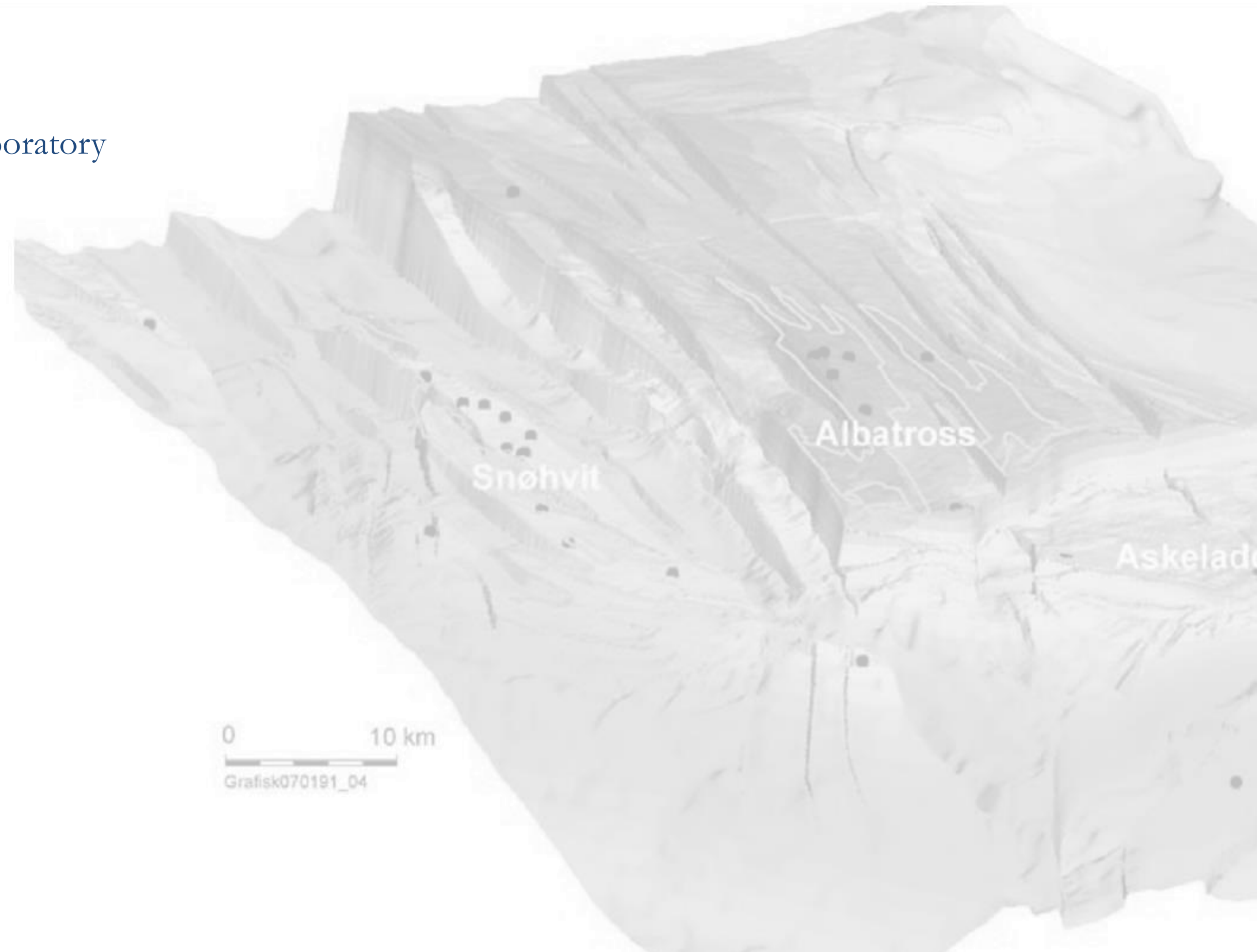
Pressure management and geomechanical behavior at industrial partner projects

Joshua White & Thomas Buscheck

Project Number:
FWP-FEW0191-Task 4

Lawrence Livermore National Laboratory



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 multi-rate / multi-well gauge data
  - Active pressure management strategies using pre-production and co-production of brine

Performance Period

May 2016 to April 2019

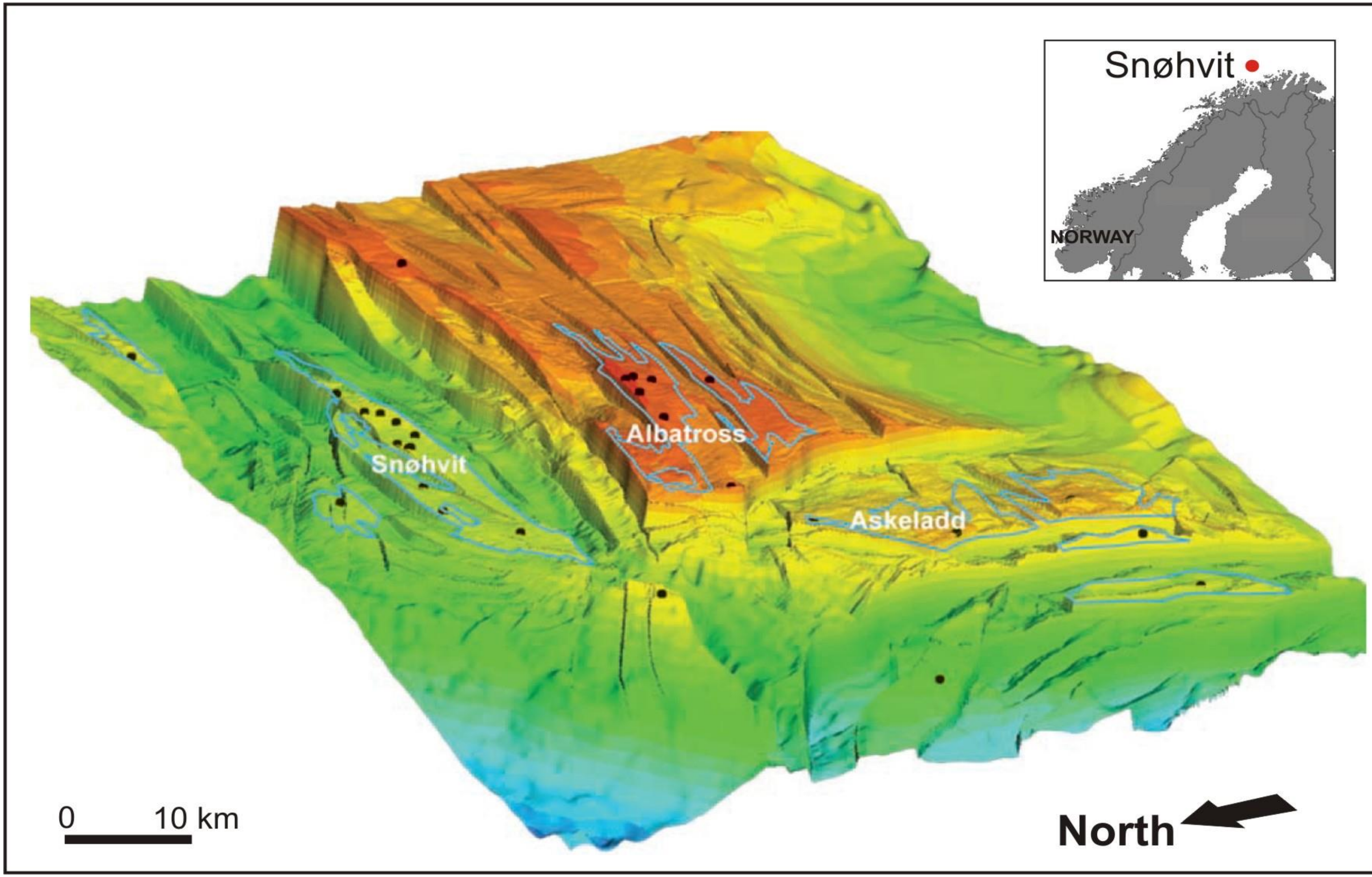
FY16-17 Task Status

Task	Status
① Statoil data transfer & pre-processing	**Complete**
② Active pressure management study	**25%**
③ Pressure toolkit development	**25%**

Team

- Joshua White -- geomechanics and reservoir engineering
- Thomas Buscheck -- hydrogeology and reservoir engineering

