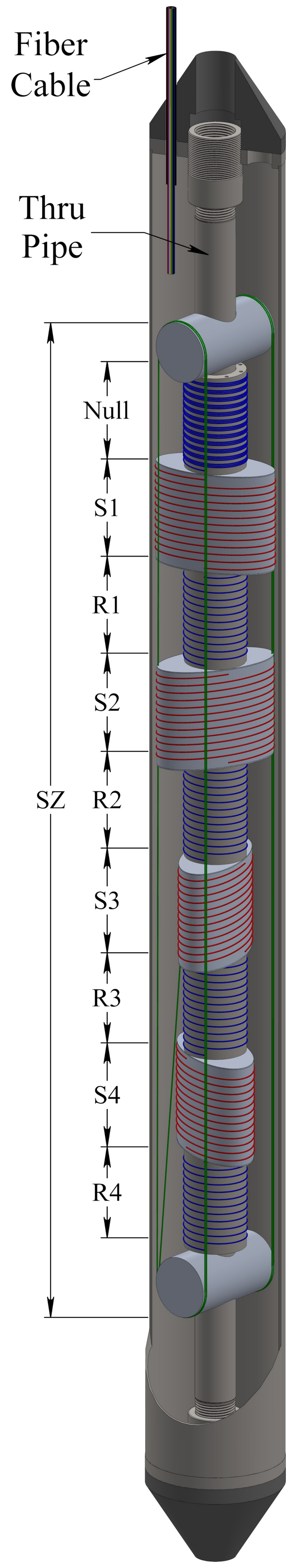
The time evolving strain field contains a wealth of information that can be used to interpret subsurface behavior. For example, injecting or removing fluids from reservoirs or aquifers causes deformation that can be used as a diagnostic signal in some cases, while it can interfere with geodetic interpretations in other cases. We've previously demonstrated the feasibility of measuring the strain tensor at a depth of 30m caused by injection into a reservoir at 530m. The observed strain signals were interpreted using four independent analytic and numerical methods that resulted in estimates of the poroelastic properties and geometry of the reservoir that was consistent with data from well logs. However, studies like these are only possible if these deformations can be reliably measured.

Years of lab and field work has culminated in the development of a novel borehole strainmeter capable of resolving multiple components of strain using embedded optical fibers configured as Michelson interferometers. It features four horizontal gauges separated by 45° to resolve the horizontal strain tensor as well as a vertical strain gauge and a sixth null component for state-of-health monitoring. The downhole sensing package also includes an open pipe through its center for grout circulation during single-trip deployments and a fully welded stainless steel exterior for robustness and longevity. These instruments have a resolution of $2x10^{-13}$ strain that can easily measure the solid earth tides.

Preliminary data are available from four strainmeters in shale at our Oklahoma site and four in compacted sand and gravel in Utah. These are deployed from 40-60m, except one of the strainmeters in Oklahoma is deployed at 500m. The data include strains from the initial grout curing, comparisons to predicted earth tide models and in-situ calibration results, barometric pressure admittances and spectral analyses as well as signals from underground injections and surface waves from teleseismic events. Preliminary analyses indicate behavior consistent with other strainmeter deployments, and comparison to data from a Gladwin strainmeter at the Oklahoma site validate the performance of the new design. Analyses from a suite of six well tests at the Oklahoma site show for the first time how the strain tensor field varies with location during well testing.

