NRAP workshop

- Introduction
- Fluid Migration Characterization
- State-of-stress Characterization
- Risk-based Area of Review
- U.S. DOE's SMART Initiative
- Plume Dynamics and Conformance
- Induced Seismicity Management
- Monitoring for Leak Detection
- Site Closure
- Discussion

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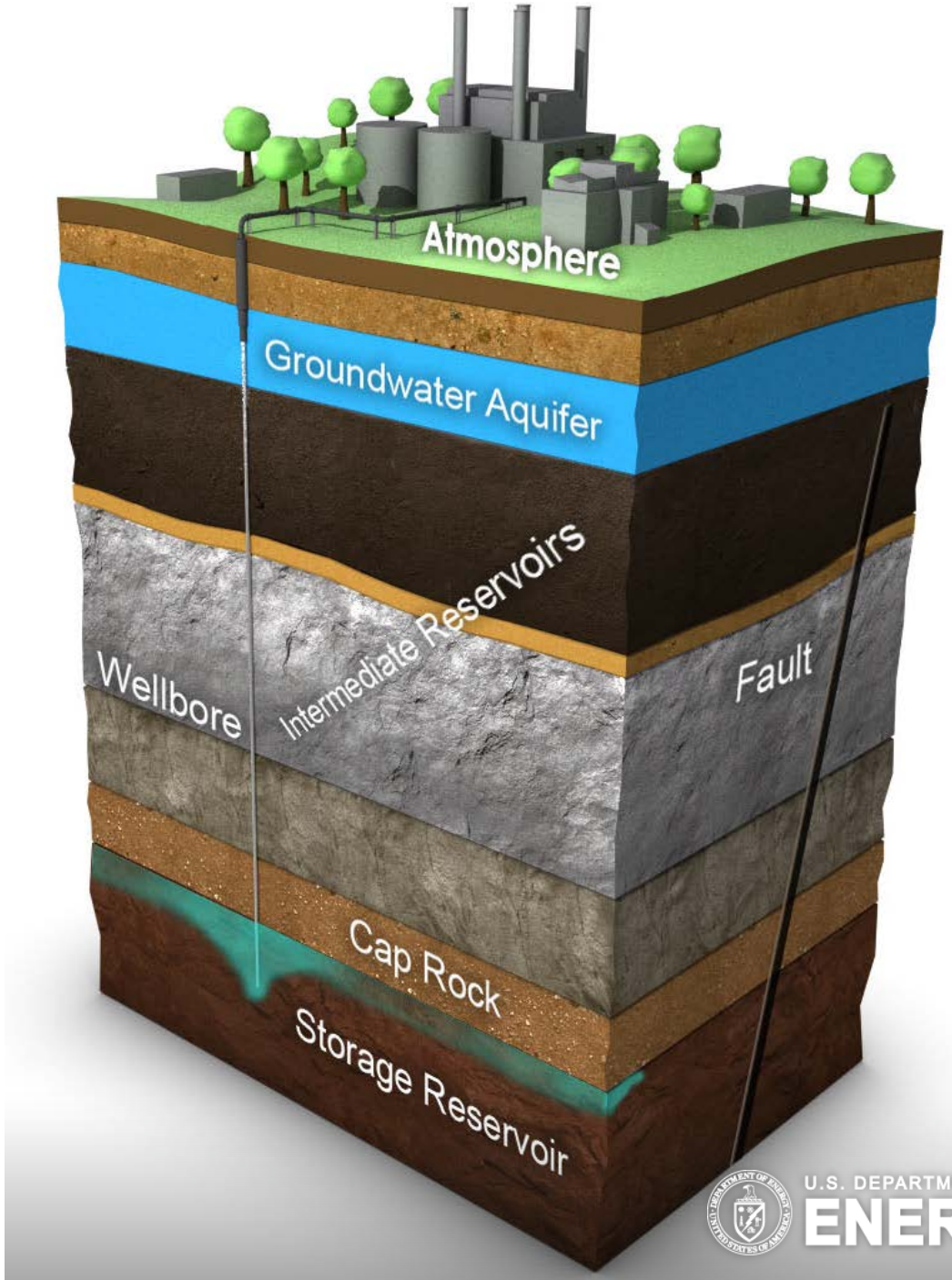
Building confidence in GCS through conformance evaluation

Presenter: Dylan R Harp

Contributors: Curtis Oldenburg, Bailian Chen, Rajesh Pawar, Bob Dilmore, Christine Doughty, and Veronika Vasylkivska

February 19, 2020

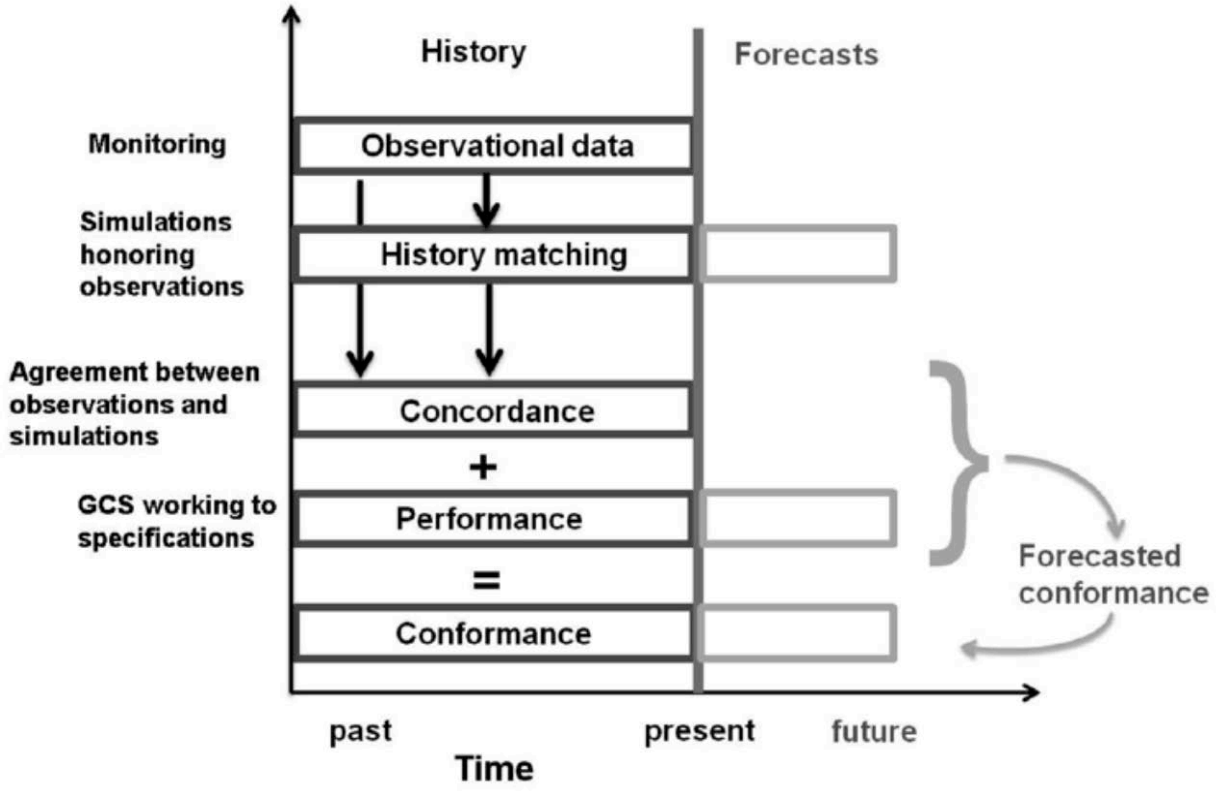


Definition of Conformance

Conformance – regulatory designation indicating that a GCS operation is performing and will continue to perform within acceptable levels of risk and within the bounds of its permit and related legal requirements.

