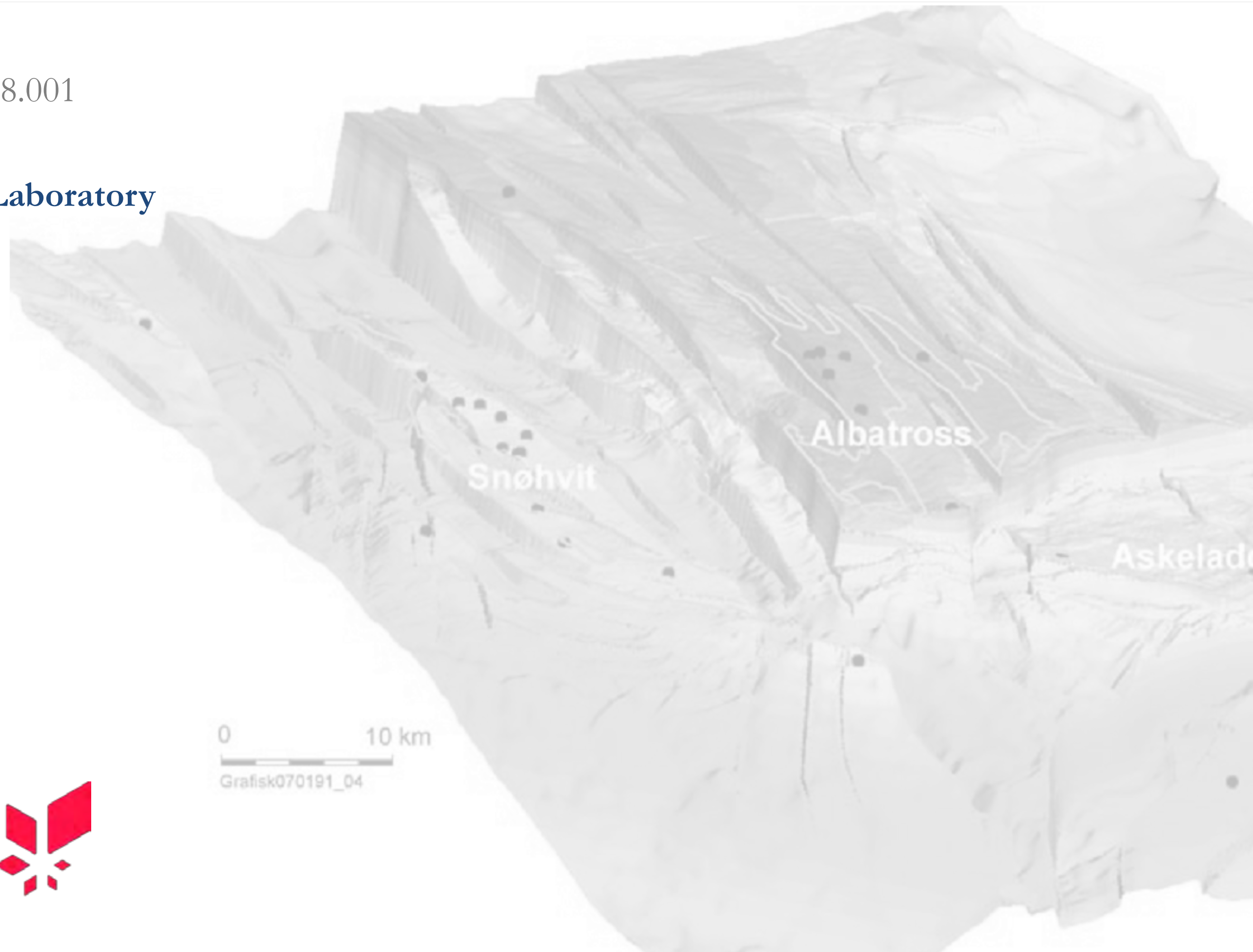
Pressure Analysis Toolkit

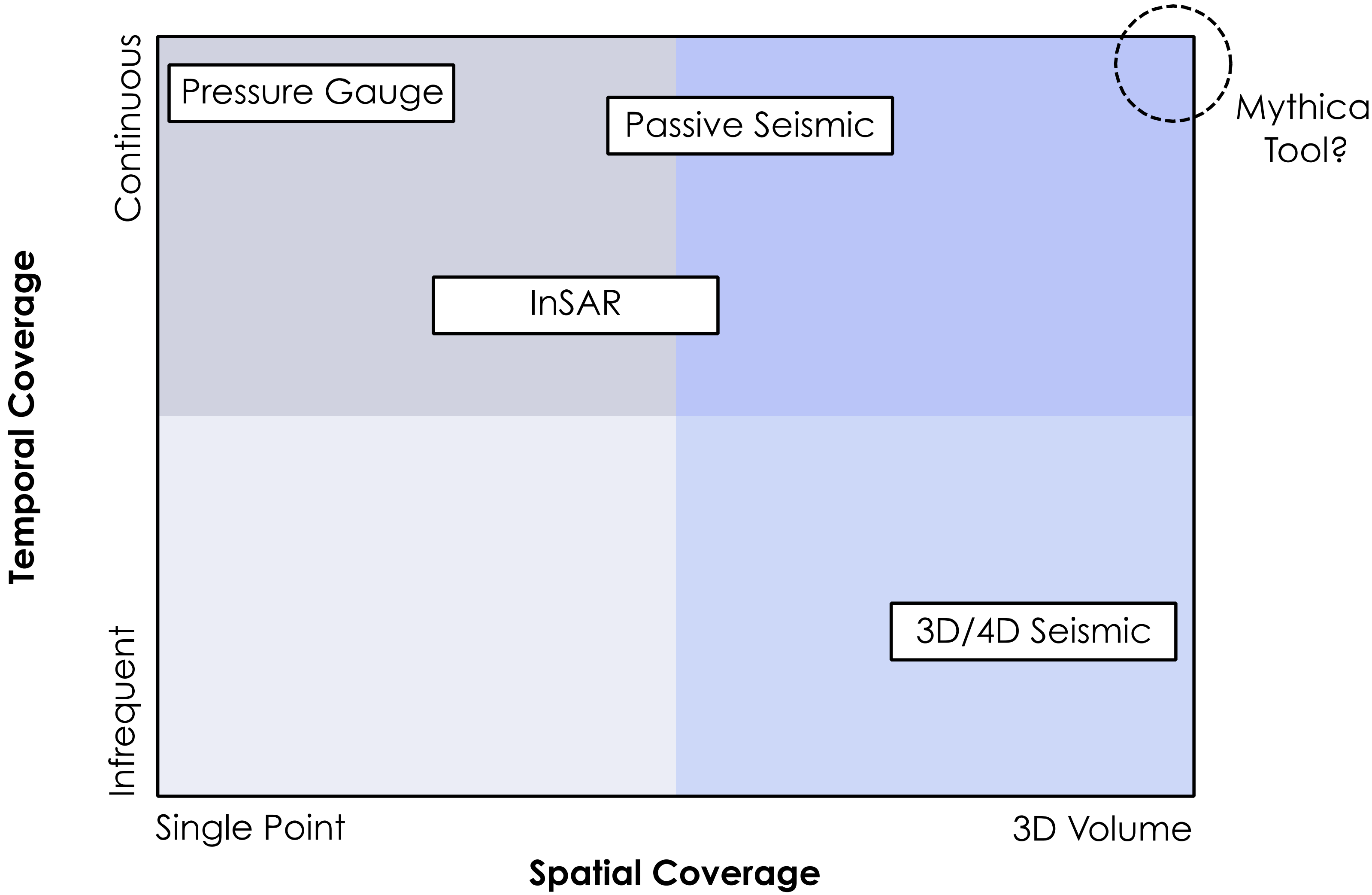
Joshua White

Project Number:
FWP-FEW0191-Task 4
LLNL-Equinor CRADA TC002228.001

Lawrence Livermore National Laboratory



Fundamental question: How to design a monitoring program to adequately balance effectiveness vs. cost?



