JUTUL.JL: FULLY DIFFERENTIABLE FINITE-VOLUME SIMULATION IN JULIA

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17th World Congress on Computational Mechanics (WCCM)
10 th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS)
19 - 24 July 2026, Munich, Germany

Jutul.jl in 30 seconds

Jutul.jl – Open-source Julia package for fully implicit finite volume simulation[1]

- Fully differentiable: Gradients with respect to any parameter
  - Automatic differentiation
  - Adjoint method[2]
- MPI parallel with BoomerAMG and threads
- GPU support through CUDA + AMGX
- Open source (MIT License)
  - https://github.com/sintefmath/Jutul.jl
  - Installation on any OS (Julia 1.8+)
- Several demonstrators built on top
  - JutulDarcy: Darcy-scale porous media flow simulator: Oil & gas, geothermal, CO_2 sequestration, etc.

[1] Møyner (2024) DOI: 10.1007/s10596-025-10366-6
[2] Bradley (2024), PDE-constrained optimization and the adjoint method

Jutul

Experimental Julia framework for fully differentiable multiphysics simulators based on implicit finite-volume methods with automatic differentiation

```
Using Pkg; Pkg.add("Jutul")
```

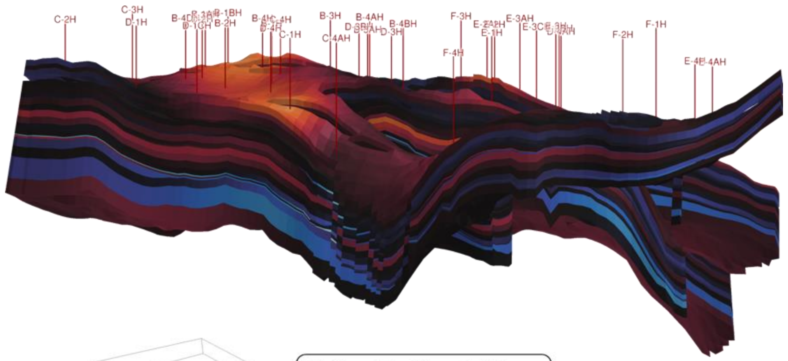
JutulDarcy

JutulDarcy.jl is a high-performance Darcy flow simulator and the main demonstrator application for Jutul

```
Using Pkg; Pkg.add("JutulDarcy")
```

SINTEF

Fast automatic differentiation

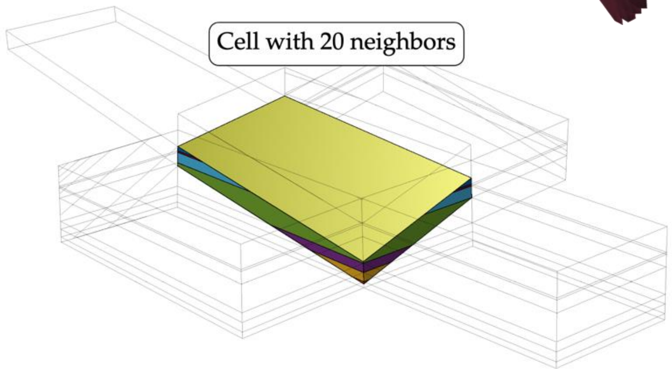


Jutul.jl uses a tailored approach to automatic differentiation that:

- Supports complex sparsity patterns (unstructured grids and complex wells)
- Allows for equations and variables on different entities (cells, faces, wells, …)

Key ideas:

1. Detect sparsity pattern of equations at start of simulation
2. Allocate dense memory for storage of dual numbers, in the order of evaluation
3. Manage properties in a precomputed dependency graph
4. Avoid (significant) heap allocation during simulation and make GC happy

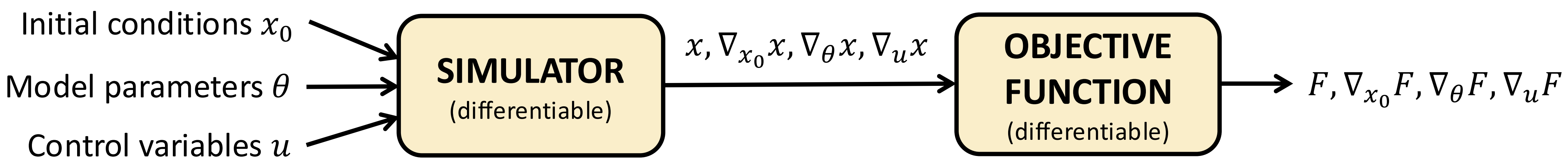


General AD for any discrete equation (Wells, facilities, coupling terms) → General finite-volume scheme (TPFA, NTPFA, MPFA, …) → Two-point flux scheme (TPFA)

Specialization and performance

What is a fully differentiable simulator?