The Snøhvit CO_2 Storage Project



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

Snøhvit CO_2 Storage Project

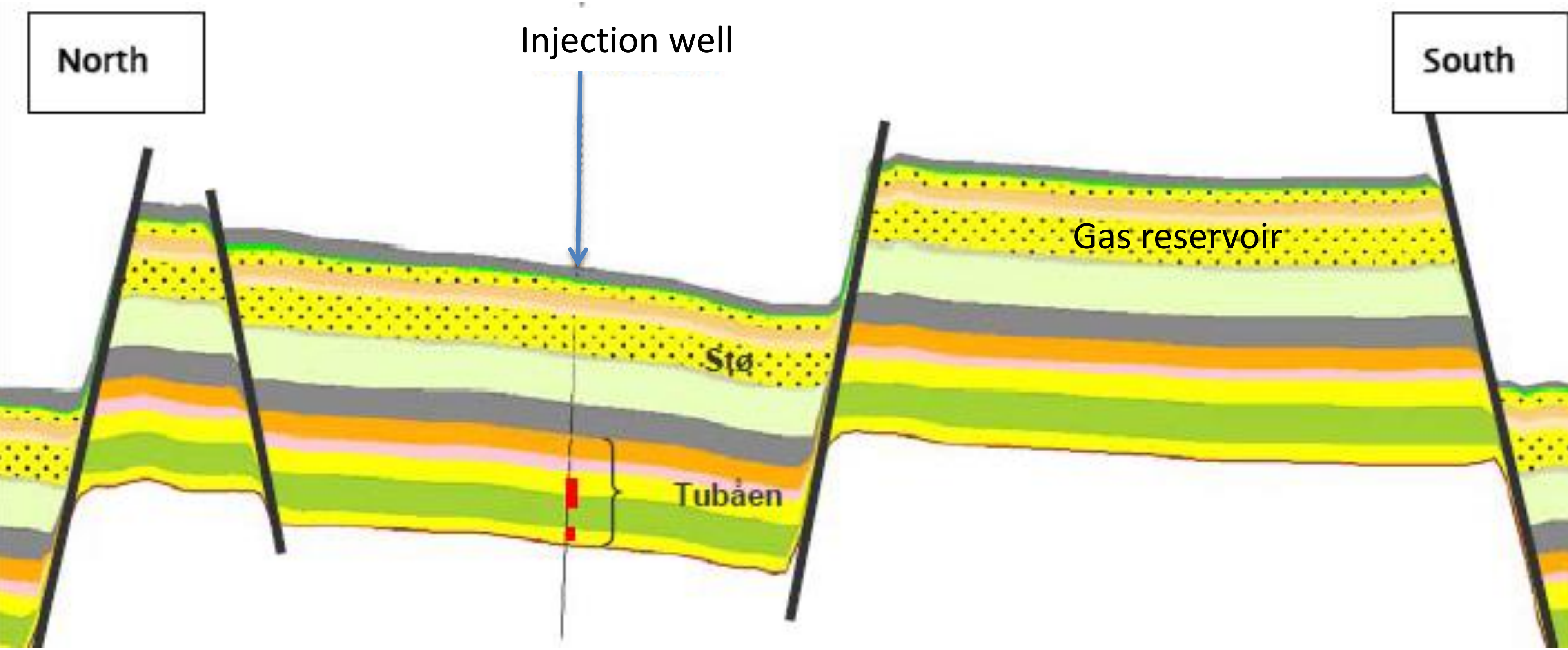
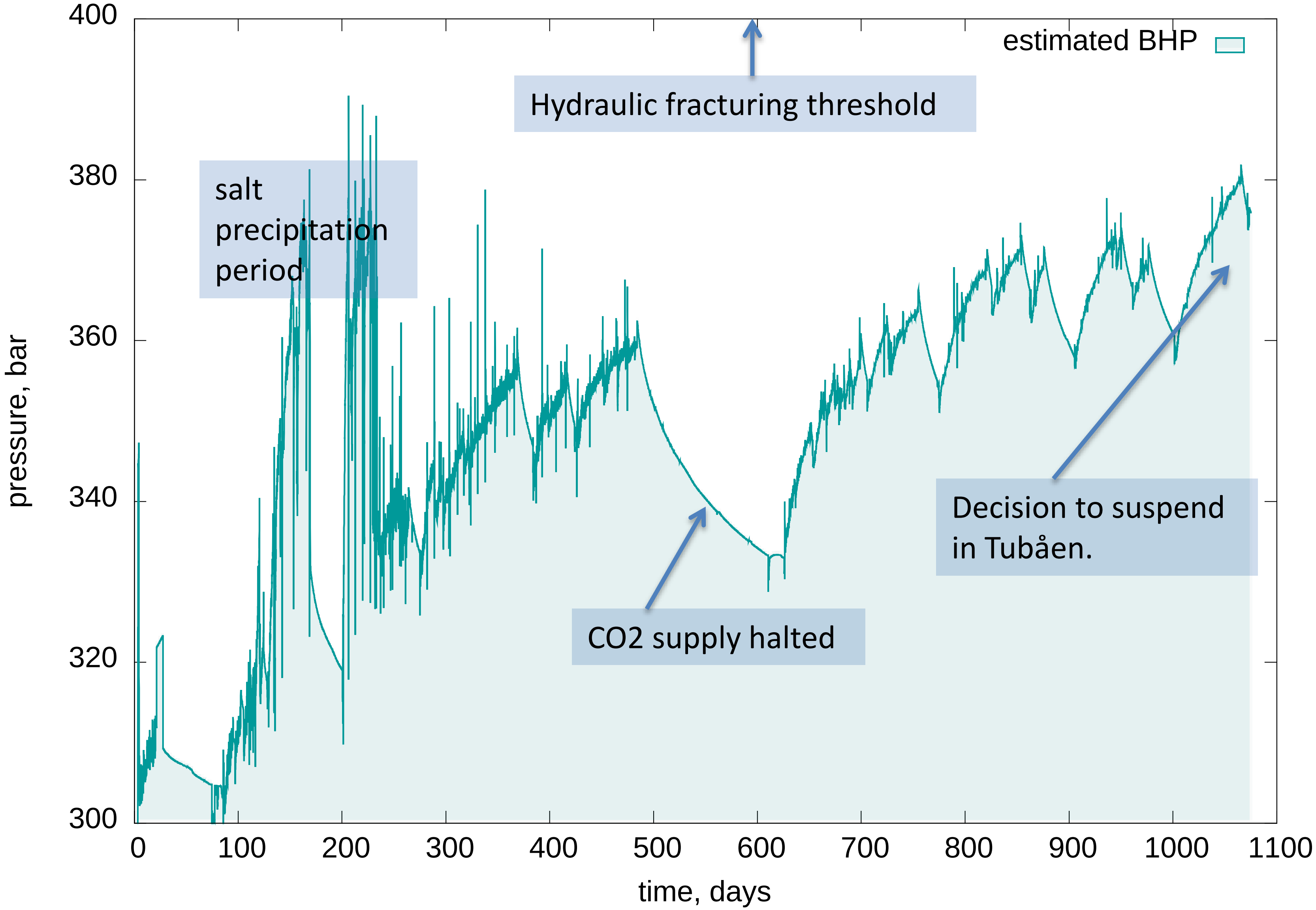


Figure: N-S vertical cross section through stratigraphy

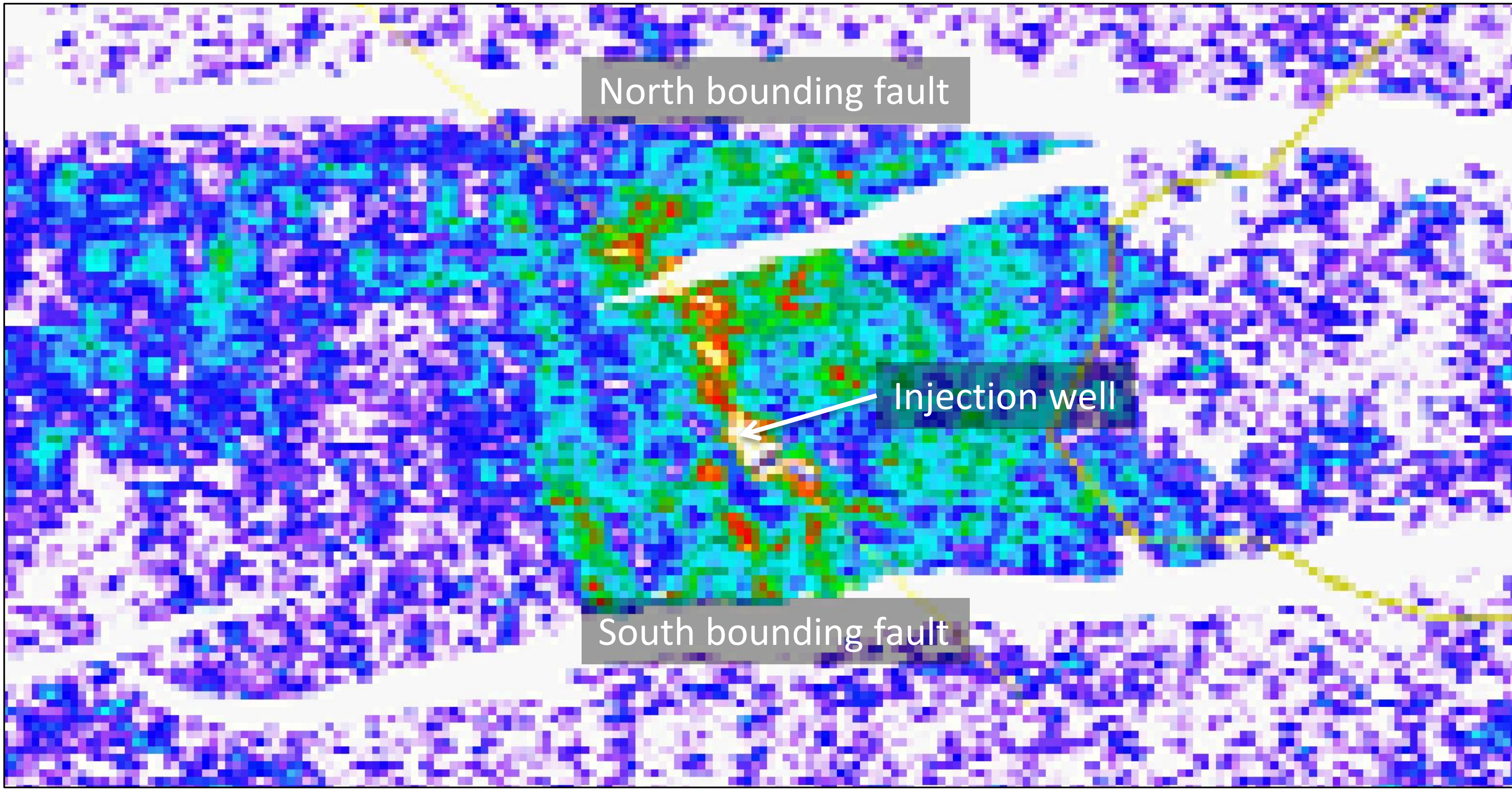
- **2008 to 2011**: ~1 Mtpa injection into Tubåen Formation
- **2011**: Well re-completion
- **2011 to present**: ~1 Mtpa into Stø Formation

Getting CO_2 into the Tubåen Fm. was harder than expected



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)

Snøhvit experience highlights questions faced by all carbon storage projects:

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

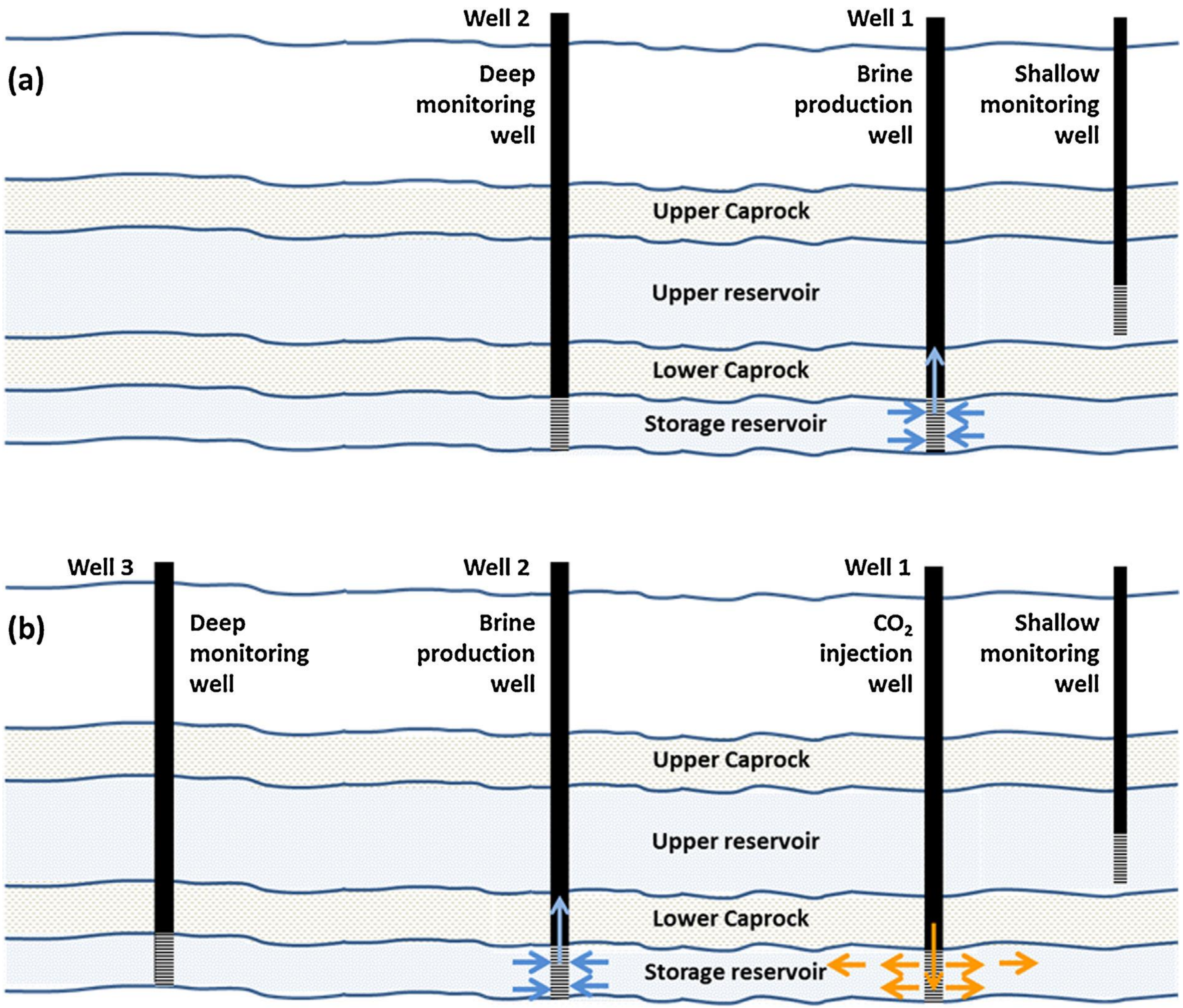
② What mix of monitoring and characterization techniques provides the best information while still being cost effective?

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

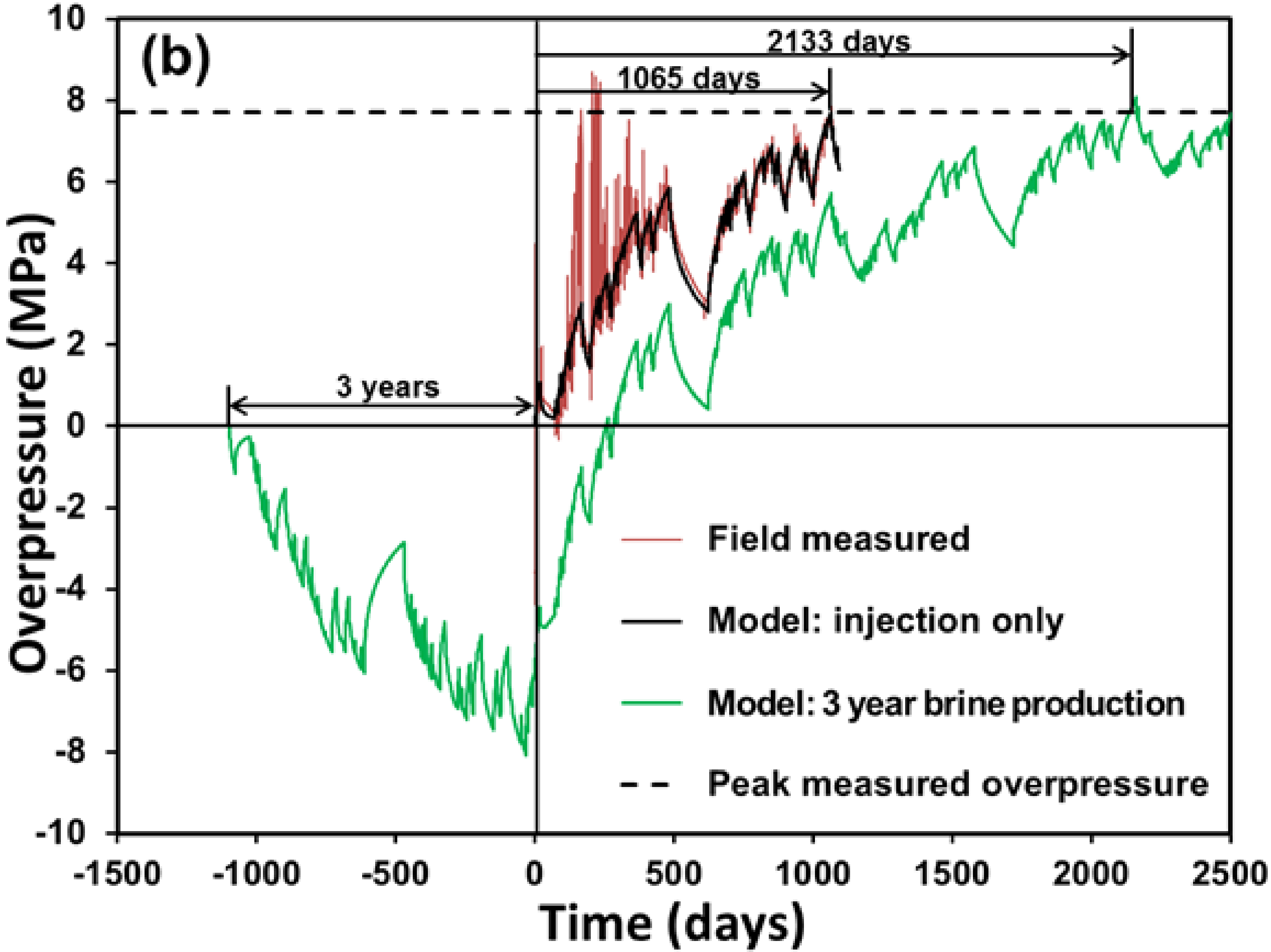
④ What engineering solutions are available to maximize storage and manage integrity risks?

Part 1. Active Reservoir Pressure Management

Active Reservoir Pressure Management



Tubåen brine pre-production case study



We have published an EES paper on Tubåen injection. We are working on a similar analysis of the Stø injection.

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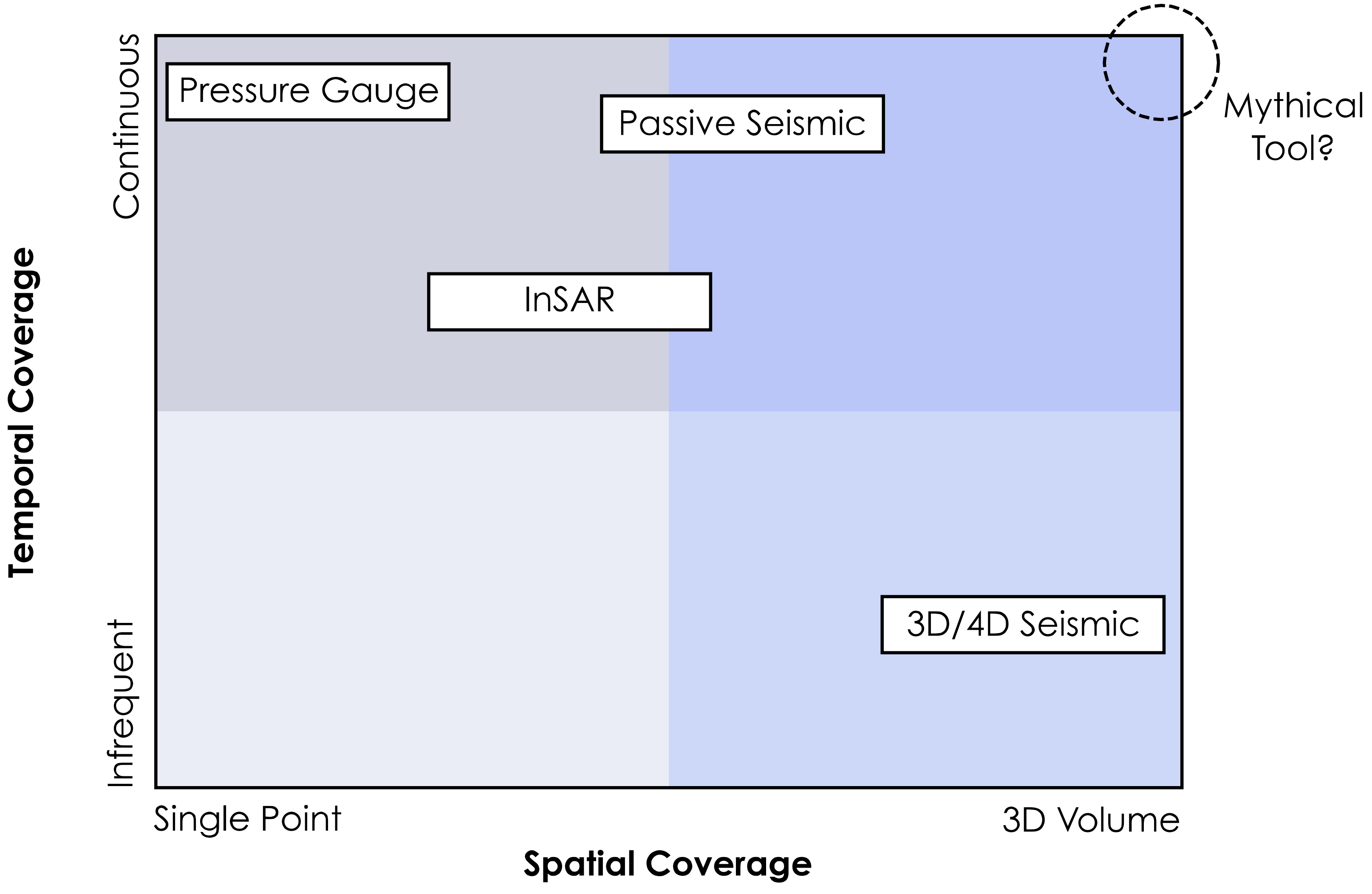
Managing geologic CO_2 storage with pre-injection brine production: a strategy evaluated with a model of CO_2 injection at Snøhvit

