Bayesian Information-Gap (BIG) Decision Analysis Applied to a Geologic CO_2 Sequestration Problem

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Unclassified: LA-UR-14-28376

Decision Scenario

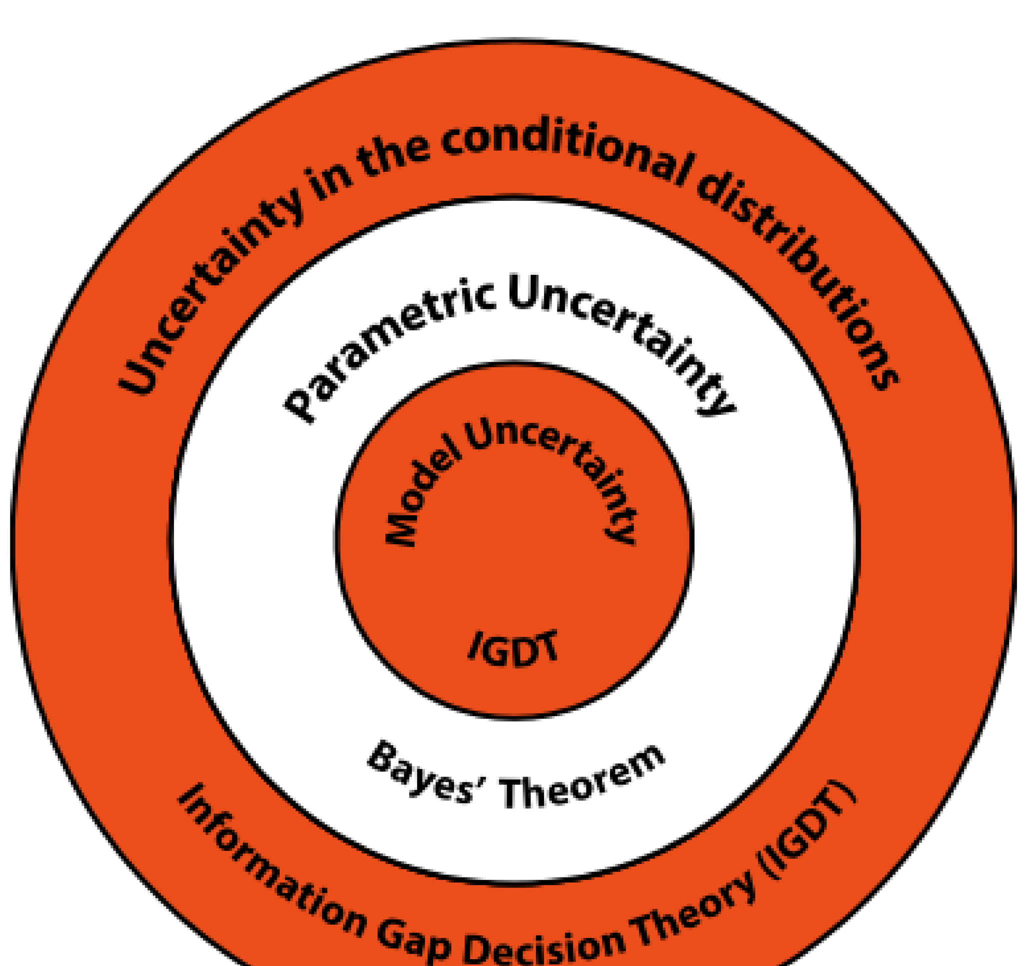
- A site is to be chosen at which CO_2 **will be injected in a deep aquifer**
- Injecting at the site must not induce a high overpressure in the host formation to **avoid induced seismisity**
- Injecting at the site must not induce a high overpressure/flow into the overlying aquifer to **avoid groundwater contamination**
- A pumping test is performed at two locations to evaluate their suitability for CO_2 injection