A fully differentiable simulator is a simulator that (in principle) can provide sensitivities for all outputs *with respect to* all inputs
– can be thought of as an end-to-end differentiable operator



A fully differentiable simulator is very useful for

1. Combining different physical models to form large, coupled multiphysics systems
2. Gradient-based calibration with respect to initial conditions x_0 and model parameters θ
3. Gradient-based optimization of objective with respect to controls u

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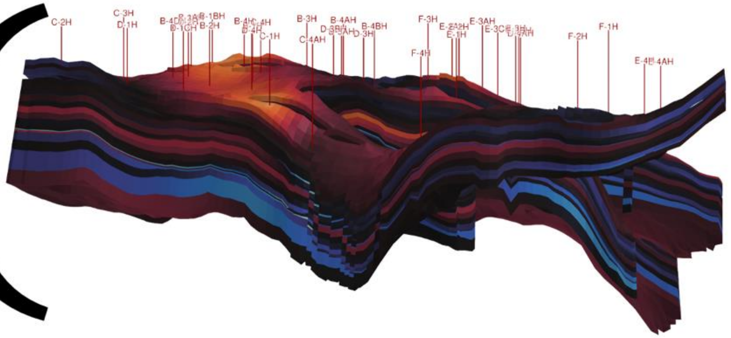
NUMERICAL EXAMPLES

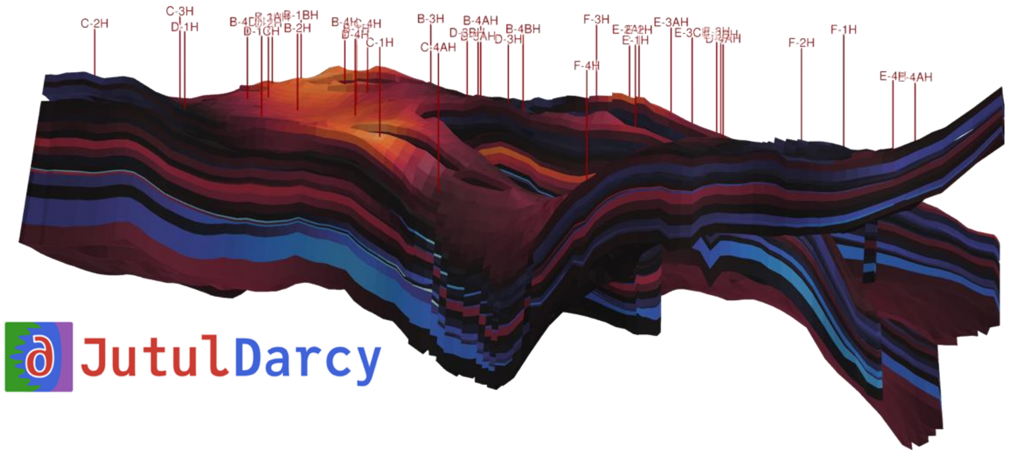


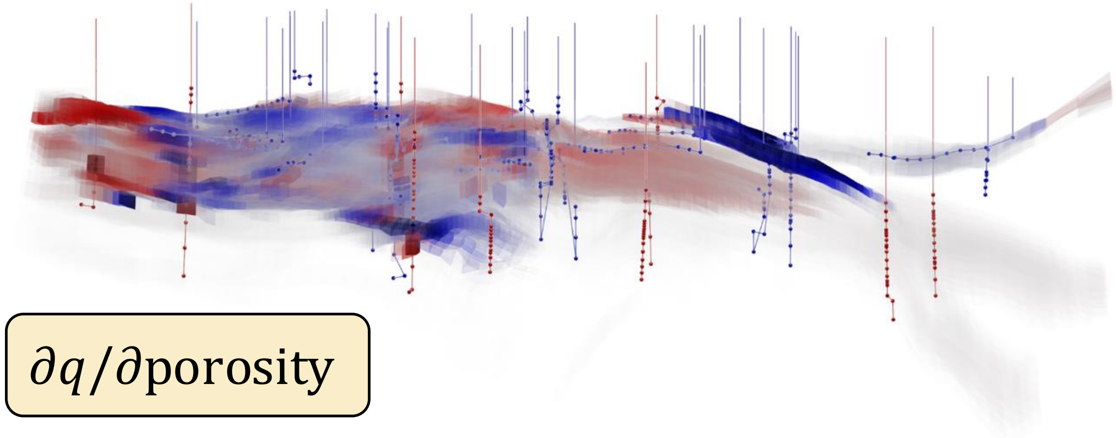
$$\frac{\partial\left(\qquad\right)}{\partial\theta}$$