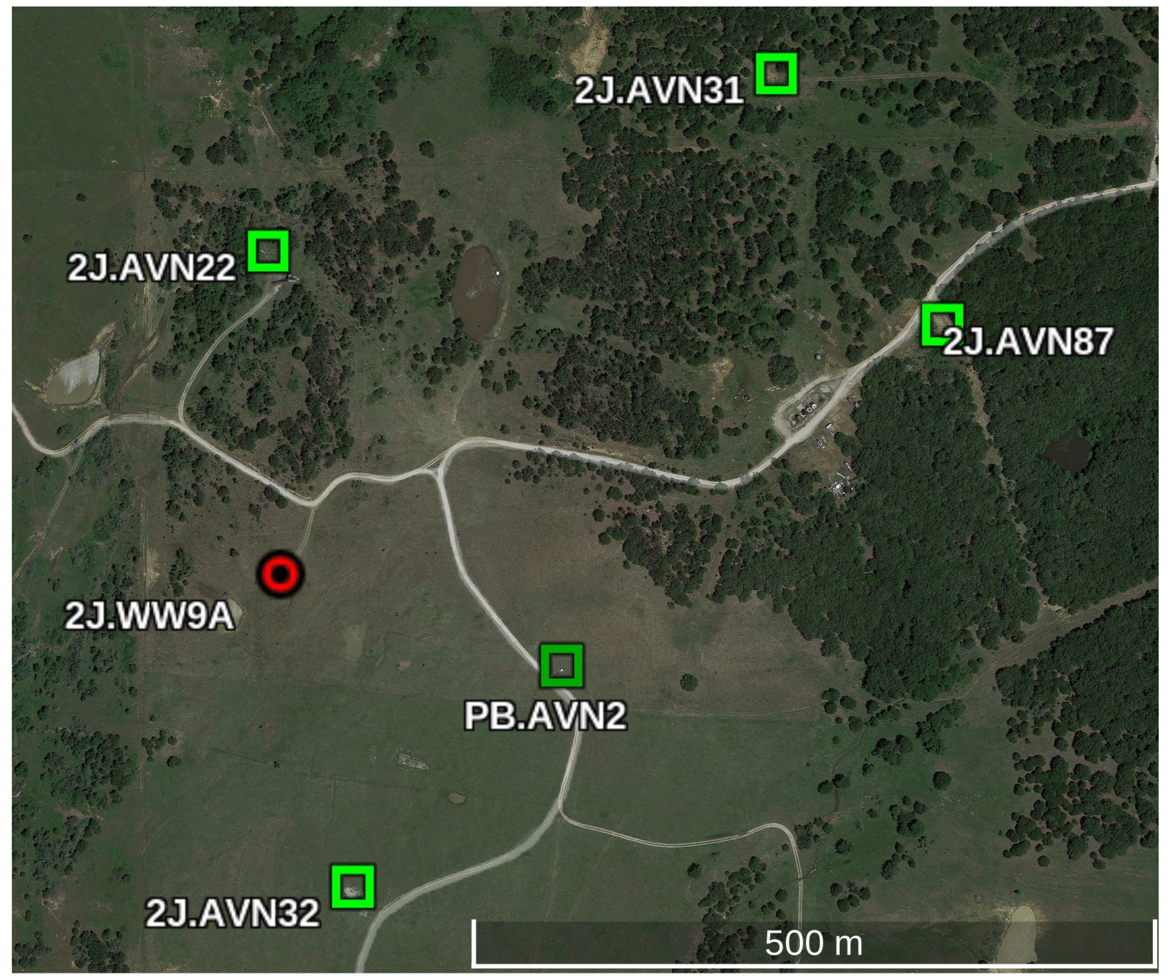
1. Elliptical Ring Tensor Optical Fiber Strainmeter

