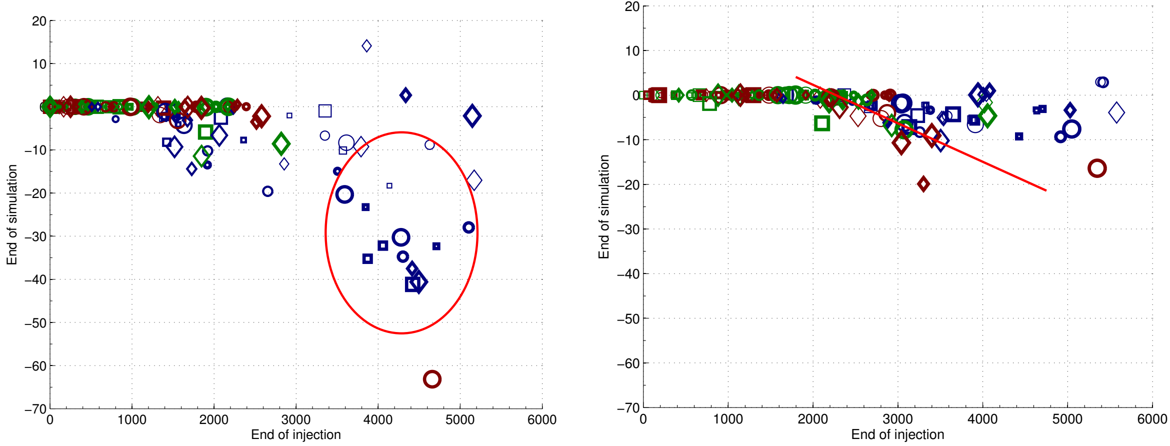

Figure 4: Cross-plot of CO_2 flux out over the down-dip boundary for linear (left) and quadratic (right) relative permeabilities. Positive values represent outward fluxes and negative values represent inward fluxes.

3.3 Plume migration

The direction in which the CO_2 plume moves in the medium will primarily impact the amount of residual (and structural) trapping, but as we will see later, also significantly change the risk for leakage through breaches and holes in the caprock. When evaluating the safety of a long-term storage operation, there are several potentially conflicting aspects that need to be considered with regard to plume migration. On one hand, we prefer the plume to spread out laterally to enhance residual trapping and mixing of CO_2 and brine, while on the other hand we want to confine the plume to the smallest volume possible to minimize the the risk of leakage and contamination into other aquifers, minimize the contact with potential leakage points and simplify monitoring operations. To investigate this aspect, we will study the sweep efficiency in local regions. On the other hand, if a big movable plume connects with a leakage pathway through the caprock, large volumes of CO_2 may escape, and for this reason, it may be better if the injected CO_2 splits into many small plumes. In our analysis, we will therefore also consider the number of plumes and their volumes.

3.3.1 Boundary fluxes

The sweep efficiency of the CO_2 plume, i.e., the percentage of the aquifer volume that has been in contact with CO_2, is positively correlated with the amount of residual trapping (and mixing of CO_2 and brine). Herein, we will consider the flux out of the open boundaries as an indirect measure of volumetric sweep efficiency. The model has open boundaries on three sides, which are modeled by imposing huge pore-volumes multipliers in the outer cells, while no-flow boundary conditions are imposed along the top faulted side. Using large pore-volume multipliers to represent an open boundary enables us to model flow both in and out of the domain, and this way, we can represent volumes of CO_2 leaving and later re-entering the aquifer. (In addition, this method will contribute to eliminate effects from Dirichlet type boundary conditions).

The lower boundary is closest to the injection point and hence the most likely place that injected CO_2 volumes will be lost. Figure 4 shows two cross-plots of the CO_2 across this boundary at the end of injection and the end of simulation. Towards the end of injection, most cases have positive flux values, which means that parts of the main plume connected to the injection point has been forced to leave the domain in the down-dip direction by the increased injection pressure. However, after injection stops, many cases have small negative fluxes, which means that a small volume of CO_2 reenters the domain. Once again, we observe that cases with low aggradation angle stand out from the rest. In these cases, the injected plume is almost entirely confined to the bottom of the model because of poor vertical communication. Hence, a large portion of the injected volume will be forced out of the domain in the down-dip direction. After the end of injection, gravity forces will gradually cause some of these lost volumes to move up-dip again and reenter the domain. We notice that cases with closed faults (shown in the red circle in the left plot of Figure 4) show a relatively higher return