

DTU



Tobias K. S. Ritschel
Assistant Professor (tenure track)
Department of Applied Mathematics and Computer Science
Technical University of Denmark

Process control and optimization with stochastic adaptive control algorithms

17.30 – 17.50, Monday, June 12th, 2023
CERE Discussion Meeting
Hotel Marienlyst, Helsingør, Denmark

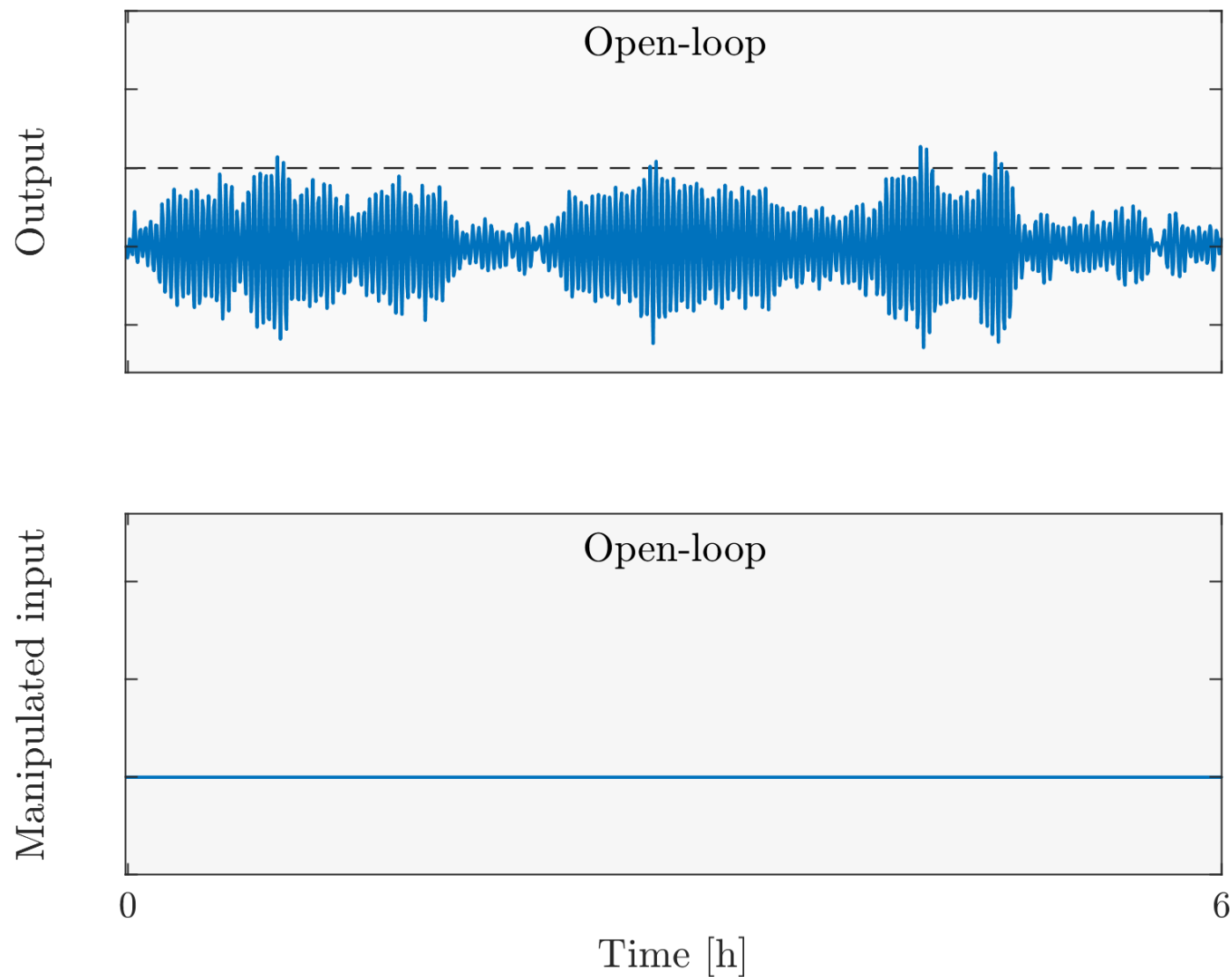
What does adaptivity mean?