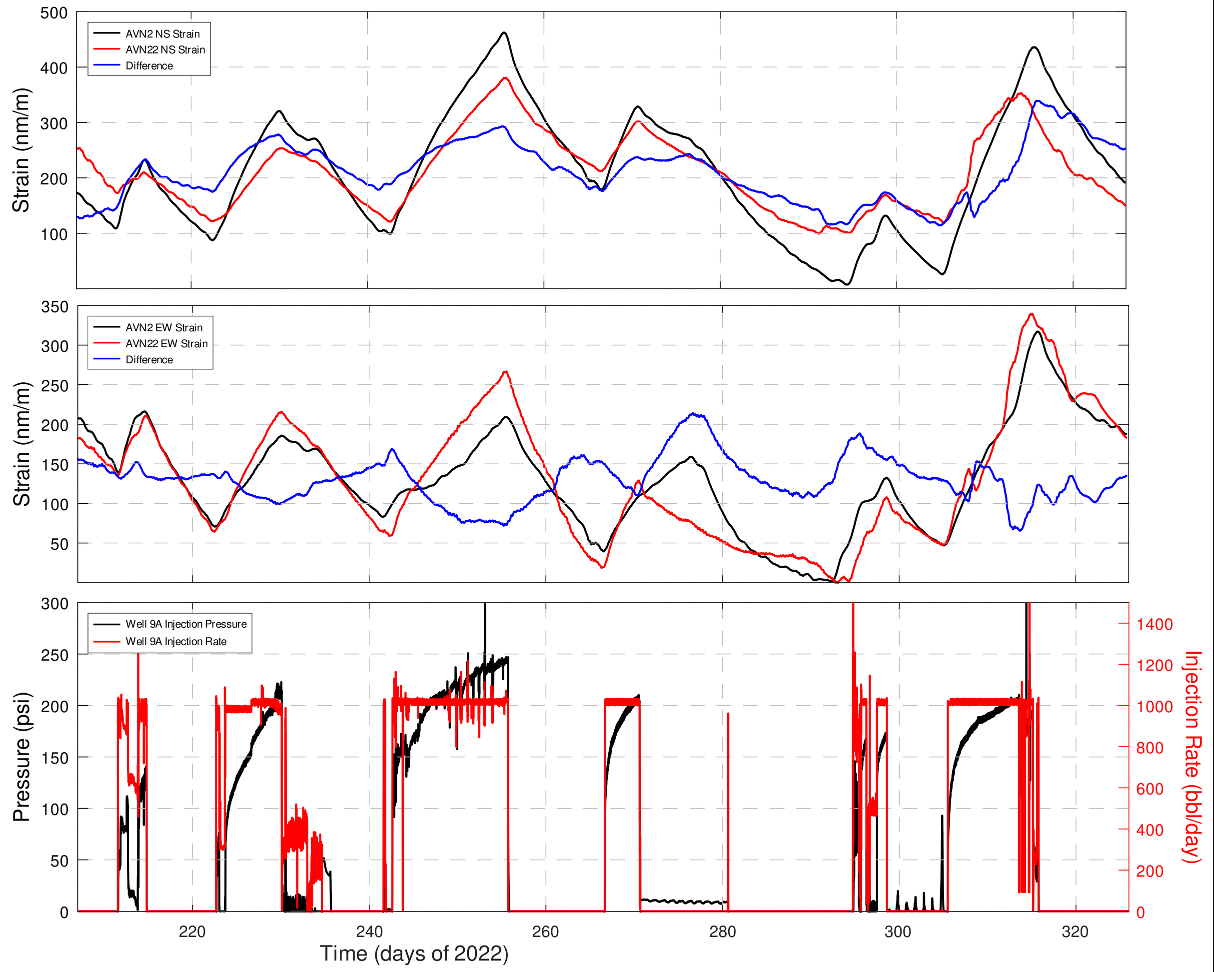
The optical fiber tensor strainmeter developed at Clemson University is now available commercially as the Tensor Sensor™ through our new venture Tensora, Inc. It features four stacked horizontal strain gauges, a dedicated vertical strain gauge and a standalone reference. It can be deployed wire, pipe or casing.

