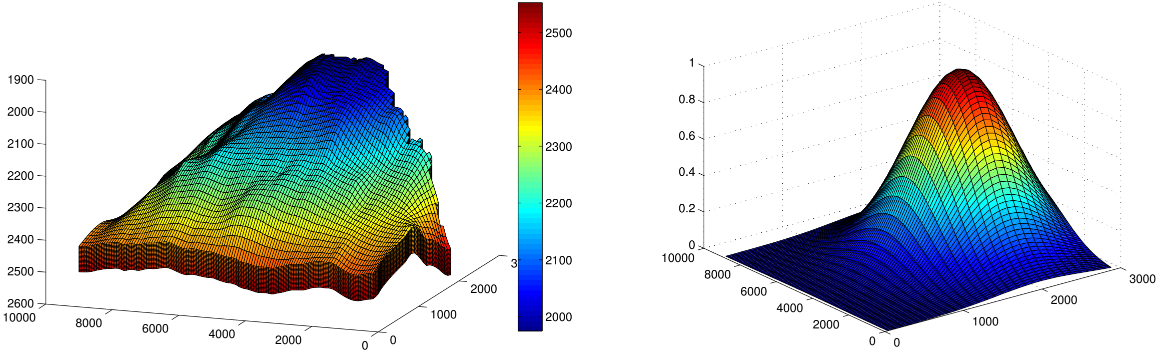

Figure 14: The left plot shows a sample grid geometry with depth values shown in meters. The right plot shows the Gaussian probability distribution for point leakage through the caprock. The distribution is centered at a point on the crest which is in the same slice as the injection point.

5 Risk for Point-Leakage

The capillary-sealing potential of the caprock is typically expressed in terms of the maximum overpressure that the brine-saturated caprock can sustain, and leakage will only take place if the pressure of the CO_2 column exceeds this capillary entry pressure. The entry pressure is controlled by the interfacial tension between brine and CO_2, the water-wettability of caprock minerals, and the pore size distribution within the caprock [35, 15, 16, 14, 48]. The water-wettability is altered in the presence of CO_2 under pressure conditions that are typical for a storage site. Pore-size distribution is due to depositional factors.

The SAIGUP study does not supply any information about the caprock and its geomechanical properties (including breaches and other regions of "high permeability" that may form potential leakage paths). We are therefore only able to conduct a conceptual study of the risk associated with point leakage through imperfections in the caprock. To this end, we assume that each point on the top surface has a prescribed probability for being a leakage point. In lack of any useful information, we will simply assume that the probability for point leakage follows a standard 2D Gaussian distribution centered at a given point on the crest, see Figure 14. This is physically unrealistic, but simple to treat mathematically. Moreover, we will also disregard the effects of capillary entry pressure and wettability alterations, which contribute to reduce potential leakage rates, and simply assume that all mobile CO_2 (except for the residual portion) will escape through the caprock if a plume comes in contact with a leakage point. We have seen above that the heterogeneity and tilt of the medium will cause the injected CO_2 to be distributed under the caprock as a number of plumes with variable sizes. For each cell along the top surface, we now define the risk as the probability of point leakage weighted by the volume of the CO_2 plume that the cell is part of. We then sum the values for all the topmost cells, normalize this sum, and use the resulting single number as a measure of leakage risk. The worst possible case would be if all the injected CO_2 volume forms a mobile plume that contacts every point along the top surface; this gives a risk value equal to one. For all reasonable cases, however, the risk value will be less than one because not all of the CO_2 will be mobile (because of residual trapping and loss of volumes across the open boundaries), because the mobile volume may form more than one plume, or because not all the mobile volume has reached the top due to reduced vertical mobility.

Figure 15 shows the resulting leakage risk for all cases at the end of simulation computed using linear relative permeabilities. Similarly, the left plot in Figure 16 shows how the risk changes during the seventy year period from the end of injection to the end of simulation, whereas the right plot shows a cross-plot of the leakage risk versus the total volume of mobile CO_2. The plots lead to the rather obvious conclusion that improved vertical connection will increase the risk of mobile CO_2 migrating upward to connect a potential breach in the caprock, and hence that there is a positive correlation between the volume of mobile CO_2 in the system and leakage risk. However, we also observe that there are cases which have zero risk for leakage through the caprock. These are cases with low aggradation, for which the flow stays in the injected layers and moves laterally toward the open boundaries, resulting in a low amount of mobile CO_2 in the system. Furthermore, these cases have