Selection of Stochastic Realizations

Application to Geological Storage of CO_2

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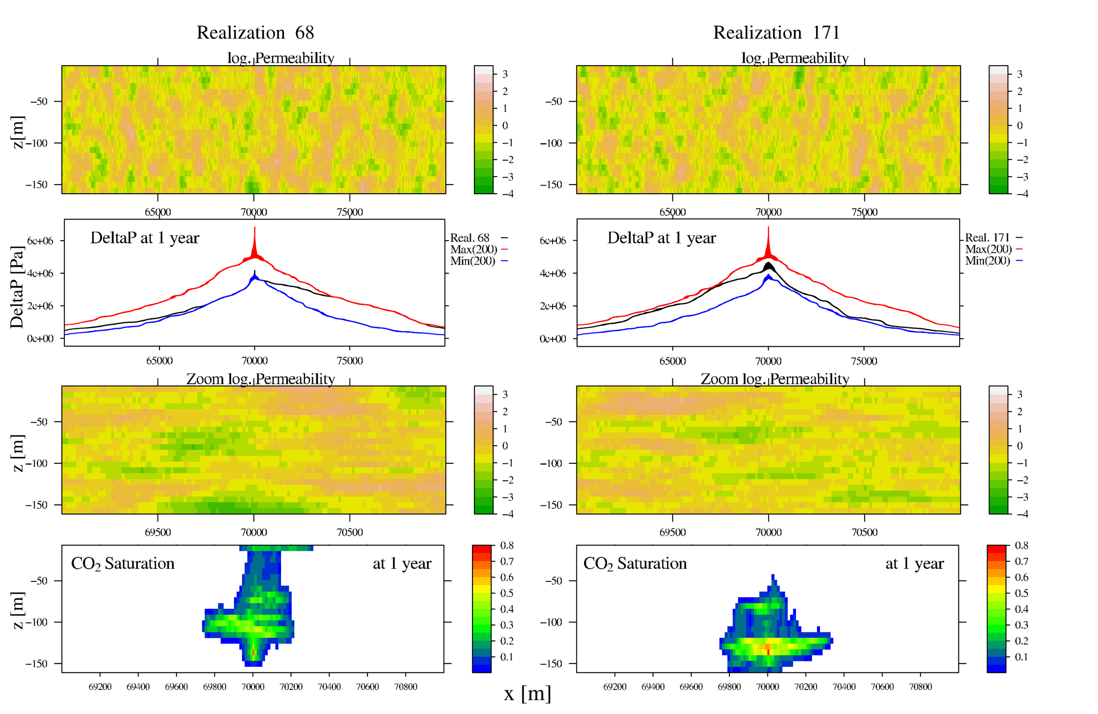
Context & Objectives

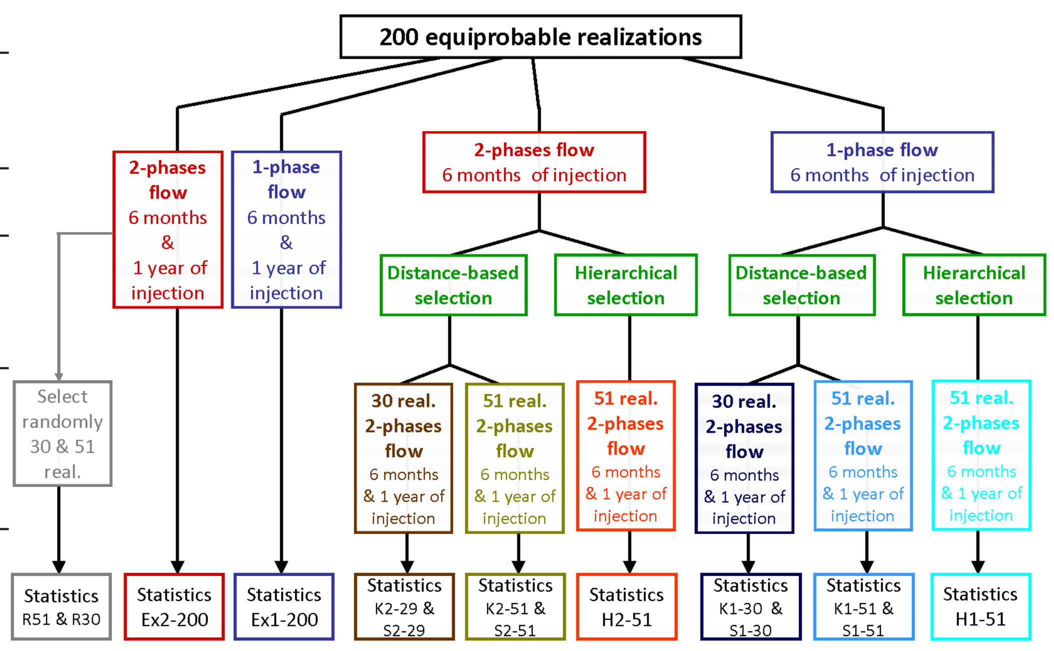
Projects of geological storage of CO_2 require to examine risks of interferences between uses of underground storage and limiting factor for injectivity and capacity storage. These risk and factors depend on pressure response which varies spatially. This response is influenced by spatial variability of permeability field and needs to be characterized by a spatial distribution at large scale.
To evaluate uncertainties, flow simulations are conducted on geostatistical numerical models of permeability field. But multiphase-flow simulation on thousands of grid cells is time-consuming and cannot be achieved on numerous sets of realizations. Is it possible to isolate a sub-set of realizations which reproduces minimum, maximum and mean behavior of an exhaustive set of realizations?
Methods of selection are examined to reduce the number of realizations for full-flow simulations and consequently computational cost but still returning acceptable statistic properties of flow system response.