Norne field gas production

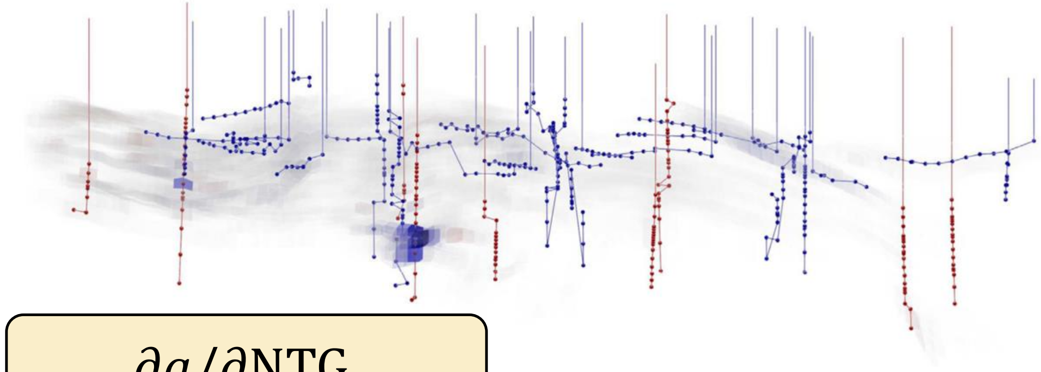
SETUP
Real oil & gas field in the Norwegian Sea
Corner-point grid with 44,431 active cells, 36 active wells
Complex, layered geology with faults and low-permeable zones

QUESTION
How does porosity and net-to-gross (NTG) affect gas production q?





$\partial q / \partial \text{porosity}$



$\partial q / \partial \text{NTG}$

Exampe from Møyner (2024) DOI: 10.1007/s10596-025-10366-6

Emission of Volatile Organic Compounds (VOC) from cargo tank ships

BACKGROUND

4% of national emissions in 20-year perspective, up to 30% by 2050. Increasing focus internationally (OGMP 2.0)

SYNTHETIC EXAMPLE

Finding “unknown” scaling parameter for liquid injection rate (initialized to 0.5, correct value is 1.0)

Calibrate against simulated emission of methane with added noise (≈ measurement errors)

