Risk-Based Conformance Evaluation at Geologic Carbon Storage Sites

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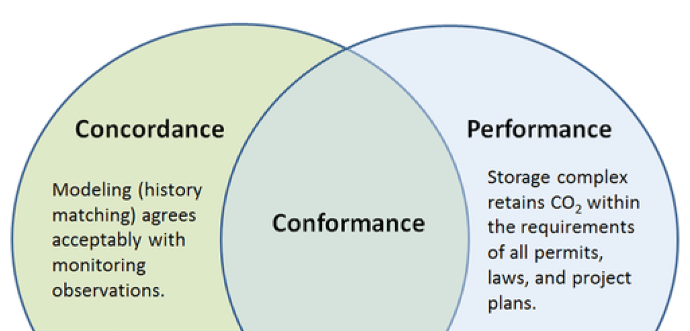
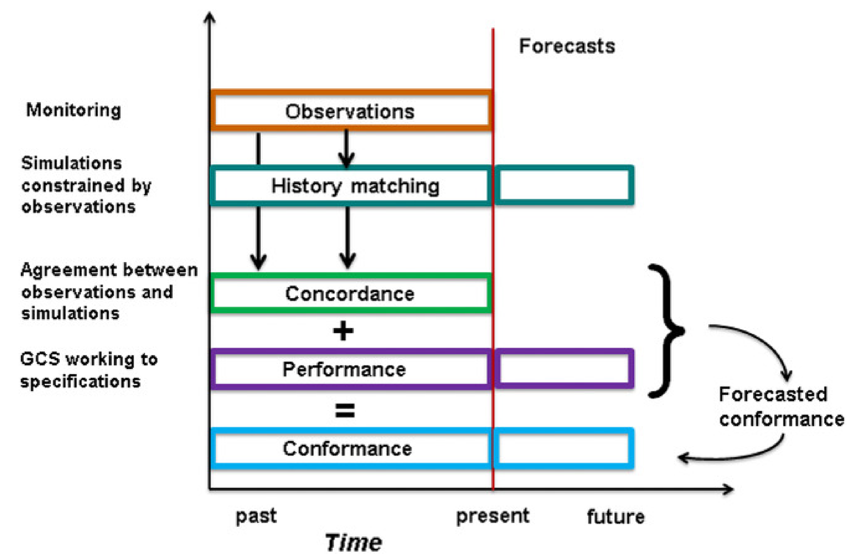
National Risk Assessment Partnership

Summary

- **A recommendation on a geologic carbon storage (GCS)-specific meaning of the word "Conformance" is provided.**
- **A metric for quantifying the conformance robustness of a GCS project during its operational phase is defined and demonstrated.**
- **A framework based on a data assimilation approach (ES-MDA) coupled with NRAP-Open-IAM is proposed to perform conformance evaluations and quantify uncertainty reduction in predictions of risk metrics, such as plume area, wellbore leakage rates, and aquifer impacts (pH/TDS plume size).**

Conformance of a GCS System

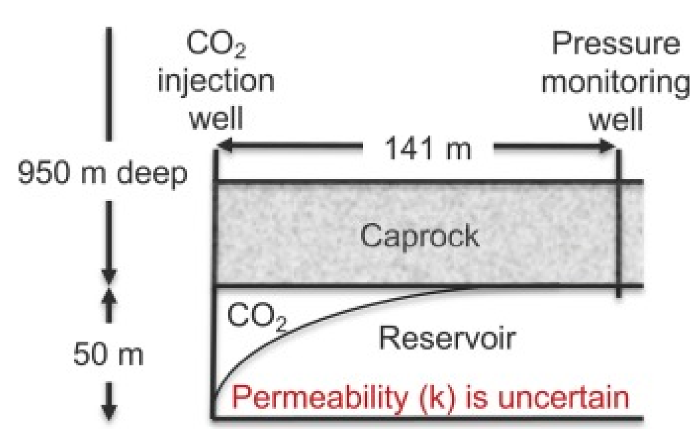




- **Conformance of a GCS system is the condition under which there is acceptable concordance and acceptable performance.**

Conformance Robustness Analysis

- **We use a simplified CO_2 sequestration scenario (see the figure to right) to demonstrate a probabilistic/non-probabilistic approach to quantify the robustness of a designation of GCS conformance using info-gap theory.**



- **The conformance robustness metric requires four components: (1) the system model (Eq. 1), (2) the concordance metric (Eq. 2), (3) the performance criterion (Eq. 3), and (4) the uncertainty model (Eq. 4).**

Eq. 1: $P_{F,\max}(k) = \max_{i \in M-N} P_{N+i}(k)$

Eq. 2: $\sigma_c = \sqrt{\sigma_e^2 (\mathbf{J}'\mathbf{J})^{-1}} = \sqrt{\frac{\sum_{i=1}^{N} (P_i - \widehat{P}_i)^2}{N-1} (\mathbf{J}'\mathbf{J})^{-1}}$