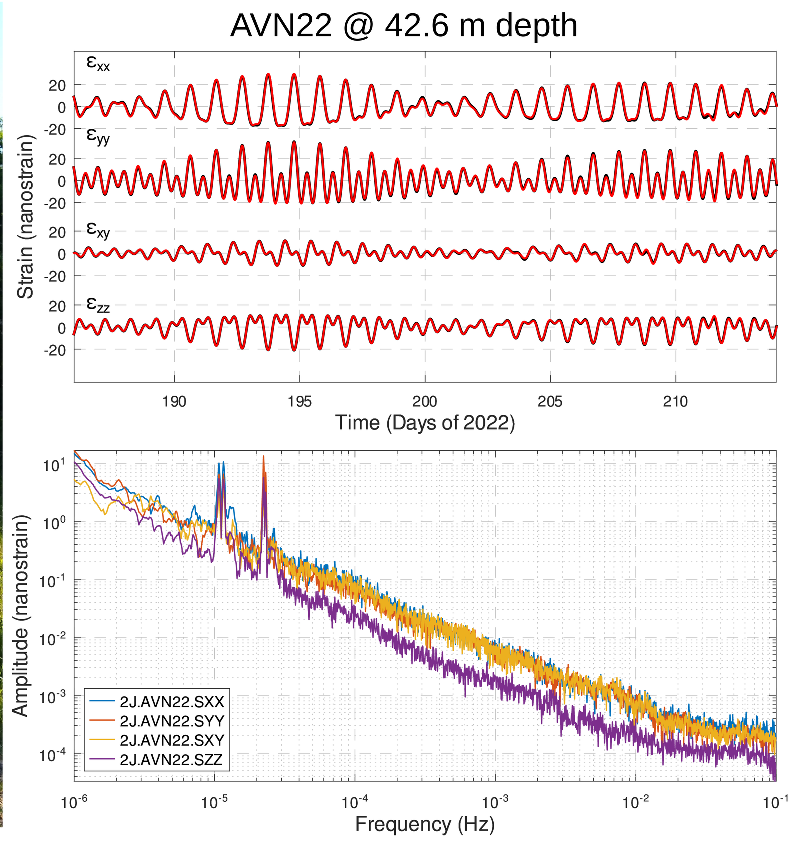


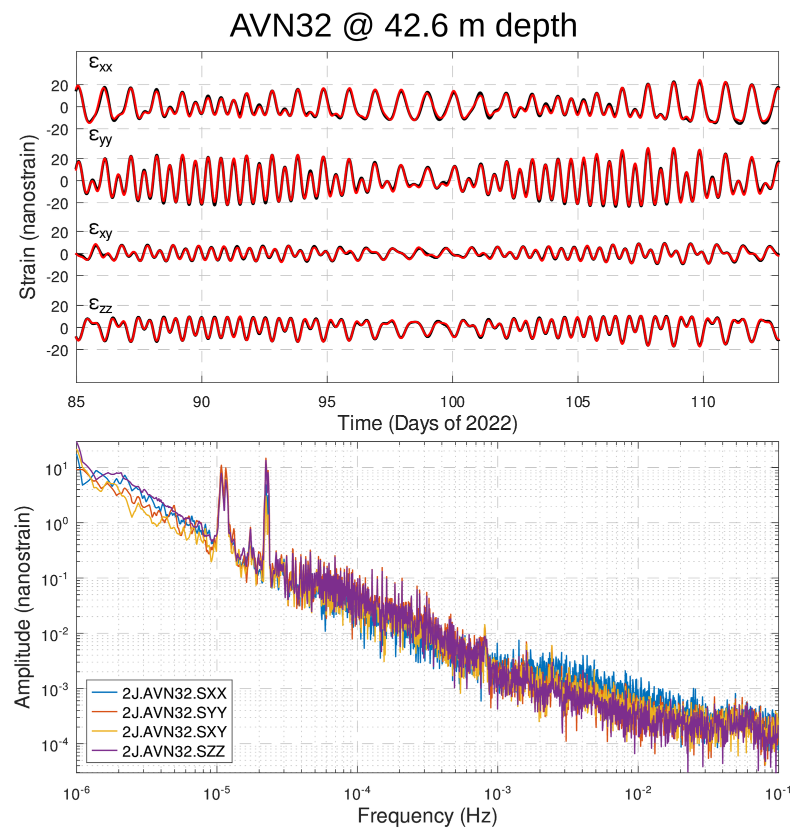
2. CO2 Injection Analog Site at the North Avant Field, Barnsdall, Oklahoma

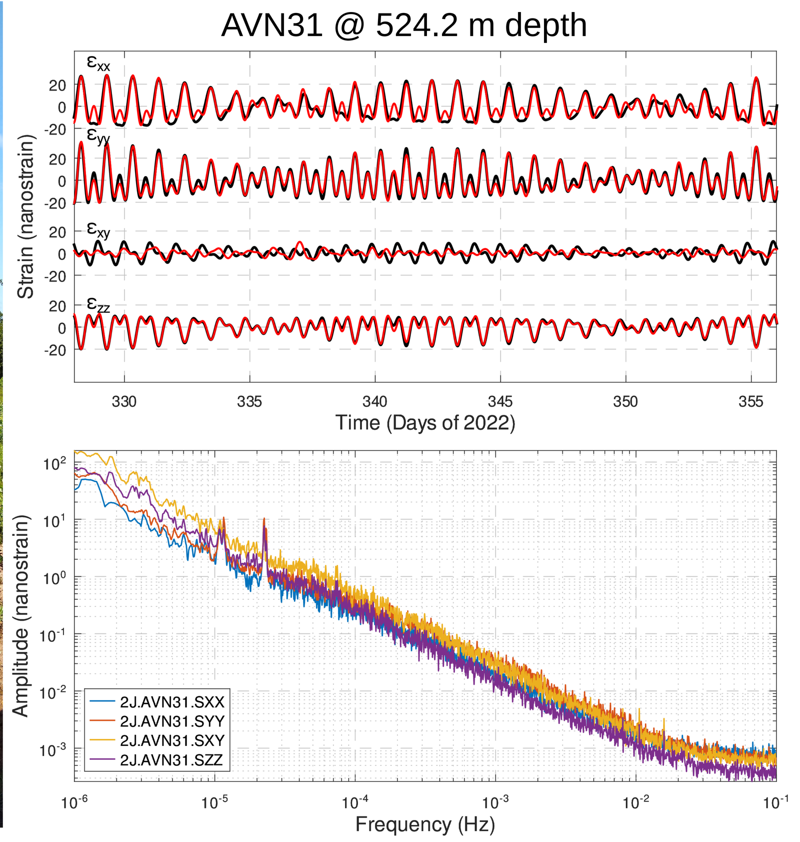
We deployed an array of four new Tensor Sensors™ in March of 2022 at our Oklahoma demonstration site and successfully monitored water injections into a nearby well 9A as an analog to geologic carbon storage. This built on our existing infrastructure that includes a Gladwin Tensor Strainmeter at well AVN2. Three were deployed at ~40m in new wells, and one was deployed at reservoir depth (~530m) in an existing well drilled over 100 years ago (AVN31).