What is stochastic adaptive control?

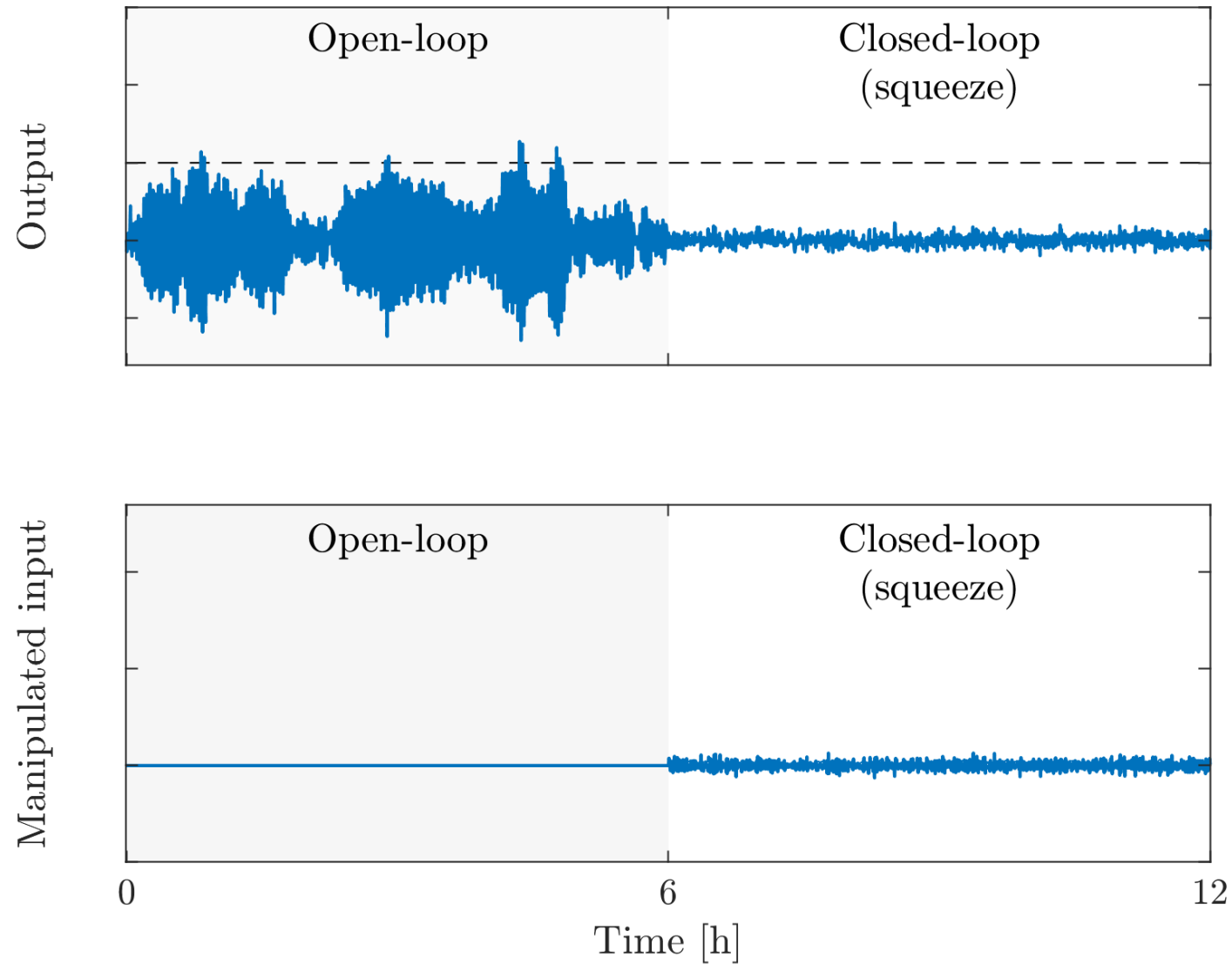
**What does it have to do
with reservoir engineering?**