Eq. 3: $P_{F,\max}(k) < P_c$

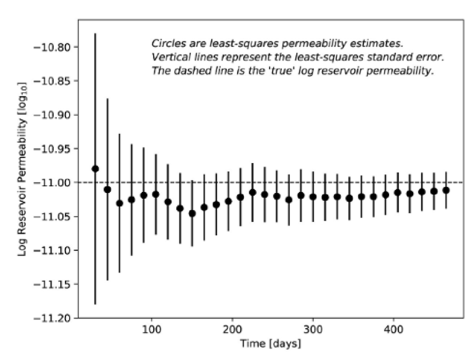
Eq. 4: $U(h) = \left\{k : 0 \le \frac{\log_{10}(\tilde{k}) - \log_{10}(k)}{\sigma_c} \le h\right\}, h \ge 0$

- **These components are utilized to define the conformance robustness as:**

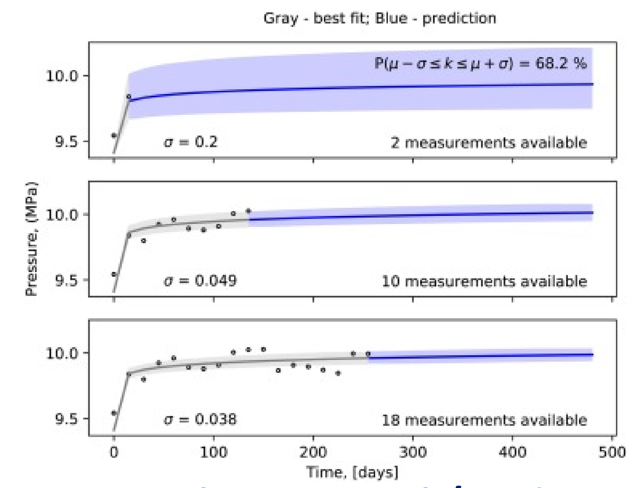
$$\widehat{h}(P_c, \boldsymbol{\theta}) = \max\left\{h : \left(\max_{k \in U(h)} P_{F,\max}(k)\right) \le P_c\right\} \quad \text{(Eq. 5)}$$

- **The conformance robustness (Eq. 5) quantifies the degree to which our nominal estimate (best guess) of reservoir permeability (*k*) can be uncertain and still not cause (p) to exceed a critical (failure) threshold, as defined by Eq. 5.**

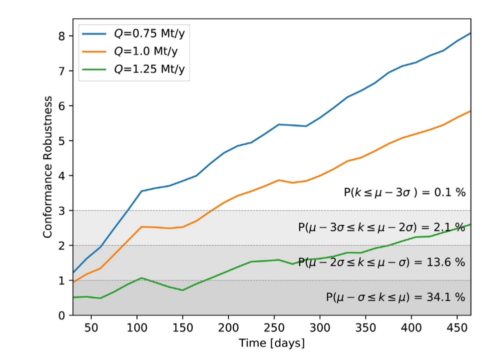
- **Results**



***k* estimate over time**



Pressure history match/predictions



Evaluation of conformance robustness

- ✓ In the first plot, confidence in the permeability estimate improves over time as more measurements are obtained.
- ✓ The second plot indicates the increase in confidence in the GCS project conformance over time as more data become available.
- ✓ The third plot shows conformance robustness (CR) increases with decreasing injection rate; CR is low at early times; but as more monitoring data are obtained, the trend in CR quickly becomes clear.

A Data Assimilation Approach Coupling with NRAP-Open-IAM to Quantify Uncertainty Reduction in GCS

- **Site description and numerical model development**

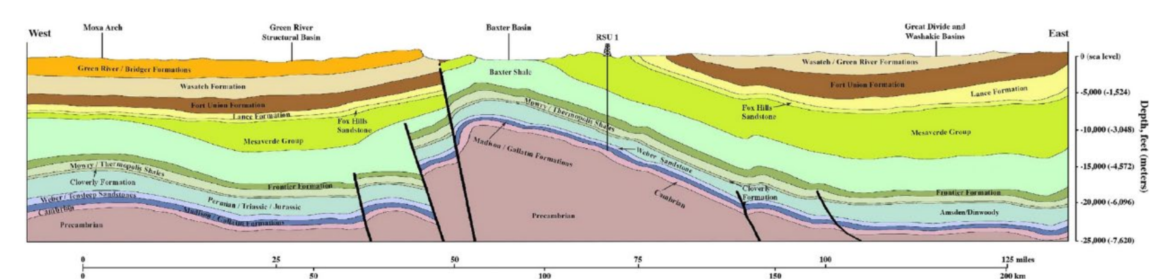
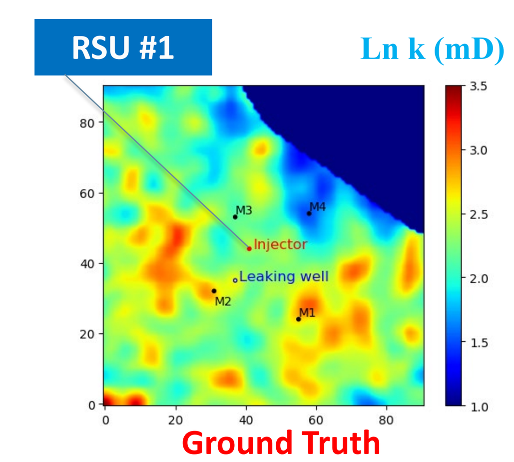