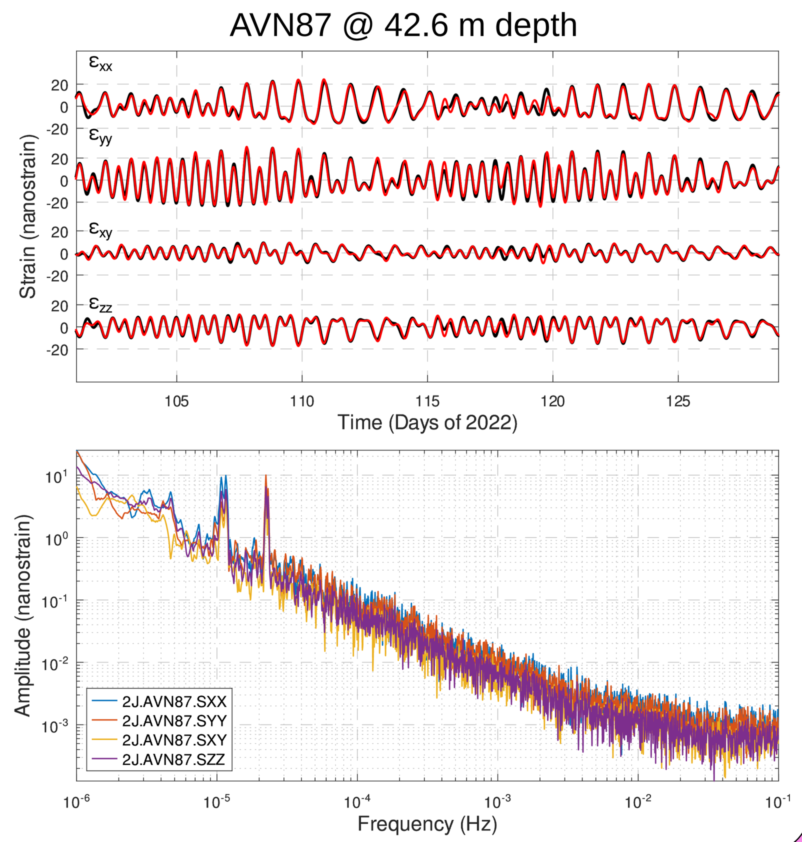






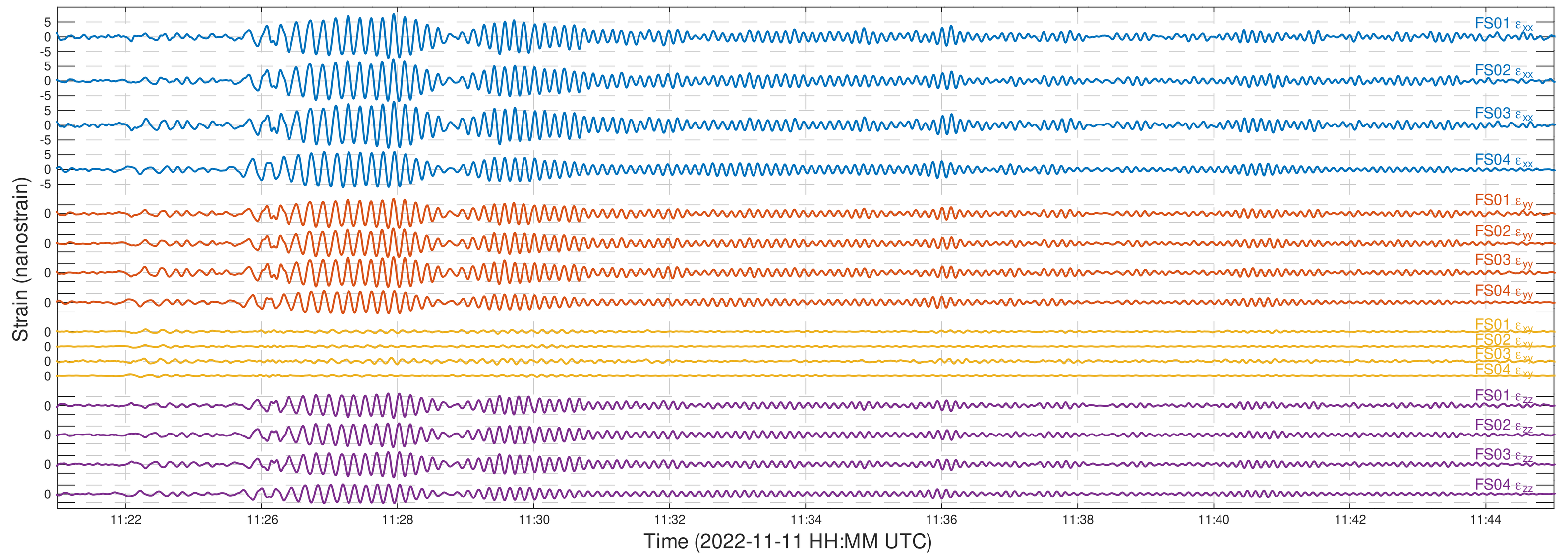


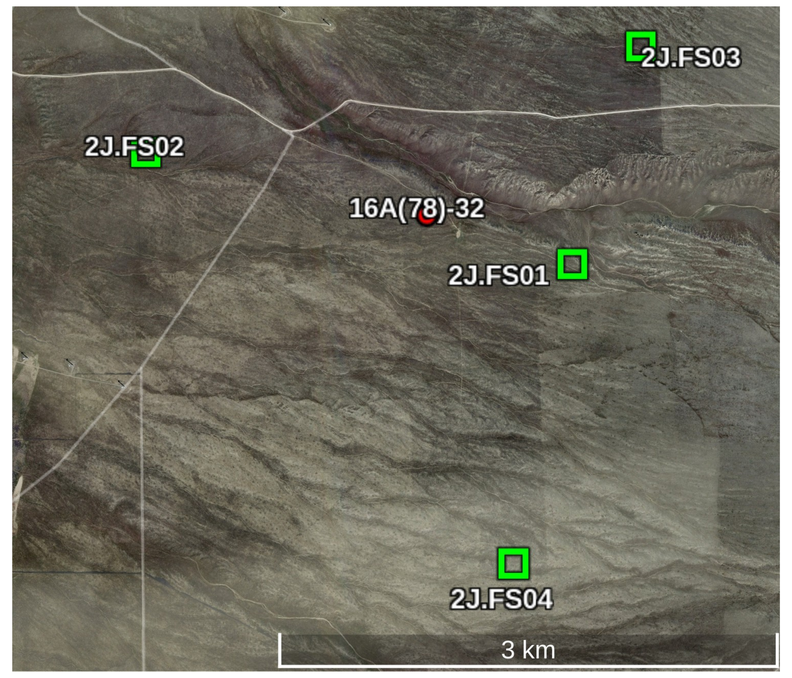