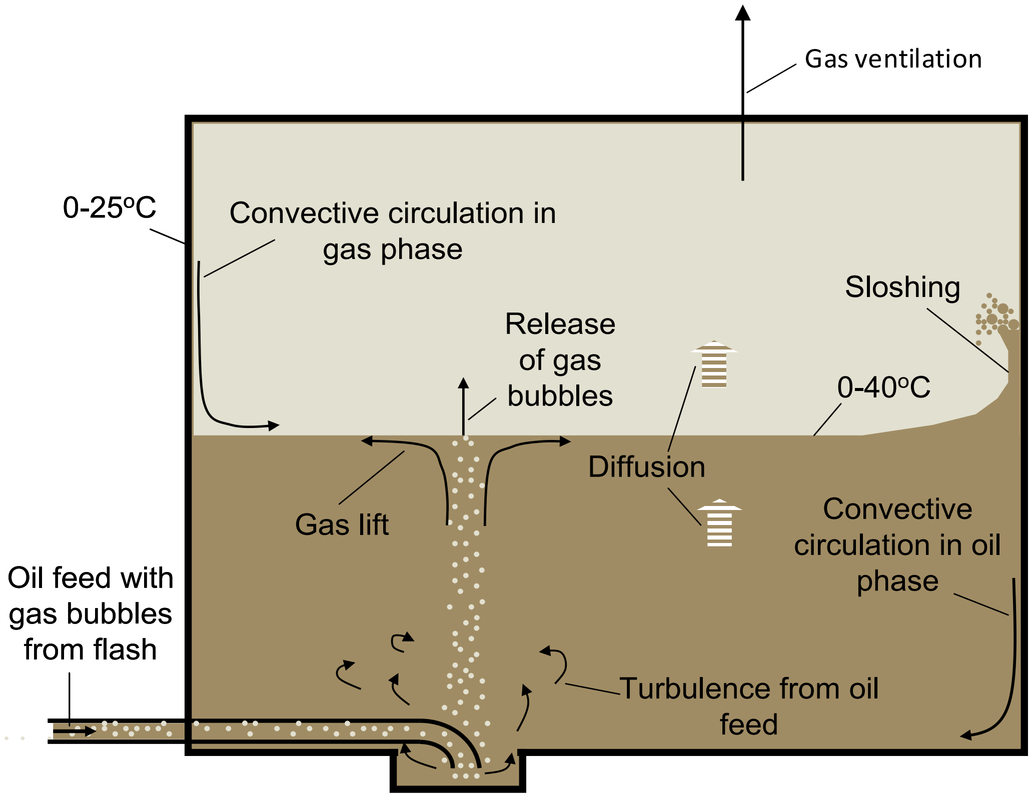


Figure from: DNV. Review of VOC in shipping for the ministry of the environment, 2013

More on VOCSim.jl on Wednesday: A. Brostrøm, *A Differentiable Simulator for Methane and VOC Emissions in Coupled Liquid–Gas Tank Systems.*
In: MS079B Computational Mechanics for Sustainable Development II, Wed, 22/07/2026, 09:45 - 11:15

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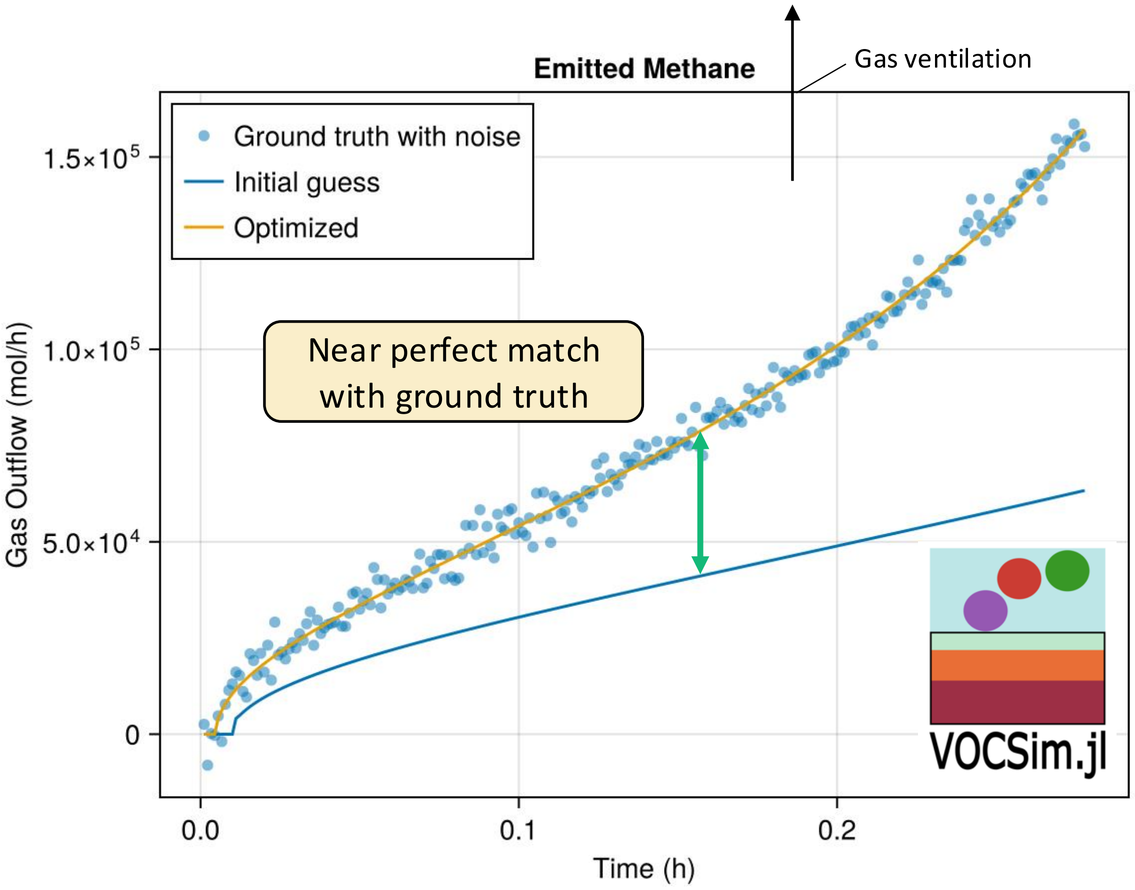

