Time-lapse monitoring of saltwater disposal in Kansas and Oklahoma using ambient noise

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Summary

The substantial rise of seismic activity observed in both Oklahoma and Kansas from 2012-2016 has been widely linked to the similar increase in downhole injection of wastewater which occurred during that time. Injection of fluids into the subsurface is typically related to the extraction of hydrocarbons, and this study investigates the feasibility of using interferometric methods to monitor these activities, with encouraging results so far. Injection increases pore pressure in the reservoir, which expands and affects surrounding elastic stresses. Models which seek to quantify this change are often poorly constrained, and so spatial measurements of the subsurface response would be excellent progress towards understanding this socially and economically important issue.

Theory / Method / Workflow

Using roughly 2 years (Oklahoma) and 5 years of seismic data (Kansas) from two networks, we investigate regions which saw high levels of both injection and seismicity (see figure 1). We use cross-correlation and stacking to create reconstructions of surface waves of two types: 'reference' stacks which represent the average state over the entire study period, and 'snapshot' stacks which comprise 30 days of data and represent the state of the subsurface for that 30-day period (Wapenaar et al., 2010a). Cross-correlations between reference stacks and successive snapshot stacks gives the shift in the arrival times of the reconstructed surface wave; the changing subsurface velocity is calculated from measurements of this shift.

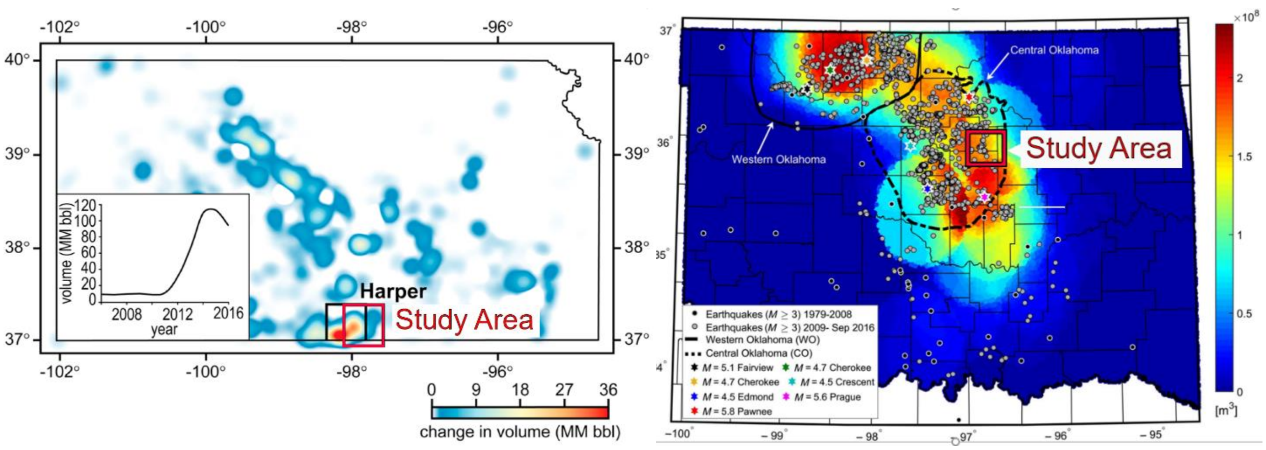

Figure 1: Study setting and locations in Kansas (left), and Oklahoma (left). Color scales refer to volumetric injection amounts, while symbols on the Oklahoma map denote seismic activity. Plots modified from Peterie et al., 2018 (left) and Langenbruch and Zoback, 2016.

We then compare the detected velocity variations to theoretical pore-pressure changes due to rainfall (Talwani et al., 2007), to look for correlations between seasonal rainfall, velocity change, and injection volumes. This will be useful as a first step towards creating corrections which may allow the effects due to injection activities to be imaged and monitored through time.