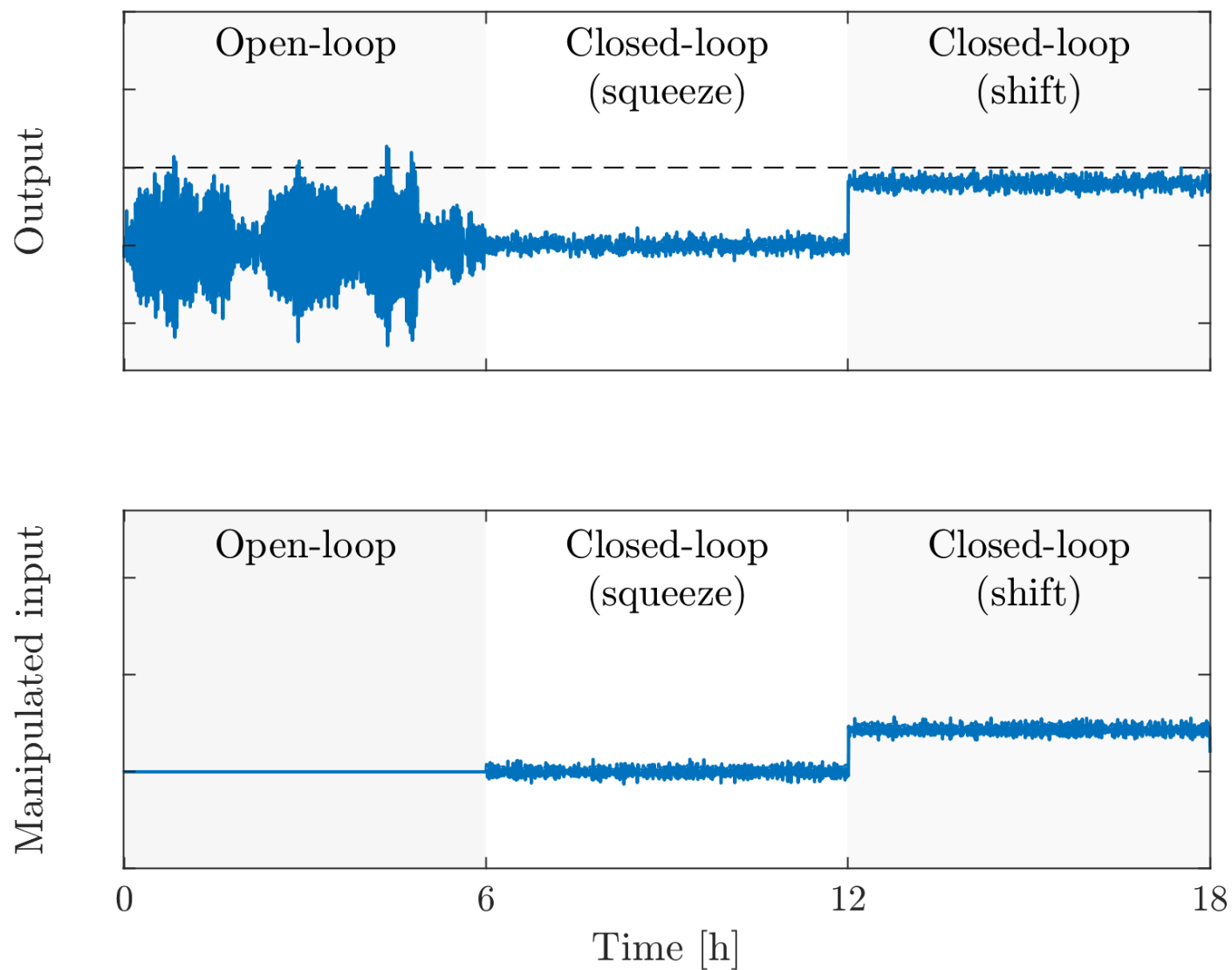
What does adaptivity mean?

