# DATA-DRIVEN FRAMEWORK FOR HISTORY MATCHING:

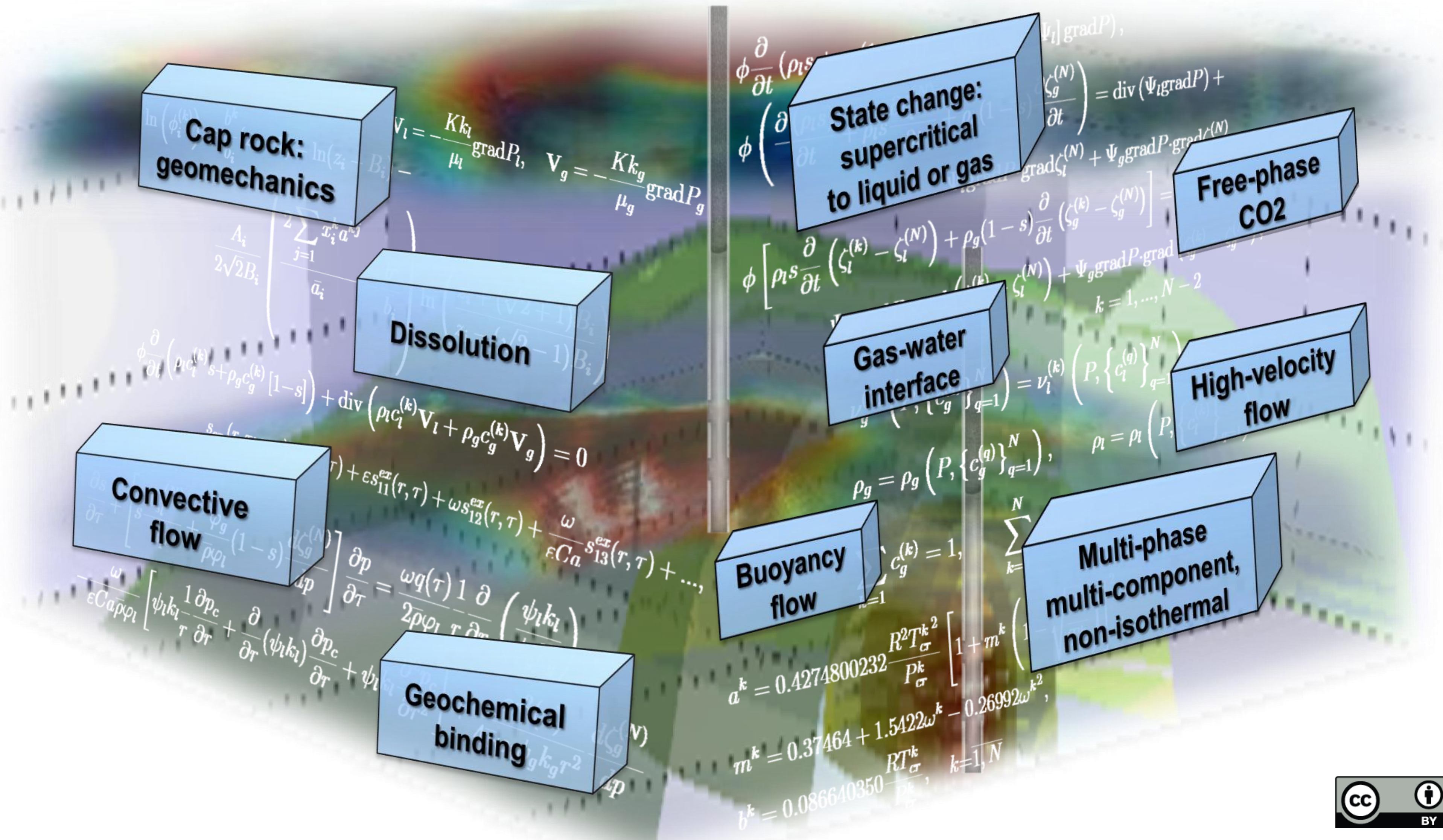
## APPLICATION TO CARBON DIOXIDE STORAGE IN GEOLOGICAL FORMATIONS

SERGEY OLADYSHKIN · HOLGER CLASS · RAINER HELMIG · WOLFGANG NOWAK

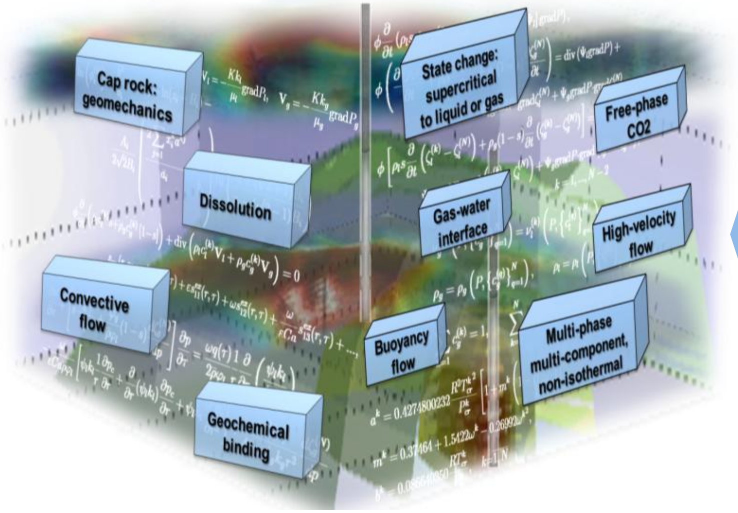
SIMTECH CLUSTER OF EXCELLENCE
INSTITUTE OF HYDRAULIC ENGINEERING
UNIVERSITY OF STUTTGART