Concordance – degree of coherence between simulated and observed quantities.

Performance – condition in which the GCS operation is performing satisfactorily as defined by performance criteria.



Oldenburg, Curtis M. GG:S&T (2018)

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Managing risk during GCS

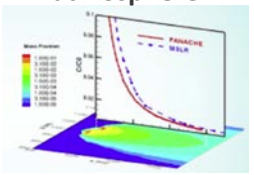
Why *conformance*?

- GCS involves several sources of risk
- A formal approach is required to manage these risks

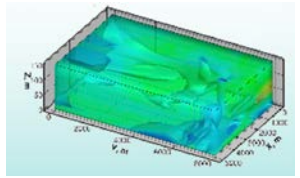
EPA Class VI Guidance:

- "Post-injection phase AoR reevaluations will involve a *comparison of newly collected data to the computational predictions* that supported the existing, approved AoR delineation, similar to those conducted during the injection phase
- "Verify that the AoR delineation model considers planned post-injection phase testing and monitoring to facilitate *a comparison of monitoring data and model predictions*."
- "…Testing and Monitoring Plan should *allow comparisons against baseline data and/or modeled predictions to support an evaluation of project operations*, confirm modeled predictions of the carbon dioxide plume and pressure front movement, and contribute to AoR reevaluations and a non-endangerment demonstration."

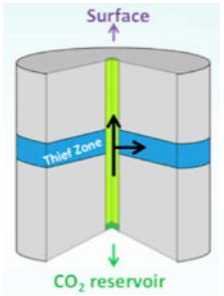
Leakage to atmosphere



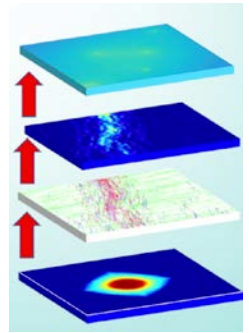
Aquifer Impacts



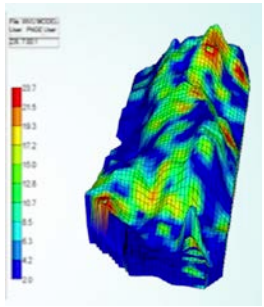
Wellbore leakage



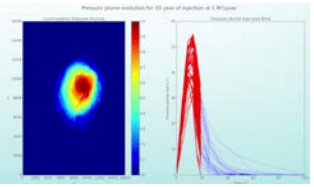
Caprock Leakage



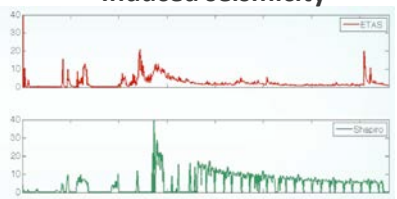
Plume stability



Reservoir pressurization



Induced seismicity



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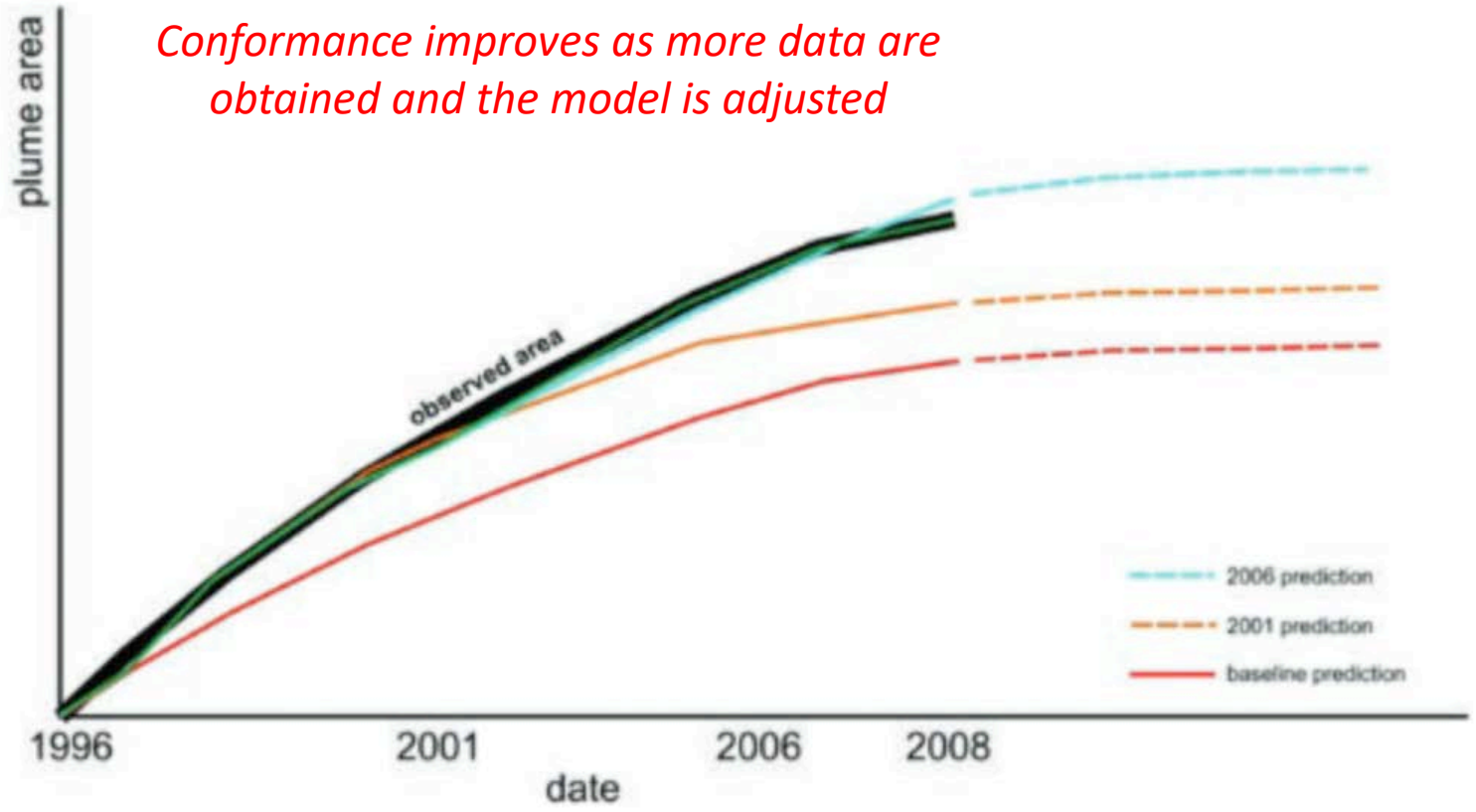
Conformance example: Sleipner

- Model uncertainties/assumptions:
  - Permeability of mudstone layers
  - Reservoir temperature
- Concordance metrics
  - Plume footprint area
  - Max lateral migration
  - Plume area at top reservoir
  - Volume at top reservoir
  - Total area of all reservoirs
  - Spreading coefficient
- Observations
  - Time-lapse 3D seismic

Conformance improves as more data are obtained and the model is adjusted



Chadwick and Noy. *Greenhouse Gases: Science and Technology* (2015).