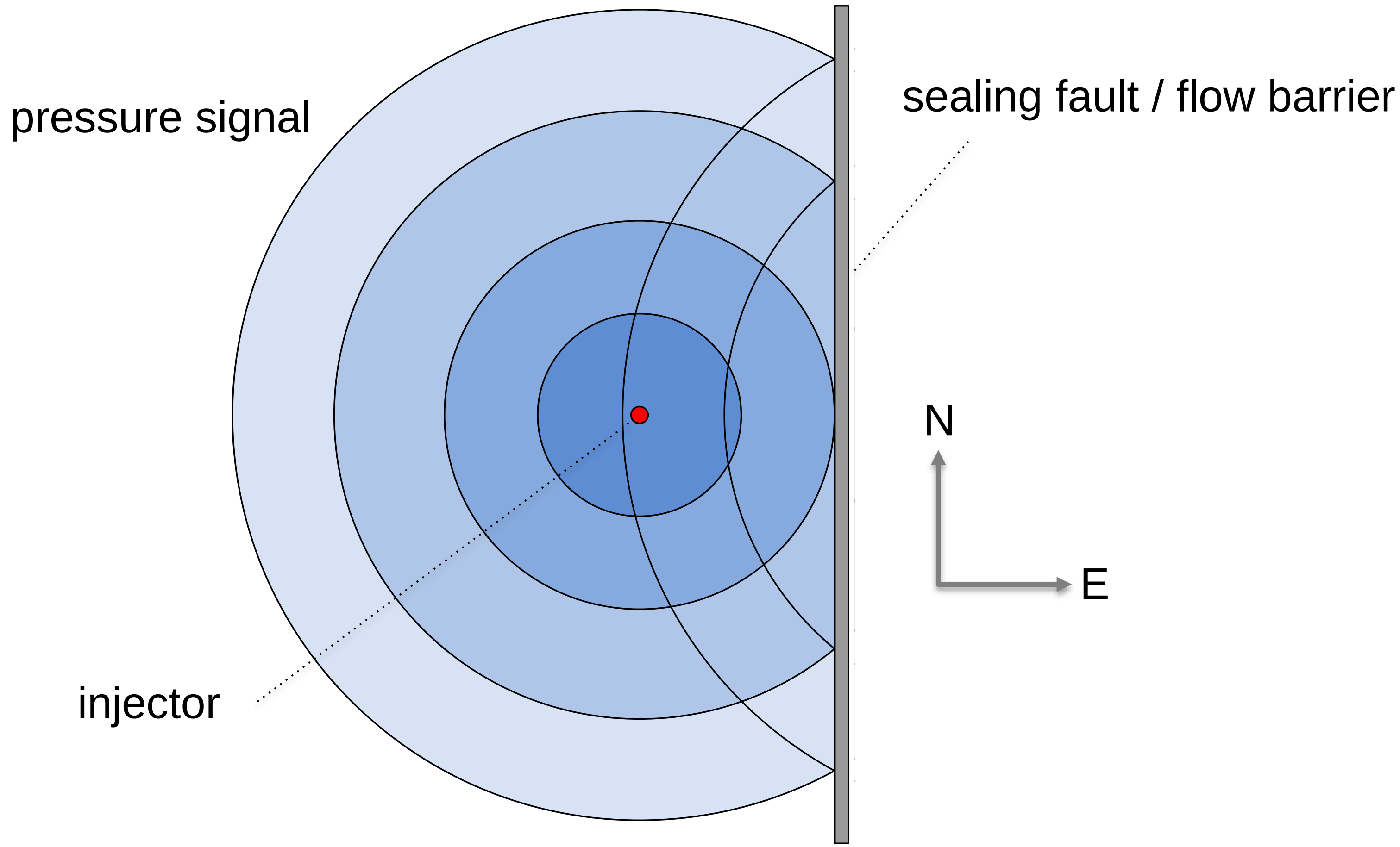
Thomas A. Buscheck,*[a] Joshua A. White,[a] Susan A. Carroll,[a] Jeffrey M. Bielicki[b] and Roger D. Aines[a]

Part 2. Pressure Analysis Toolkit

Complementary techniques are required to adequately monitor and understand subsurface behavior



Pressure measurements can provide "3D" data. They are just challenging to interpret.



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

Statoil falloff analysis shows clear indications of flow barriers

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

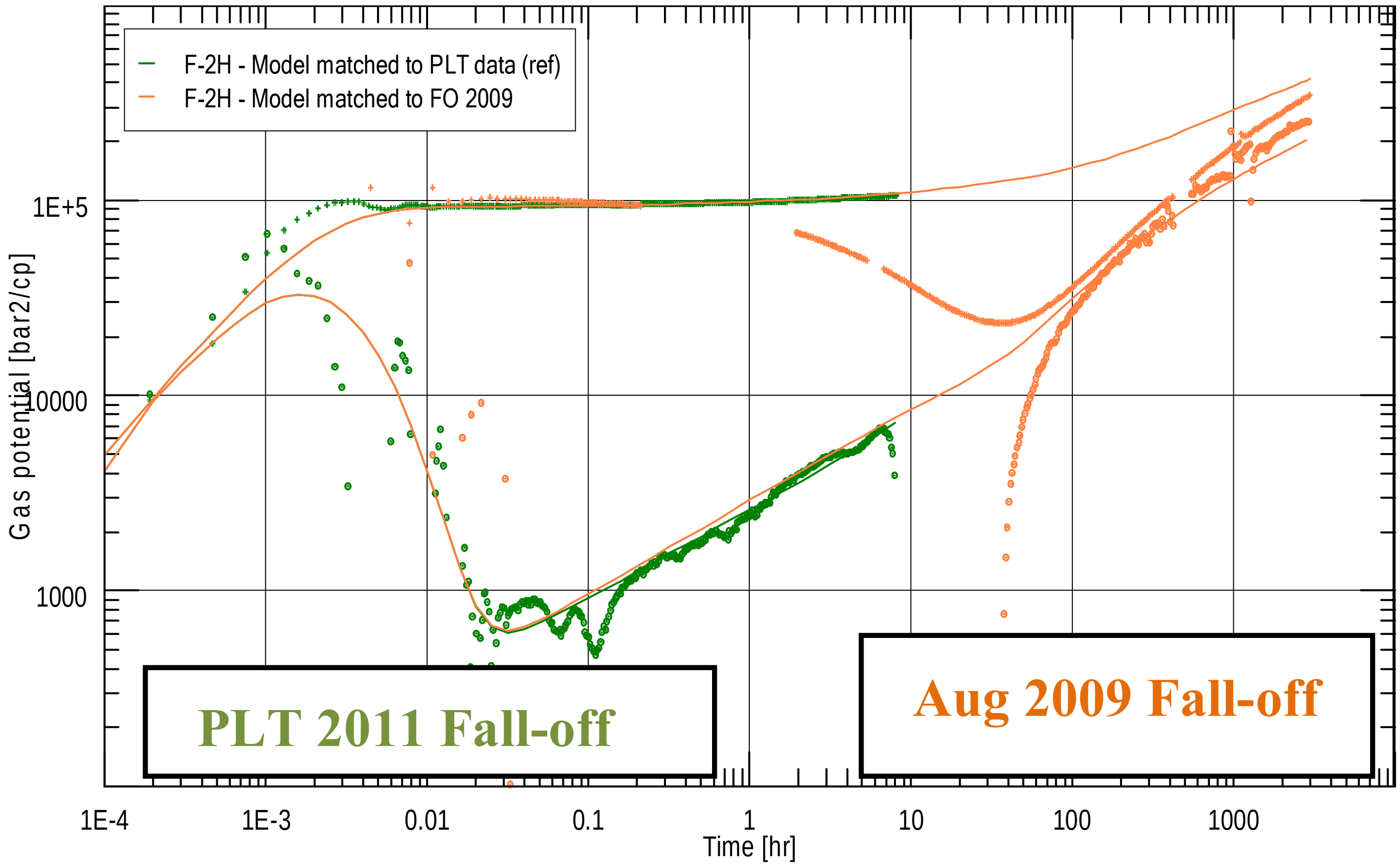
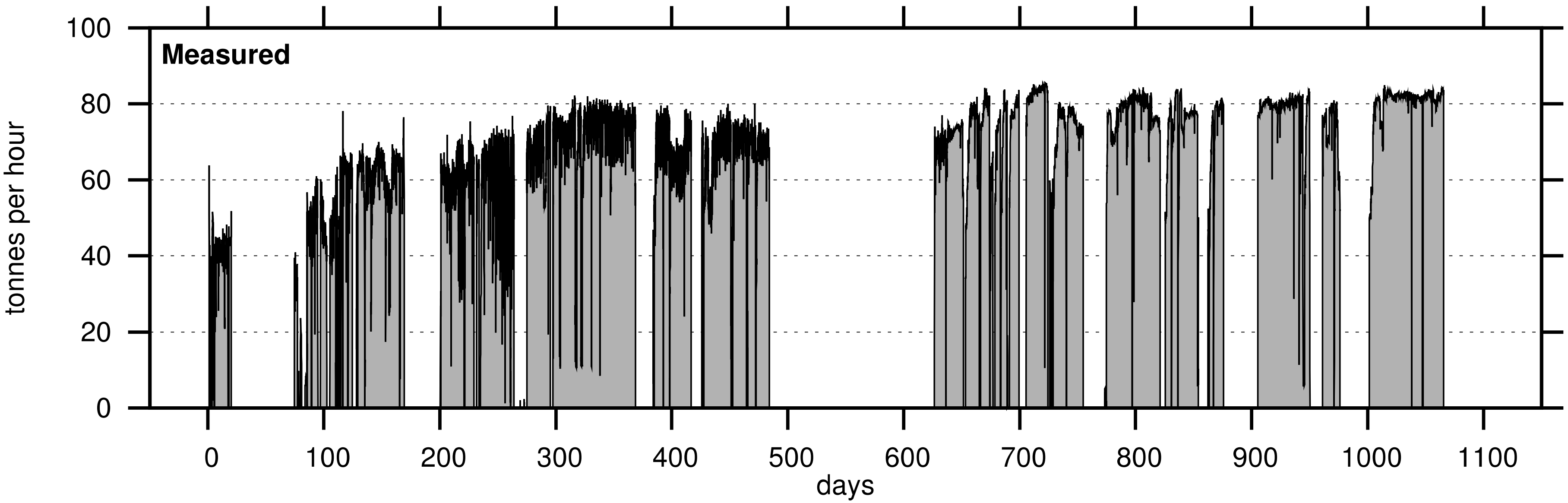