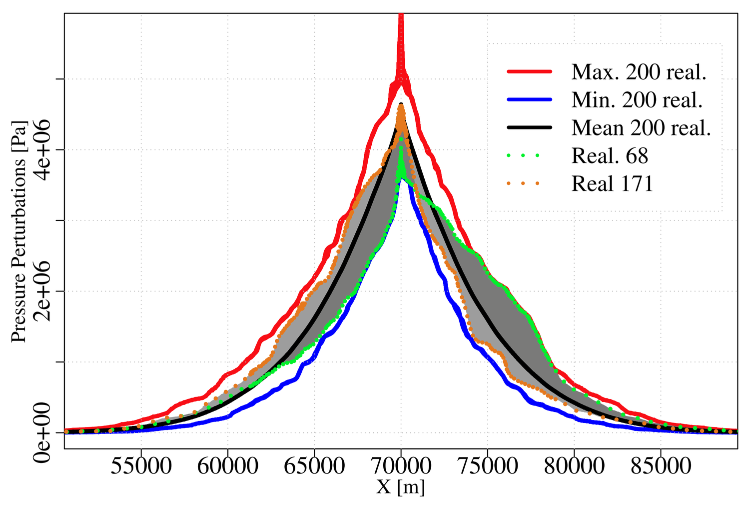
Methods of selection - Key points

1. 2D vertical section of a large scale system intersecting a horizontal well.
200 realizations of a stochastic model of spatial variability of permeability generated via the moving average method [1]: the exhaustive set (Ex2-200) is used as a reference to assess the efficiency of selections.
2. Simplified flow simulations (proxy-response) with reduced computational time: reduced period of simulated injection on 2-phases flow or approximation of this reduced period by single-phase flow [2].
3. Selection methods of a subset following a criterion of a spatially variable response at fixed time (6 months of injection): Hierarchical or Distance-based methods.
4. Full-flow simulation for 1 year of injection on the subset of selected realizations.

Selection method	Proxy-response	Number of realizations	Subset
Hierarchical	2-phases	51	H2-51
	1 phase	51	H1-51
Kernel K-means clustering	2-phases	29	K2-29
	1 phase	30	K1-30
	2-phases	51	K2-51
	1 phase	51	K1-51
Spectral initialization, Kernel K-means clustering	2-phases	29	S2-29
	1 phase	30	S1-30
	2-phases	51	S2-51
	1 phase	51	S1-51
Random	NA	51	R-51
	NA	30	R-30



Hierarchical methods of selection. The exhaustive set of proxy-response results gives maximum, minimum pressure envelopes and mean pressure profiles. No individual pressure profile of realization corresponds specifically to mean, max or min profiles => **hierarchical classification** based on proximity of realizations to each statistical properties.