BIG UQ

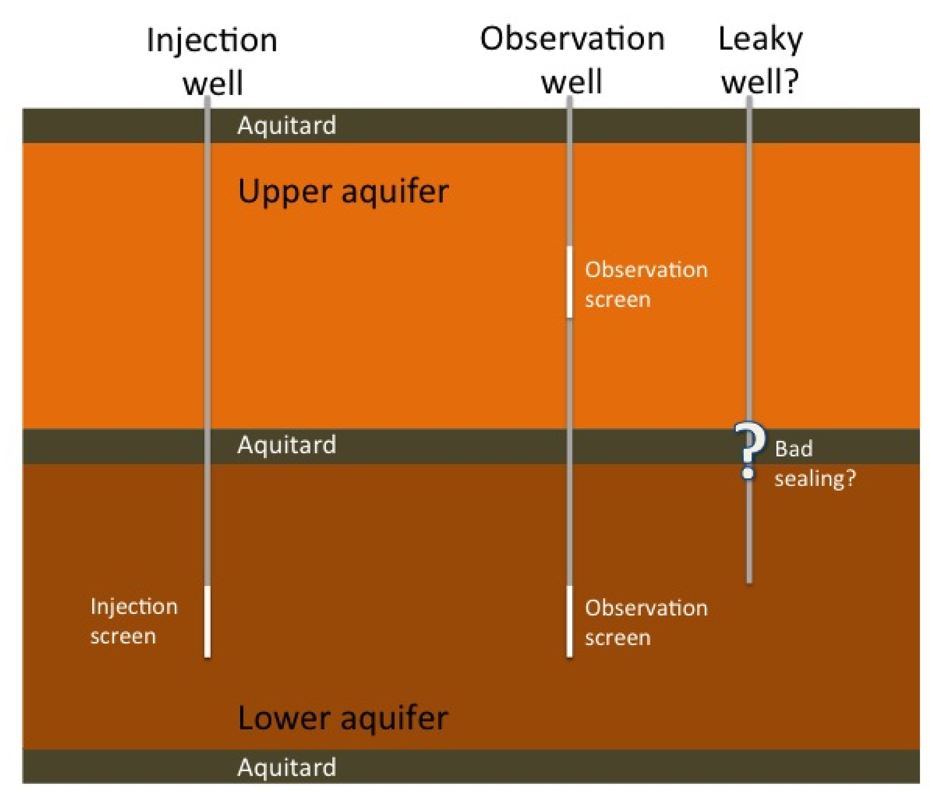
Bayesian-**I**nformation-**G**ap (BIG) Decision Analysis (DA) combines probabilistic Bayesian methods with non-probabilistic information-gap decision theory using a three-layered approach:

- Inner layer: information-gap to deal with **model inadequacy** (Here, this is related to the oversimplified physical model.)
- Middle layer: Bayesian analysis to deal with **parametric uncertainties** (Here, these are related to the location and resistivity of a leaky well.)
- Outer layer: information-gap to deal with **uncertainty in the conditional distribution** used in the Bayesian analysis (Here, these are related to the fact that the residuals are not a Gaussian white noise.)