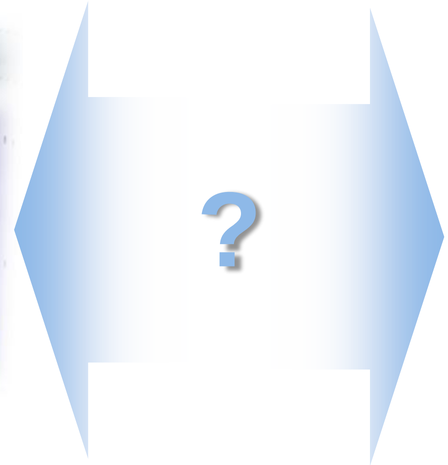
# INTRODUCTION TO HISTORY MATCHING

# COMPLEX TRULY MU$^X$ SYSTEM



# HOW GOOD CORRESPONDENCE BETWEEN MODEL AND REAL-WORLD SYSTEM?




**OBSERVATION**

**+**

**?**

**MODEL**

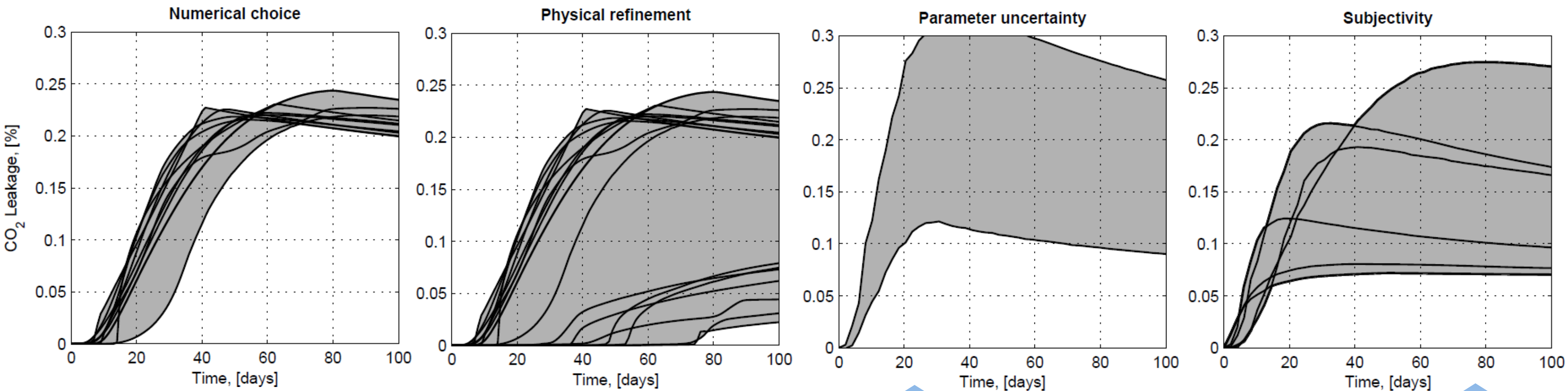
**REAL-WORLD**

**HISTORY MATCHING CAN HELP TO CLERIFY THIS QUESTION**

# BENEFIT OF HISTORY MATCHING

**Possible prediction of CO2 Leakage: impact of model complexity (test case study)**

QUALITATIVE | QUANTITATIVE




HISTORY MATCHING HELPS TO ESTIMATE UNKNOWN PROPERTIES AND MINIMIZE IMPACT OF WRONG PRIOR ASSUMPTIONS ON DATA

SimTech Cluster of Excellence

Universität Stuttgart Germany

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# AUTOMATIC FRAMEWORK FOR HISTORY MATCHING