Figure: Falloff analyses using permanent gauge (2009) and PLT data (2011).

(Hansen et al. 2012)

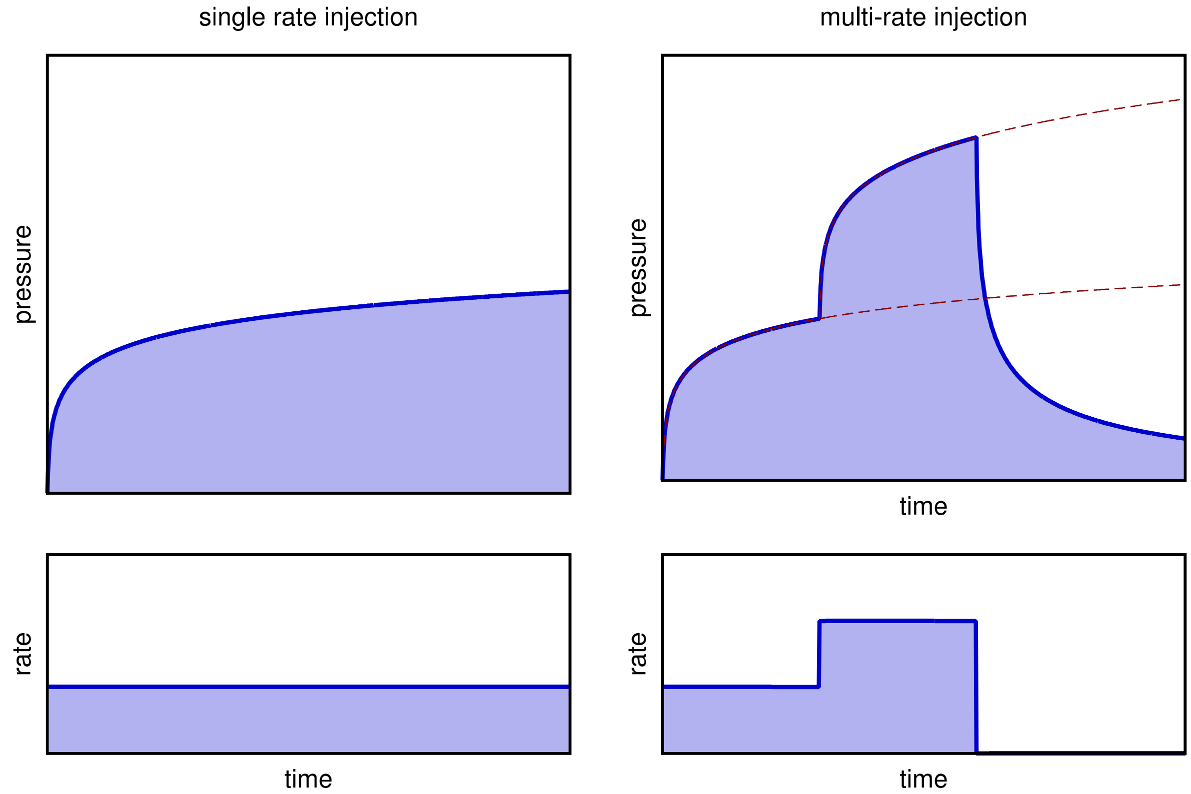
Falloff testing has proven value, but requires shutting in the well for significant periods



- **Motivating question:** Could we derive the same information from ongoing injection data, without shutting in for long periods?

Generalized superposition welltest method

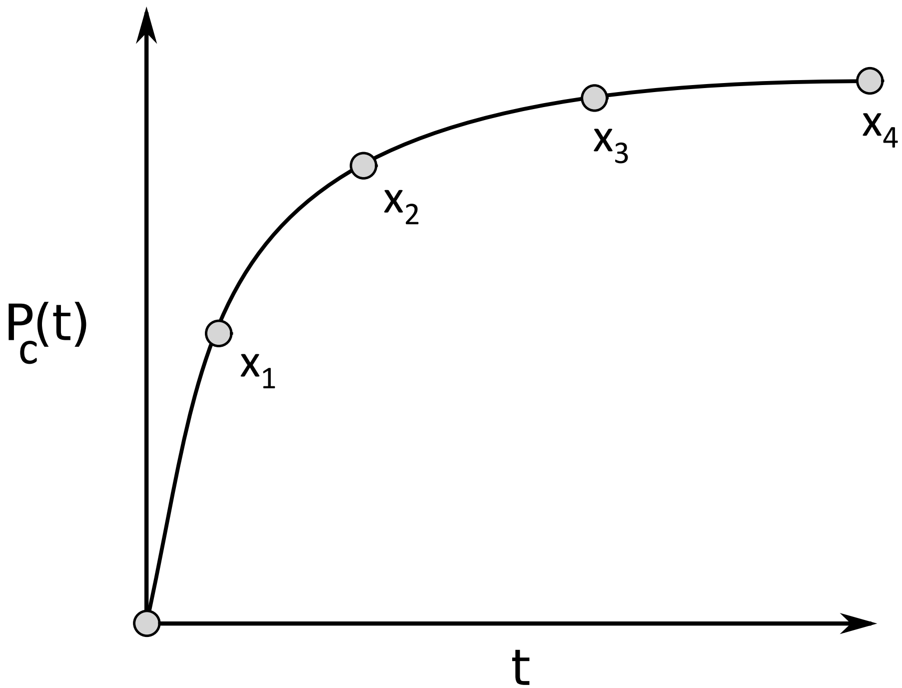
- We use a superposition principle to transform a multi-rate injection into an equivalent single-rate test.
- Equivalent buildup/falloff curve can then be analyzed using standard welltest methods



Single rate: $$p(t) = q \cdot p_C(t)$$

Multi-rate: $$p(t) = \sum_i (q_{i+1} - q_i) \cdot p_C(t - t_i)$$

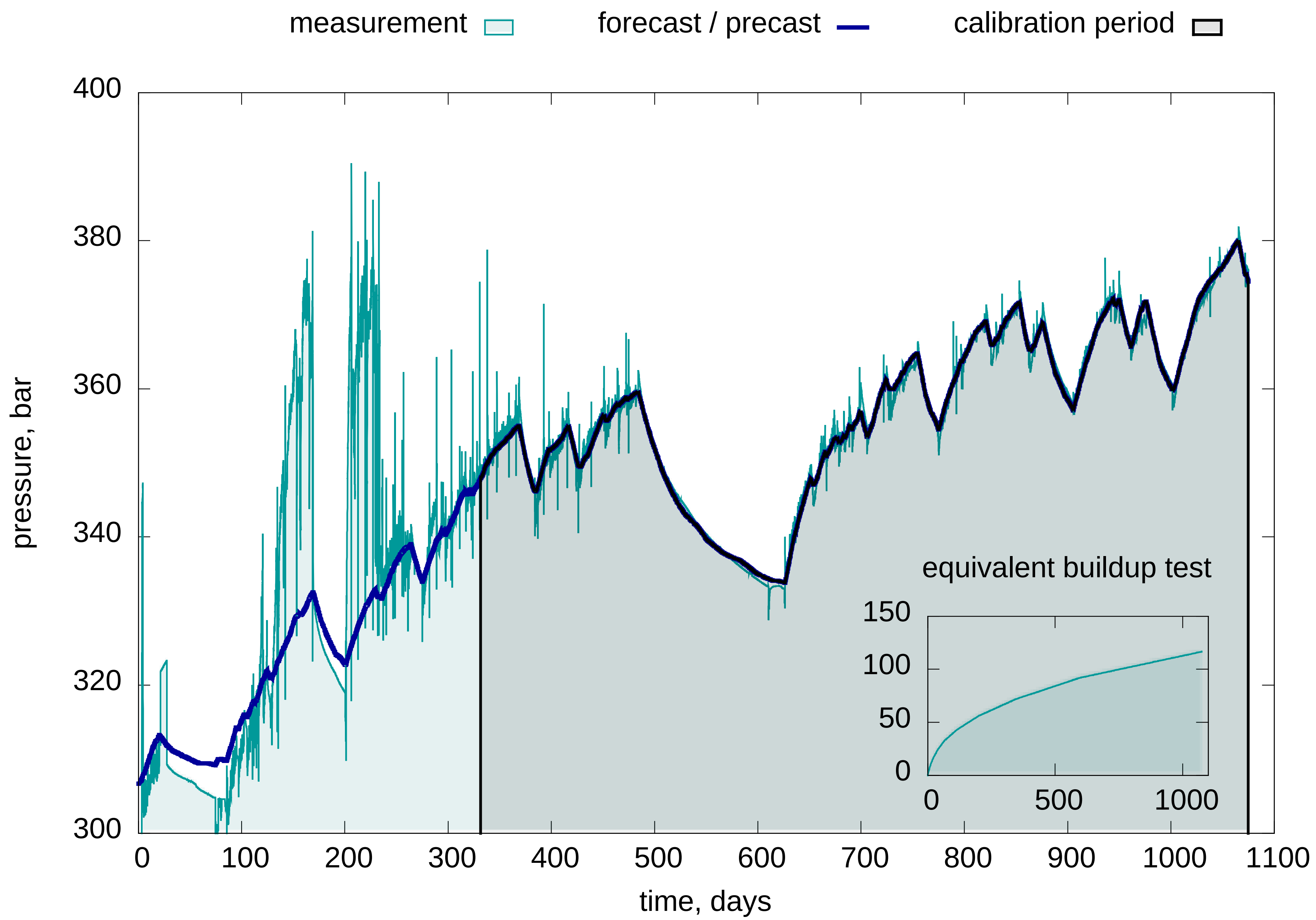
Generalized superposition welltest method