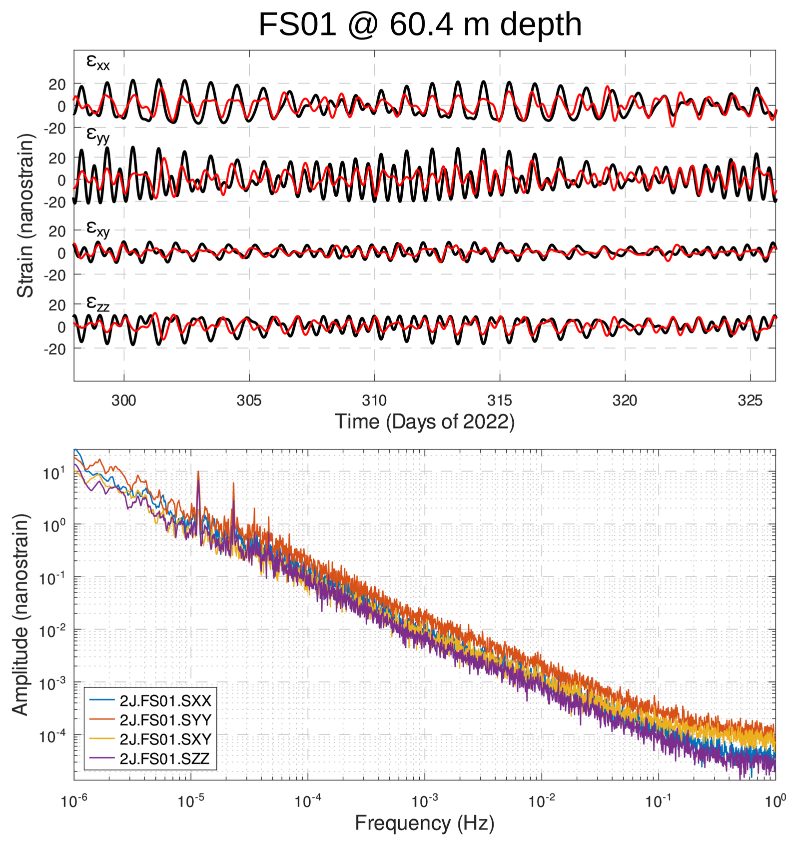


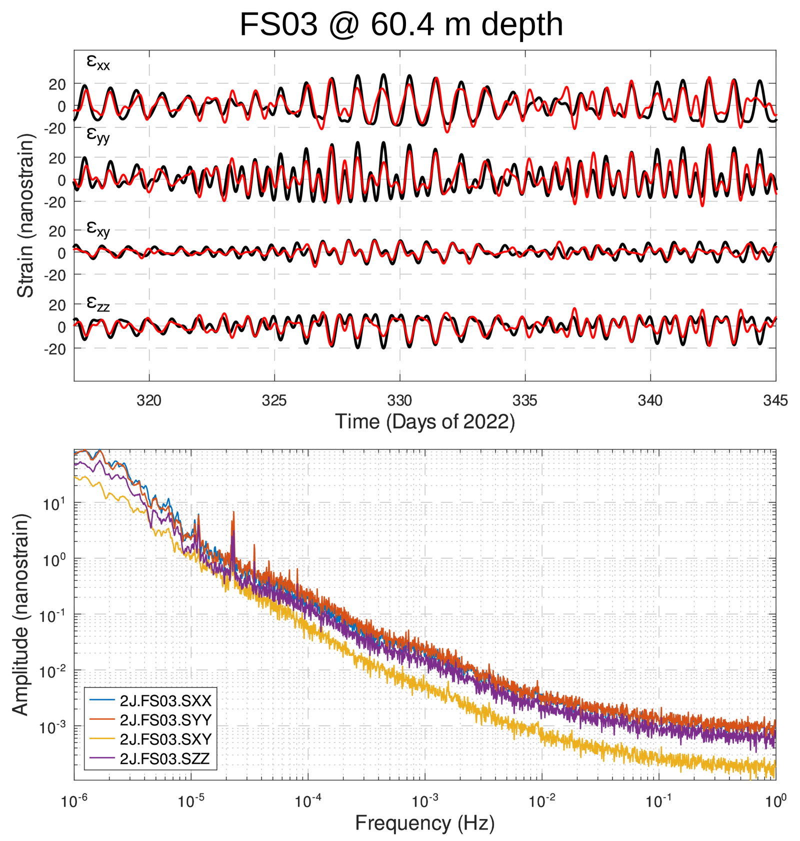
3. Frontier Observatory for Research in Geothermal Energy (FORGE) Facility, Milford, Utah