**STEP 0. PRIMER SENSITIVITY ANALYSIS**

**STEP 1. PROJECTION ONTO RESPONSE SURFACE**

**STEP 2. BAYESIAN UPDATE USING RESPONSE SURFACE**

# STEP 0. PRIMER SENSITIVITY ANALYSIS

**Goal: Redaction of analyzing parameters**

**Idea: Cheap, but useful estimations**

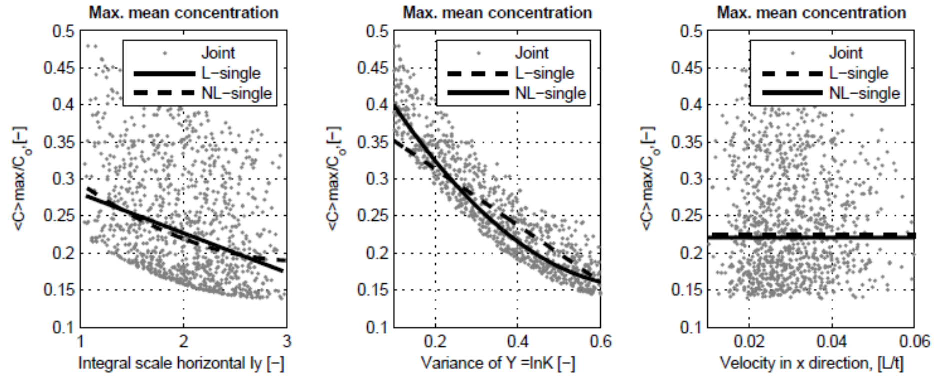
**HEALTHY COMBINATION OF
"OPTION A" AND "OPTION B"**

## OPTION A (QUALITATIVE):

**EXPERT OPINION ON PARAMETER IMPORTANCE**

## OPTION B (QUANTITATIVE):

**SENSITIVITY ANALYSIS (RANKING FOR PARAMETERS)**




GLOBAL WEIGHED SENSITIVITY ANALYSIS

*Details in Paper:*

*Oladyshkin S., de Barros, F. P. J. and Nowak W. Global sensitivity analysis: a flexible and efficient framework with an example from stochastic hydrogeology. // Advances in Water Resources, Elsevier, Submitted 2011.*

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STEP 0. PRIMER SENSITIVITY ANALYSIS