Fig.: Geologic cross section through study site.



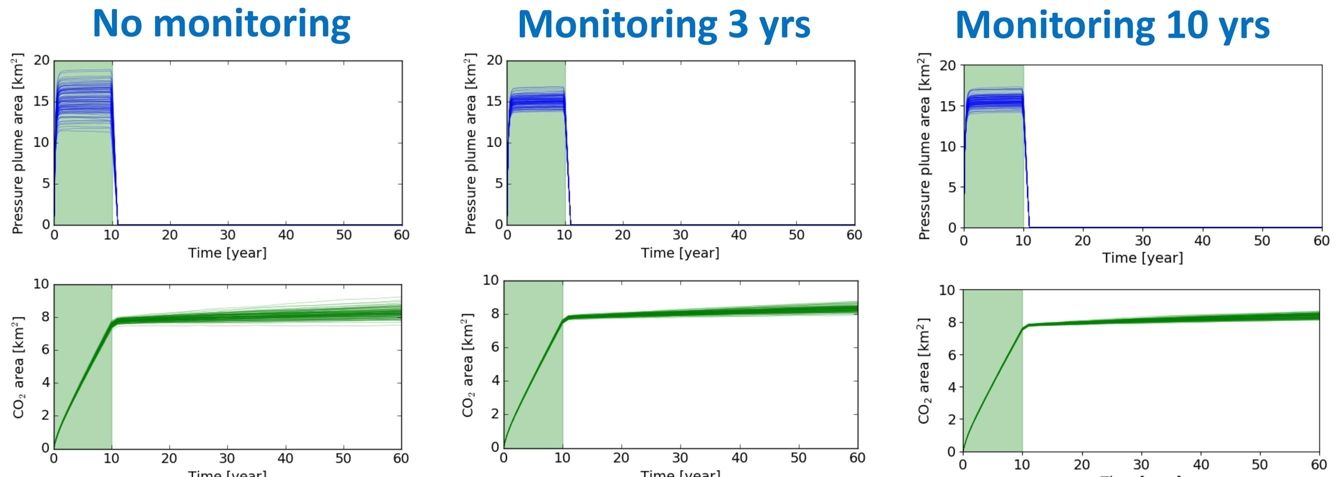
- ✓ 4 monitoring wells (M1, M2, M3, M4), 1 leaking (legacy) well.
- ✓ RSU #1 is CO_2 injection well with injection rate equal to 1 MM tons/year.
- ✓ 10 years injection and 50 years post-injection.

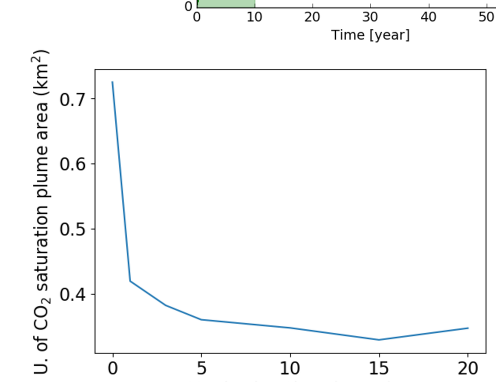
- **Uncertainty reduction analysis in plume stability metrics**