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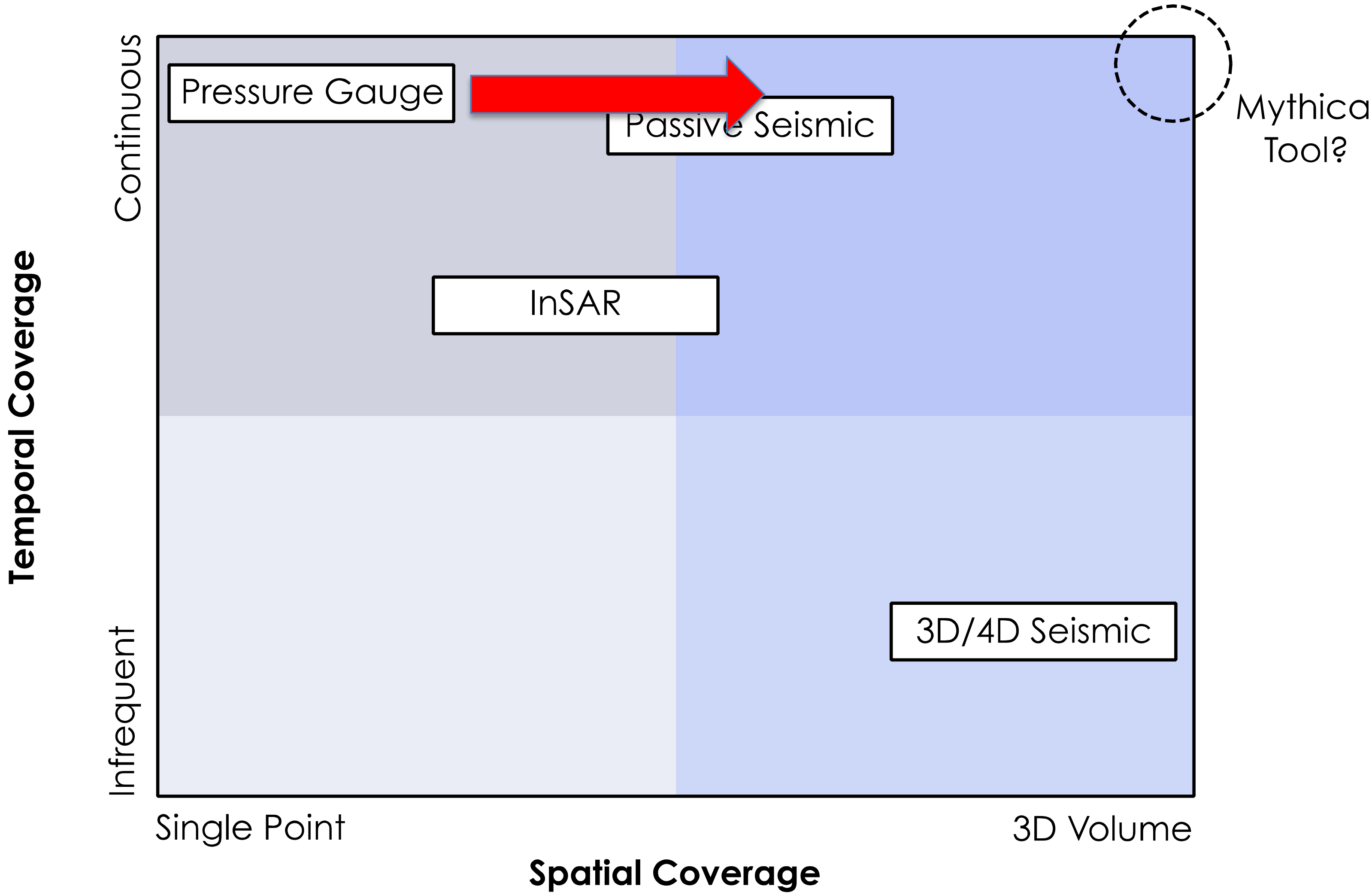
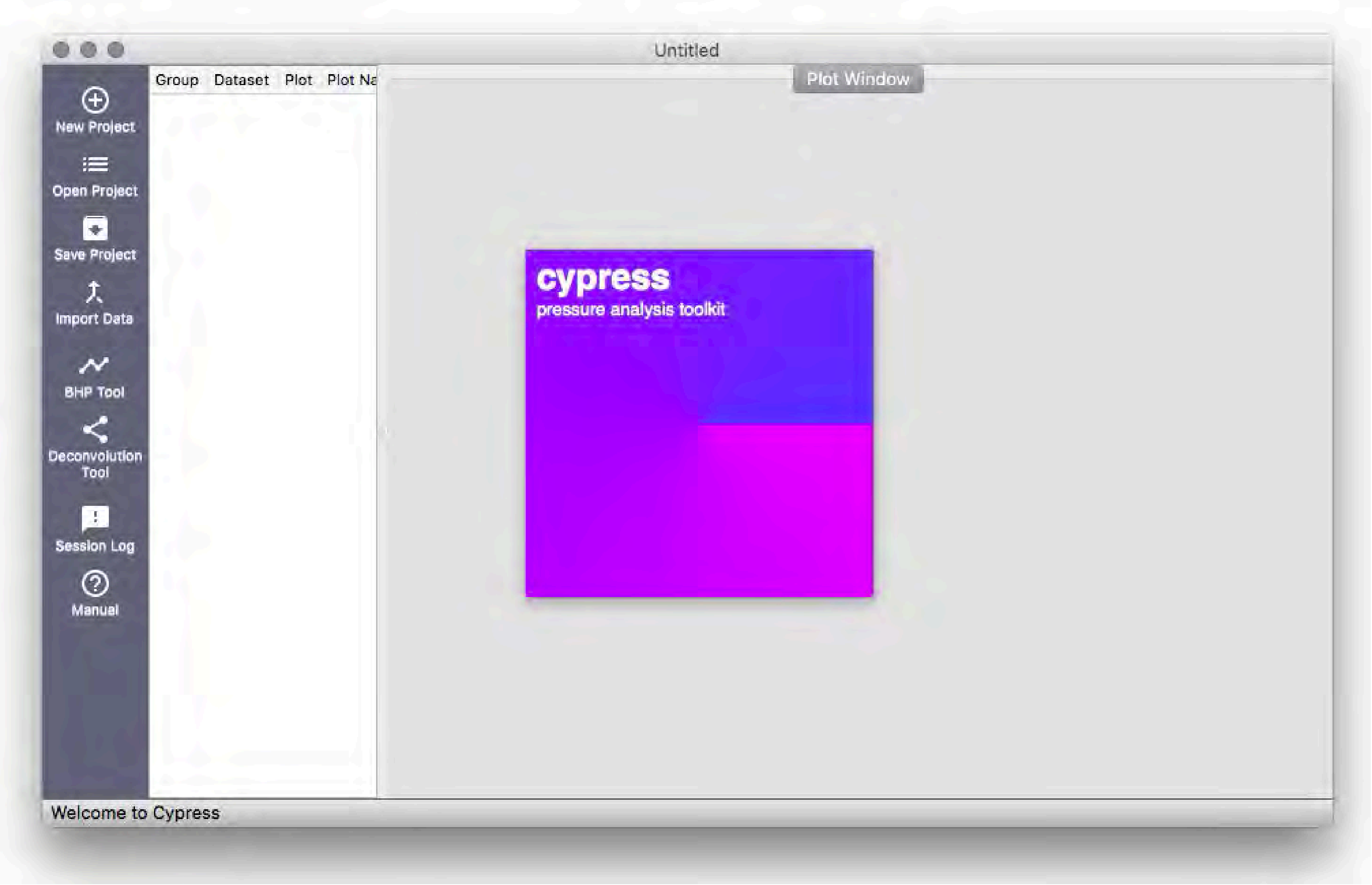


Project Objective

Develop an **open-source software toolkit** to support the development and deployment of new techniques for analyzing **well gauge data**.



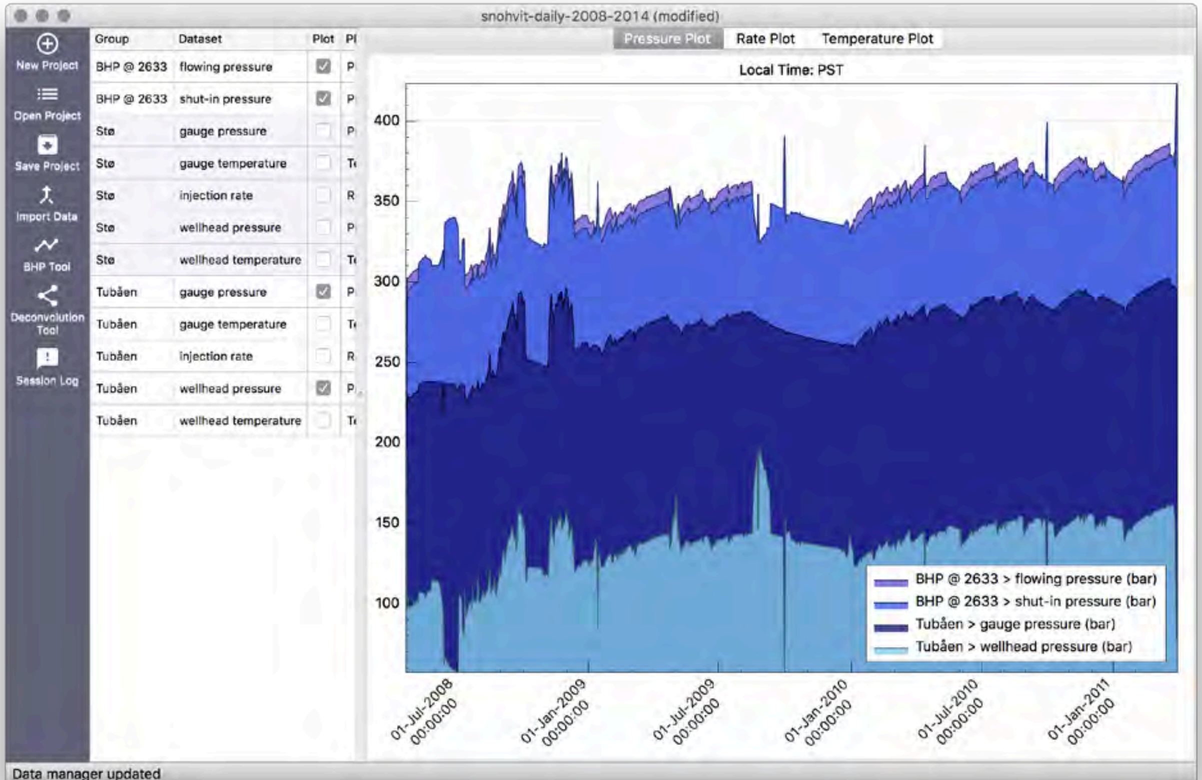
Project Timeline

May 2016 to April 2019

Deliverable Status

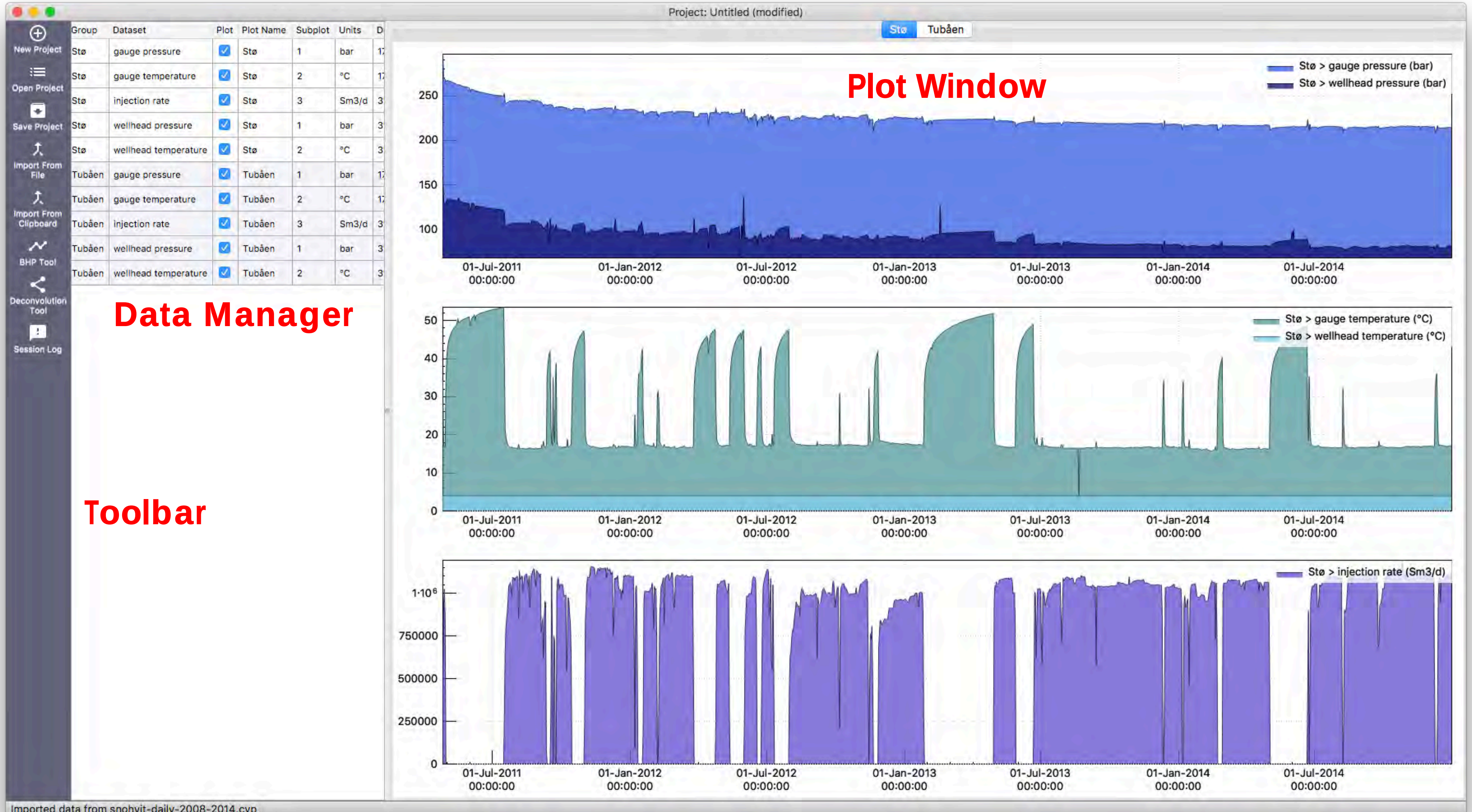
- **April 2017**: Cypress version 0.8 (pre-release) delivered for testing to Equinor
- **April 2018:** Cypress version 0.9 (pre-release) delivered for testing to Equinor
- **April 2019:** Cypress version 1.0 open-source release planned (LGPL license)