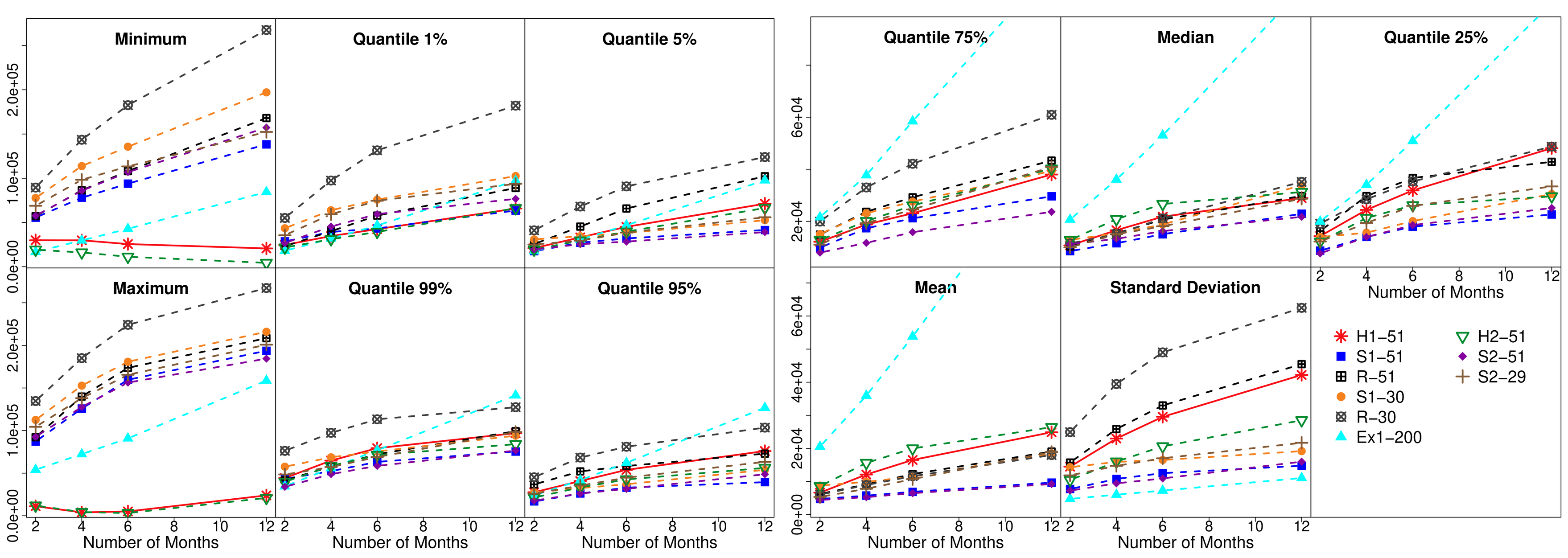


Selected subset is defined by adding iteratively realizations from each classification, until error criterion is reached.

Distance based methods of selection. Hyp: Close realizations, either in terms of permeability field or in terms of proxy-response, should behave similarly in term of full flow simulation [3].
Calculation of similarity distances (euclidean) between pressure distributions on the entire domain from proxy-response. Similar realizations are identified through spectral clustering (initialization) and Kernel K-means clustering. The closest realization to the centroid is selected for each cluster. Statistical properties from the subset of selected realizations, weighted by the cardinal of corresponding cluster, should correspond to those of the exhaustive set.