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Requirements of a conformance analysis

- System model (e.g., numerical simulator)
- Uncertainty model (e.g., probabilistic distribution of permeability)
- Concordance metric (e.g., RMSE)
- Performance metric (e.g., safe pressure threshold)
- Performance observations (e.g., monitoring well pressure)

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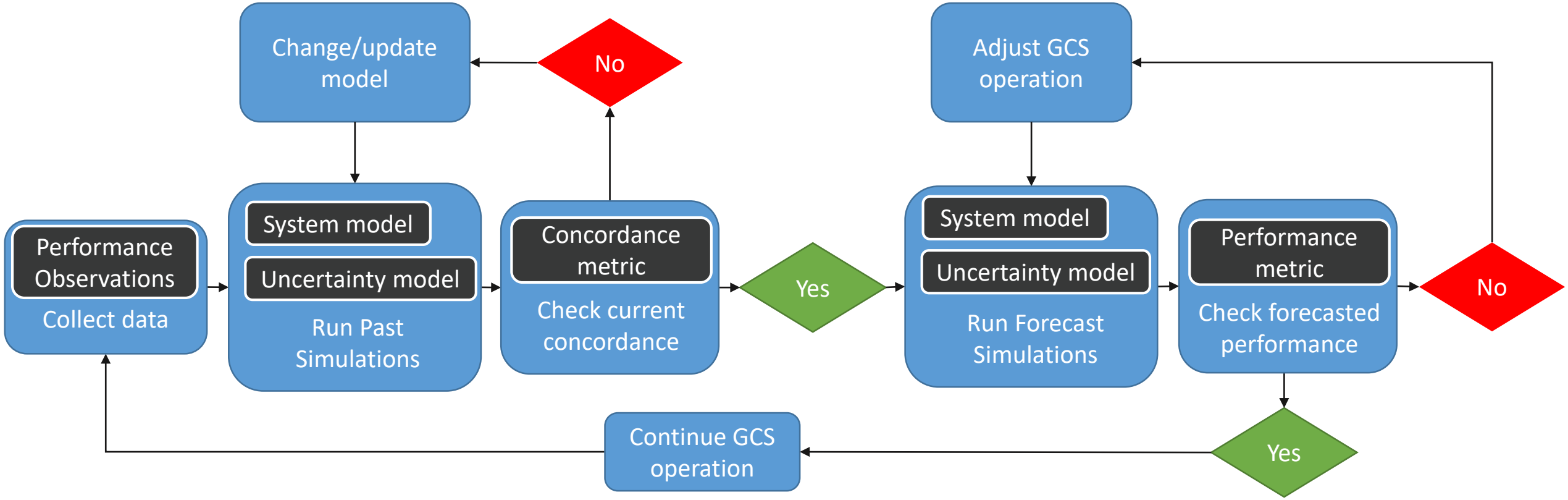
Conformance analysis



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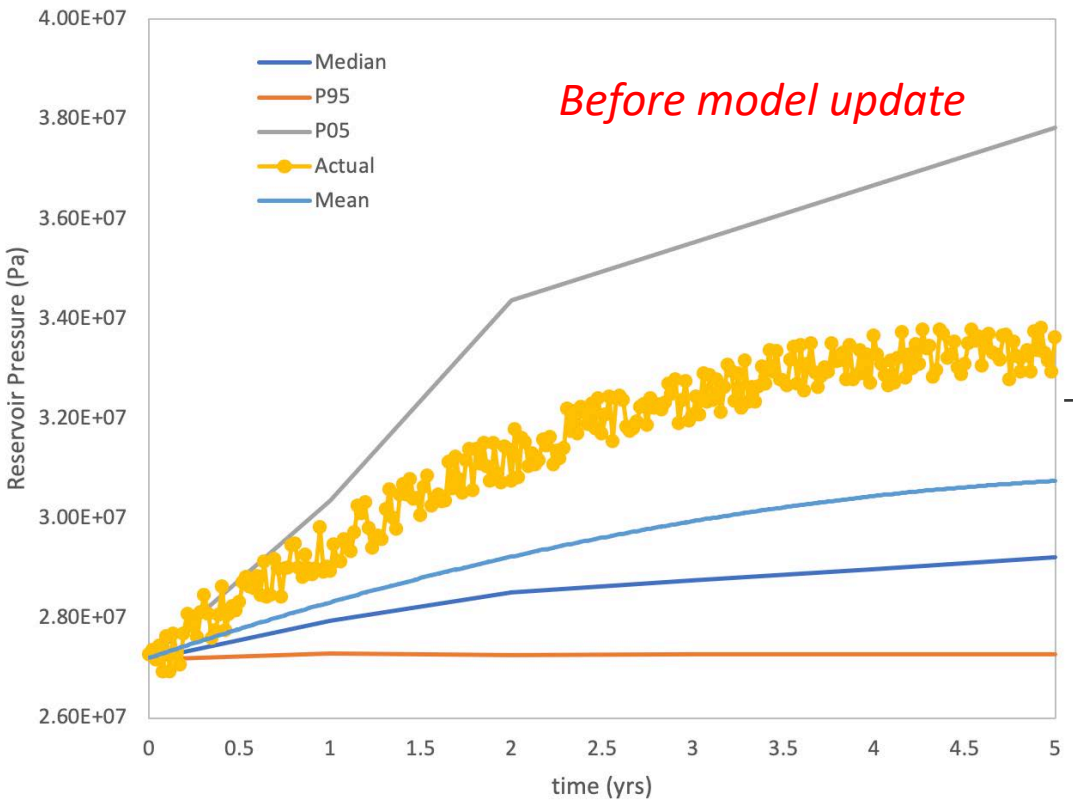
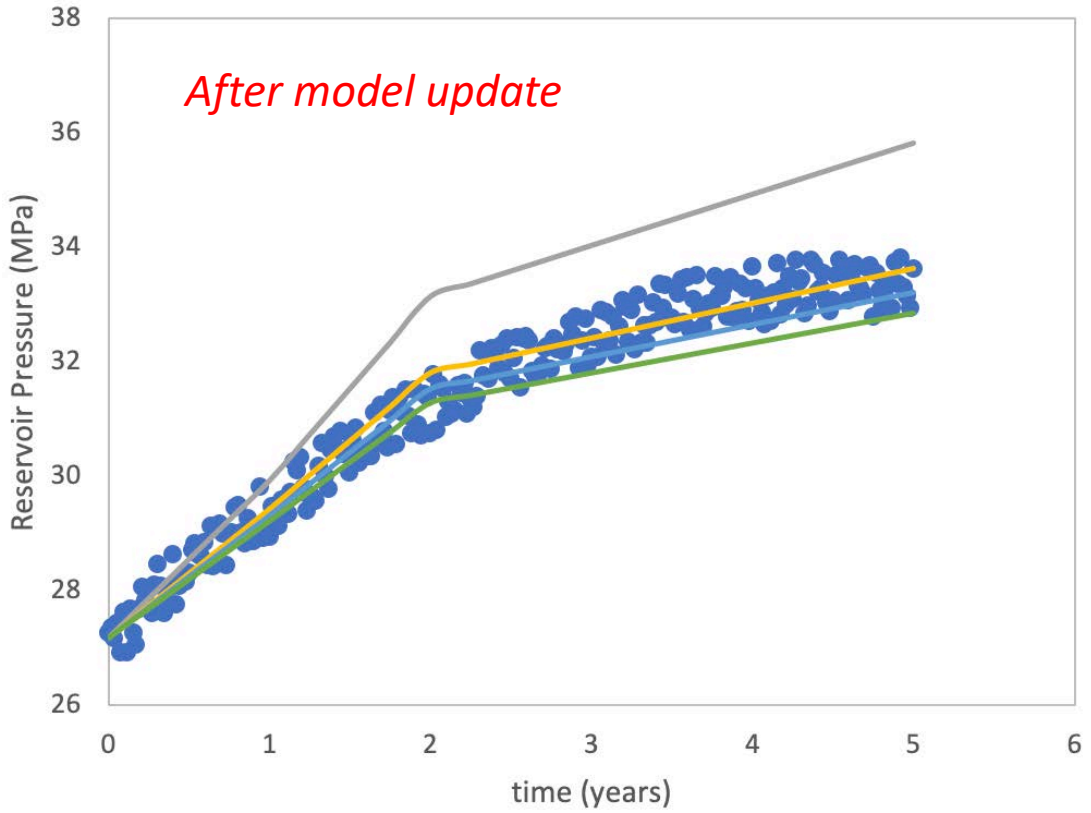
Concordance: Manual