Major Features

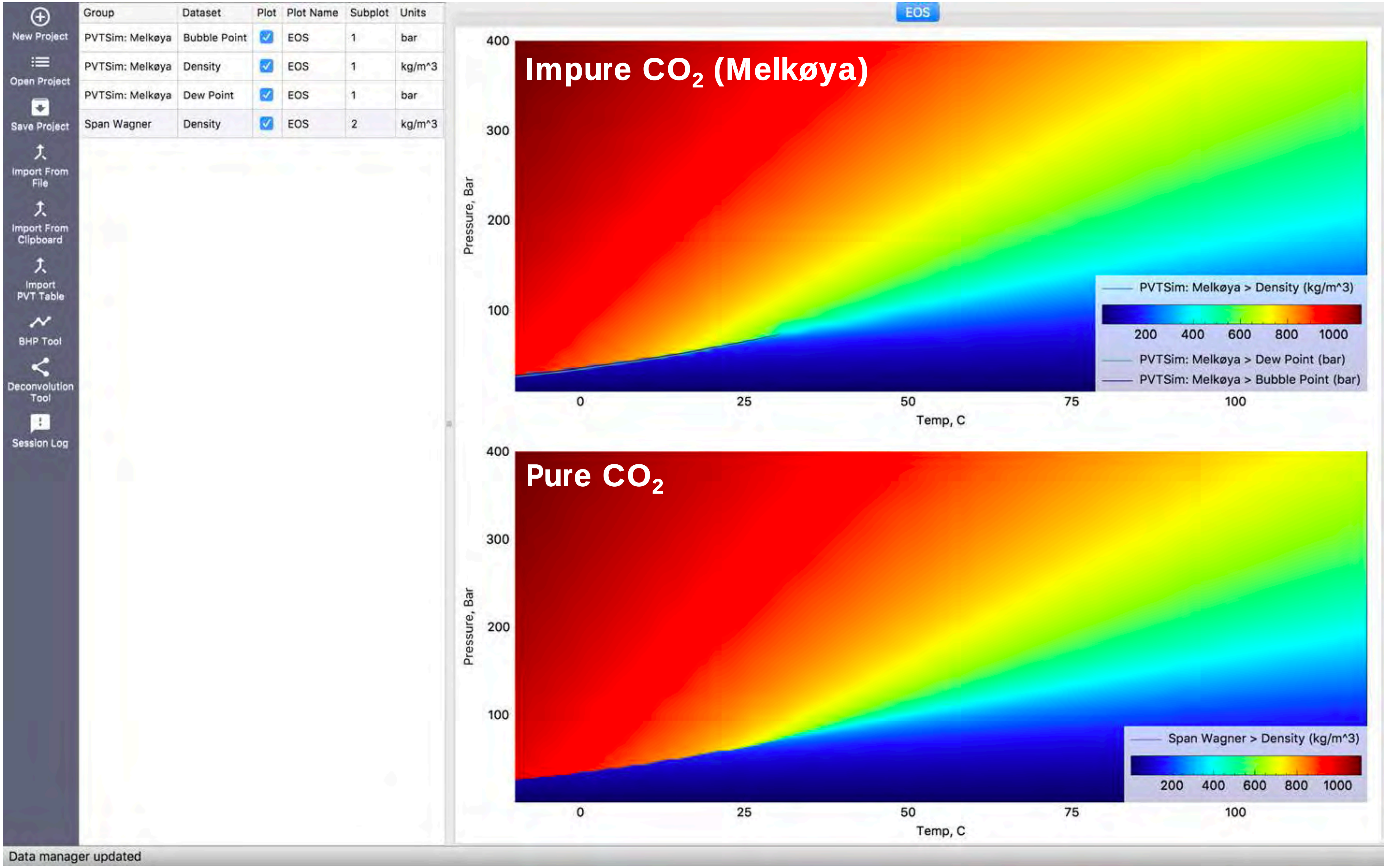


- **Data visualization and manipulation**
- **Bottomhole pressure estimation algorithms**
- **Deconvolution welltest algorithms**
- **Rapid pressure forecasting**
- Type-curve analysis support
- Fracture-pressure identification algorithms

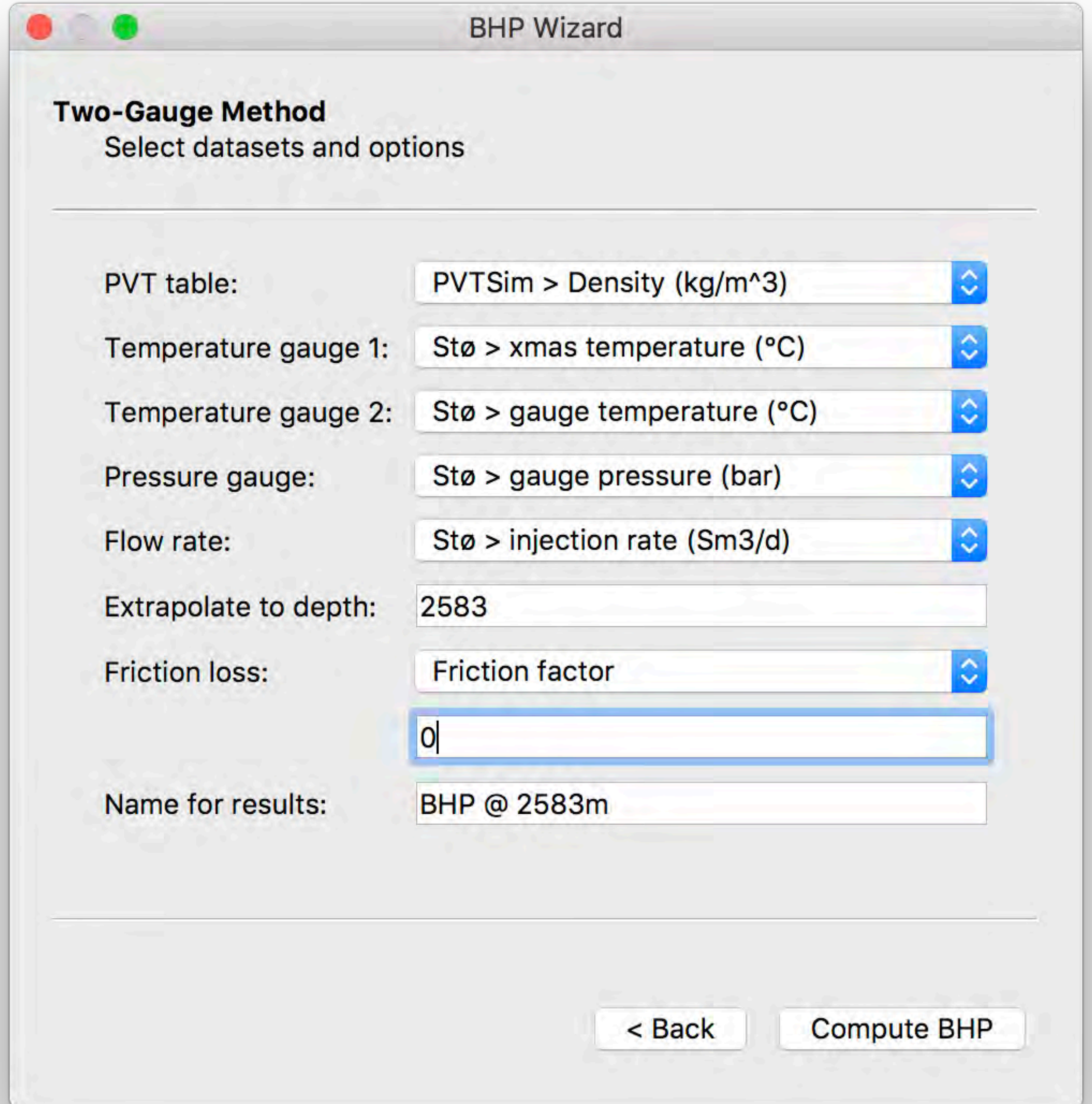
Step 1: Import gauge data



Step 2: Choose / Import a CO_2 PVT Table



Step 3: Bottomhole Pressure Estimation



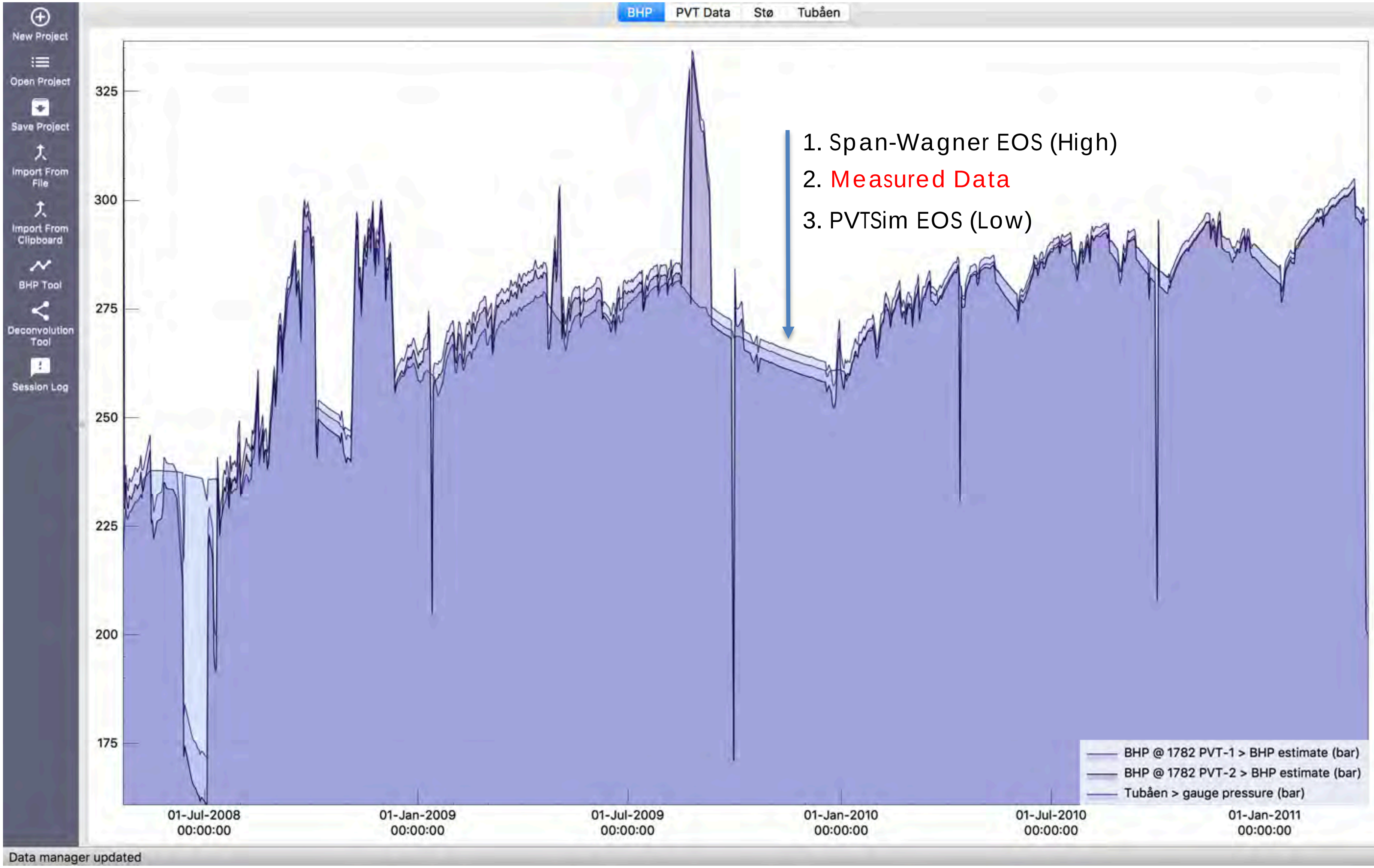
Estimation Method

Input Data

Methods:

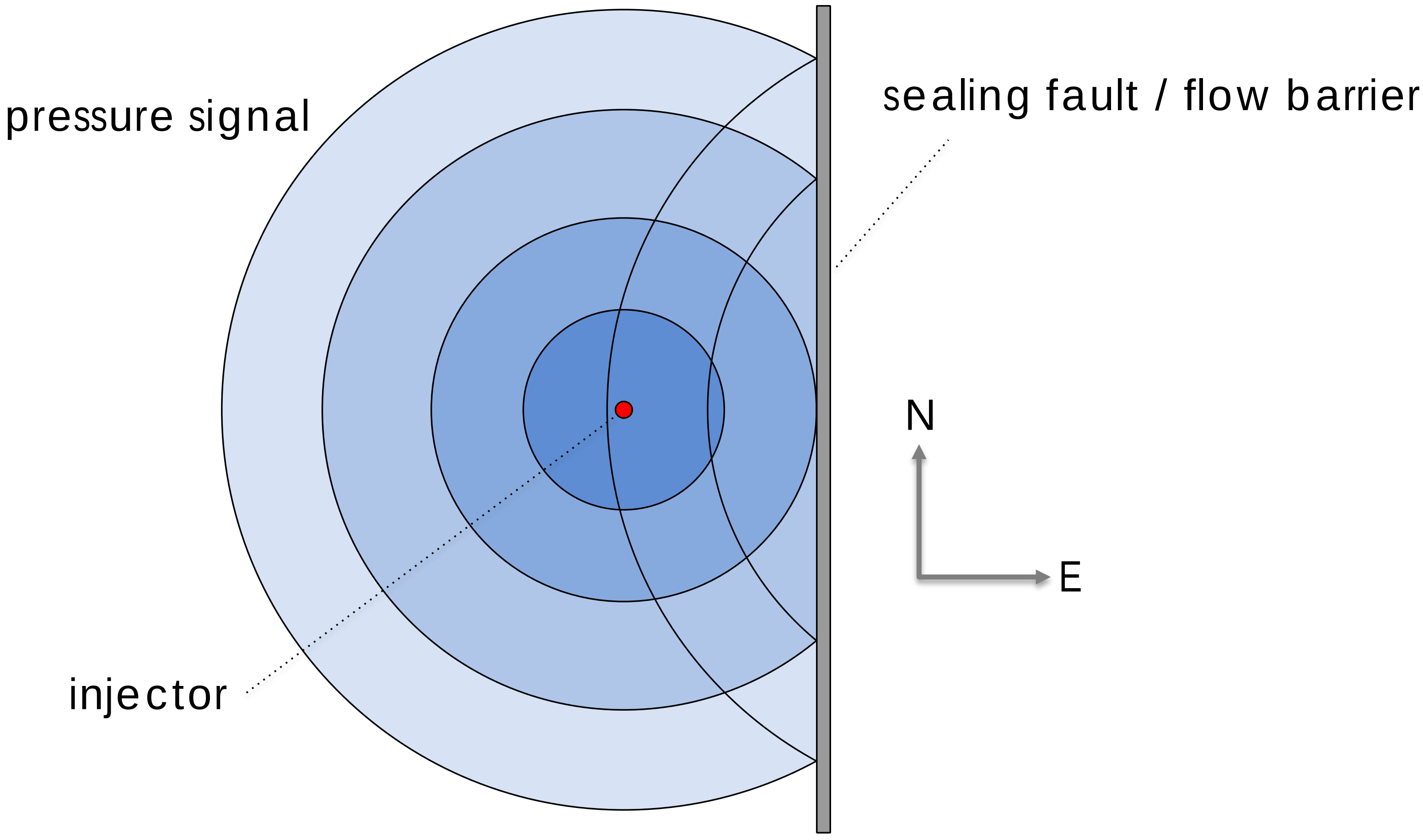
1) Single-Gauge
2) Two-Gauge
3) Multi-Gauge

BHP Estimation: Tubåen Test



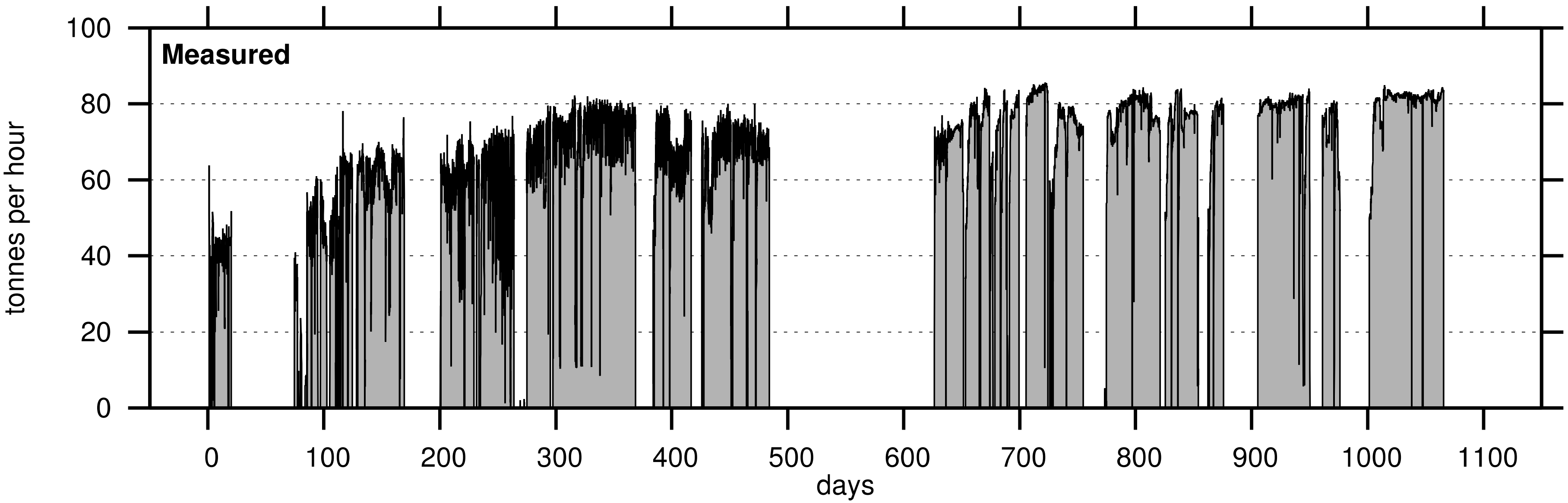
Test: Use wellhead data to estimate *known* gauge data

Step 4: Welltest Analysis



Falloff testing (and other welltests) are commonly used to probe reservoir properties and structure away from the well.

Traditional welltest techniques require shutting in the well for significant periods



Key question: Is the same information from ongoing injection data, without shutting in for long periods?

Deconvolution Welltest Analysis

Reservoir Impulse Response
(Unknown)

Convolution Integral:

$$\Delta p(t) = \int_0^{\tau} q(\tau) g(t - \tau) d\tau$$

Reservoir Pressure Change
(Measured)

Injection Rate
(Measured)

Basic Idea: Given p(t) and q(t), estimate g(t) through a deconvolution method.

[c.f. von Schroeter et al. 2001, 2004; Gringarten et al. 2003, 2005; Levitan et al. 2005,2006; Vasin et al. 2010]

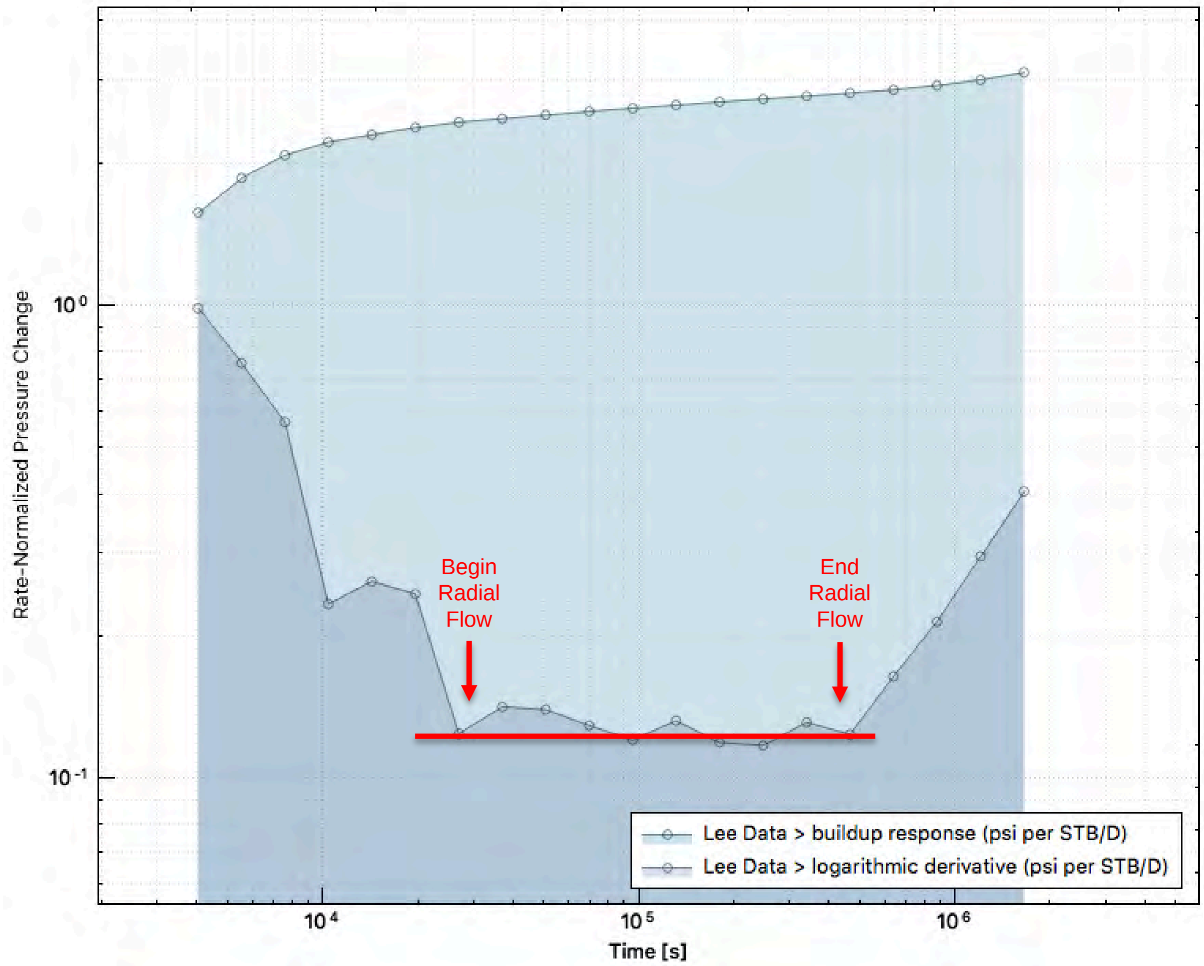
Deconvolution results can then be readily converted to a traditional diagnostic plot format

Buildup (or Falloff) Response:

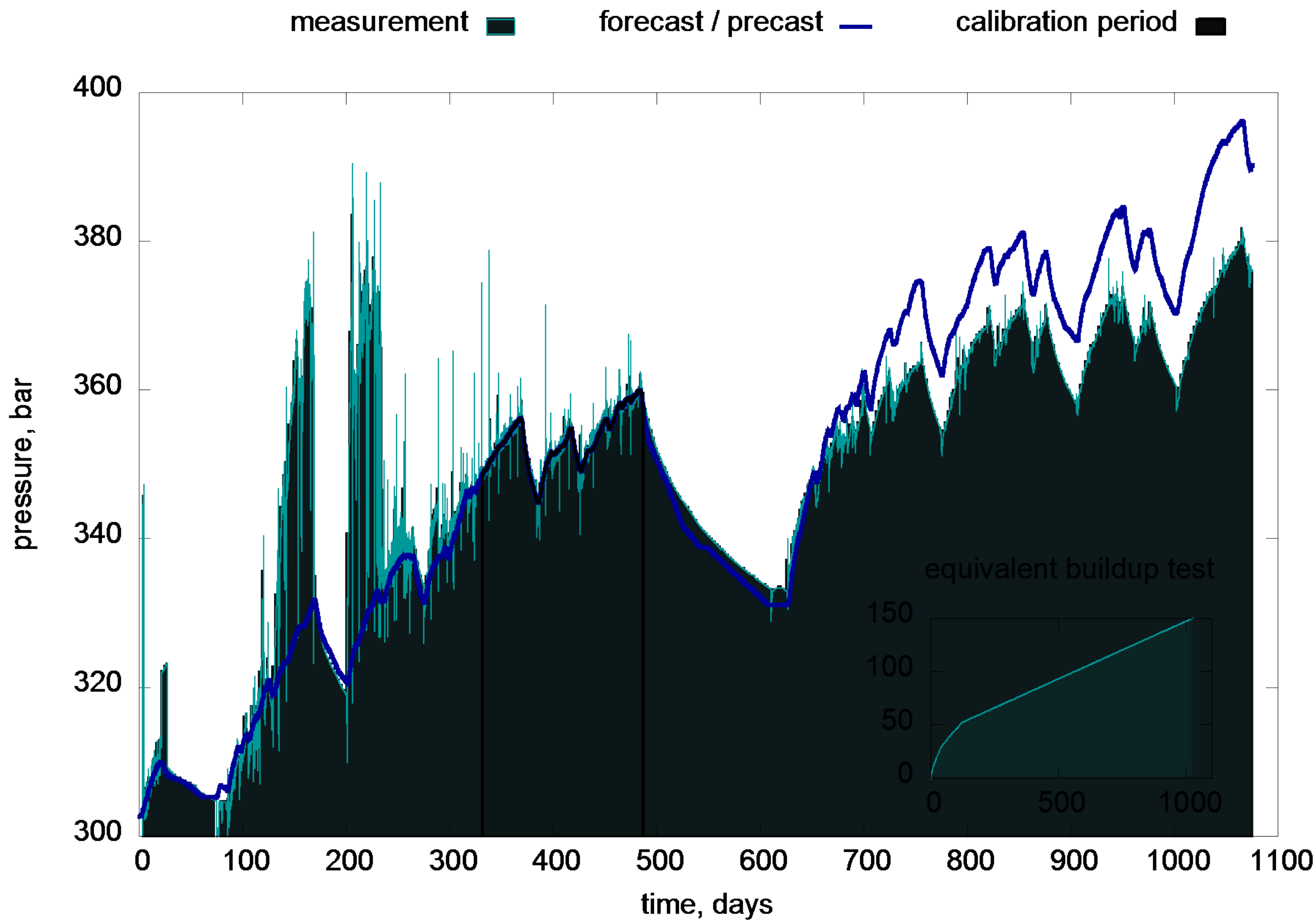
$$P_u(t) = \int_0^t g(t)dt$$

Logarithmic Derivative:

$$\frac{dP_u}{d\ln t} = tg(t)$$



Deconvolution Analysis: Tubåen Data



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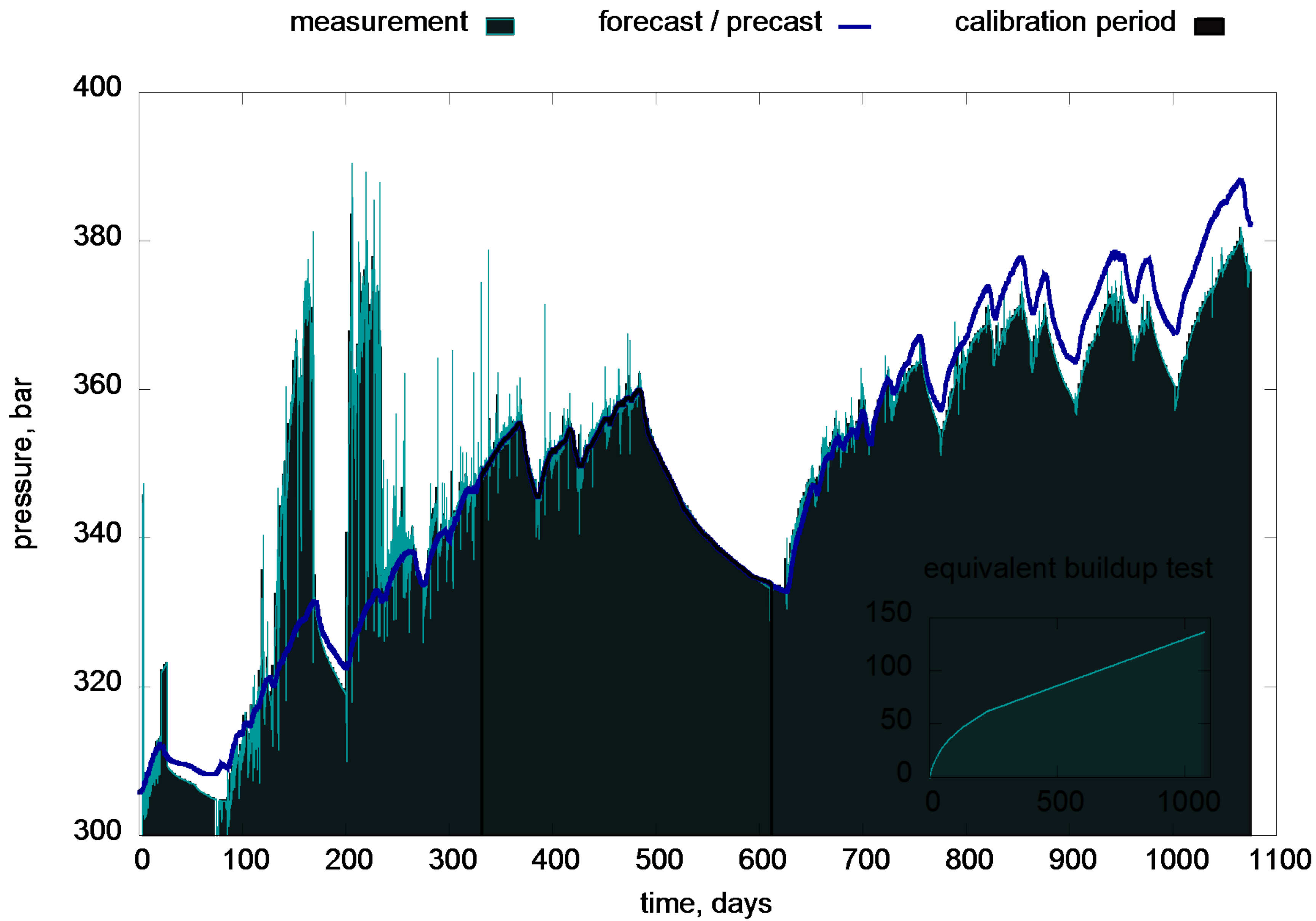

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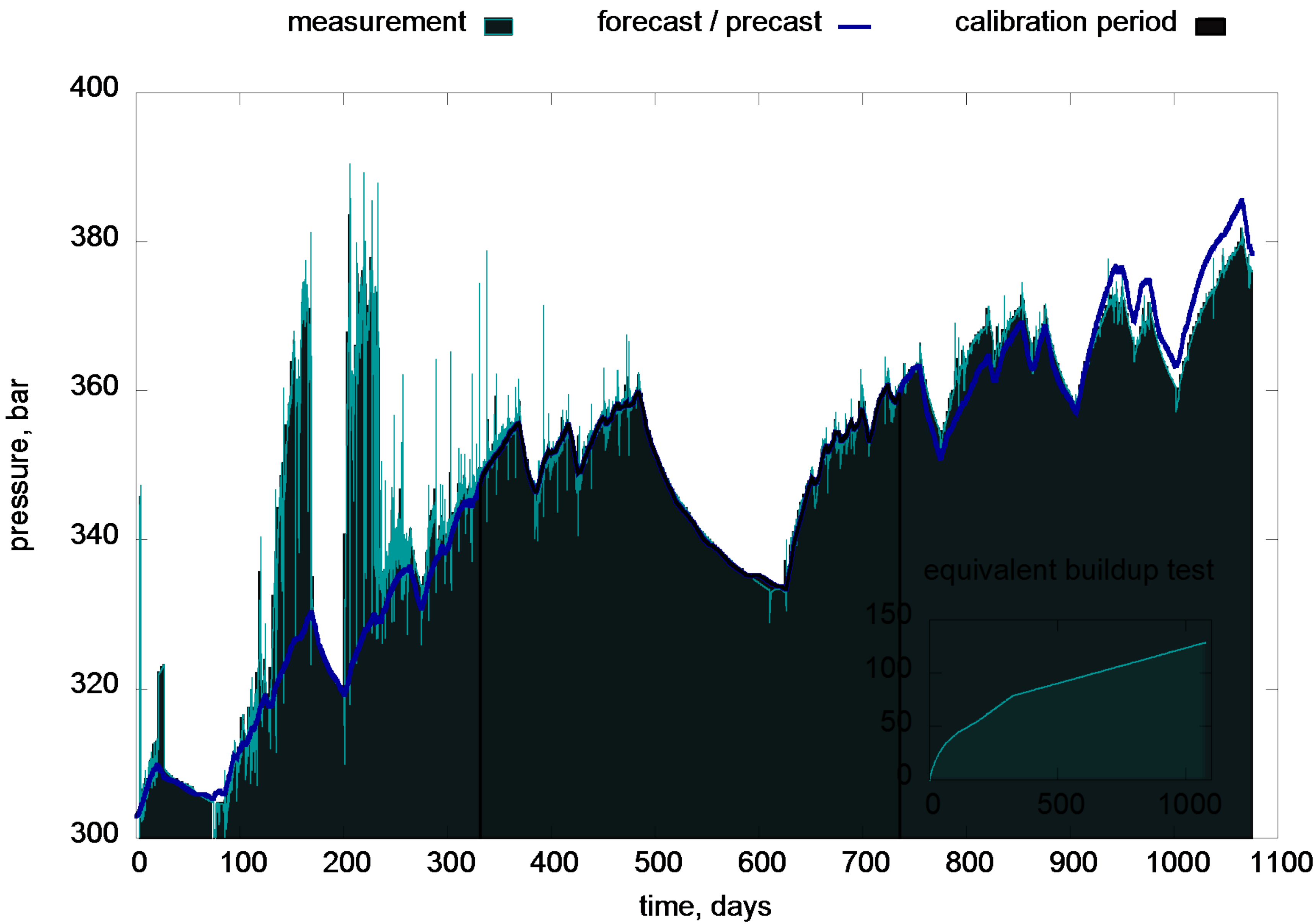