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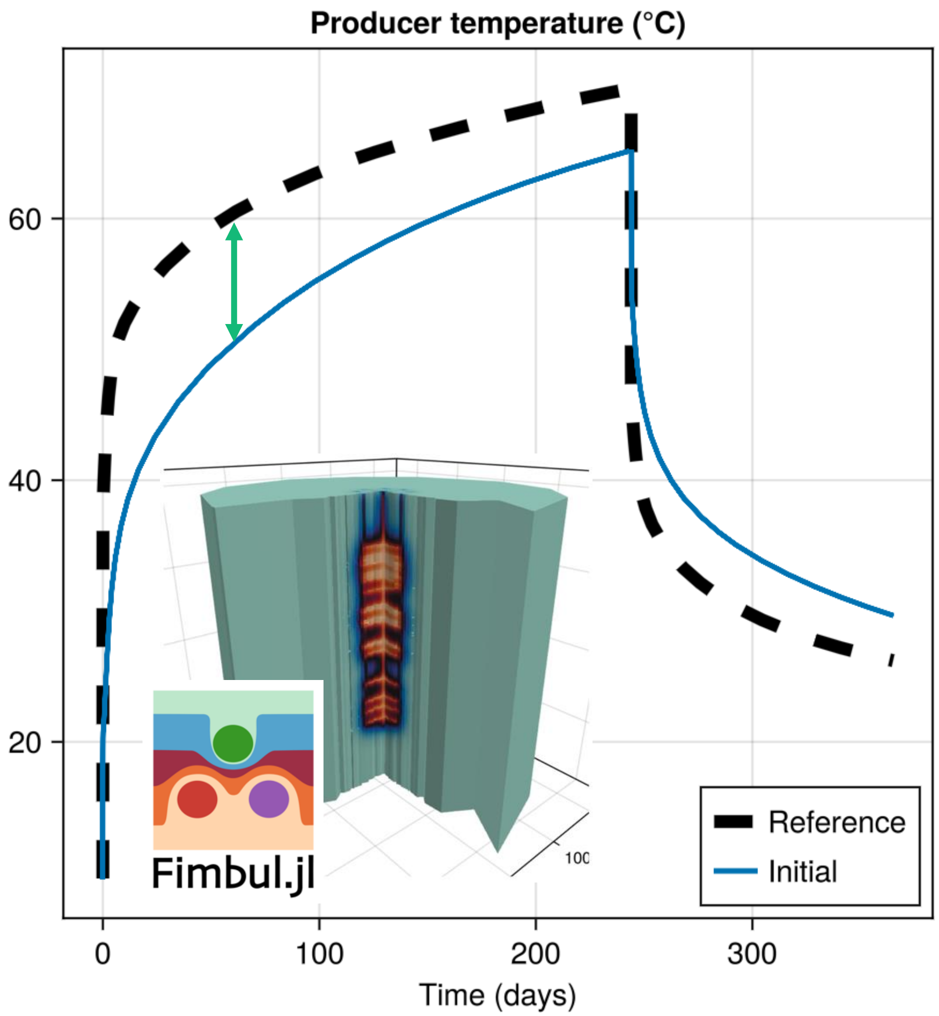
Fracture thermal energy storage



SETUP

Underground thermal energy storage by circulation of hot water through fracture network