(Oldenburg and Doughty, LBNL)

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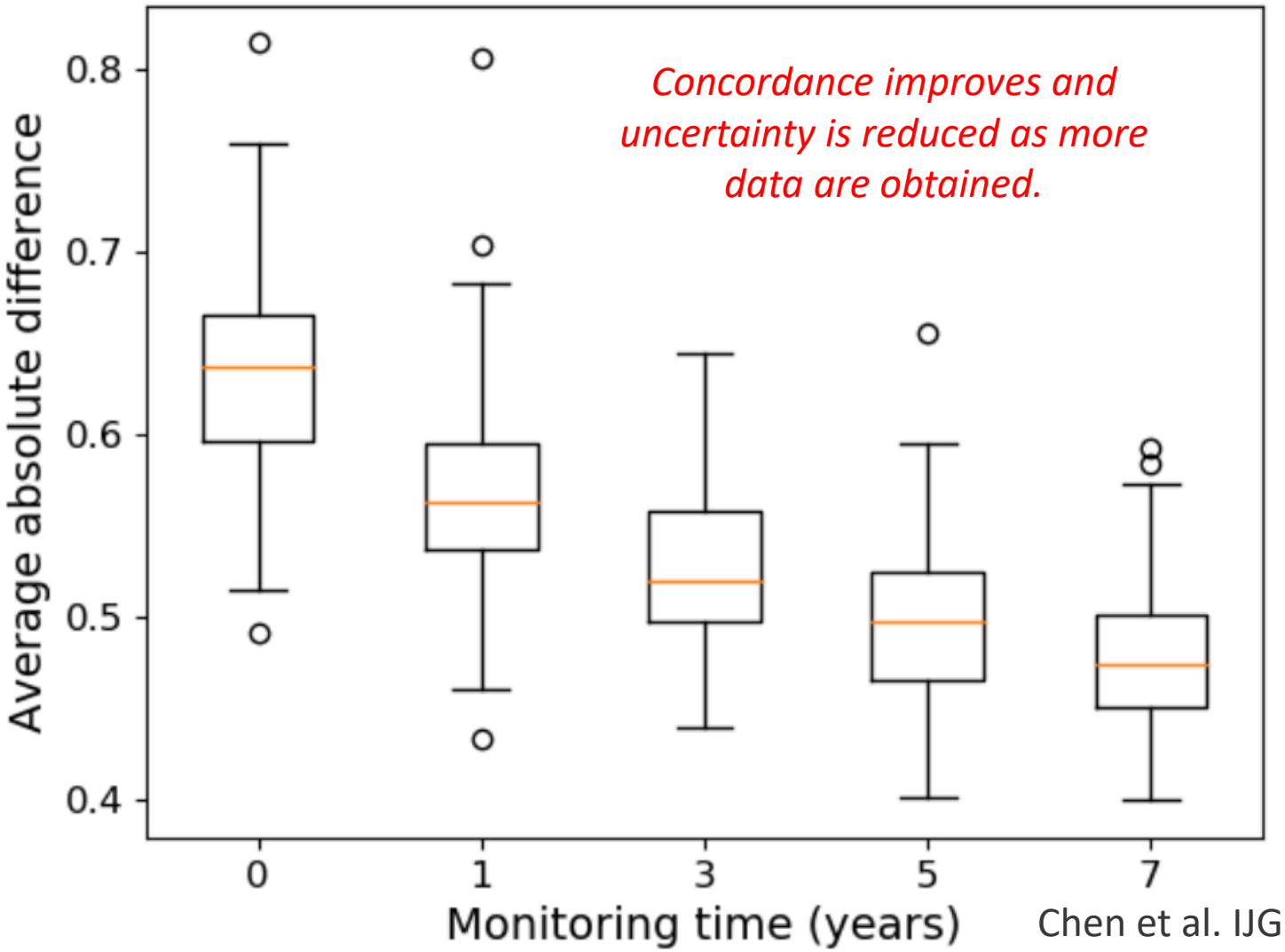
Concordance: Data Assimilation



Chen et al. IJGGC (2020)

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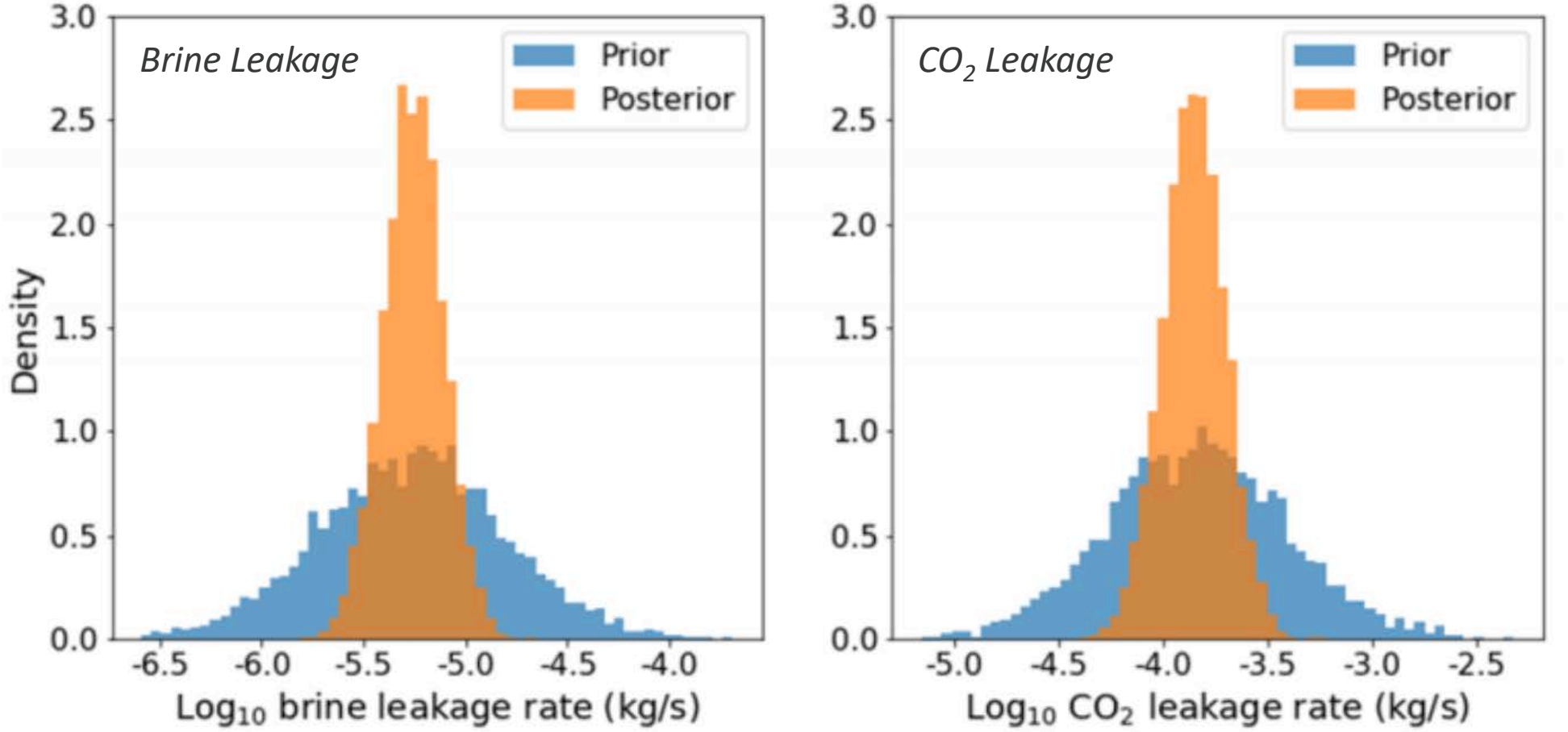
Concordance: Markov Chain Monte Carlo

