Surface Seismic Monitoring of CO_2 injection operations at multiple field sites around the United States

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One part of a multifaceted plan to lessen the long-term climate impact of greenhouse gas emissions is to inject anthropogenic carbon dioxide (CO_2) into underground saline reservoirs for permanent storage. CO_2 can also be injected into depleted oil and gas reservoirs to produce additional hydrocarbon resources and to permanently store part of the injected CO_2. This process is commonly referred to as enhanced oil recovery (EOR). Coal seams are another option for the safe, underground storage of CO_2 because CO_2 displaces CH_4 from the coal's microporous structure. The injected CO_2 is permanently stored within unmineable coal seams while the desorbed CH_4 is produced to the surface for commercial use. This process is called enhanced coalbed methane (ECBM) recovery. Induced seismicity is a long-standing concern with subsurface injection, particularly when large volumes of wastewater are being injected near the crystalline basement. However, at EOR or ECBM sites, injection is accompanied by production thereby maintaining a constant, well controlled reservoir pressure, which should limit induced seismicity. As expected, seismic monitoring at EOR or ECBM sites have only recorded a few instances of increased seismicity that can be confidently attributed to CO_2 injection. However, continued seismic monitoring at these sites is prudent to provide early warning of changing stress conditions.

Towards this end, we analyzed surface seismic data recorded at two EOR sites located in the Texas Panhandle (Farnsworth) and southern Kansas (Wellington), respectively. Additionally, we analyzed seismic data recorded at a small-scale CO_2 injection test in a coalbed methane reservoir in southwest Virginia. For the Texas Panhandle site, seismic data was collected using eight broadband seismometers around the CO_2 injection well. The surface seismic data in southern Kansas was acquired using 15 short period seismometers, whereas in Virginia, a buried network of 28 geophones were used to collect seismic data during Phase I of CO_2 injection. We identified 160 discrete seismic events in the Texas Panhandle and 71 events in southern Kansas that strongly differ from traditional microseismic events. These events are characterized by low frequency content (1-5 Hz) and longer time duration (lasting for 30-60 seconds for Texas data and several minutes long for Kansas data). We compared the location of low frequency events with the field-scale reservoir model for the CO_2 plume and pore pressure variation in Farnsworth, Texas and found spatial overlap with four events. As most of the low frequency events are located outside the region encompassing pore pressure changes due to CO_2 injection in Farnsworth, we think that they are perhaps related to small scale tectonic deformation or complex subsurface fracturing triggered by other nearby injection activities that were active during the monitoring period. Further, we compared the location of selective LPLD events with the reservoir model of the CO_2 plume and the alkalinity response polygon around the treatment well in Wellington, Kansas. Our analysis suggests that the uniquely recorded LPLD events in Kansas are perhaps linked with local CO_2 injection that triggered slow slip events along pre-existing faults and fractures in the subsurface. For the ECBM site in Virginia, we identified 376 unique events recorded by a local seismic array with their waveform characteristics (time duration) that are similar to the events observed at the EOR site in the Texas Panhandle. Compared to both EOR sites, events observed at the ECBM site in Virginia has higher frequency content, with dominant concentration of energy between 10 to 15 Hz. We are unable to determine the location of events recorded at the ECBM site due to their unclear seismic phase arrivals, however, their unique recording by the local seismic array do suggest local subsurface origin likely linked to either CO_2 injection operation or some other undocumented anthropogenic activities.