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Near Field – URL FE/ATLAS

Feliks Kiszkurno[2,1], Jörg Buchwald[2,1], Thomas Nagel[1,3]

[1] Institut für Geotechnik, Technische Universität Bergakademie Freiberg
[2] Helmholtz-Zentrum für Umweltforschung GmbH – UFZ, Leipzig
[3] TUBAF-UFZ Zentrum für Umweltgeowissenschaften

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OUTLINE

DoE-based history matching

Parameter Uncertainties: FE-Experiment

Model Uncertainties: Thermo-Osmosis

DoE-based history matching

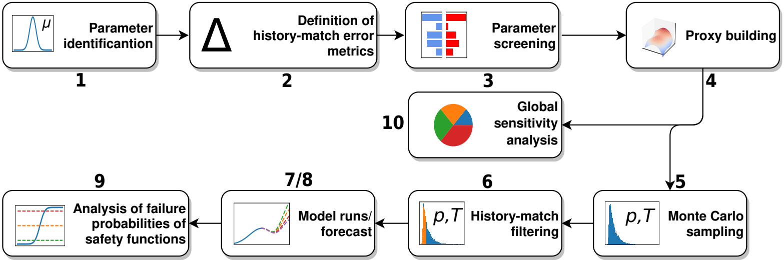
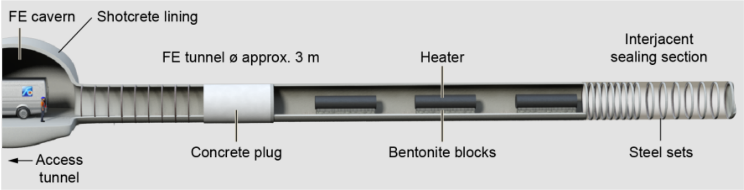


Fig. 1: Schematic sketch of the workflow. From Buchwald et al. 2020

- Workflow implemented in Python integrating a number of well-tested and own packages: pyDoE2, GPy, SALib, scipy, statsmodels, ChaosPy, ogs6py, vtk...
- workflow applied for treating **parameter uncertainties** (3D model of FE-experiment) and **model uncertainties** (thermos-osmosis in the ATLAS experiment)

Parameter Uncertainties: FE-Experiment



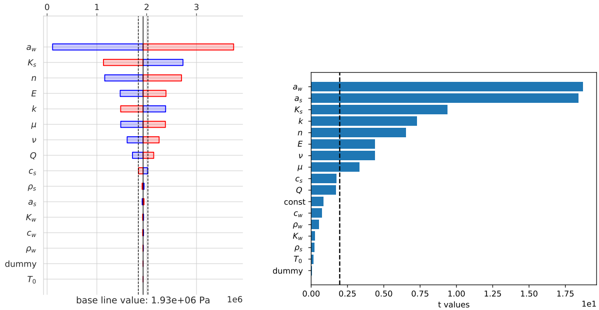
- Biggest heater experiment at Mt. Terri
- Modelled phases: excavtion, shotcreting, emplacement, heating
- Parameter study for clay parameters on relative temperature and pressure changes in clay while heating
- Use of TH(m) model for forward runs (Buchwald et al. 2021).

Parameter Uncertainties: FE-Experiment

1. identifying parameter distributions, we restricted our analysis only to clay-related parameters
   - For clay 15-20 parameters; mostly min/best/max data available
   - uniform distributions were used
   - different resources → conflicting data
2. experiments (like the FE-Exp. at Mont Terri) allow for calibration/uncertainty reduction
   - use history-match error as objective function:

$$e^{\mathrm{HM}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(d_i^{\mathrm{obs}} - d_i^{\mathrm{sim}})^2}. \tag{1}$$

3. used screening methods to identify heavy hitters/negligible parameters: one-variable-at-a-time, folded Plackett-Burman design to build Pareto charts

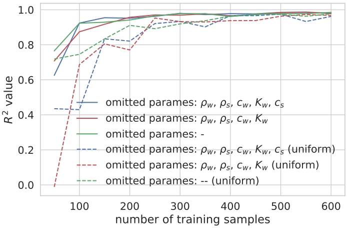


(a) OVAT tornado chart

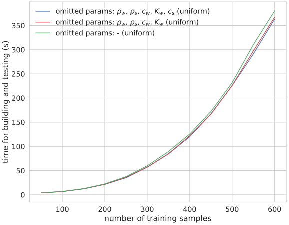
(b) PB pareto chart

Fig. 2: Applied screening methods to temperature and pressure

4. Proxy building using Gaussian Process regression on a Latin-hypercube sampling plan



(a) R^2

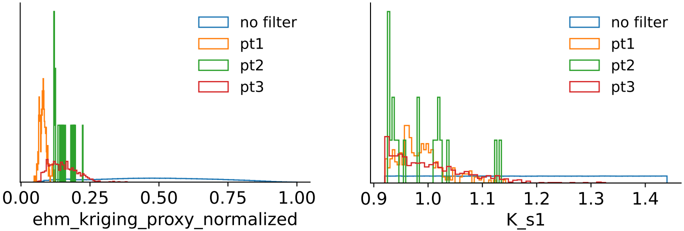


(b) time for proxy building

Fig. 3: proxy quality measure and time for proxy building

5. Direct Monte-Carlo sampling on proxy

6. history-matching of Monte Carlo samples; thresholds based on proxy RMSE and subjective guesses for model error