Prior – Before model update

Posterior – After model update



Chen et al. GHGT (2018)

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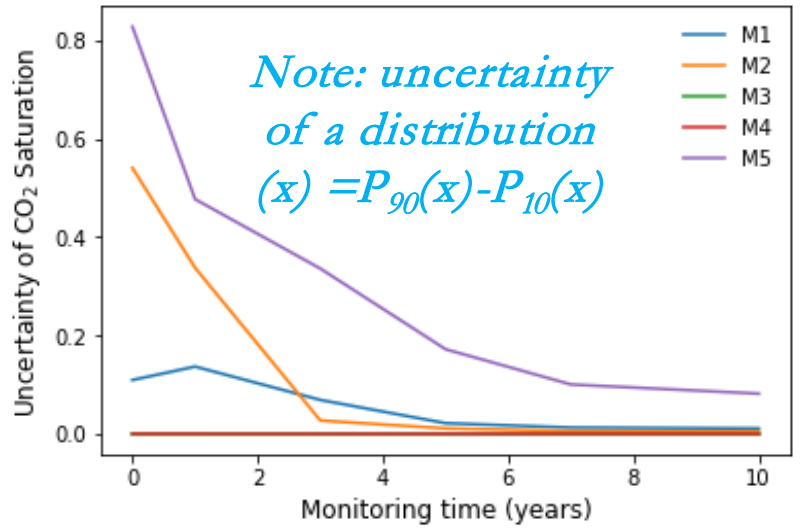
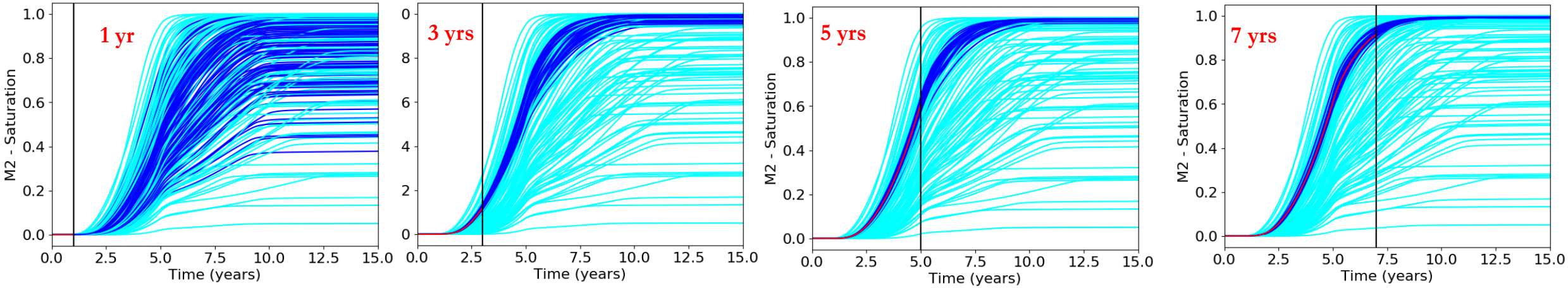
Conformance: Uncertainty reduction techniques

- Ensemble-based approach
- Reduced uncertainty -> reduced risk -> increased confidence in conformance





Cyan: prior models Blue: posterior models

(Chen LANL)

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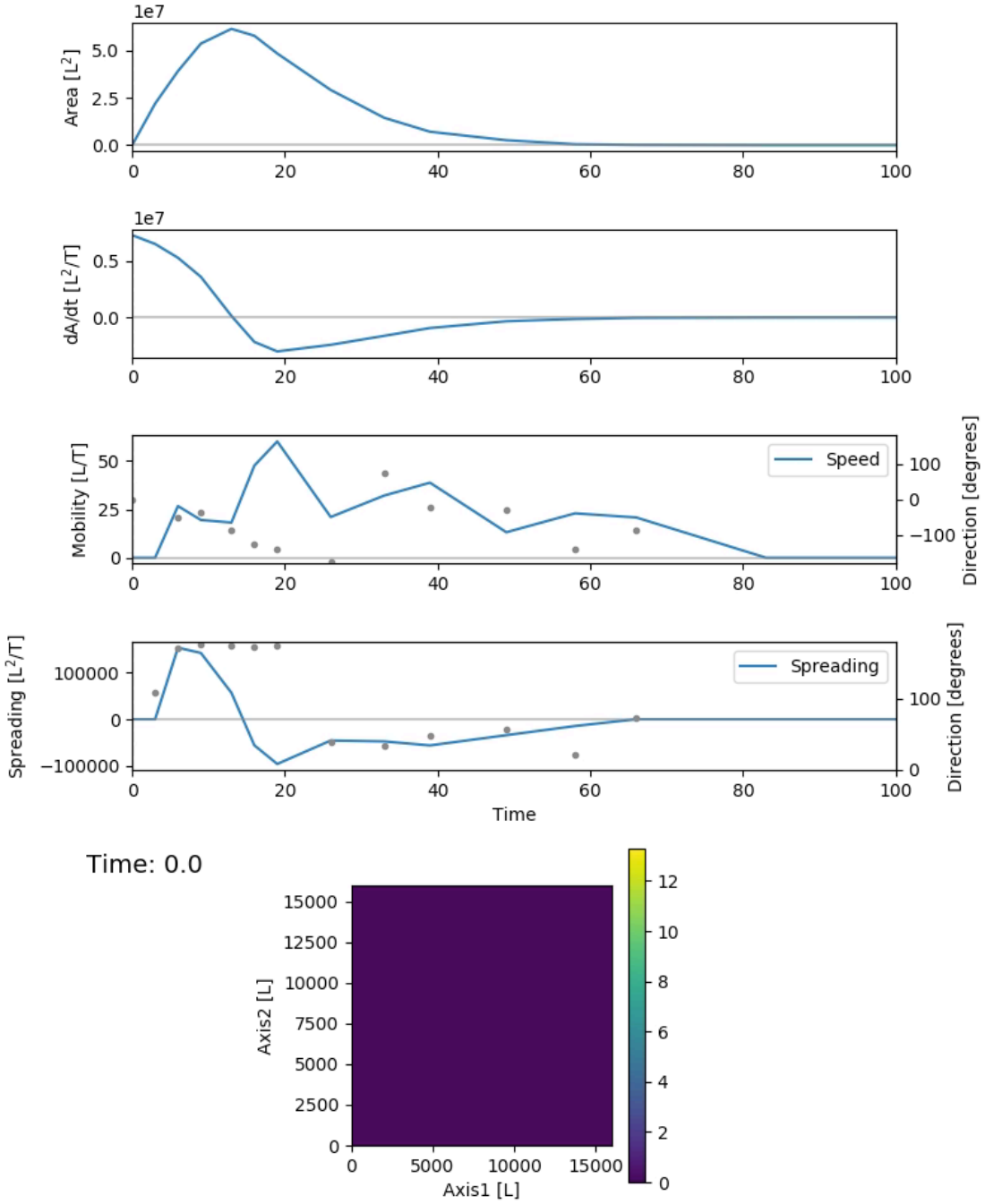
Conformance: Plume stability

Why quantify plume stability?