If there are M pressure data points, these equations can be written as a $M \times N$ linear system,

$$A\vec{x} = \vec{p} \qquad \text{with} \qquad A_{ij} = \sum_{n=0}^{n<i} (q_{n+1} - q_n)\, H_j(t_i - t_n)$$

Automatic calibration to Snøhvit data (~5 seconds)



Tool can potentially be used in two modes:

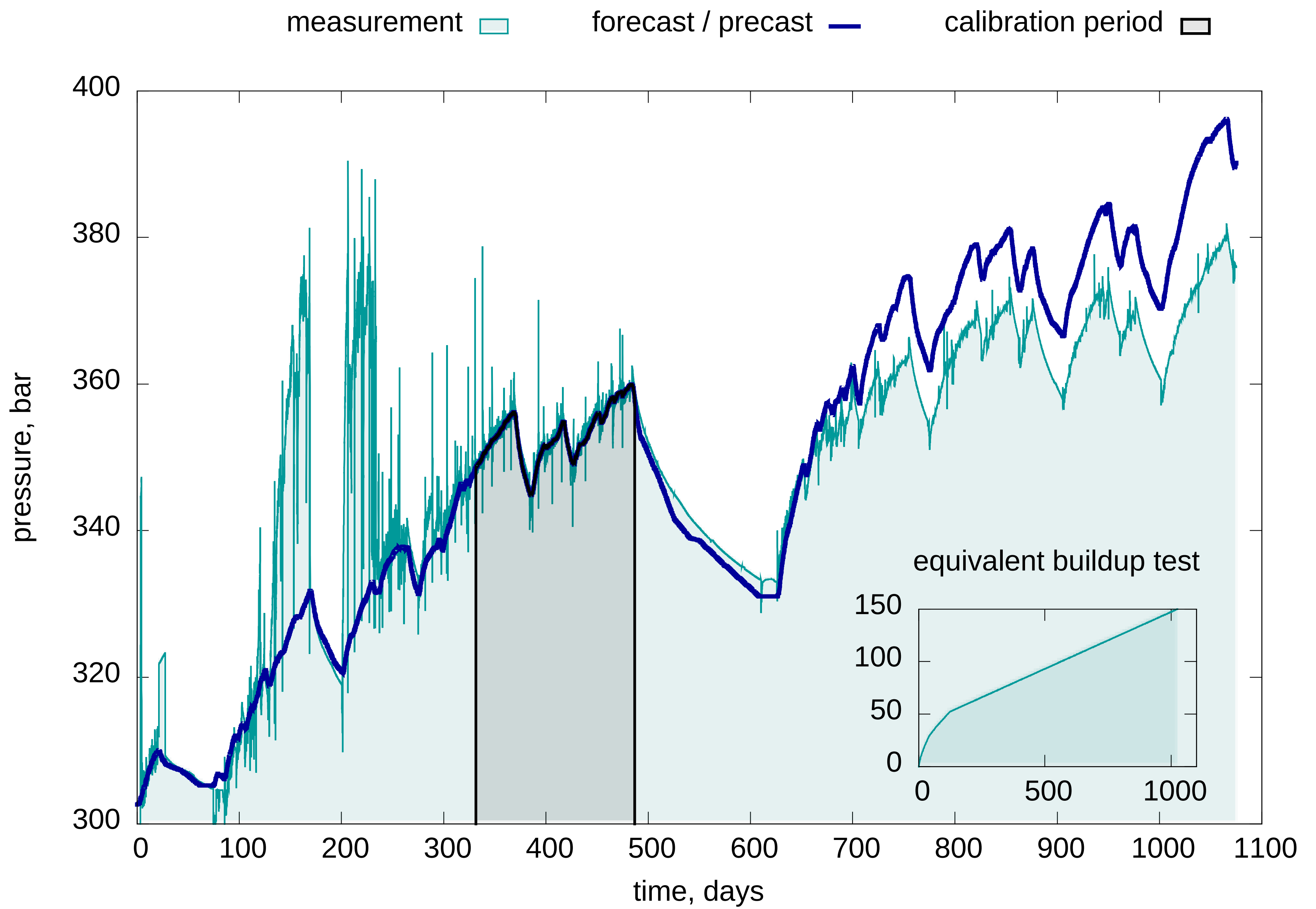
① **Reservoir characterization mode**

- Calibrate to gauge data, extract equivalent falloff test
- Apply standard welltest analysis techniques to results

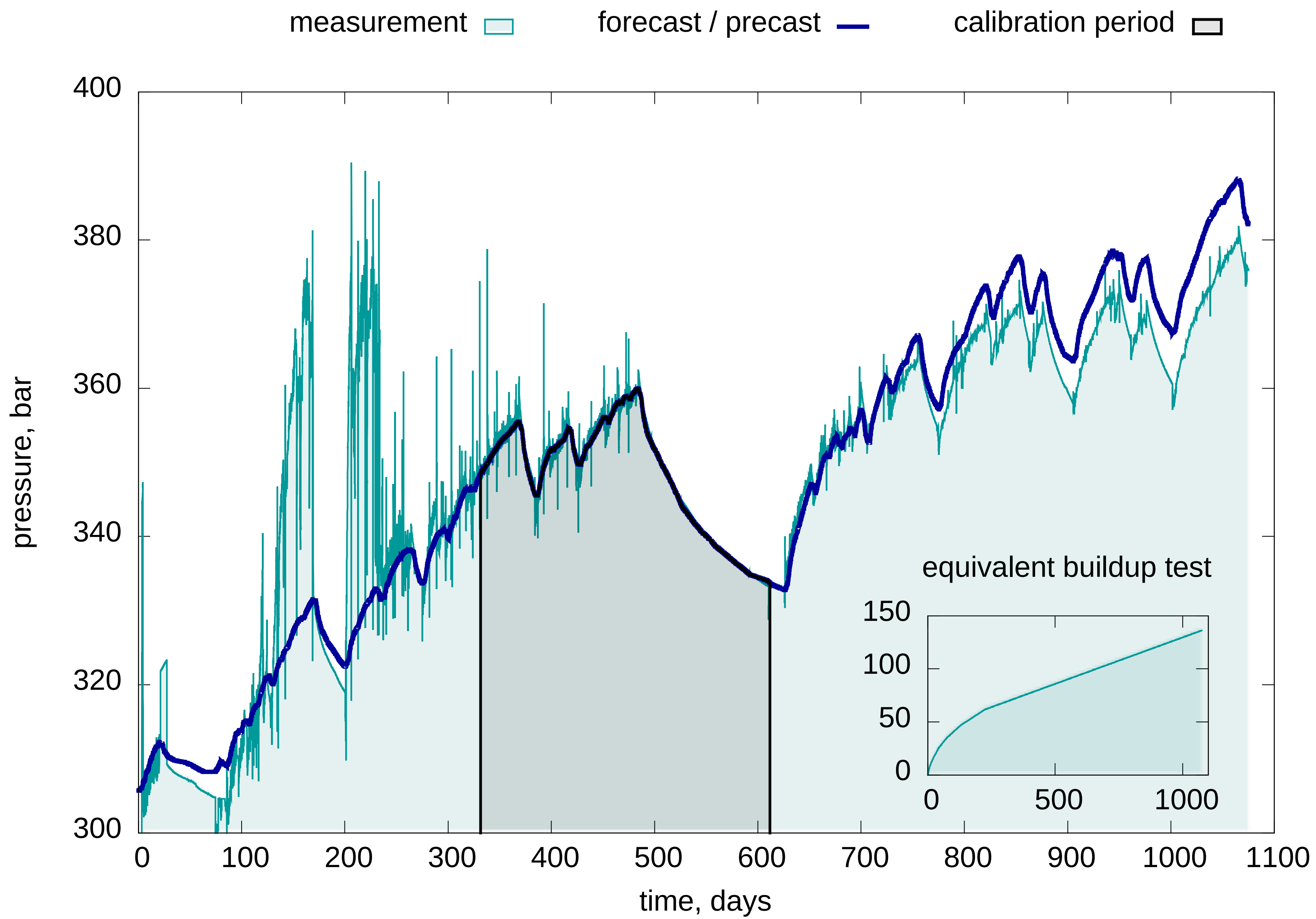
② **Pressure forecasting mode**

- Calibrate to gauge data, project forward in time
- Quickly explore alternative injection scenarios