Results, Observations, Conclusions

Results from each station pair within a network are averaged to give a network-wide result. Figure 2 shows examples of individual station pairs from the Kansas network before averaging takes place and shows that while the magnitude of the signal varies, the signs are generally consistent.

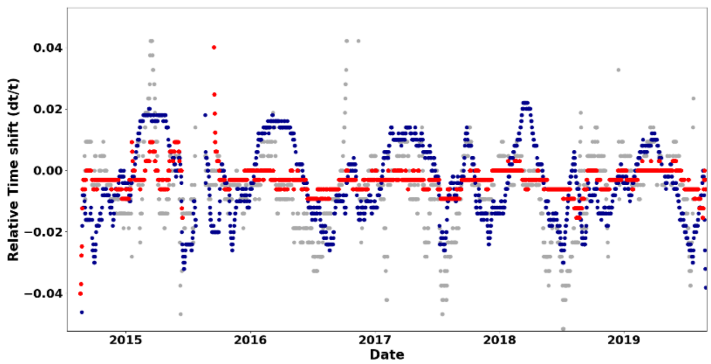

Figure 2. Weekly results of cross correlations between reference and snapshot stacks for three station pairs, for the Kansas network. KAN14:KAN13 in blue, KAN14-KAN01, KAN14:KAN05 in red and grey, respectively.

Final calculations show up to 5% yearly swing for the Kansas network, and a 1.5% change for the Oklahoma network. As seen in figure 3 and 4, the yearly velocity variations (black line in all plots) seem to be well correlated with seasonal rainfall (blue line in top plots), with several sharper shifts coinciding with larger-than-usual injection volumes (grey bars). Source frequency (green line) also

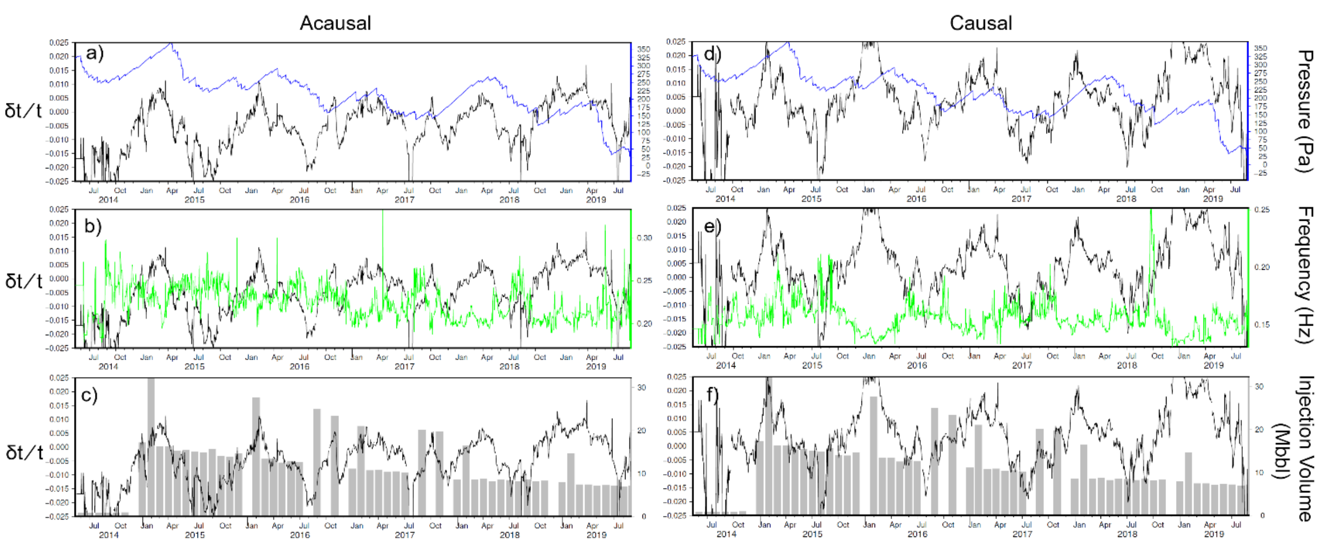

Figure 3. Final velocity variations through time for the Kansas network, compared to possible source mechanisms, for both the acausal (left) and causal (right) branches. Top plots compare to pore-pressure due to rainfall, middle plots compare to frequency of the peak of the power spectrum, lower plots compare to injection volumes for the area within 60km of the center of the network.