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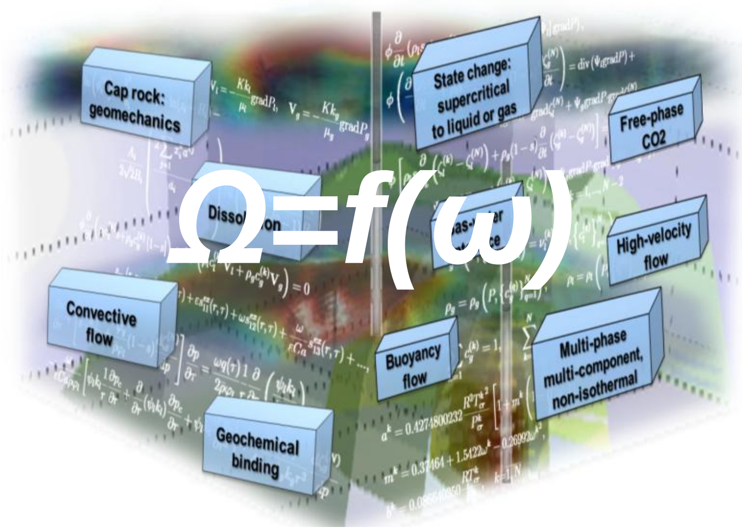
# STEP 1. PROJECTION ONTO RESPONSE SURFACE




**MODEL**

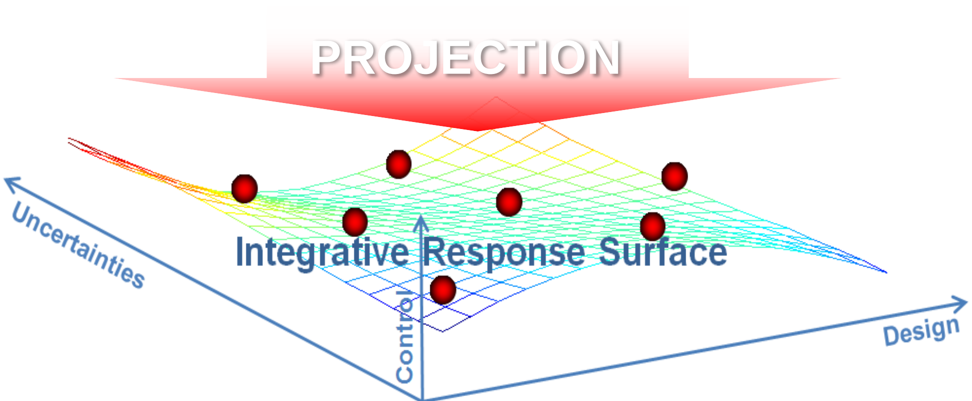
## Input Parameters $\omega=\{\omega_1,\ldots,\omega_N\}$

