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Monitoring with earth tides at the CO2CRC Otway Project

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Abstract

The measurement of pressure is ubiquitous in sub-surface operations. Modern gauges can produce reliable measurements of pressure with a noise level around 0.01 psi. At this level, the pressure variations caused by earth tides are well above the noise level, and the amplitude (and phase) can be measured as a function of time. Earth tides are a well-known and well-understood phenomenon to hydrologists, and the pressure response contains information about the geomechanical properties of the reservoir in which the pressure variations are measured. These properties include the effective compressibility of the rocks, which is strongly affected by the compressibility of the fluids saturating the pore space. In the case of supercritical CO2, which is very compressible, a small change in the saturation can produce a dramatic change in compressibility and hence in the magnitude of the pressure response to earth tides. For geological CO2 storage, this effect was first observed during the Nagaoke experiment. As in in that case, the measurement of the earth tide response at a monitoring well is potentially a way of detecting the approach of a CO2 plume.

The CO2CRC Otway Stage 3 storage project has injected 15 kt of CO2 at an injection well and measured the pressure response (amongst other things) at five other monitoring wells approximately surrounding the plume and up to 700m from it. These pressure measurements provide a rich dataset of earth tide responses before, during and after the injection. We detect the approach of the plume at all wells, and in some cases are able to detect it moving away again as it drifts past the monitoring well and moves up-dip. A novel aspect of the measurements is that we are able to obtain reliable estimates of phase, that it, the delay between the predicted earth tide and the pressure response that results. The phase contains additional information which, to some extent, allows us to break the degeneracy in measurements of amplitude alone. That is, amplitude cannot distinguish between a large plume a long way away and small one close by, but with the addition of phase it is possible to do so.

There are additional features in our data which we cannot currently explain but are potentially a rich source of further insights into detailed aspects of the propagation of the plume. Specifically, when the CO2 plume has a strong effect on the earth tide response, the pressure oscillations become a poorer match in overall shape to the driving earth tide stresses. Additionally, the character of these mismatches can change within a day or two, which is very fast by composition with the expected pressure diffusion time. Finally, we see systematic changes in goodness-of-fit which coincide with the lunar cycle. We believe these reflected loading of the Earth's crust by ordinary ocean tides, as we are only 10km from the Southern Ocean, but we cannot explain these effects in detail.

However, the broad features of the pressure responses to earth tides are consistent are consistent with fully coupled models of our CO2 injection. These models include the fluid flow, the earth tide forcing, the geomechanical

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response, and the coupling between them. This consistency gives confidence in the use of earth tides as a simple ancillary monitoring method that would warn of the approach of CO_2 to a monitoring well where pressure was being measured in the storage reservoir. Depending on the details of the rock properties (mainly permeability) the range of the measurement could be several hundred meters.

Keywords: geological storage; monitoring; pressure; earth tides