- Heat conduction from fluid to bedrock

GOAL

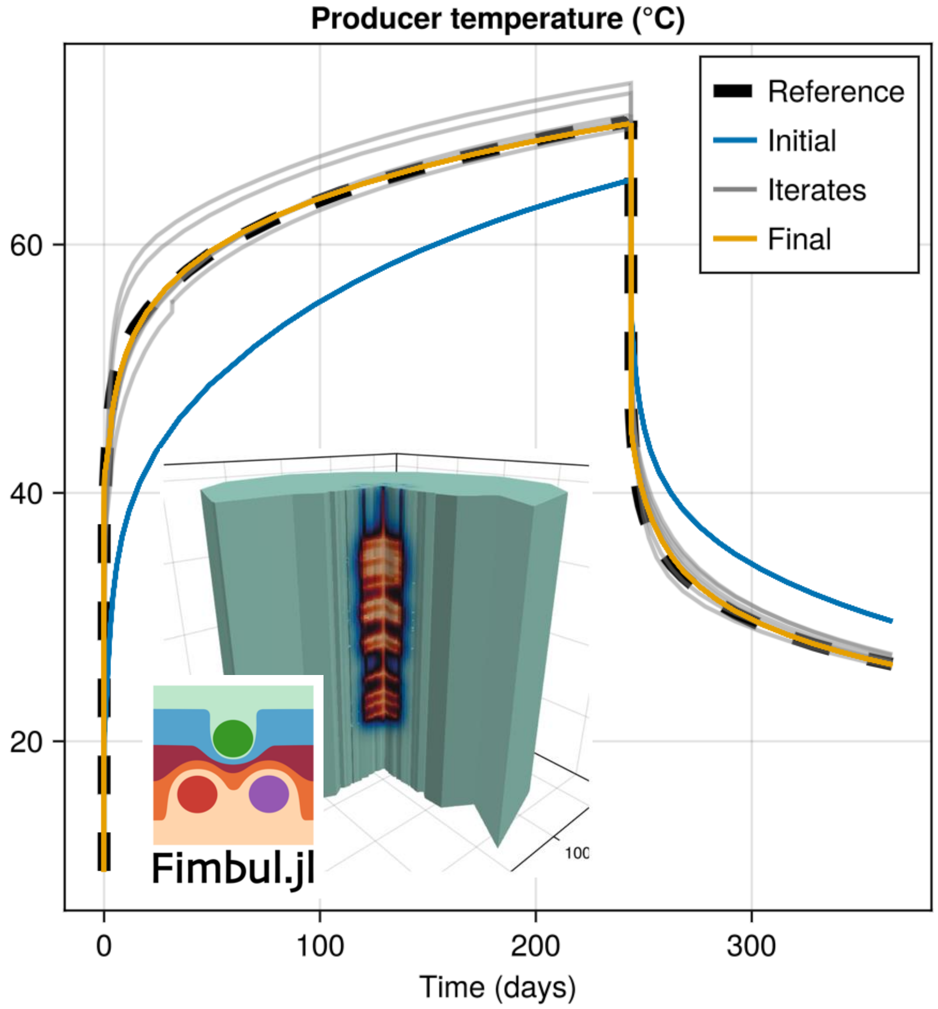
Calibrate idealized model so that production temperature matches reference simulation

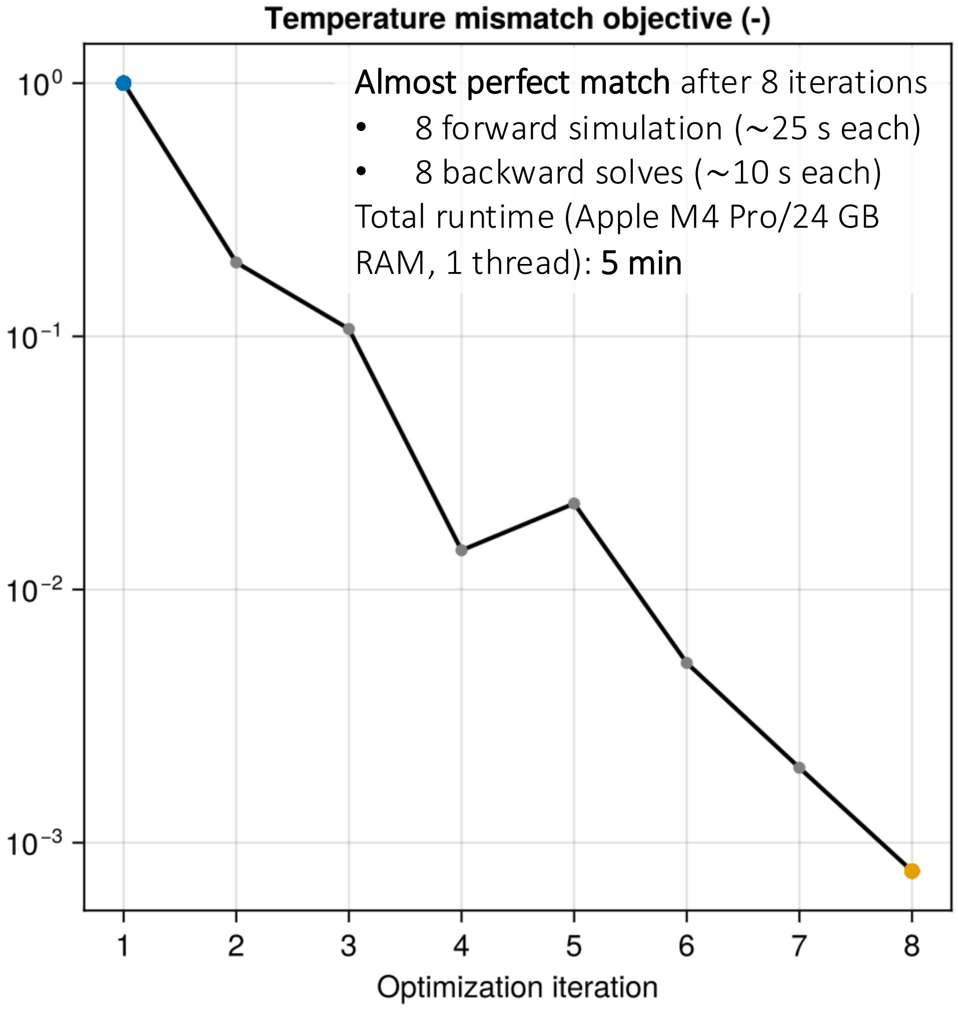
$$\frac{1}{t_{\mathrm{tot}}}\sum_n (T^n_{\mathrm{Ref}} - T^n_{\mathrm{Id}})^2 \Delta t^n$$