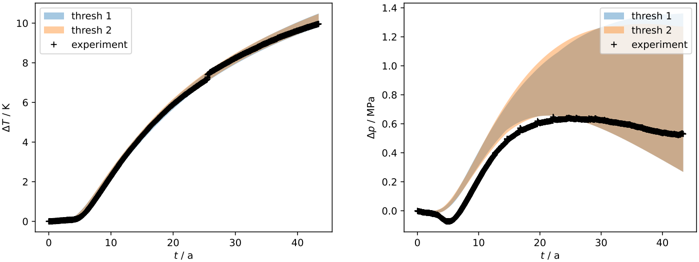


(a) sampling output of history-mach error (b) parameter estimation based on thresholds

Fig. 4: History-Matching based on three different thresholds

Parameter Uncertainties: FE-Experiment

7. forward model runs



(a) sampling output of history-mach error (b) parameter estimation based on thresholds

Fig. 5: History-Matching based on three different thresholds

8. CDF based on last time step of response function

9. GSA based on Proxy

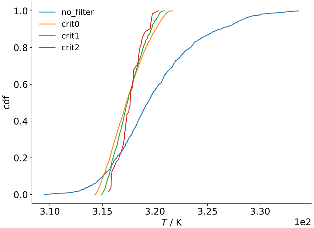


Fig. 6: CDF for temperature response

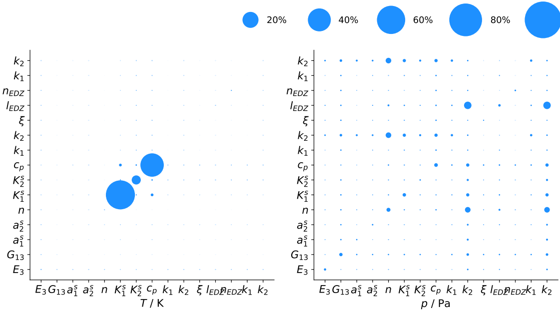


Fig. 7: first and second order Sobol indices

Parameter Uncertainties: FE-Experiment

Main outcome

- temperatures can be matched very well
- Parameter uncertainties of other materials need to be considered as well
- features might be missing in the model or are not modeled well (geom. uncertainties, EDZ, etc.

Model Uncertainties: Thermo-Osmosis

EQUATIONS

Mass balance

$$\frac{\mathrm{d_s}}{\mathrm{d}t}\left(\rho^{\mathrm{W}}\varphi\right) + \nabla\cdot\mathbf{J}^{\mathrm{w}} + \rho^{\mathrm{w}}\varphi\nabla\cdot\frac{\mathrm{d_s}\mathbf{u}}{\mathrm{d}t} = q_{\mathrm{W}} \tag{2}$$

where:

$$\mathbf{J}^{\mathrm{W}} = -\rho^{\mathrm{w}}\frac{\mathbf{k}_p}{\mu}\left(\nabla p - \rho^{\mathrm{W}}\mathbf{g}\right) - \rho^{\mathrm{W}}\,\mathbf{k}_{pT}\,\nabla T \tag{3}$$

Heat balance

$$\frac{\mathrm{d_s}}{\mathrm{d}t}\left(\left(C^{\mathrm{s}}\rho^{\mathrm{s}}(1-\varphi) + C^{\mathrm{w}}\rho^{\mathrm{w}}\varphi\right)T\right) + \nabla\cdot\mathbf{i} + \\ + \nabla\cdot\mathbf{J}_{\mathrm{E}}^{\mathrm{W}} = q_{\mathrm{E}} \tag{4}$$

where:

$$\mathbf{i} = -\left(\mathbf{K}^{\mathrm{s}}\left(1-\varphi\right) + \mathbf{K}^{\mathrm{w}}\varphi\right)\nabla T - T\,\mathbf{k}_{pT}\,\nabla p \tag{5}$$

and

$$\mathbf{J}_{\mathrm{E}}^{\mathrm{W}} = C^{\mathrm{w}}\rho^{\mathrm{w}}\mathbf{v}^{\mathrm{w}} \tag{6}$$