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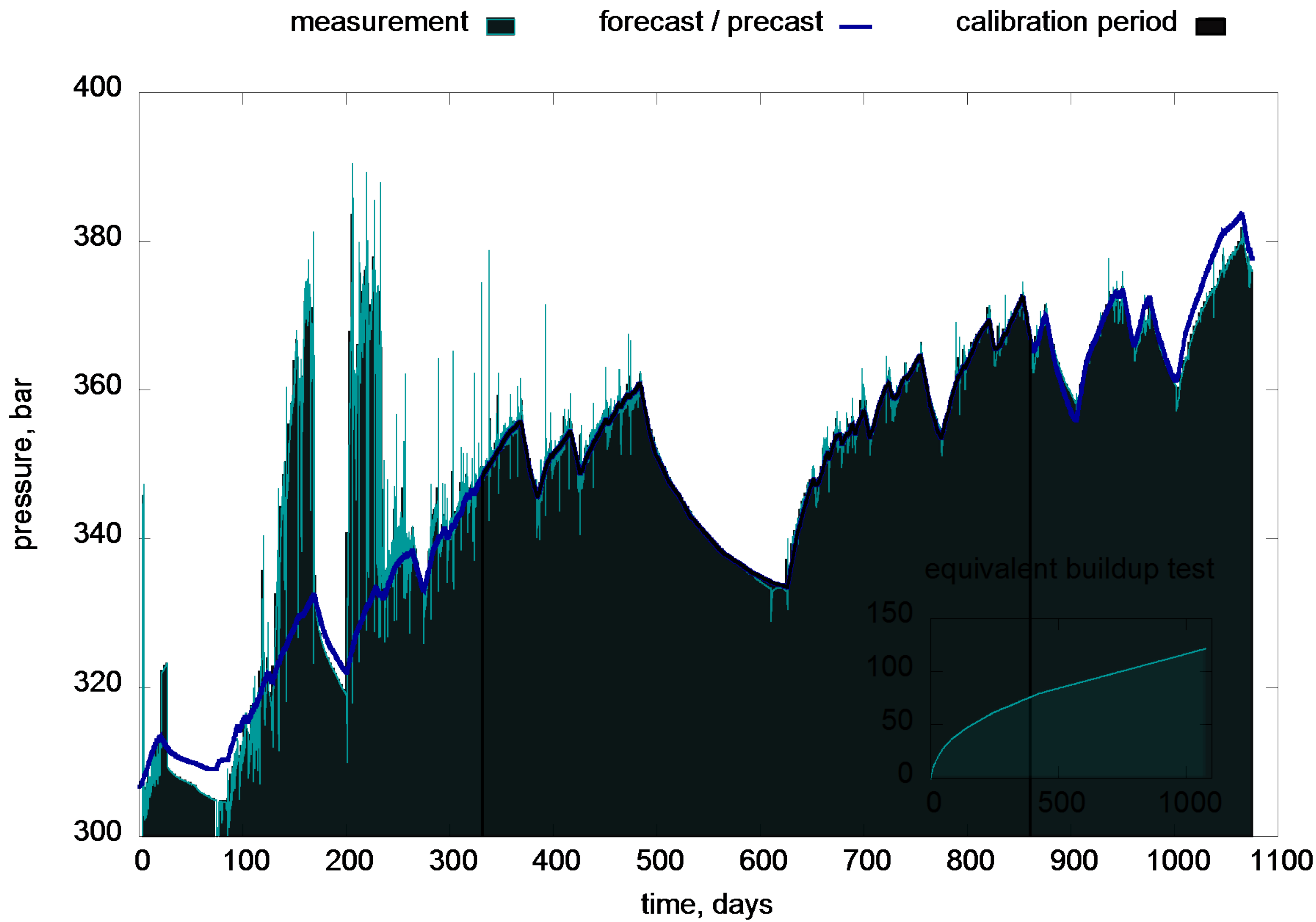

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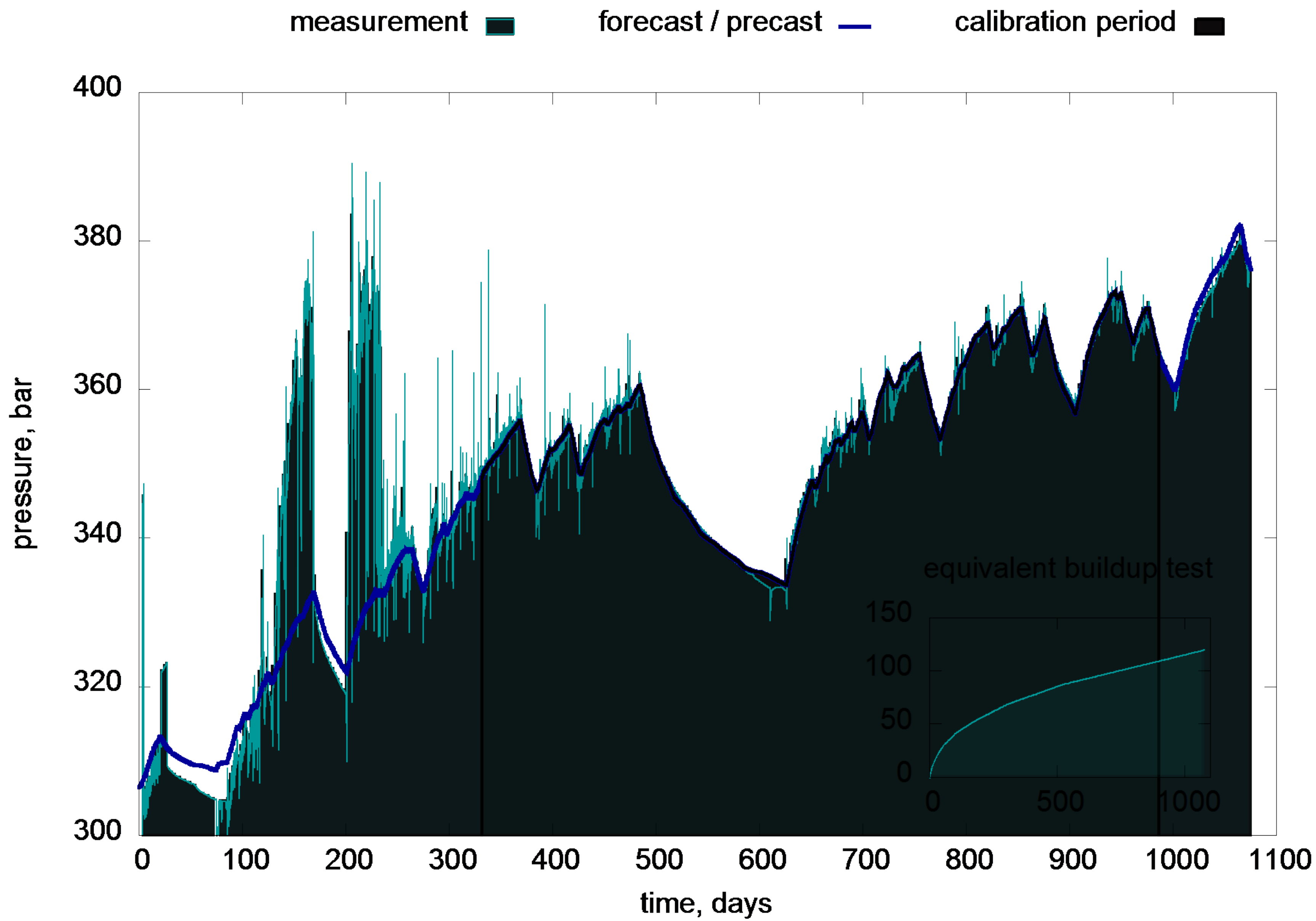

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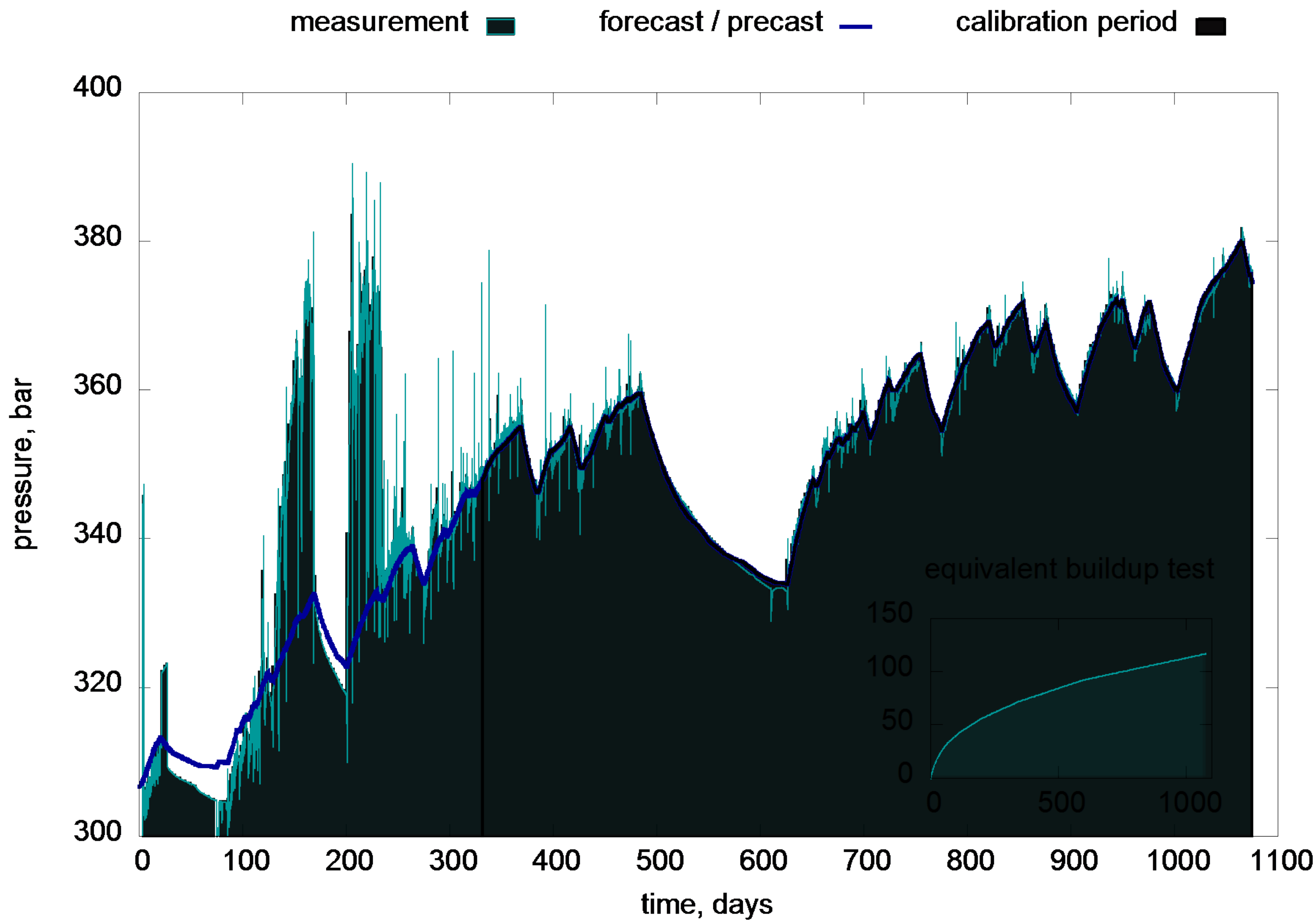