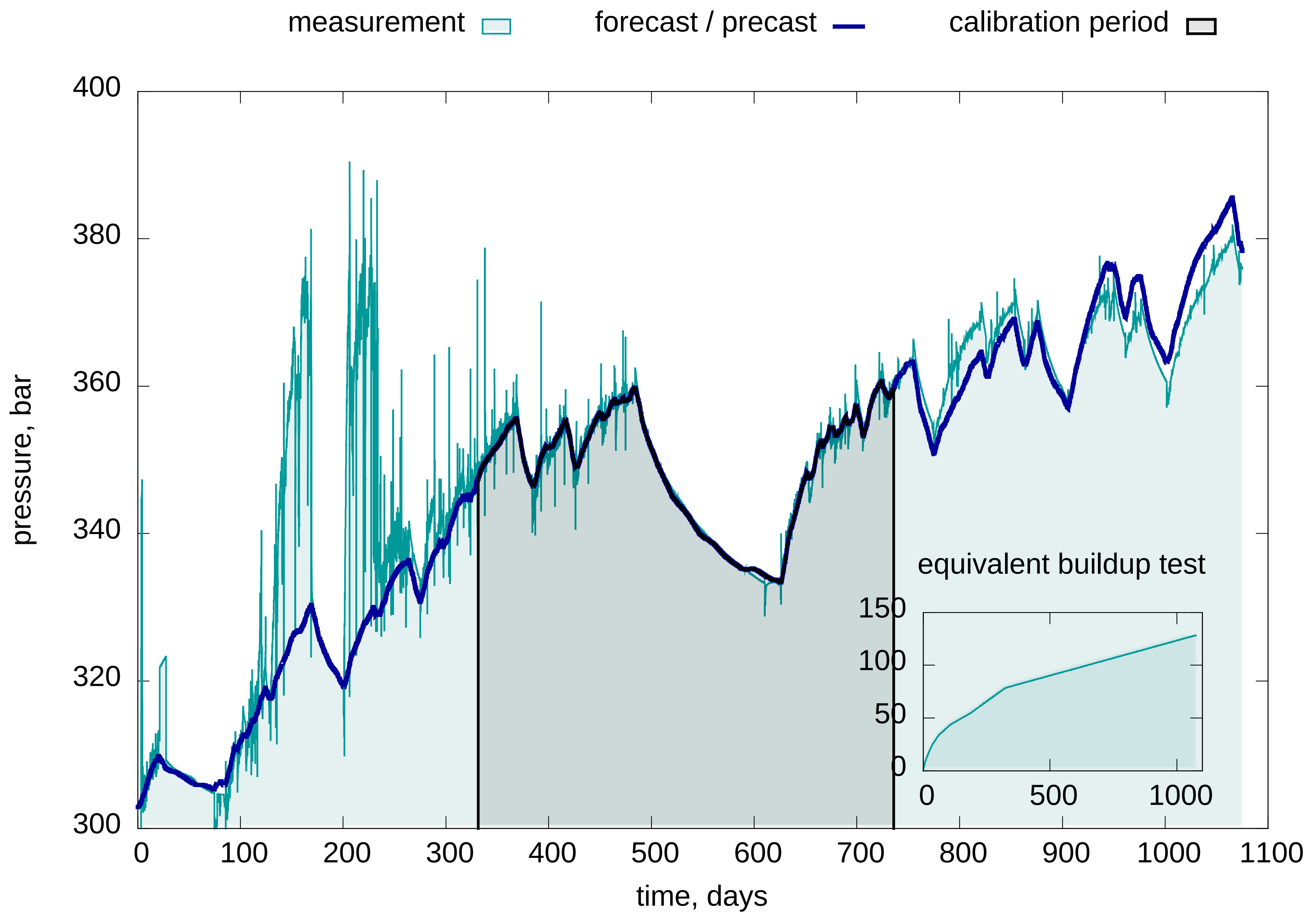
Fast-running pressure forecasting



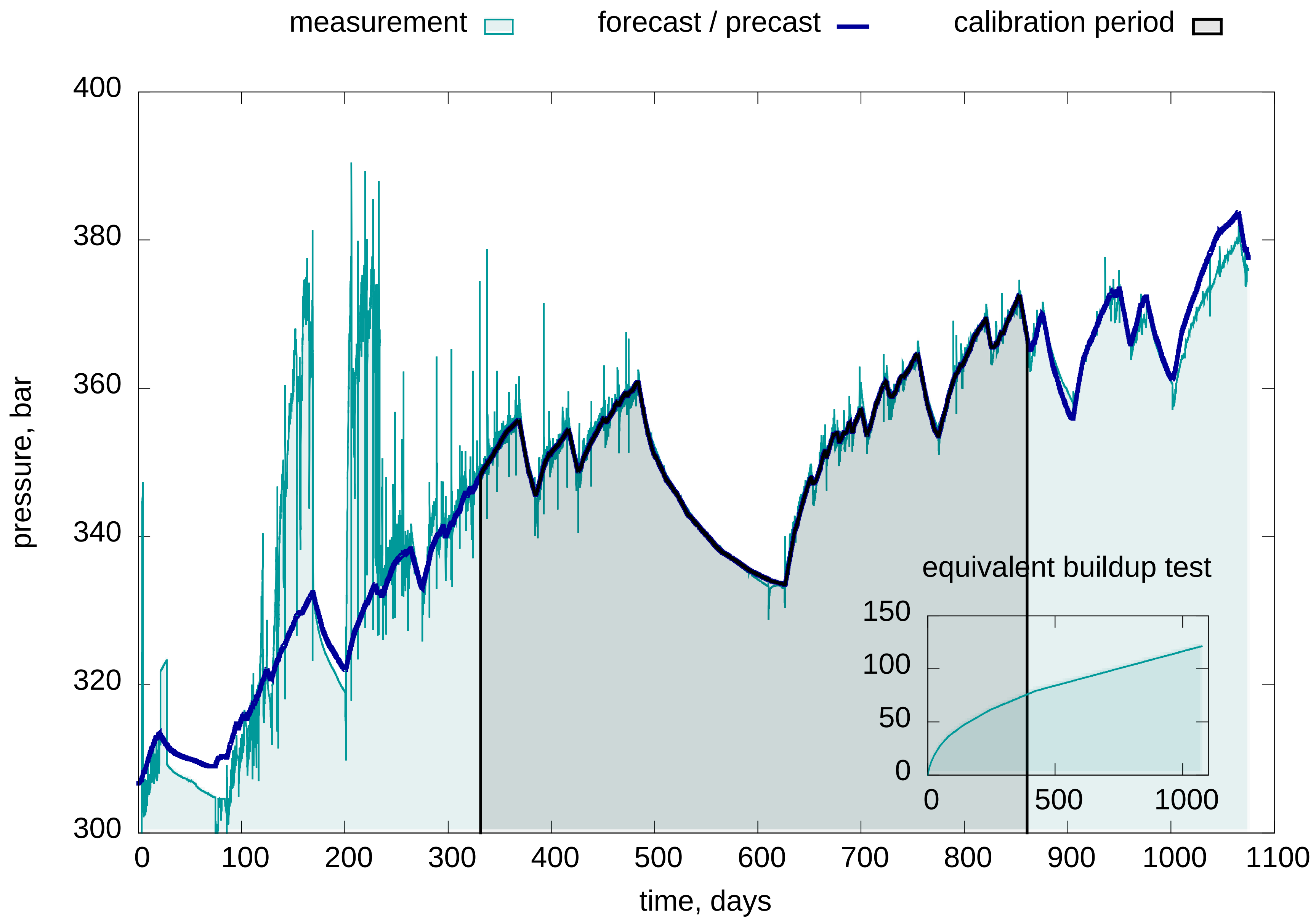
Fast-running pressure forecasting



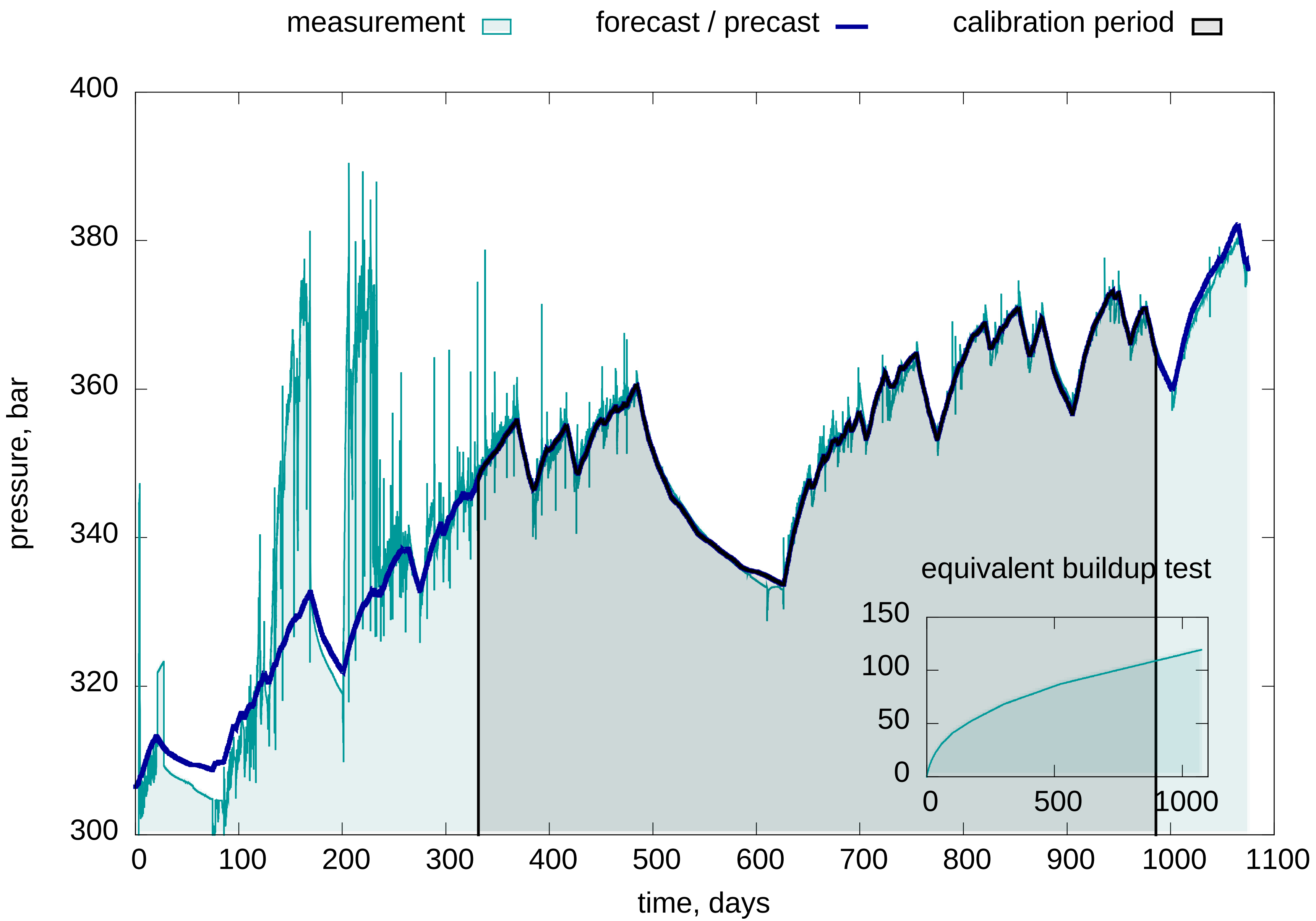
Fast-running pressure forecasting



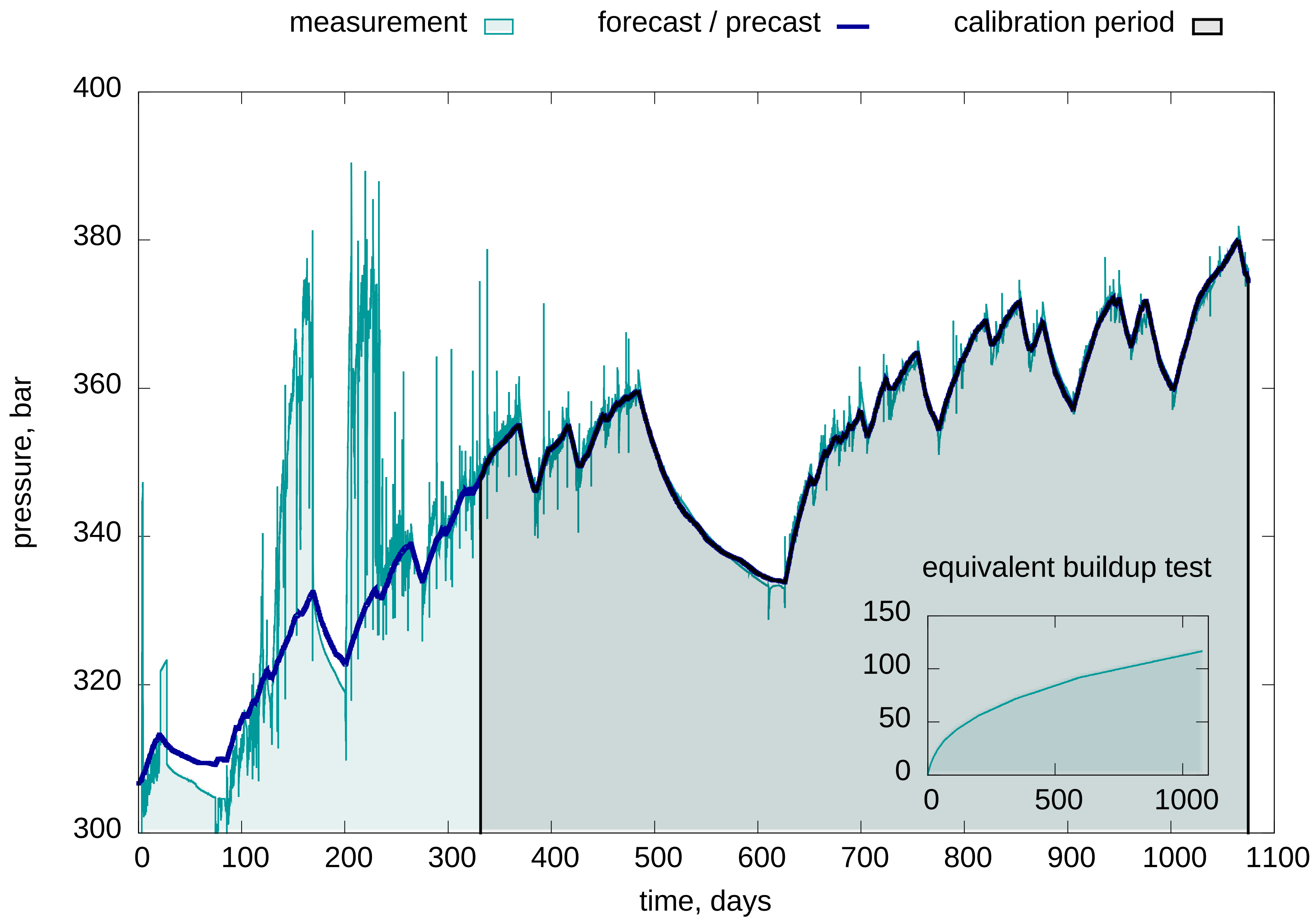
Fast-running pressure forecasting



Fast-running pressure forecasting



Fast-running pressure forecasting



Accomplishments to date

We have demonstrated the utility of several techniques

1. Pre-production of brine as an alternative to co-production in an active pressure management scheme.

2. Dynamic welltest analysis, in which ongoing injection data is used to probe reservoir properties without shutting in the well.

Future plans

① Implementing pressure analysis algorithms in an open-source toolkit, freely available to interested parties.

- Also including multi-well analyses, to look at pressure & poroelastic interactions between wells.