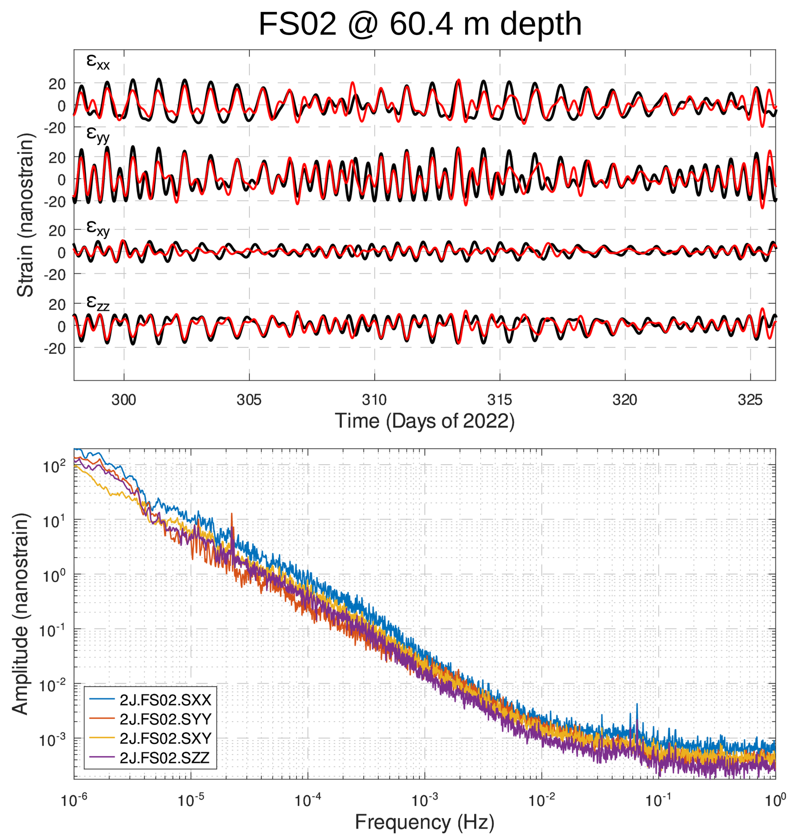
In February and October of 2022 we deployed an array of four new Tensor Sensors™ at the FORGE research facility to monitor strain changes from enhanced geothermal well operations. While the installations were successful, poor formation stability has prevented the detection of EGS signals.

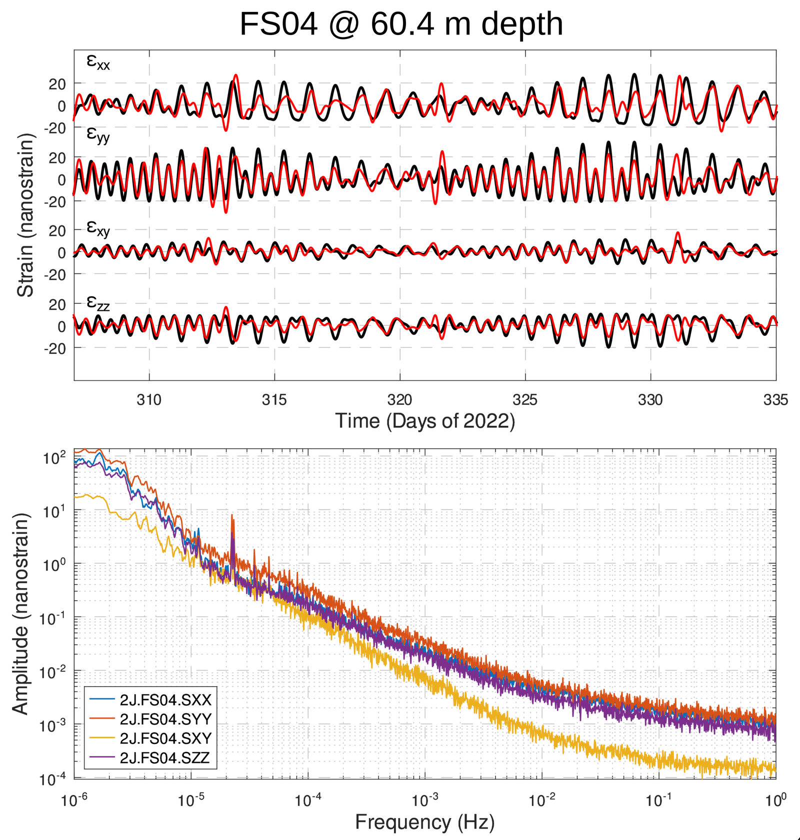












4. Conclusions

Two arrays of novel tensor optical fiber strainmeter were successfully deployed in Oklahoma and Utah

- Able to clearly measure tides, teleseisms and directional strains from subsurface fluid injections in Oklahoma
- Barely able to resolve the tides, but clear teleseisms in Utah
- Don't grout strainmeters into gravel

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