Stø Injection

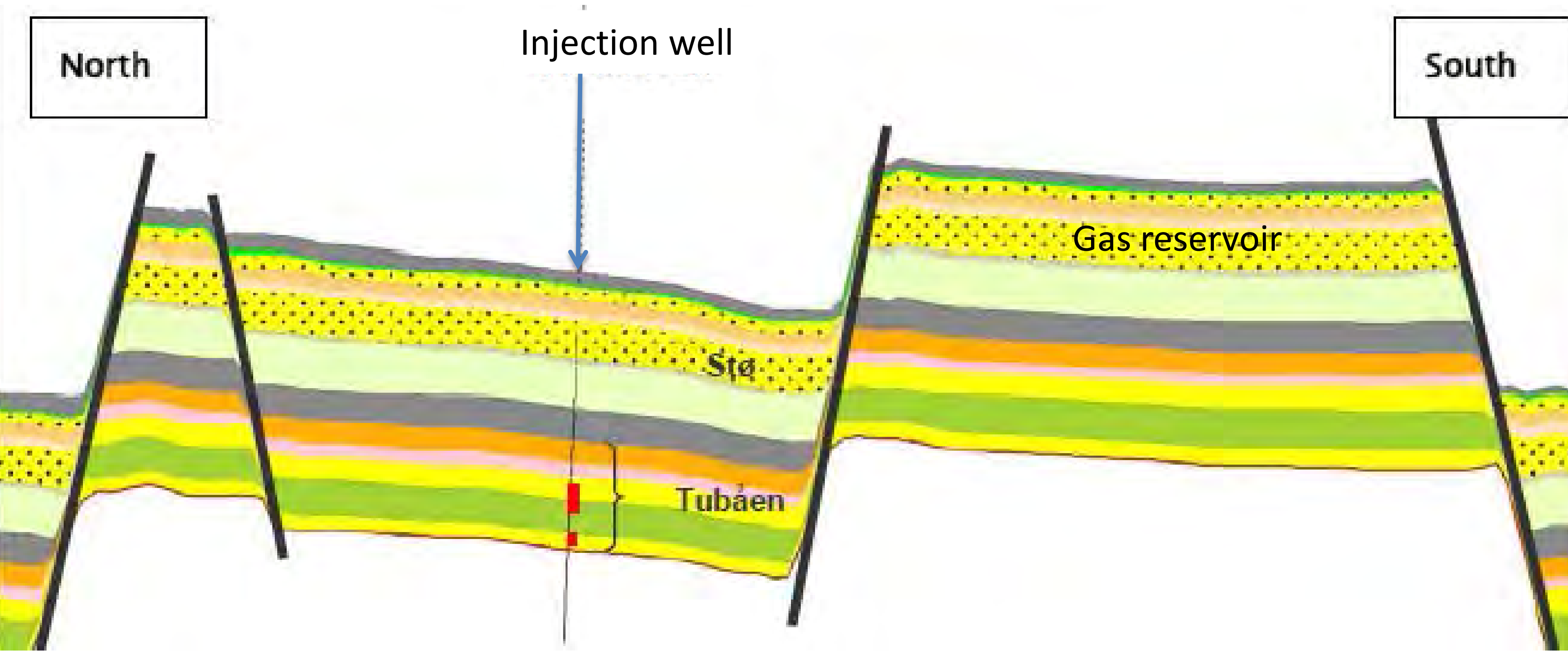
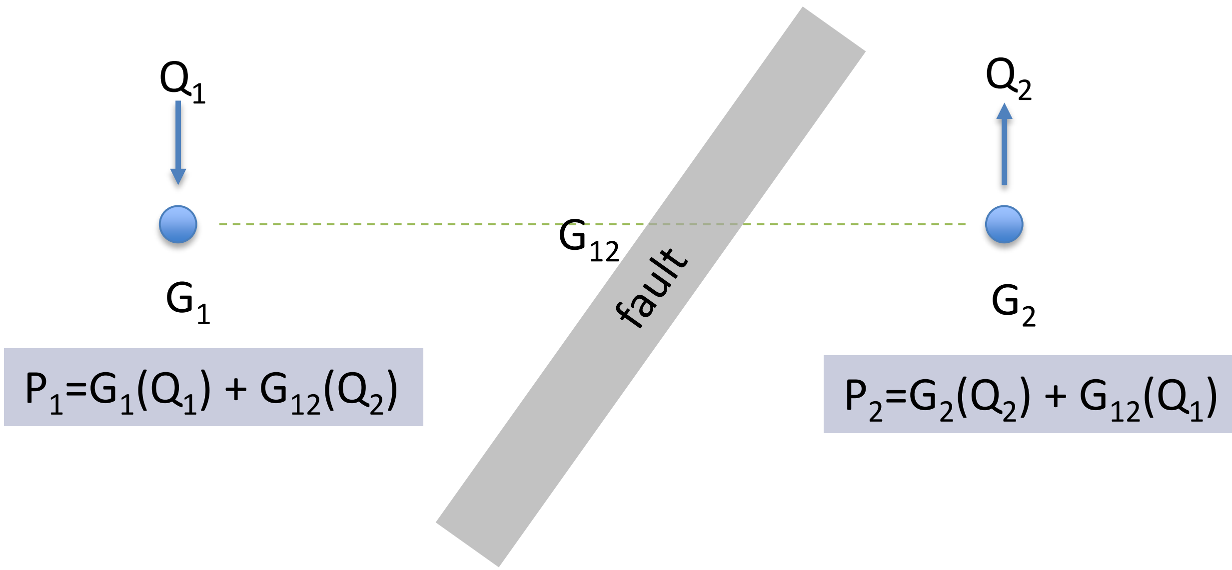


Figure: N-S vertical cross section through stratigraphy

- **2008 to 2011**: ~1 Mtpa injection into Tubåen Formation
- **2011**: Well re-completion
- **2011 to present**: ~1 Mtpa into Stø Formation

Recent Work: Multi-well Interference

- When multiple wells interfere with one another, data deconvolution can be performed simultaneously on all wells to extract build-up response functions (G).



Multi-well Interference: Stø Dataset

Looking forward, our goal is to provide a research platform to help answer the following questions:

① How can operators identify (and understand) reservoir properties and structure as quickly as possible?

② What mix of monitoring and characterization techniques provides the best information while still being cost effective?

③ How can operators forecast reservoir behavior to make informed and timely decisions?

④ What engineering solutions are available to maximize storage and manage integrity risks?

Synergistic Opportunities

We welcome new ideas for pressure analysis algorithms that might be included in the toolkit.

We are also happy to partner with operators to further validate the proposed methods on real field cases.

Acknowledgements

- This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Funding was provided by the DOE Office of Fossil Energy, Carbon Sequestration Program and by Equinor SA.

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Appendix: Program Management

Program Goal No. 4

- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Benefit Statement

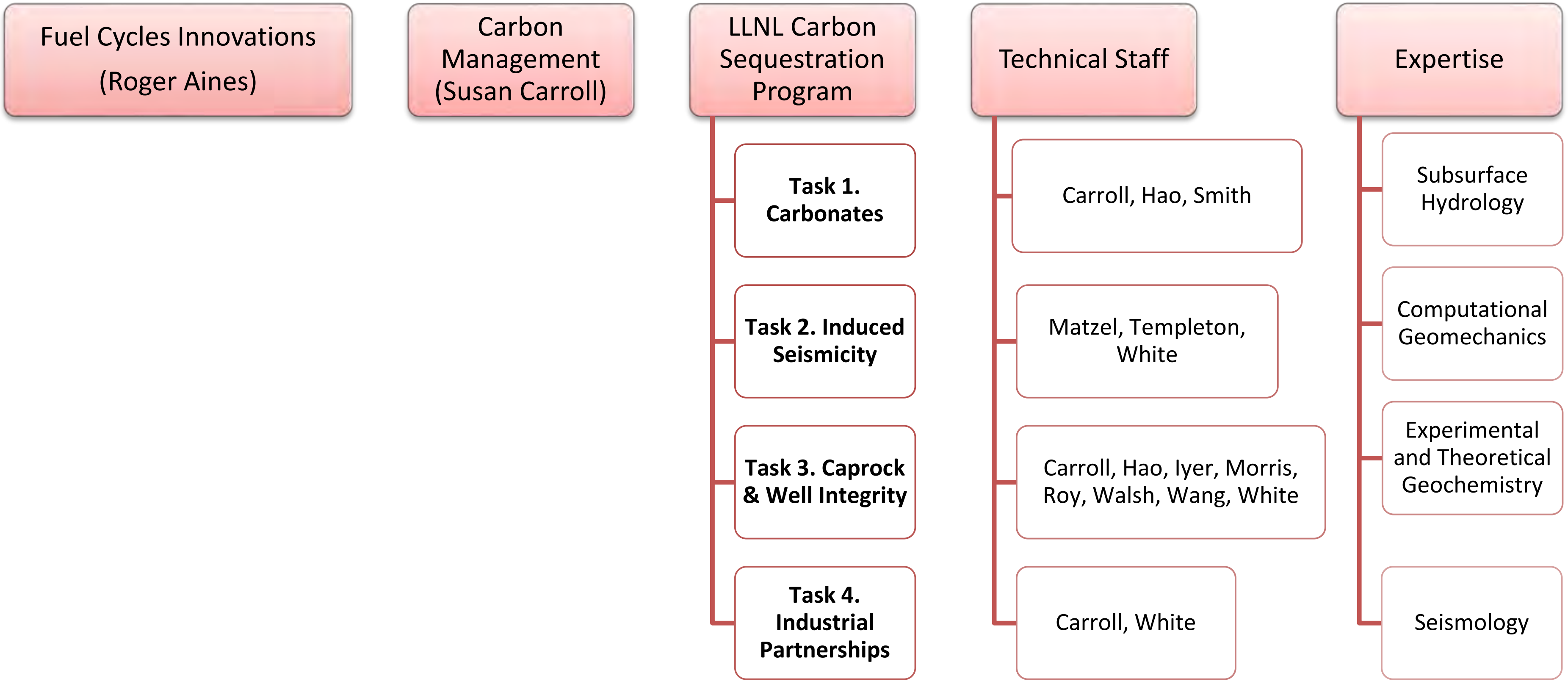
- An understanding of hydro-mechanical interactions is essential for effective monitoring and management of reservoir performance.

- This project seeks to develop:

    - An open source toolkit to support dynamic well-test analysis using well gauge data

    - Best practices for using gauge data to cost-effectively monitor reservoir performance

Org Chart


Fuel Cycles Innovations
(Roger Aines)
Carbon Management
(Susan Carroll)
LLNL Carbon Sequestration Program
Task 1. Carbonates
Task 2. Induced Seismicity
Task 3. Caprock & Well Integrity
Task 4. Industrial Partnerships
Technical Staff
Carroll, Hao, Smith
Matzel, Templeton, White
Carroll, Hao, Iyer, Morris, Roy, Walsh, Wang, White
Carroll, White
Expertise
Subsurface Hydrology
Computational Geomechanics
Experimental and Theoretical Geochemistry
Seismology