Injection Rate, Screening Interval, Permeability, Porosity, …

## Model Output $\Omega(\omega)$

$CO_2$ Leakage Rate, Reservoir Pressure, $CO_2$ Saturation,…

**“SMART” CONSTRUCTION OF INTEGRATIVE RESPONSE SURFACE**



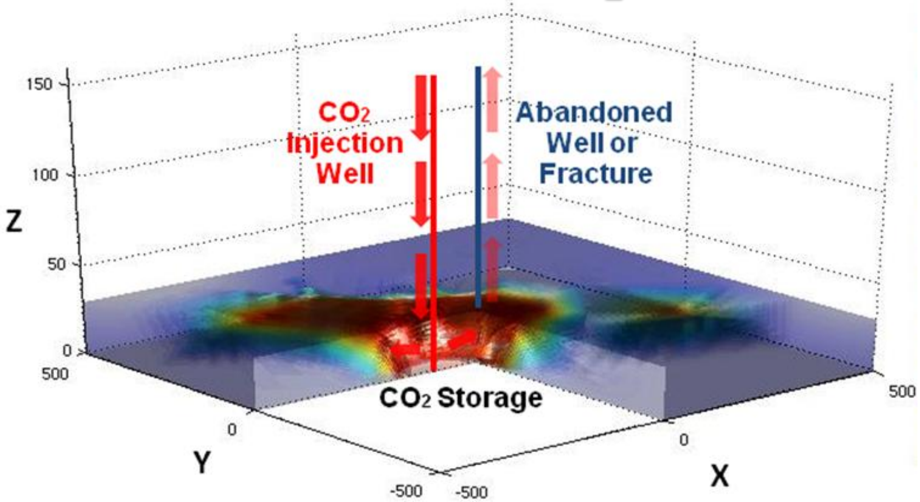

Chaos Expansion

$$\Omega(\omega) = c_0 + \sum_{i=1}^{N} c_1\, P_1(\omega_i) + \sum_{i=1}^{N}\sum_{j=1}^{i} c_{ij}\, P_2(\omega_i,\omega_j) + \cdots$$

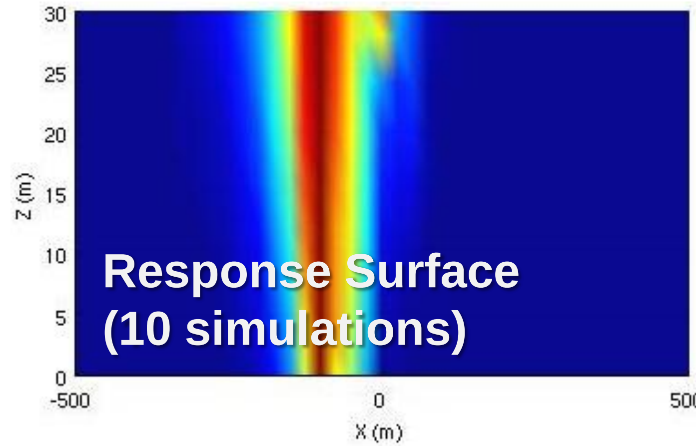
*Collocation approach on orthonormal polynomial basis*

# STEP 1. PROJECTION ONTO RESPONSE SURFACE

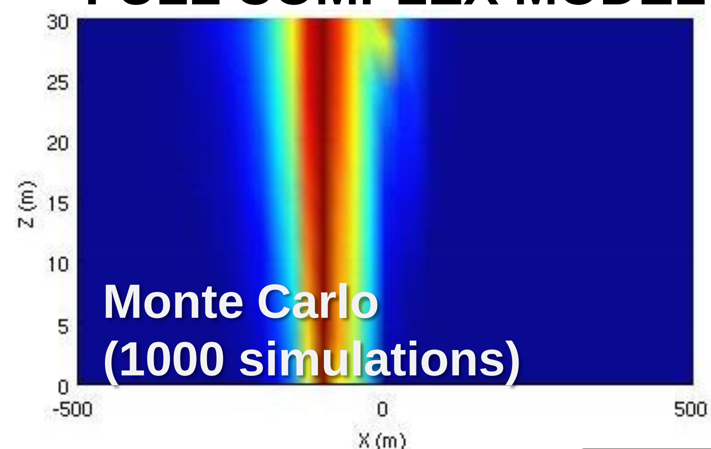
## CASE STUDY FOR MODELLING OF $CO_2$ STORAGE




RESPONSE SURFACE




FULL COMPLEX MODEL




Section Plot - Mean of $CO_2$ Saturation (30 days)

*Details in Paper:*

*Oladyshkin, S., Class, H., Helmig, R., Nowak, W., Open an integrative approach to robust design and probabilistic risk assessment for CO2 storage in geological formations // Computational Geosciences, Springer, 2011, DOI: 10.1007/s10596-011-9224-8*

# AUTOMATIC FRAMEWORK FOR HISTORY MATCHING

STEP 0. PRIMER SENSITIVITY ANALYSIS

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# STEP 2. HISTORY MATCHING TO OBSERVED DATA