② Testing the effectivness of pressure management in “open” reservoirs where fluid recharge may impact drawdown effectiveness.

Synergistic Opportunities

We are always looking for opportunities to partner with industrial operations.

Goal is always to provide a two-way benefit:

① We validate our tools on real field data, and ensure they are relevant for high-priority operational decisions.

② We provide back novel analyses and insights useful for an operator.

Acknowledgements

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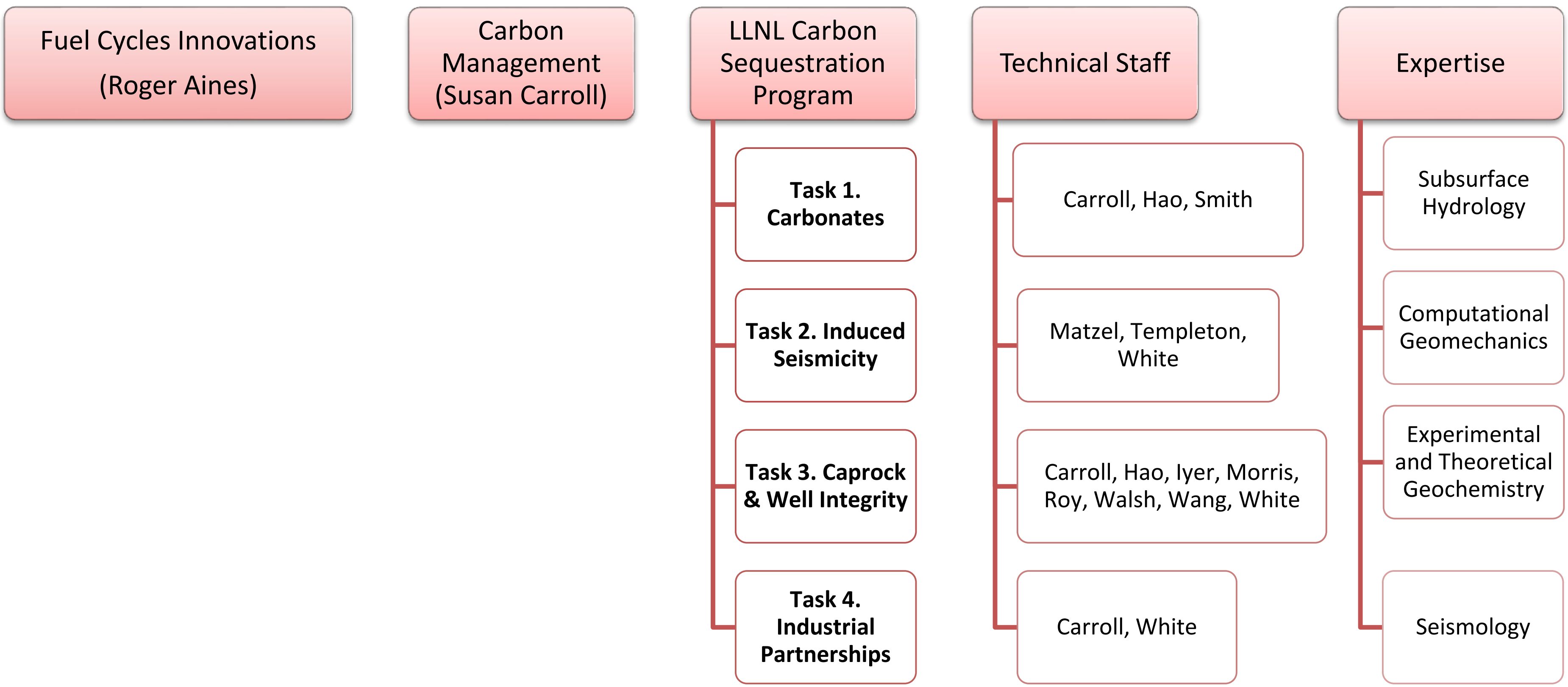
Appendix: Program Management

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

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- T.A. Buscheck, J.A. White, S.A. Carroll, J.M. Bielicki, and R.D. Aines. Managing geologic CO_2 storage with pre-injection brine production: A strategy evaluated with a model of CO_2 injection at Snøhvit. *Energy & Environmental Science*. DOI: 10.1039/C5EE03648H, 2016.

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