Project Timeline for FEW0191

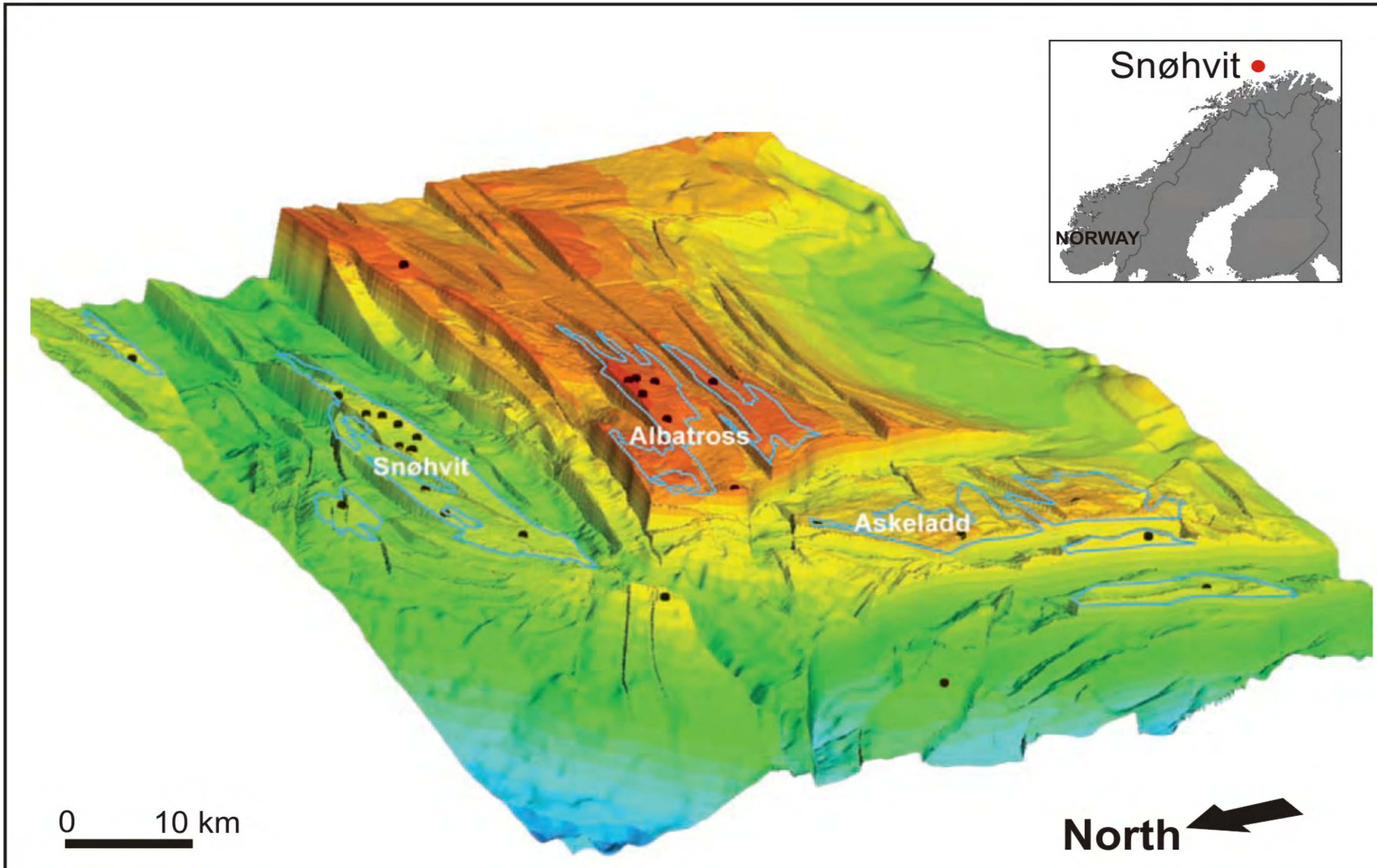
Task	Milestone Description*	Project Duration	Start : Oct 1, 2014						End: Sept 30, 2017					Planned Start Date	Planned End Date	Actual Start Date	Actual End Date	Comment (notes, explanation of deviation from plan)
		Project Year (PY) 1				PY 2				PY 3								
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12					
1.1	Calibrate Reactive Transport Model						x							1-Oct-14	30-Mar-15			
1.2	Calibrate NMR Permeability Estimates						x							1-Oct-14	30-Mar-15			
1.3	Scale Reactive Transport Simulations from the core to reservoir scale										x			1-Jul-15	28-Feb-17			
1.4	Write topical report on CO2 storage potential in carbonate rocks												x	1-Dec-16	30-Sep-17			
2.1	Algorithm development and testing				x									1-Oct-14	30-Sep-15			
2.2	Array design and monitoring recommendations								x					1-Oct-15	30-Sep-16			
2.3	Toolset usability and deployment												x	1-Oct-16	30-Sep-17			
3.1	Analysis of monitoring and characterization data available from the In Salah Carbon Sequestration Project				x									1-Dec-14	30-Sep-15			
3.2	Wellbore model development				x									1-Oct-14	30-Sep-15			
3.3	Analysis of the full-scale wellbore integrity experiments										x			1-Mar-14	28-Feb-17			
3.4	Refining simulation tools for sharing with industrial partners												x	1-Oct-16	30-Sep-17			
4.1	Engage with industrial partnerships		x											1-Oct-14	28-Feb-15			Future tasks pending discussions with industrial partners
4.2	Develop work scope with industrial partners				x									1-Mar-14	30-Sep-15			

* No fewer than two (2) milestones shall be identified per calendar year per task

Bibliography

- J.A White. Cypress User Manual Version 1.0, April 2017, LLNL-SM-730935.

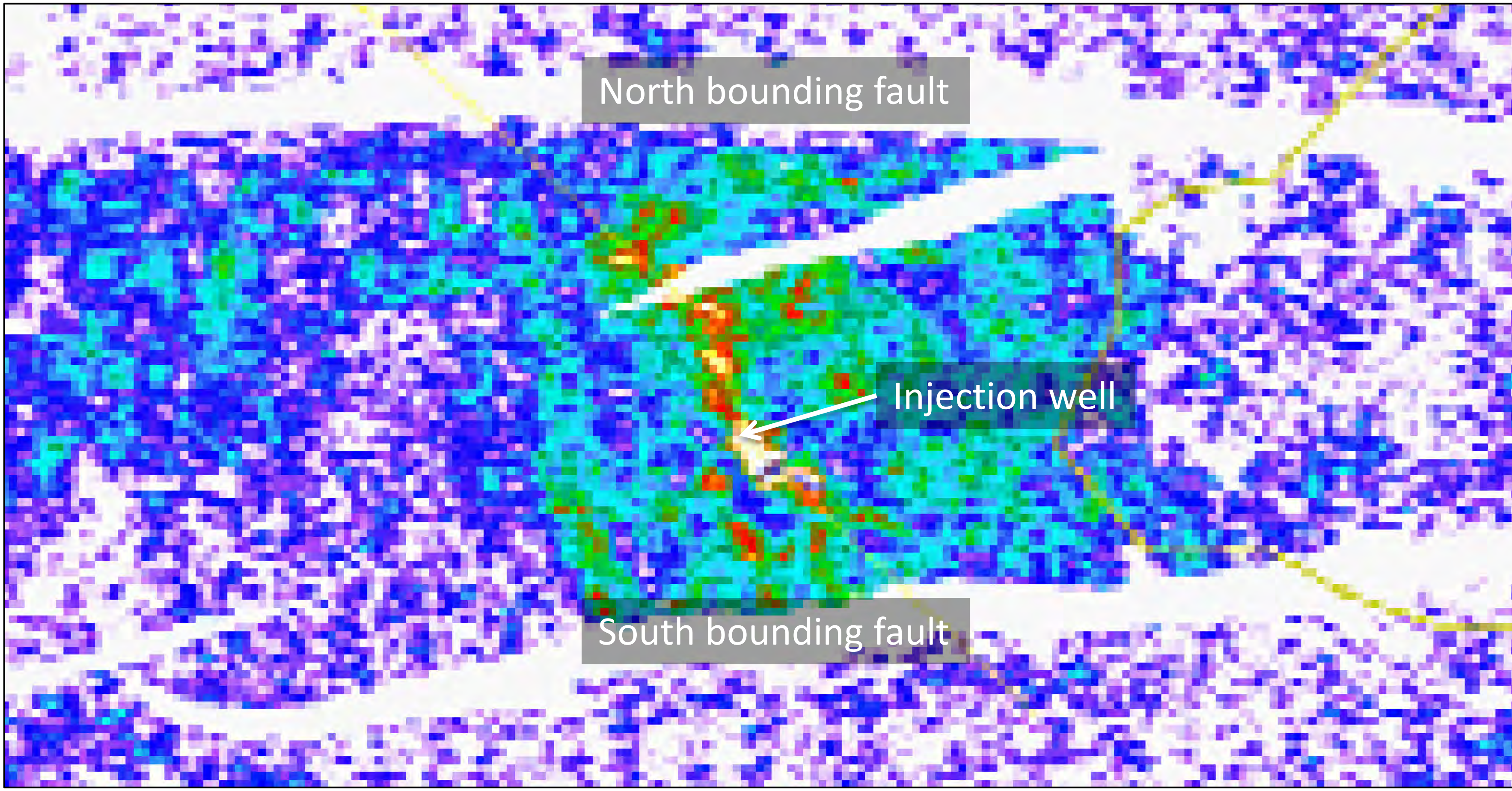
The Snøhvit CO_2 Storage Project



[Spencer et al. 2008; Chiaramonte et al. 2014]

Depositional environment controls pressure behavior

- CO_2 and pressure confined to narrow sand channels, with limited connectivity between channels



4D difference amplitude map, 2003-2009, lower perforation.

(Hansen et al. 2012)

Statoil falloff analysis shows clear indications of flow barriers

- Welltest model suggests flow barriers at 110, 110, and 3000m

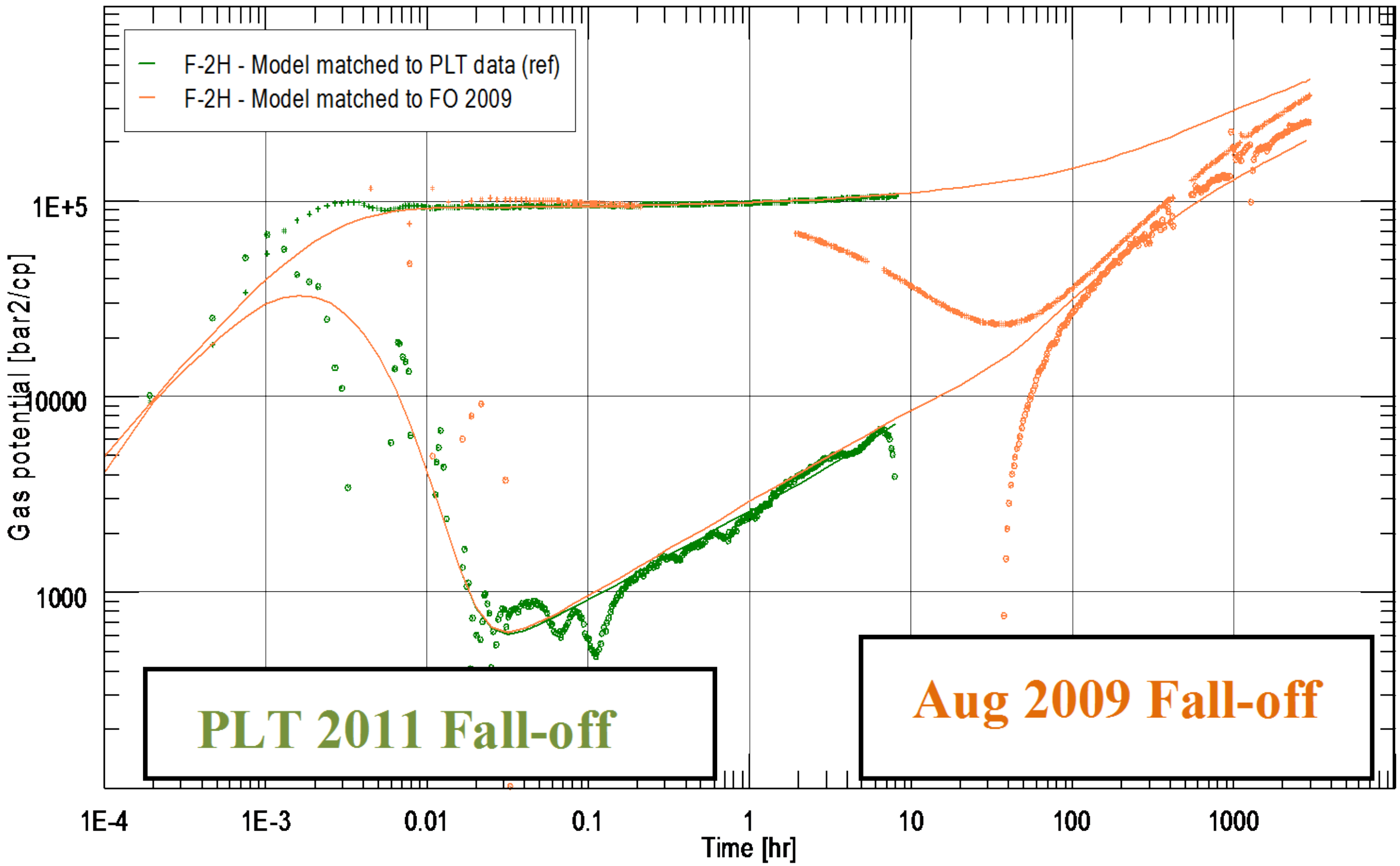


Figure: Falloff analyses using permanent gauge (2009) and PLT data (2011).

(Hansen et al. 2012)