Open-loop (no process control)

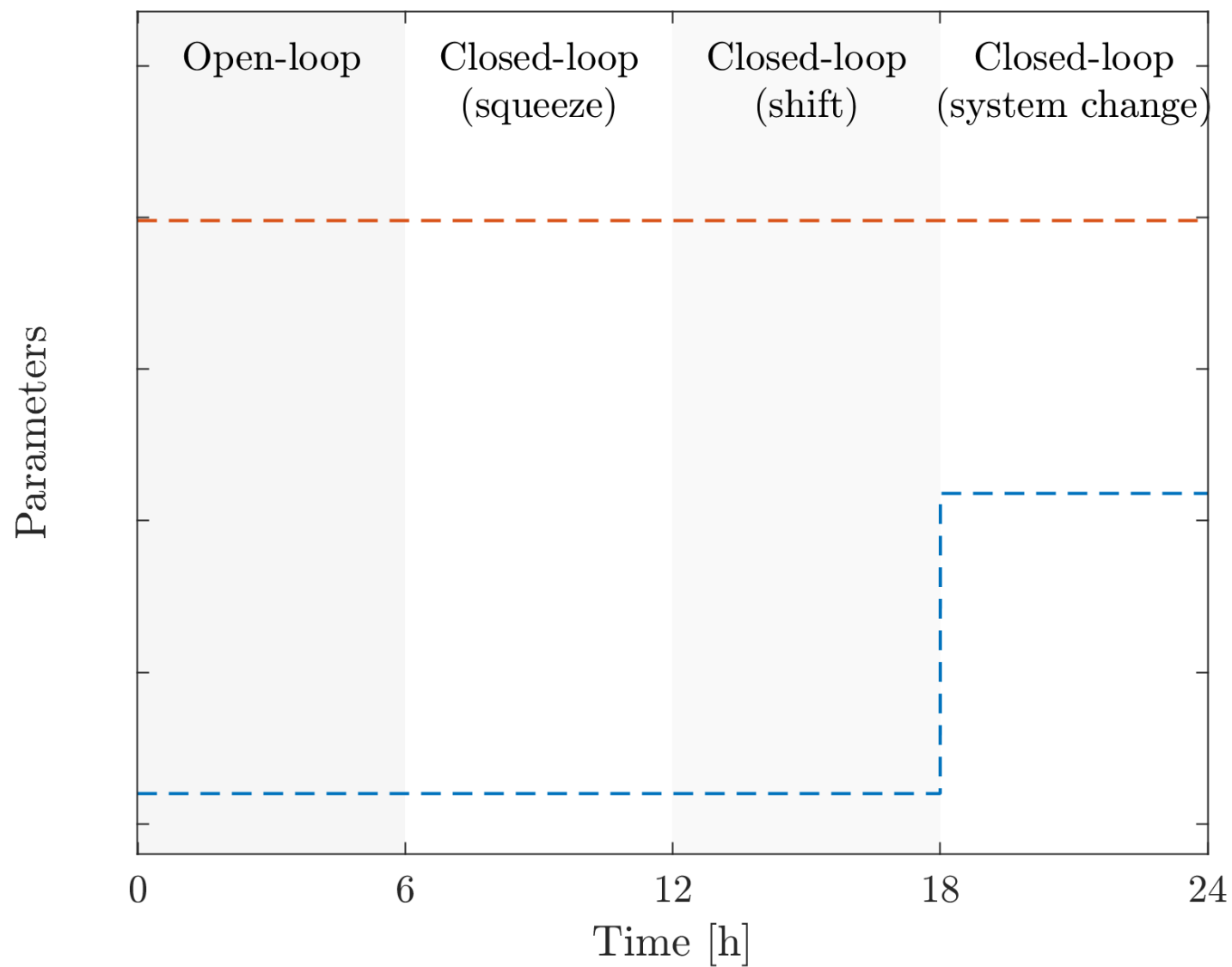


Squeeze

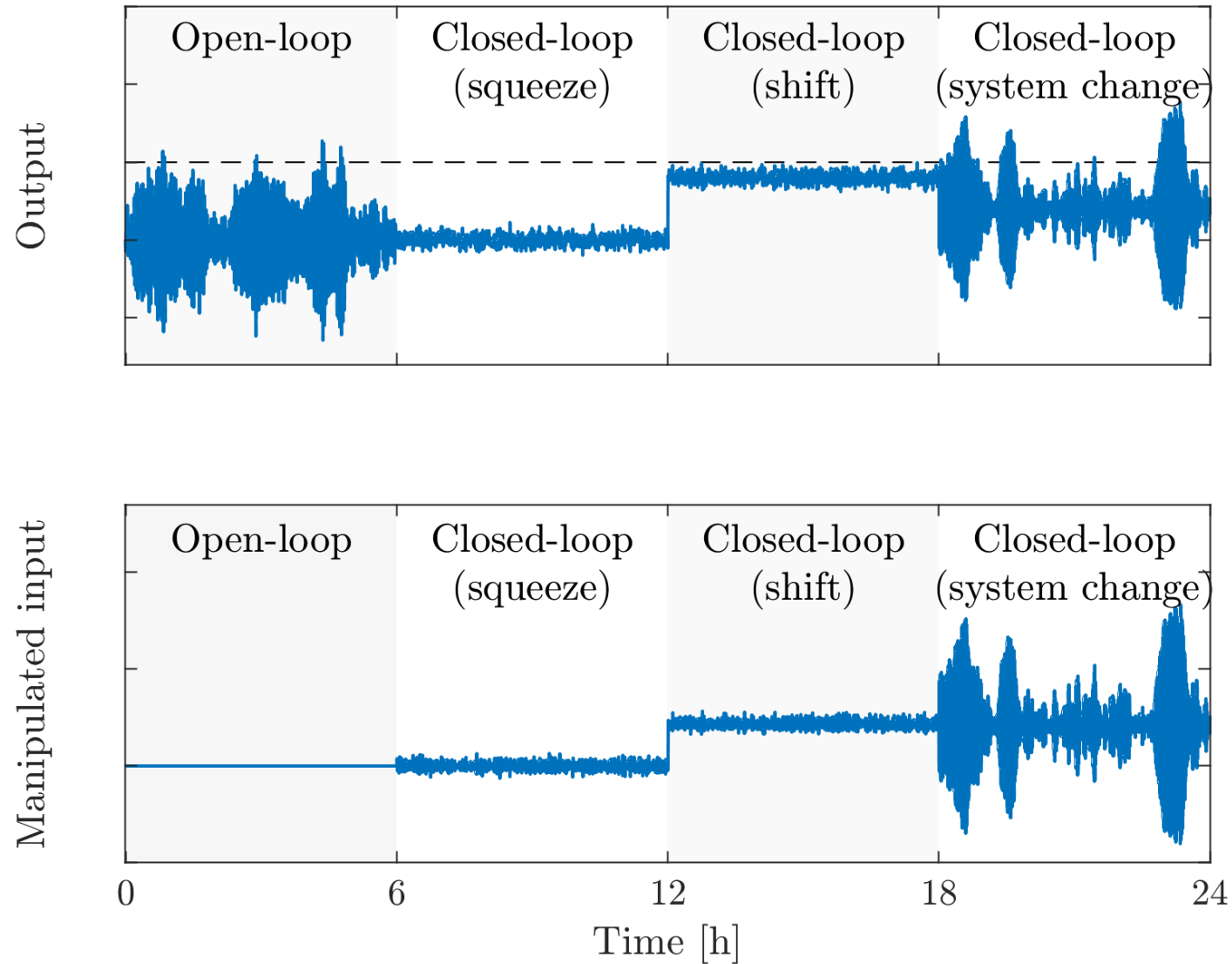


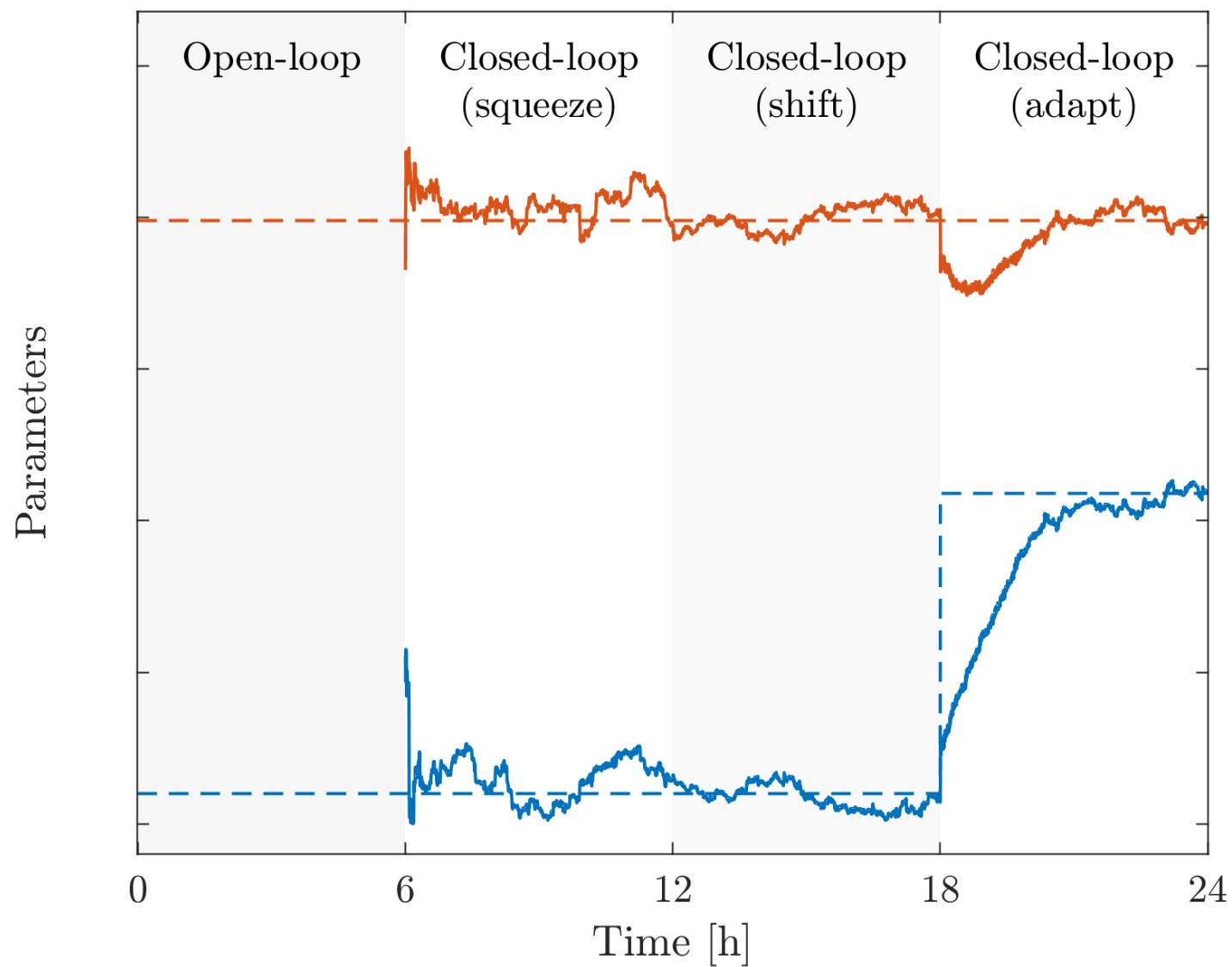


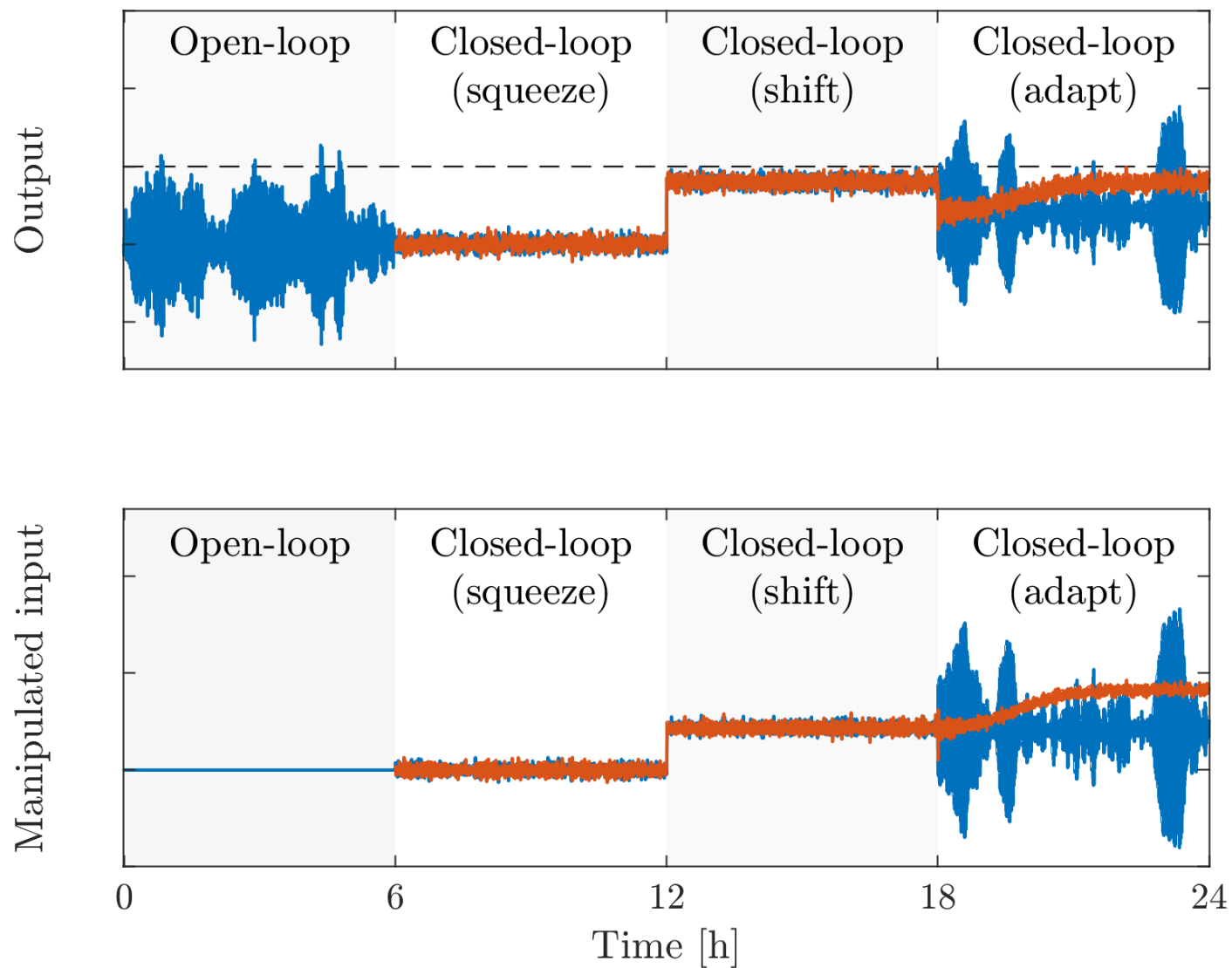
System change



System change