Parameter	Reference	Idealized
Fracture dip [°]	$N(0.0, 2.5)$	0.0
Aperture [mm]	$N(0.5, 0.15)$	0.5
Matrix th. cond. [W/mK]	2.5	4.0

Klemetsdal et al., 2025, DOI: 10.3997/2214-4609.202521164

Fracture thermal energy storage





Klemetsdal et al., 2025, [DOI: 10.3997/2214-4609.202521164](https://doi.org/10.3997/2214-4609.202521164)

WESSELKVARTALET

FRACTURE THERMAL ENERGY STORAGE

Underneath parking garage – 97 wells coupled in eight groups

Gravel layer: 2m, rapid discharge of heat
Accumulator (fractured bedrock): 18 m, long-term storage

OPERATION

Residential heating: 30 000 m^2/Deicing: 30 000 m^2 city streets

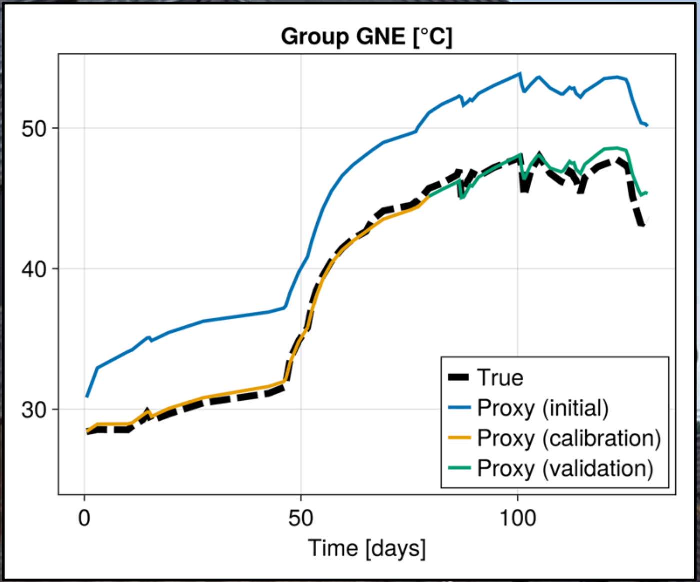
GOAL

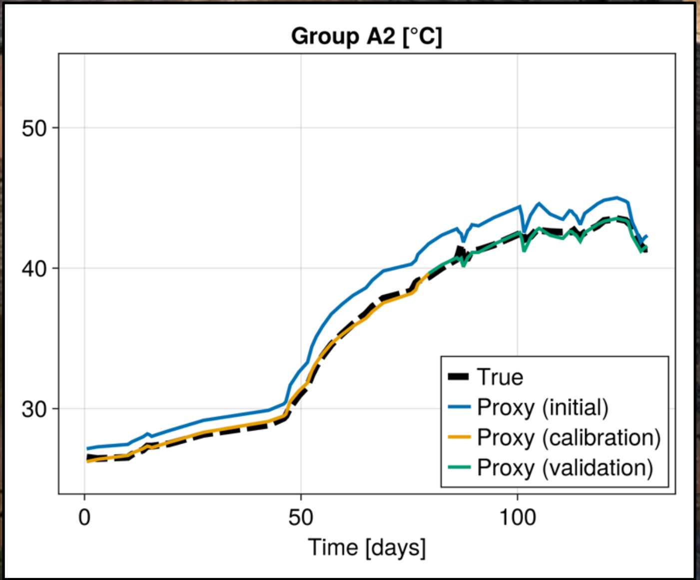
Calibrate low-fidelity (proxy) simulation model parameters so that output matches real observations

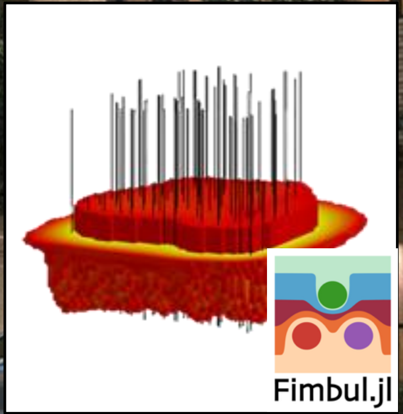
Wesselkvartalet

Mixed commercial/residential building in Asker, Norway

https://www.wesselkvartalet.no/

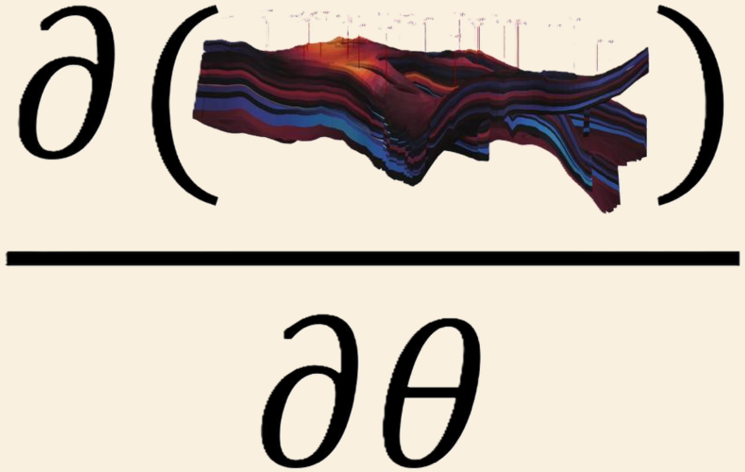






Concluding remarks

- Jutul.jl is a **fully differentiable simulator**
  - Built from the bottom up using automatic differentiation
  - Highly performant (sparsity detection, hard-coded for specific stencils) without compromising flexibility
- Gradient-based optimization with the adjoint method