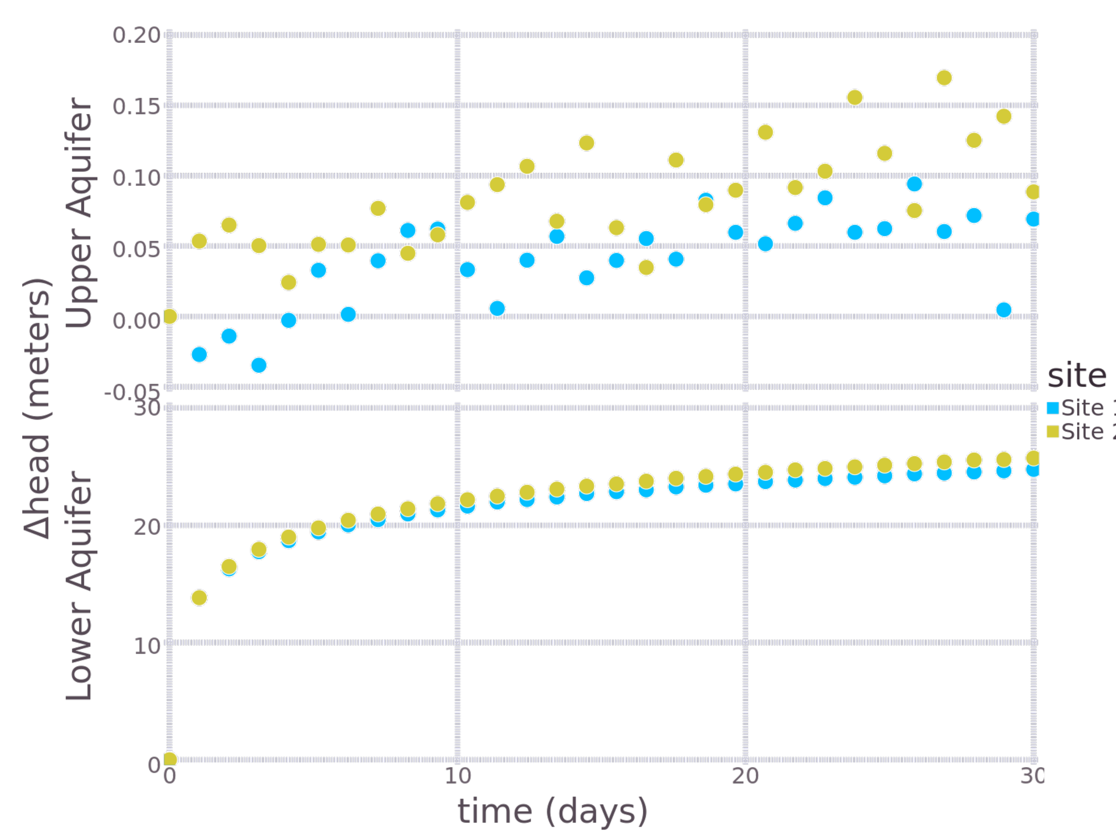
Utilizing information-gap decision theory in the outer layer enables a **robust decision analysis**. The details are described in [1].



Hydrogeological Setup



Observed Data



Data Assimilation

- Data is assimilated via Bayes theorem
- Residuals are produced by subtracting the observed data from the model predictions
- Nominally, the residuals are a Gaussian white noise
- Actually, the residuals are a correlated Gaussian noise
- The outer layer deals with uncertainty in the distribution of the resdiuals

Sites

Knowns

- Hydrological parameters: permeability, aquifer thickness, specific storage
- Injection parameters: injection rate, well geometry