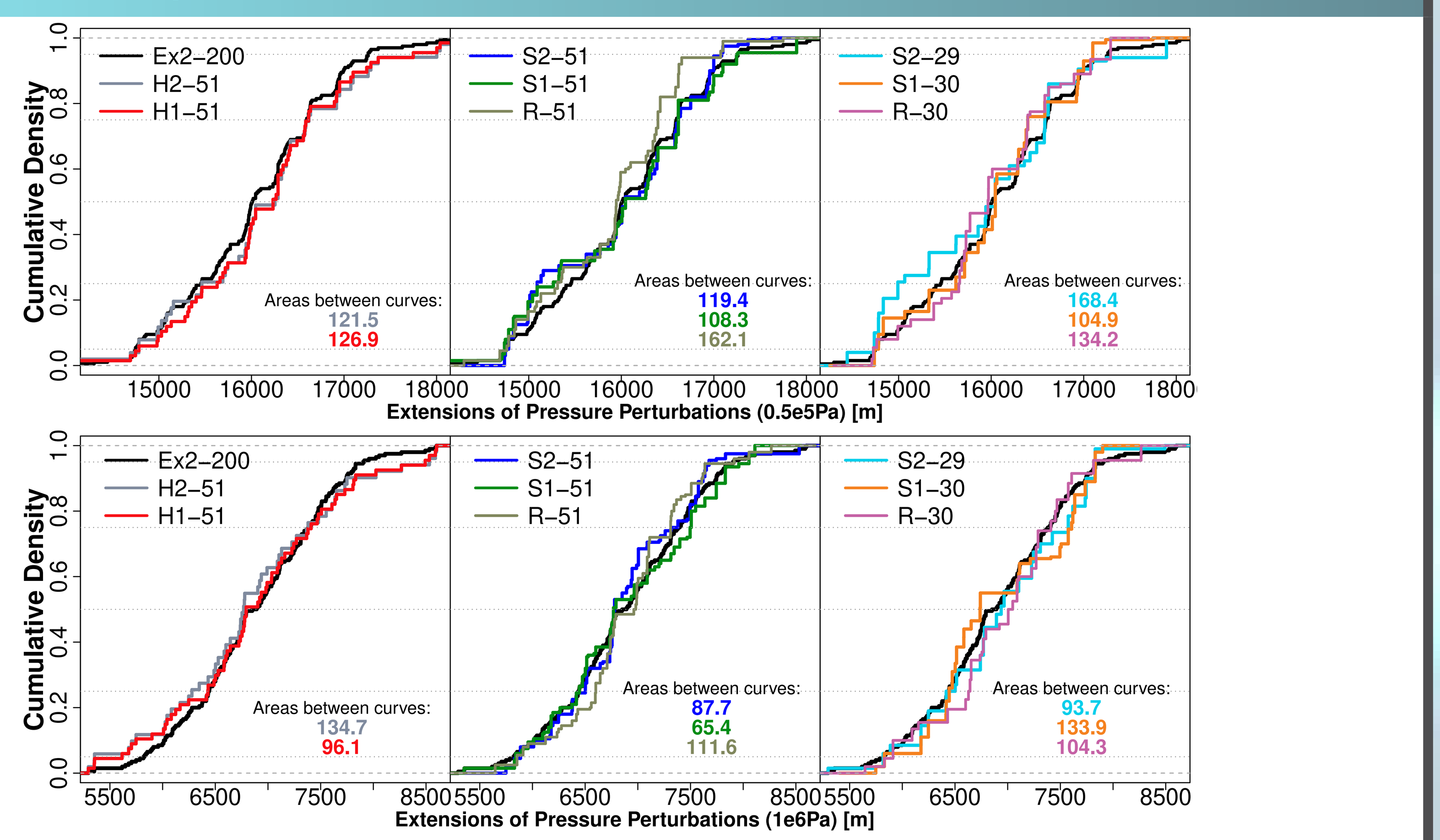
Comparison of selection methods: global error

RMSE of Pressure Perturbations between Ex2-200 and selected realizations [Pa]



◇ Except for standard-deviation, single phase flow on the exhaustive set (Ex1-200) fails to approximate pressure behavior of 2-phases flow (Ex2-200).
◇ Only hierarchical method gives a sufficiently low error for minimum and maximum.
◇ Distance-based method improves results for quantiles, mean and standard deviation, gives equivalent or better results for quantiles between Q95 and Q5 with a lower number of realizations than hierarchical method.
◇ Random selections are always less efficient for a same number of realizations.
◇ Globally, no significant differences between the different proxy-responses.

Comparison on local measurements



For 51 realizations, maximum and minimum are achieved with hierarchical methods whereas distance-based method better preserves distribution and are more efficient than random selection.
The quality of selection decreases with a subset of 30 realizations.
The criterion of selection can be adapted depending on the studied response (i.e. use criterion for local measurements to get its specific selection).

Conclusions

Hierarchical method of selection is mainly based on error criterion compared to minimum and maximum pressure profiles. Distance-based method focuses on global dispersion based on pressure results in the entire reservoir. Consequently, hierarchical method is more accurate to approach minimum and maximum response of exhaustive set and distance-based method is able to reproduce mean and dispersion around this mean.
Use of single-phase flow as proxy-response is sufficient to get efficient selections and divides computational time by 4 or 6. But multiphase-flow needs to be conducted on this selection to get accurate statistic distribution.
To assess uncertainty in spatially variable response related to geological parameters, the following procedure is proposed:

◇ Single-phase flow simulations on a large set of stochastic realizations, potentially for a short period
◇ Selection of few representative realizations depending on required time and type of studied response
◇ Full flow simulations on selected realizations for the whole period

References

[1] Chilès, J.P., Delfiner, P. *Geostatistics: Modeling Spatial Uncertainty.* John Wiley & Sons, Inc. (1999).

[2] Nicot, J.P., Hosseini, S.A., Solano, S.V. *Are single-phase flow numerical models sufficient to estimate pressure distribution in CO2 sequestration projects?* In: Energy Procedia, vol. 4, pp. 3919–3926 (2011).

[3] Scheidt, C., Caers, J.: Representing Spatial Uncertainty Using Distances and Kernels. Mathematical Geosciences **41**(4), 397–419 (2008).