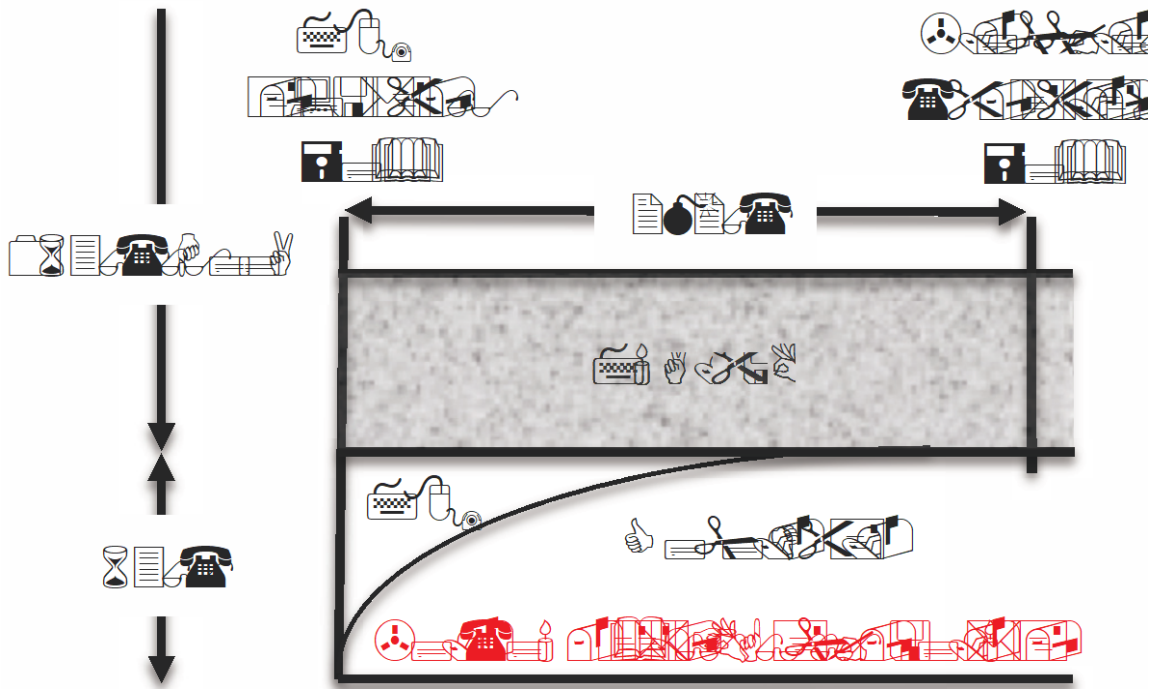
- Plumes can be complicated
  - Geology/stratigraphy
  - Injection/extraction regimes
  - Physical processes, e.g., dissolution
  - Internal plume redistribution
- Plume stability can support conformance

Harp et al. *Greenhouse Gases: Science and Technology* (2019).



Example conformance analysis: Setup

- System model:
  - NRAP-Open-IAM Simple Reservoir Model
- Uncertainty model:
  - Uncertain reservoir permeability
- Concordance metric:
  - Std. error of (permeability) estimate
- Performance metric:
  - Pressure threshold at monitoring well
- Performance observations
  - Pressures at monitoring well



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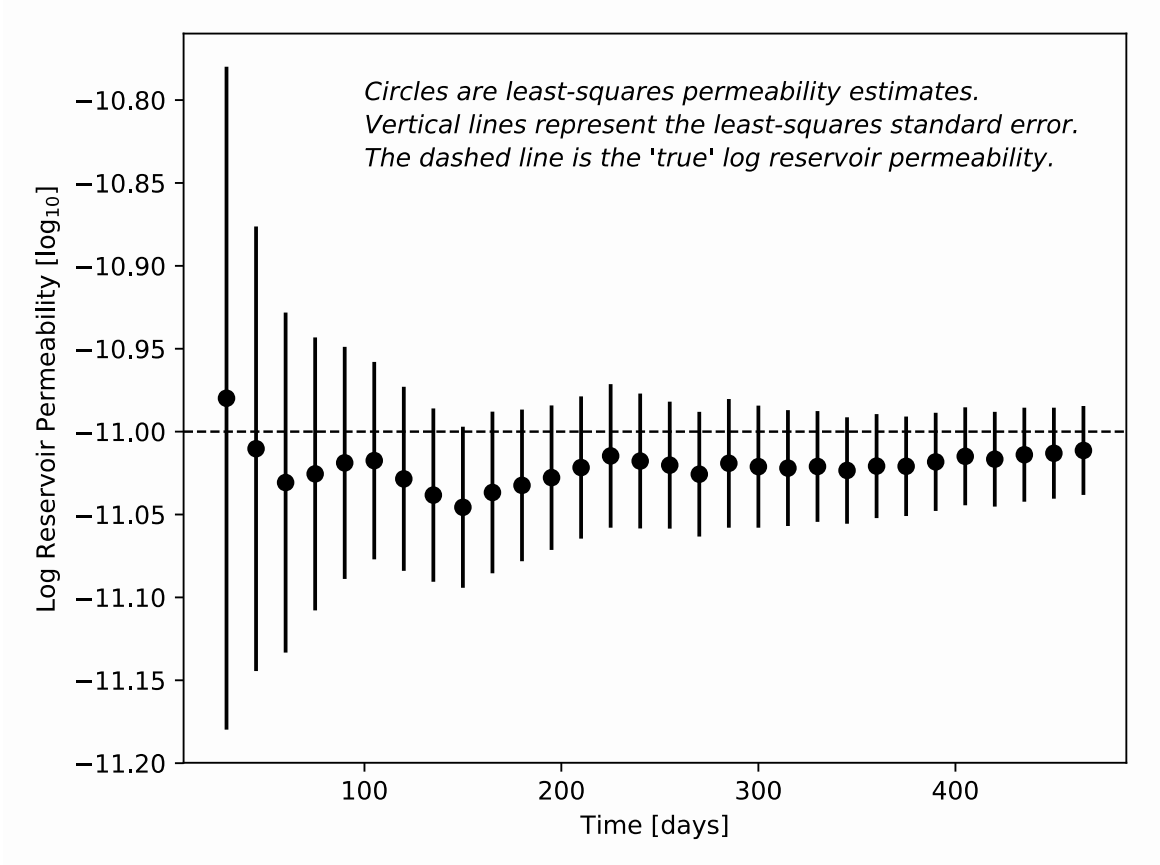
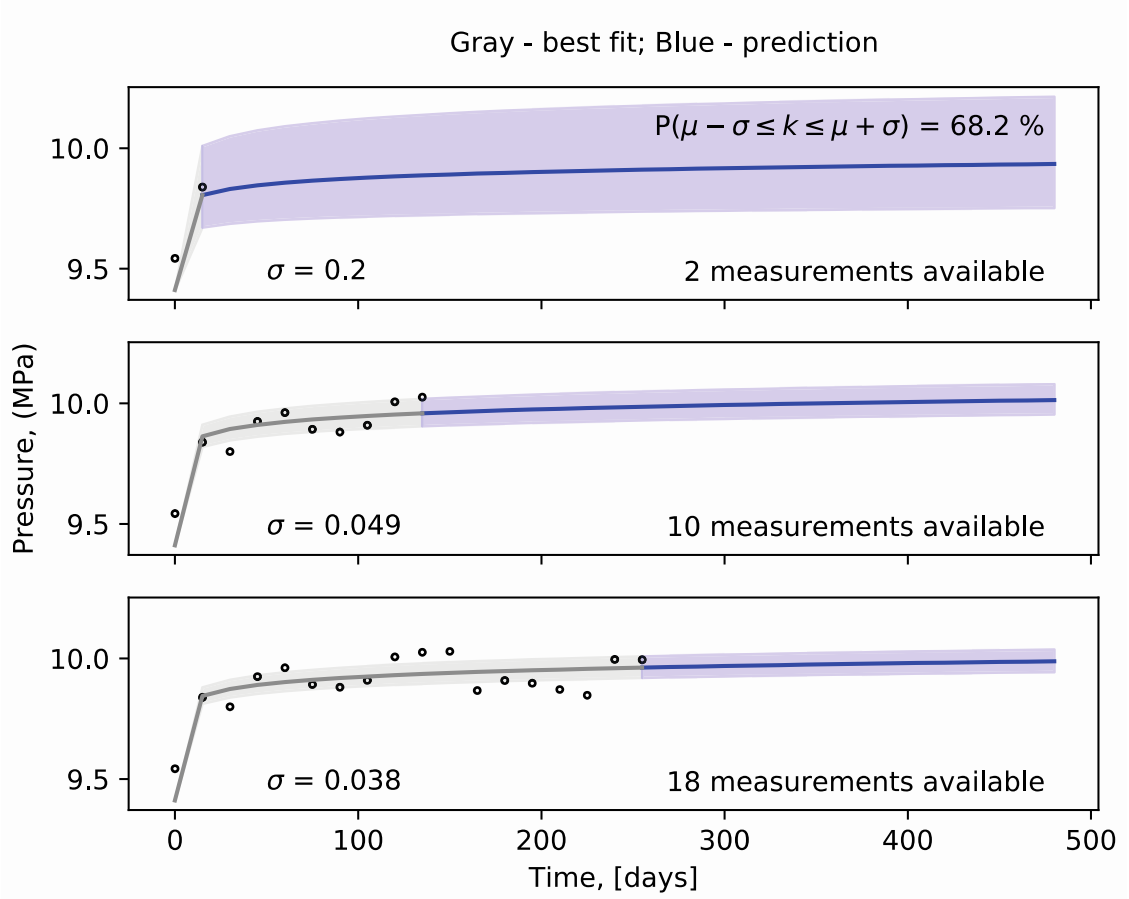
Example conformance analysis: Metrics