plays a role but the relationship is harder to determine at this point. Interestingly, the overall magnitude of injection volumes is much higher for Kansas, and so the correlating velocity shifts appear much larger as well, as can be seen by a comparing the lower panels in figure 3 and 4.

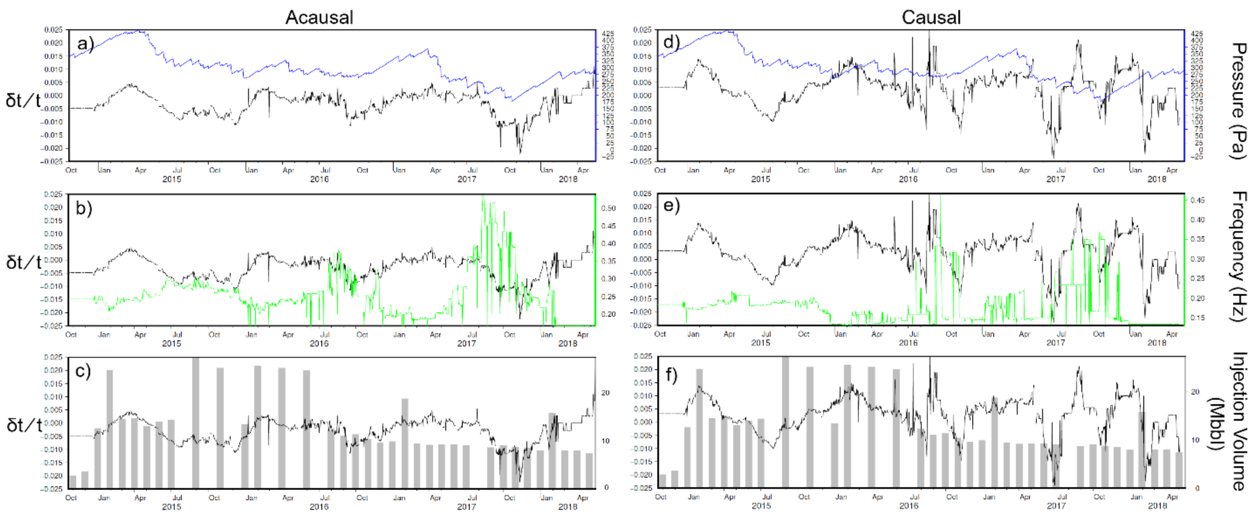

Figure 4. Final velocity variations through time for the Oklahoma network, compared to possible source mechanisms, for both the acausal (left) and causal (right) branches. Top plots compare to pore-pressure due to rainfall, middle plots compare to frequency of the peak of the power spectrum, lower plots compare to injection volumes for the area within 60km of the center of the network.

The changing velocities revealed by this method are expected to be due to poroelastic stresses varying in response to both natural and anthropogenic effects. Thus, this method could prove useful in both placing constraints on poroelastic modelling studies, as well as being used as a monitoring technique for both industrial and regulatory processes. As injection and seismicity are though to be related to poroelastic responses to injection for this region (Barbour et al., 2017), this may be also helpful towards understanding and mitigating seismic hazards.

Novel/Additive Information

Seasonal velocity changes of this magnitude have not been seen before for land-based networks. While ambient cross-correlation methods have been used to monitor a variety of natural phenomenon, if this technique proves successful, then it may provide a cost-effective method for monitoring disposal activities and mitigating hazards related to induced seismicity.

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