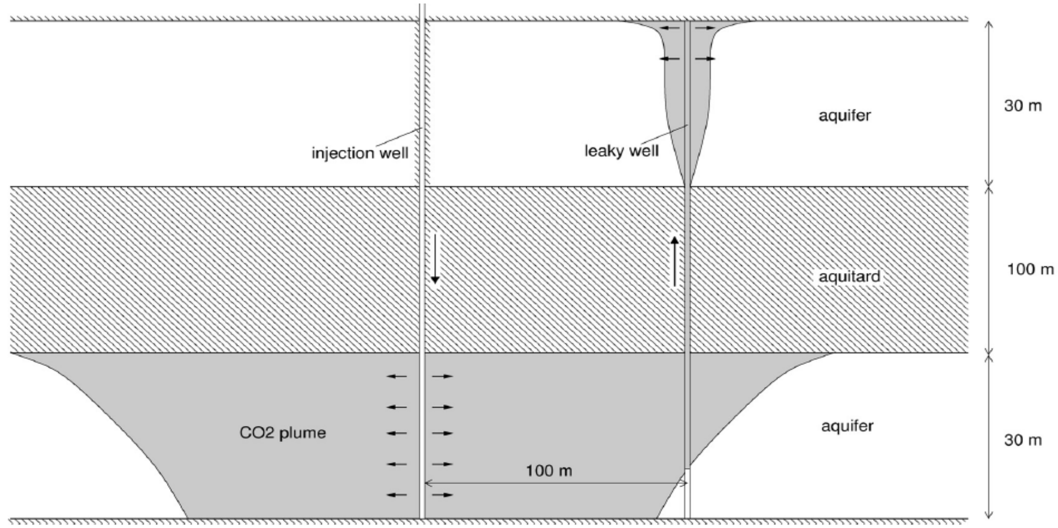
## **Case Study:** Matching of Pressure on Leakage Well (Monitoring)

**Uncertainties:** Permeability, Porosity, Leakage Well Permeability

**Observation:** Measurement of Pressure during 200 days (*Synthetic Information form Fine Grid Simulation*)

**Modeling:** Coarse Grid Simulation for Benchmark Problem

**Incorporated Error:**
Measurement Error + Conceptual Error




3D Benchmark for $CO_2$ Leakage

**Methodology: Bayesian updating using Particle Filtering**

**Advantage: Non-linear approach**

**Feasibility: In combination with response surface**

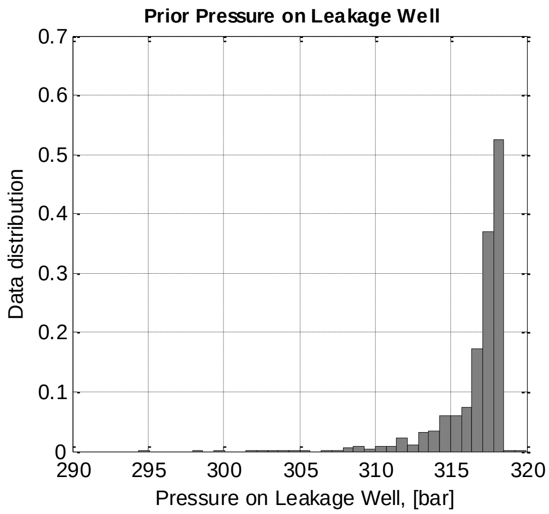
# STEP 2. HISTORY MATCHING TO OBSERVED DATA