No monitoring **Monitoring 3 yrs** **Monitoring 10 yrs**

Pres. plume area

CO_2 plume area

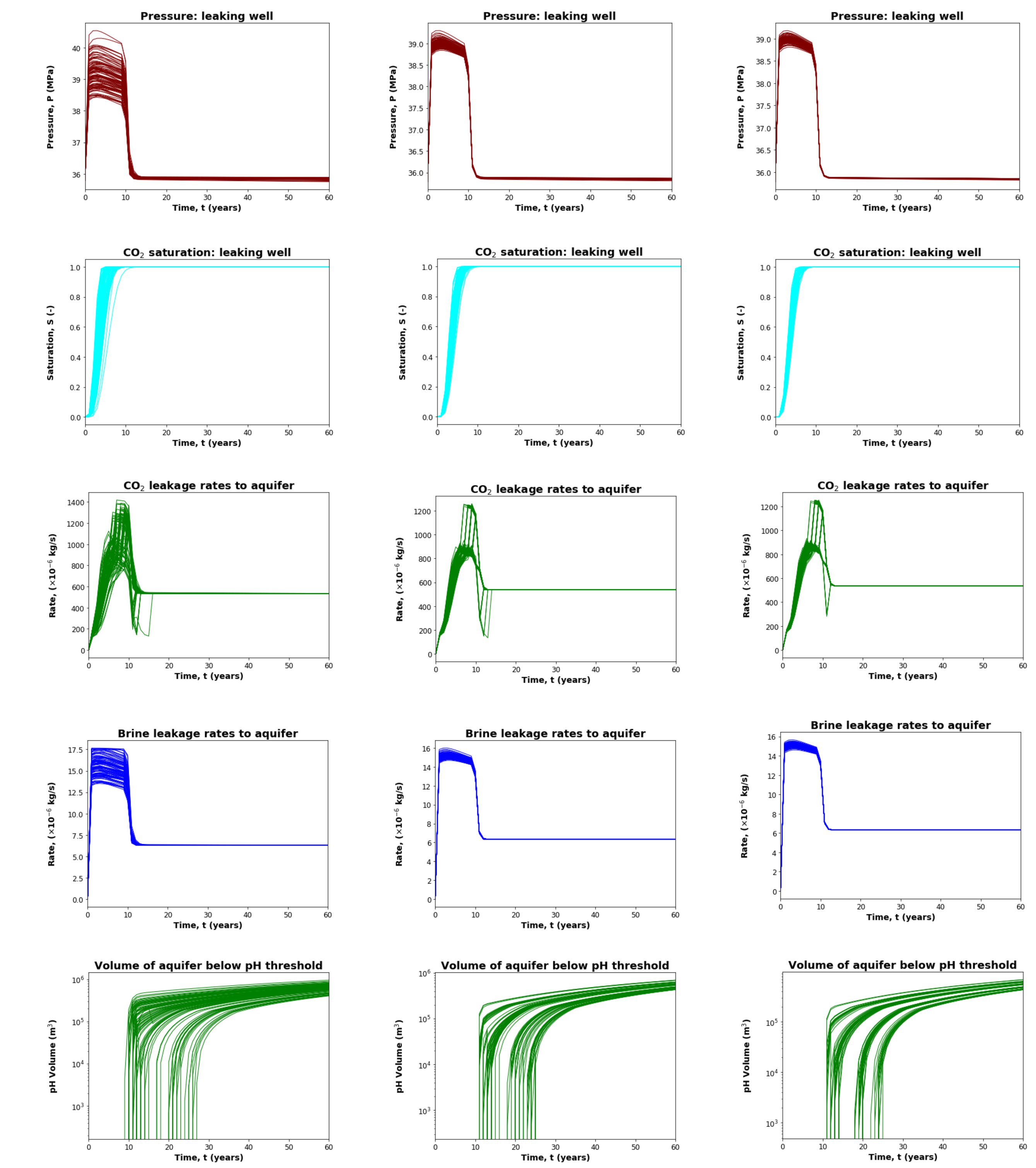




- ✓ Uncertainty reduction in plume area occurs only during first 15 years of monitoring.
- ✓ Mobility and spreading have uncertainty in the early stage, but not too much uncertainty at the later time (not shown).

- **Uncertainty reduction analysis in leakage risk metrics (leaking well)**

No monitoring **Monitoring 3 yrs** **Monitoring 10 yrs**



- ✓ Uncertainty reductions in leakage risk metrics (e.g., CO_2/brine leakage rates, pH plume size) are observed over the monitoring period as more data become available.

- **Reservoir model refinement**
  - ✓ The reservoir models are significantly improved/refined with repeated assimilation of monitoring data.

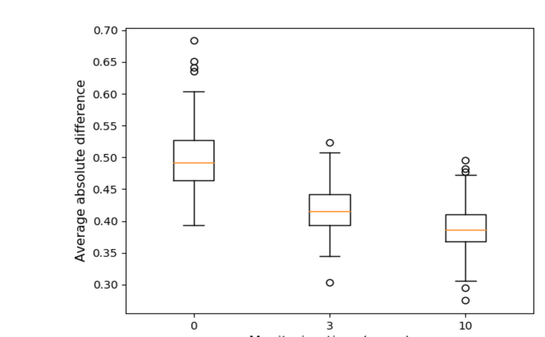


Fig.: Boxplot of average absolute difference between calibrated models and the true model.

References

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