  - Highly efficient for smooth objectives
  - … and adjoints are fast to calculate! A single linear solve per timestep of forward simulation
- Cornerstone in several simulators aimed at industry-relevant applications
  - Geoenergy: Oil & gas/CO_2 sequestration, geothermal energy
  - Emission of volatile organic compounds from cargo tank ships



Jutul

Cornerstone Julia framework for
differentiable
finite-volume simulation

```
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```

JutulDarcy

Darcy-scale porous media flow
Oil & gas, CO_2 sequestration,
H_2/gas storage, etc.

```
using Pkg; Pkg.add("JutulDarcy")
```

Fimbul.jl

Geothermal energy
IAPWS97 formulation, ATES,
BTES, FTES, EGS, AGS

```
using Pkg; Pkg.add("Fimbul")
```

SINTEF

SINTEF Digital
Applied computational science

Julia scientific software
ecosystem

Mocca.jl

Modelling of Carbon Capture
Pressure/temperature swing
adsorption of CO_2

```
using Pkg; Pkg.add("Mocca")
```

BattMo

Battery Modelling Toolbox
Continuum modelling of
electrochemical devices

```
using Pkg; Pkg.add("Battmo")
```

VOCSim.jl

Volatile organic compounds
Methane and other VOC
emissions from cargo tank ships

```
Coming soon...
```

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strene

Technology for a better society