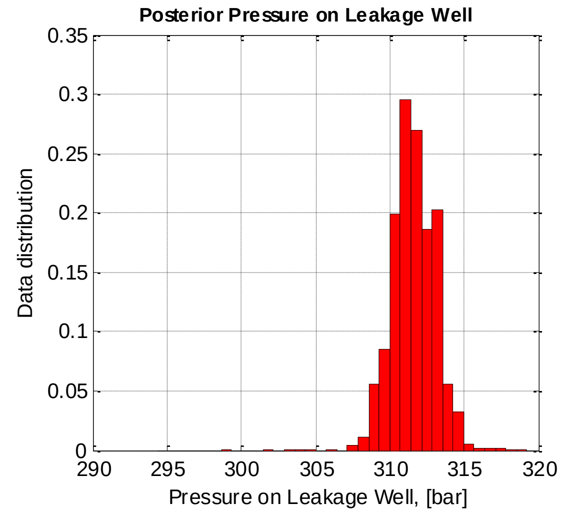


## PRIOR ASSUMTION

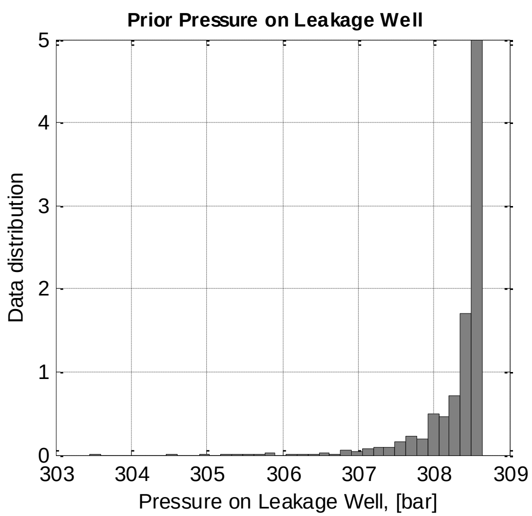
## POSTORIOR UPDATE

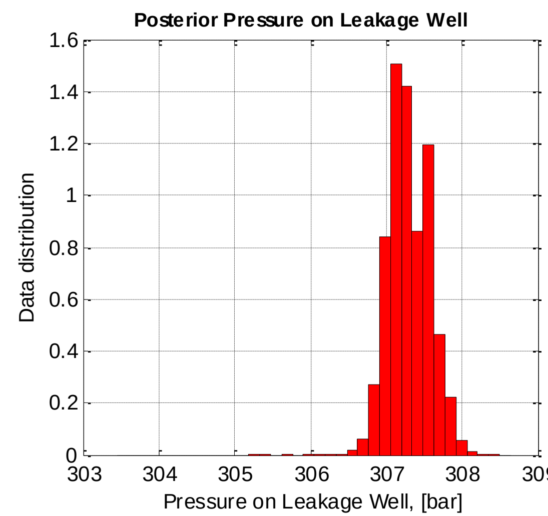
**AFTER 1 DAY**



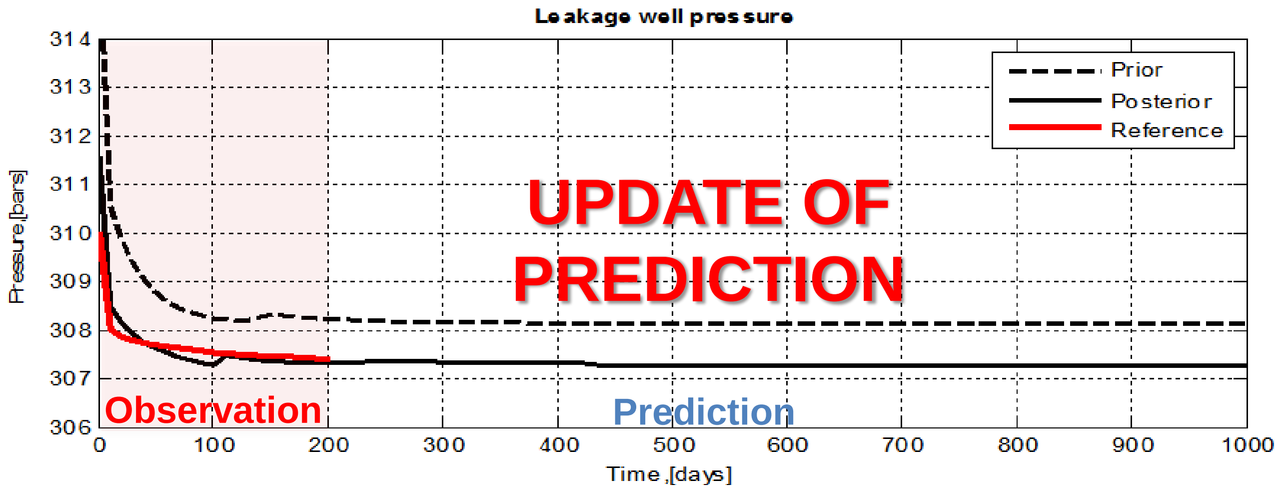



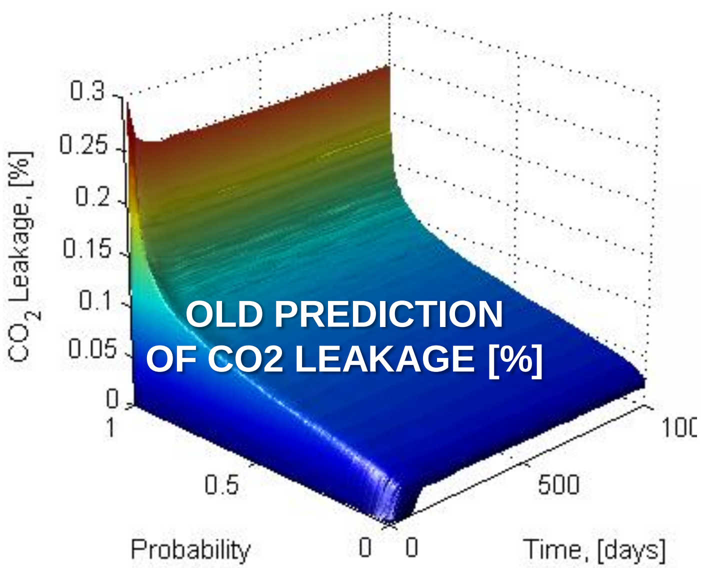

**AFTER 200 DAY**



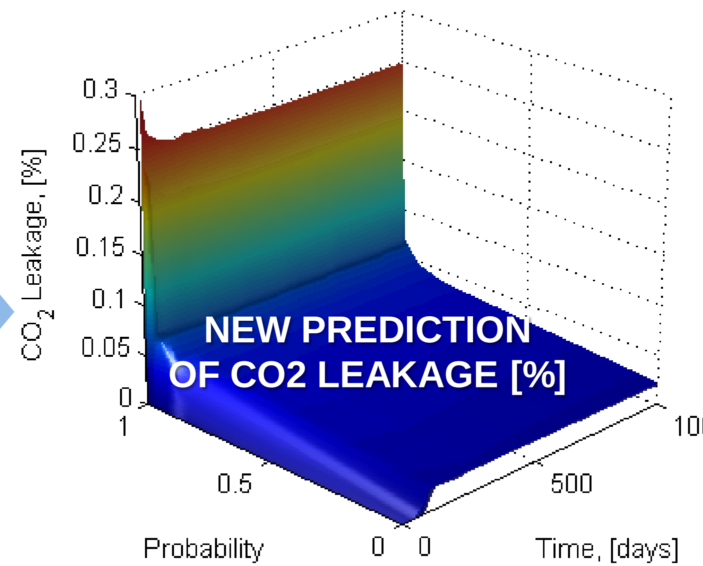



# STEP 2. HISTORY MATCHING TO OBSERVED DATA




REDUCED PREDICTION UNCERTAINTY



# CONCLUSIONS

## AUTOMATIC FRAMEWORK FOR HISTORY MATCHING

- INITIAL COMPLEX MODEL PROJECTED TO RESPONSE SURFACE

- BAYESIAN UPDATE USING PARTICLE FILTERING

## ADVANTAGES:

- KEEPING NON-LINEARITY

- FLEXIBILITY OF FRAMEWORK ("BLACK-BOX" APPROACH)

# Acknowledgements

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