In all equations above $\mathbf{k}_{pT}$ is thermo-osmosis tensor. Zhigang 2020

OVERVIEW

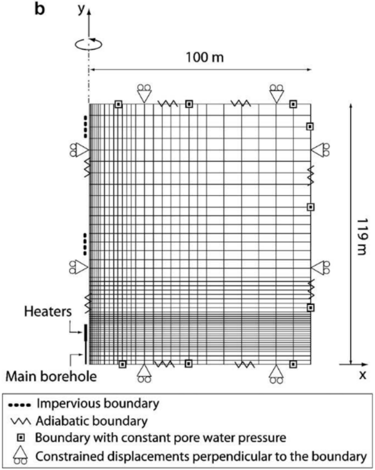
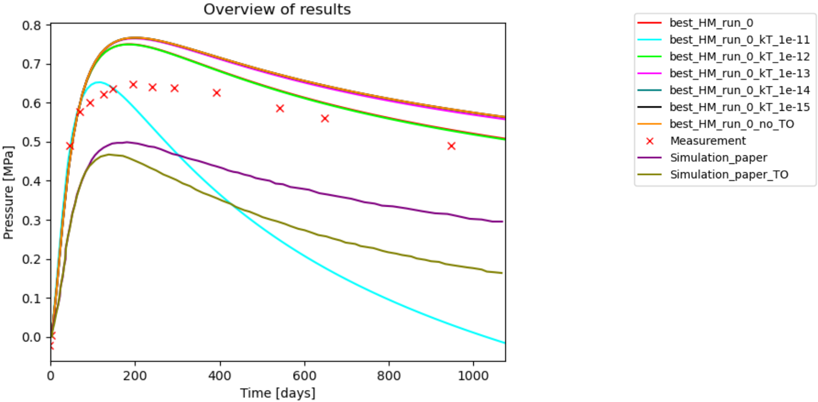


Fig. 8: Layout of ATLAS Experiment. Figure from: François, Laloui, and Laurent 2009

Model Uncertainties: Thermo-Osmosis

THE EFFECT OF K_T



OVERVIEW

Tested parameter ranges

Parameter name	Unit	Reference	Min	Max
Thermal expansivity (α_s)	K^{-1}	$1.3e-5$	$5e-5$	$5e-3$
Intrinsic permeability (k)	m^2	$2.5e-19$	$8e-20$	$4e-19$
Thermoosmosis coefficient (k_T)	$\mathrm{Pa} * \mathrm{m} * \mathrm{K}^{-1}$	-	$1e-13$	$9e-13$
Young's modulus (E)	MPa	$3.5e8$	$3e8$	$6e8$
Poissons ratio (ν)	-	0.125	0.1	0.15

Reference values after: Tamizdoust and Omid Ghasemi-Fare 2021.

Initial conditions:

Parameters	Values	Units
$\sigma_x = \sigma_y$	4.5	MPa
p_0	2.025	MPa
T_0	16.5	°C

Initial conditions after: Tamizdoust and Omid Ghasemi-Fare 2021.

Error metrics

$$e_{HM} = \sum_{1}^{n} \frac{(d_{obs} - d_{sim})^2}{n} \tag{7}$$

Model Uncertainties: Thermo-Osmosis

P AND T CURVES

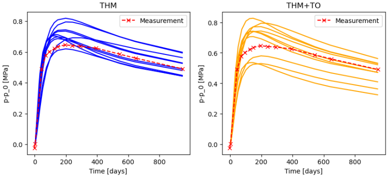


Fig. 9: Porepressure at observation point.

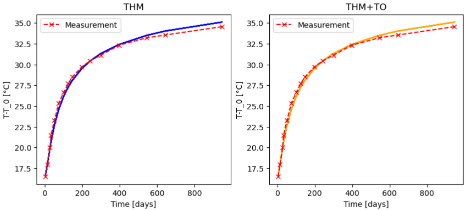


Fig. 10: Temperature at observation point.

PARAMETER ESTIMATION

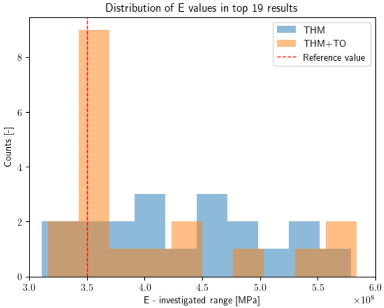


Fig. 11: Young's modulus.

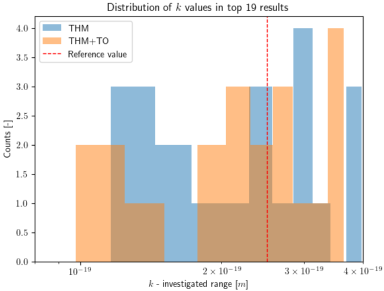


Fig. 12: Intrinsic permeability.

EHM - DISTRIBUTIONS

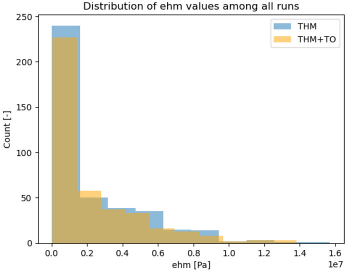


Fig. 13: Entire ehm range.

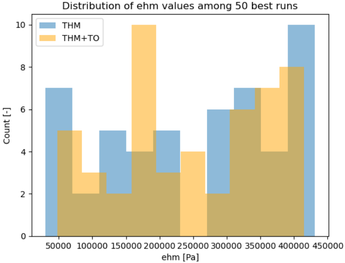


Fig. 14: Zoom-in to best runs.

Main outcomes:

- temperatures are matched very well
- No clear improvement visible by consideration of TO-effect.
- further refinements might be need
- features might be missing that could improve both matches (anisotropy)

Acknowledgements

- FE modelling Taskforce
- iCross Project
- OpenWorkFlow project

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