Concordance improves (std. error decreases) as more data are obtained.



Uncertainty in pressure forecast decreases as more data are obtained!



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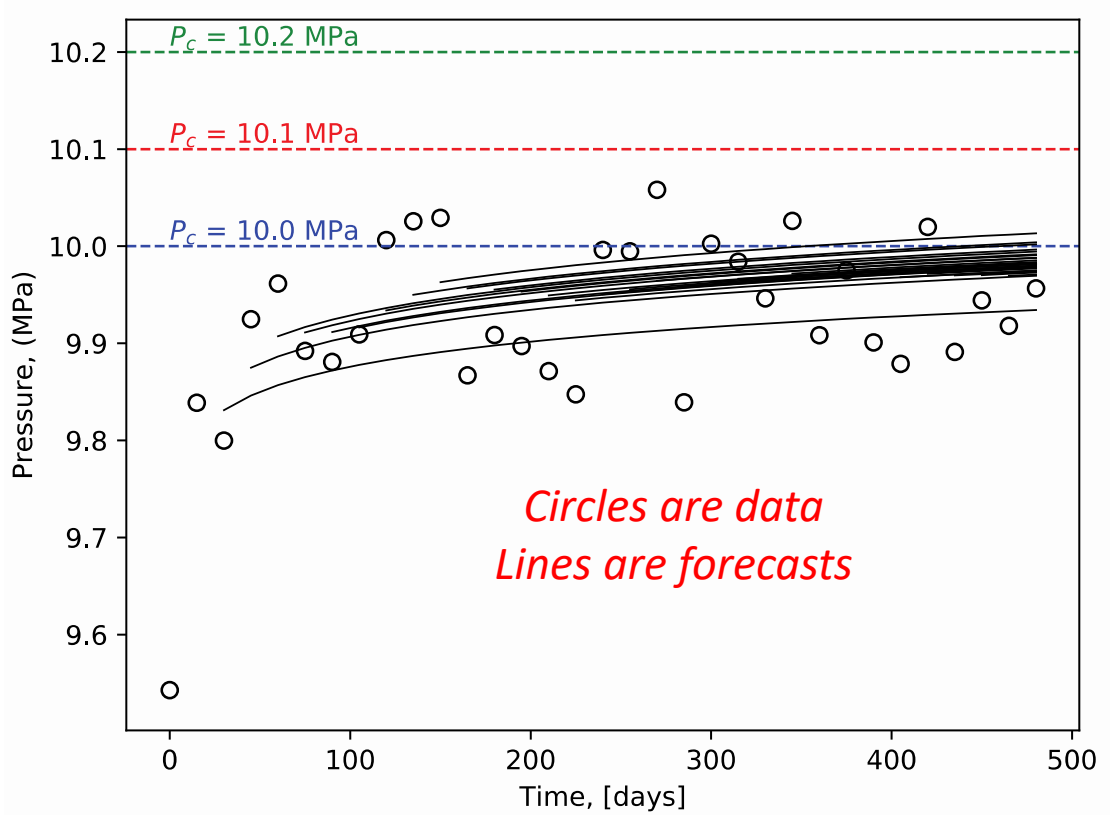
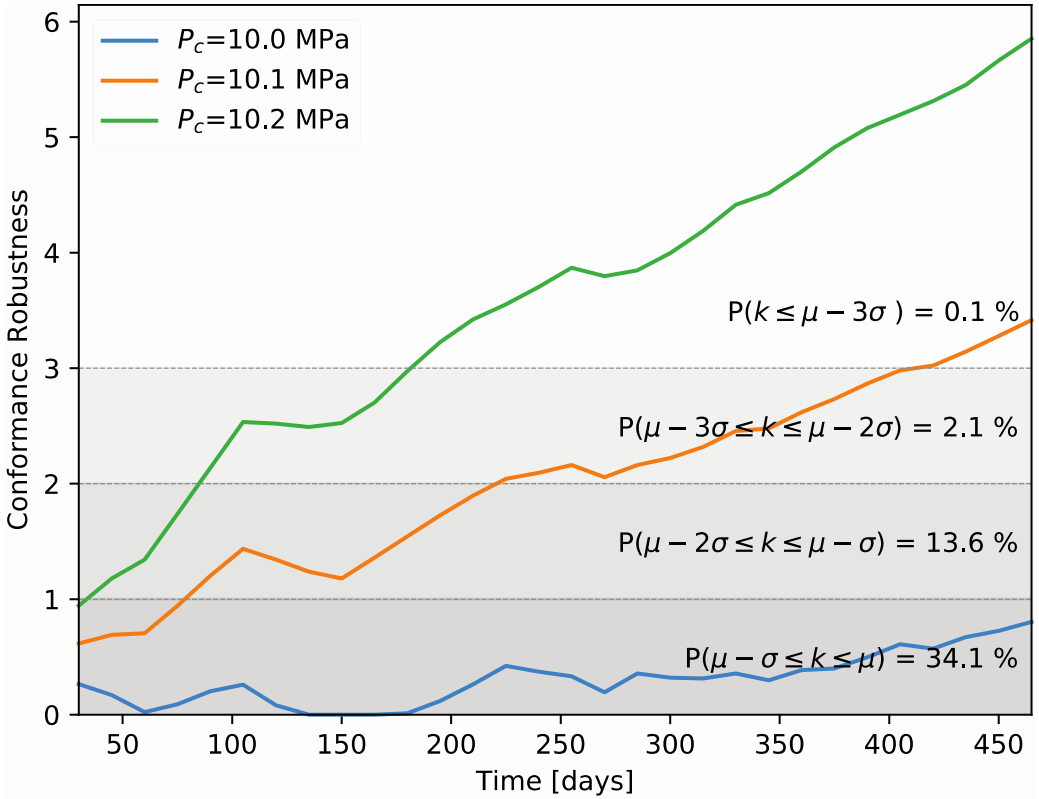
Example conformance analysis

Iterative evaluation of conformance as more data are obtained.



Confidence (robustness) in designation of conformance increases as more data are obtained!