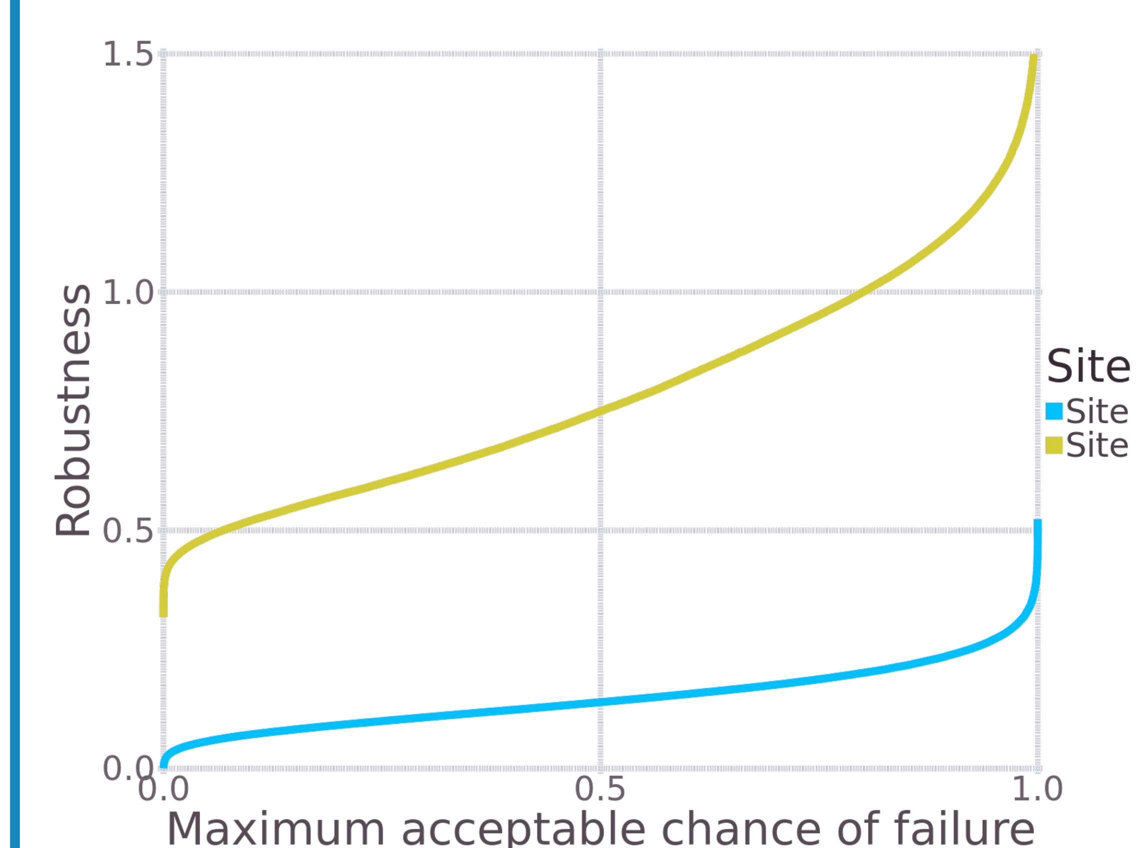
Unknowns

- Leaky well parameters: location, resistivity

Difference between two sites

- Site 1 contains a leaky well with a lower resistivity than Site 2
- Therefore, Site 2 is a better injection site

Robustness Curves



Physical Model

- Semi-analytical model for the setup described above [2]
- Predicts
  - Groundwater flow mixed with CO2 from lower to upper aquifer
  - Pressure build-up in lower aquifer
  - Pressure build-up in upper aquifer
- Assumes
  - Uniform hydraulic parameters in the upper and lower aquifers
  - Leaky well is present
- Model inadequacy is considered within the BIG analysis

Decision Analysis

- The robustness curves are used to decide between the two sites
- The decision-maker chooses a performance requirement, in this case, a maximum acceptable chance of failure
- The site with the greatest robustness for that performance requirement is preferred
- In this scenario, Site 2 has greater robustness for all performance requirements, *i.e.*, it is "robust dominant"
- Site 2 is chosen regardless of the performance requirement

Implementation

- **Physical-model independent**: easy to utilize new physical models
- **Info-gap uncertainty-model independent**: easy to utilize new info-gap uncertainty models
- **Numerous MCMC samplers** available for the Bayesian component
- Runs in **parallel**
- Implemented in julia: fast and flexible
- Part of the **MADS** framework

Conclusions

- Probabilistic analyses are not able to adequately characterize uncertainty in every application
- Subsurface applications are a prime example due to manifold & severe uncertainties
- Combining Bayes theorem with information-gap decision theory provides a viable approach to dealing with uncertainty for these applications

References

1. O'Malley, D. and V.V. Vesselinov. *A combined probabilistic/non-probabilistic decision analysis for contaminant remediation*. SIAM UQ (2014, in press)
2. Avci, C.B. *Evaluation of flow leakage through abandoned wells and boreholes*. WRR (1994).