Harp et al. *International Journal of Greenhouse Gas Control* (2019).

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Conformance analysis in NRAP-Open-IAM

- **Full conformance analysis example**
  - Uses NRAP-Open-IAM built-in *model calibration* functionality
- **Uncertainty quantification using MCMC:**
  - Single leaky well
  - Two leaky well
- **Plume stability analysis examples**
  - Rock Springs Uplift
  - Kimberlina
  - Plume stability uncertainty quantification
- **Can load your own simulations into NRAP-Open-IAM "Lookup Table"**

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Summary

- **Why *conformance* analysis? A formal approach must be in place to manage the risks involved with GCS.**
- **Features of Conformance Analysis as more monitoring data are obtained:**
  - *Concordance* improves
  - Uncertainty in forecasted *performance* decreases
  - Confidence in *conformance* increases
- **NRAP-Open-IAM facilitates conformance:**
  - Integrated assessment model
  - Uncertainty reduction
  - Model calibration
  - Data assimilation
  - Plume stability analysis
  - Own simulations can be imported as lookup tables

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Extra Slides

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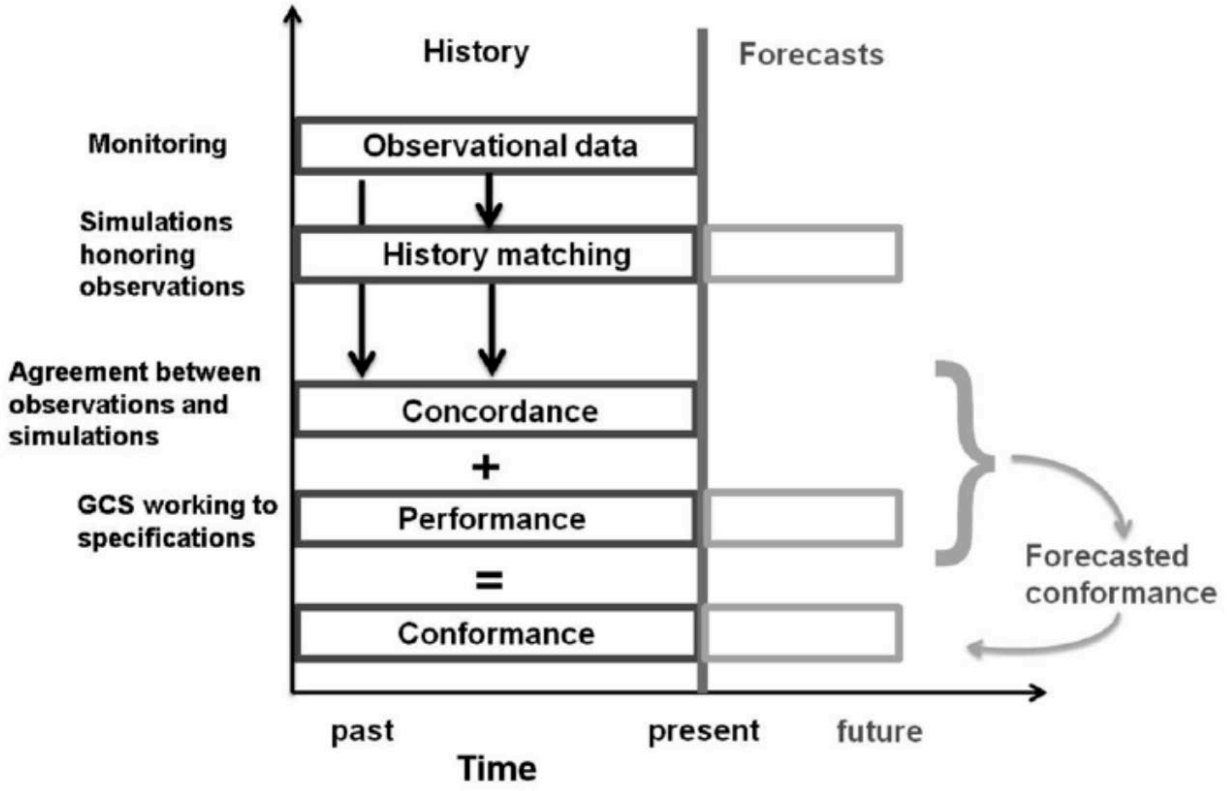
Definition of Conformance

- *Conformance*:
  - established past *concordance*
  - forecasted future *performance*



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Performance

- **Ensure that past measurements and forecast indicate that:**
  - Overpressure due to injection is equal to or lower than anticipated
  - Brine extraction volumes are acceptable
  - Injection volume is equal to or greater than anticipated
  - Induced seismicity is nonexistent or equal or less than anticipated
  - etc.

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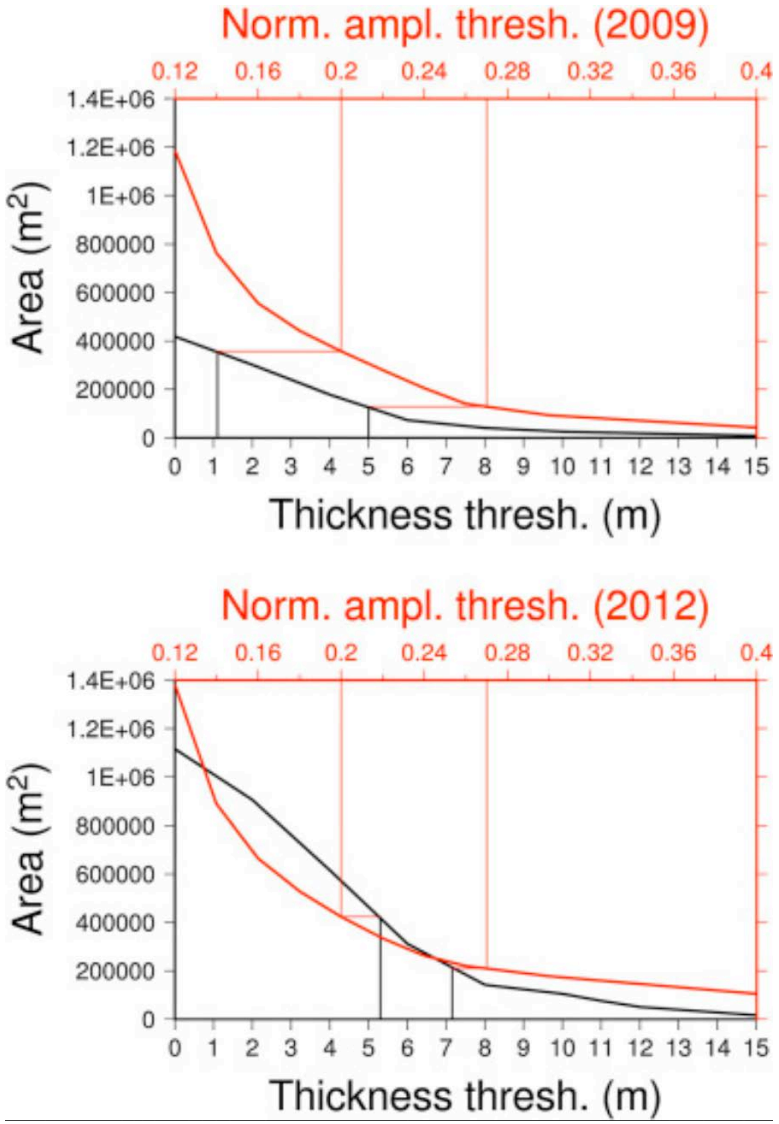
Conformance example: Ketzin

- Observations
  - 4D seismic
- Concordance metrics
  - Plume area
  - Max lateral migration
  - Plume volume
  - Similarity index

Black – simulation

Red - seismic



Lüth et al. *International Journal of Greenhouse Gas Control* (2015).

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