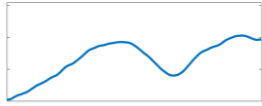


Subproblems in stochastic adaptive control and relation to reservoir engineering

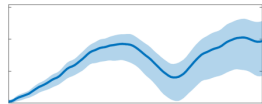
Uncertainty

Uncertainty modeling

$$\dot{x} = f(x, u, d, p)$$



$$dx = f(x, u, d, p)dt + \sigma(x, u, d, p)dw$$

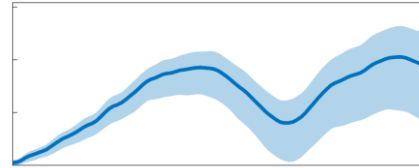


Examples of uncertainty:

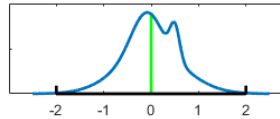
- permeabilities (*parameters, p*)
- Injection/borehole completion (*manipulated inputs, u*)
- aquifer support/water drive (*disturbances, d*)

Uncertainty quantification (UQ)

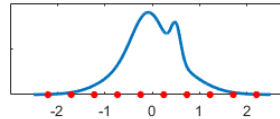
- predict by stochastic simulation



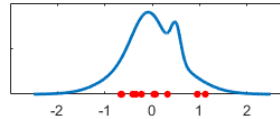
Linearization



Unscented transformation



Monte Carlo simulation



Examples of UQ:

- CO₂ plume location
- Risk/amount of CO₂ leaks
- Residual/structural trapping

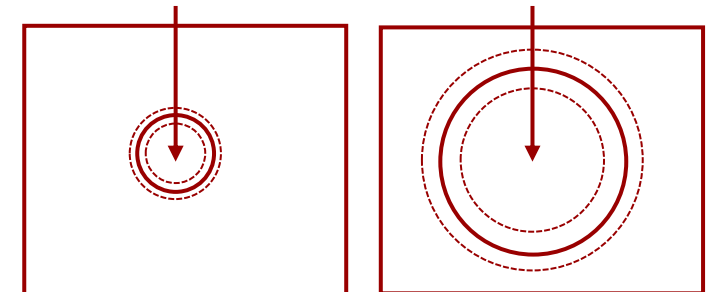
State estimation

- Integrate UQ and measurements

$$dx = f(x, u, d, p)dt + \sigma(x, u, d, p)dw$$

$$y(t_k) = g(x(t_k), p) + v_k$$

For transport processes,
uncertainty grows over time



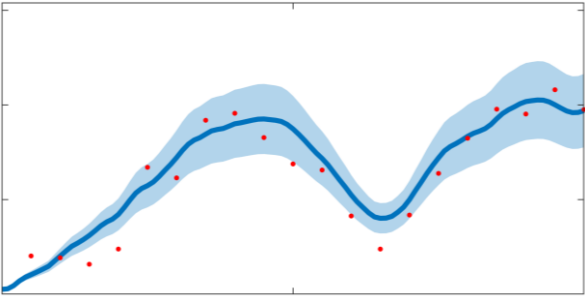
- Extended, unscented, and ensemble Kalman filters + particle filters

Adaptivity

Parameter estimation

$$dx = f(x, u, d, p)dt + \sigma(x, u, d, p)dw$$

$$y(t_k) = g(x(t_k), p) + v_k$$

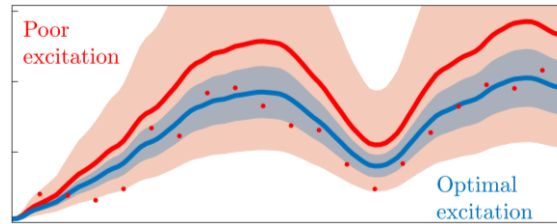
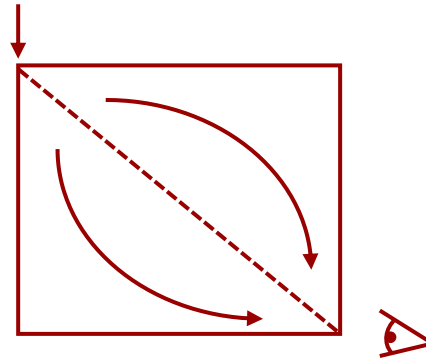


Examples:

- permeabilities (*parameters, p*)
- aquifer support/water drive (*disturbances, d*)
- uncertainty parameters (*diffusion coefficient, σ*)

Optimal experiment design

- generate informative data

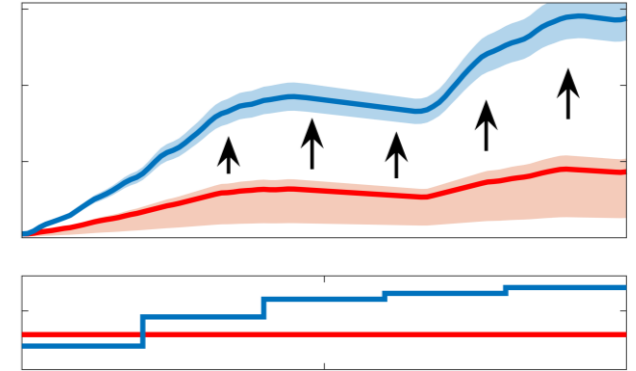


Examples:

- injection schedule (*manipulated inputs, u*)
- well placement (*parameters, p*)

Optimization under uncertainty

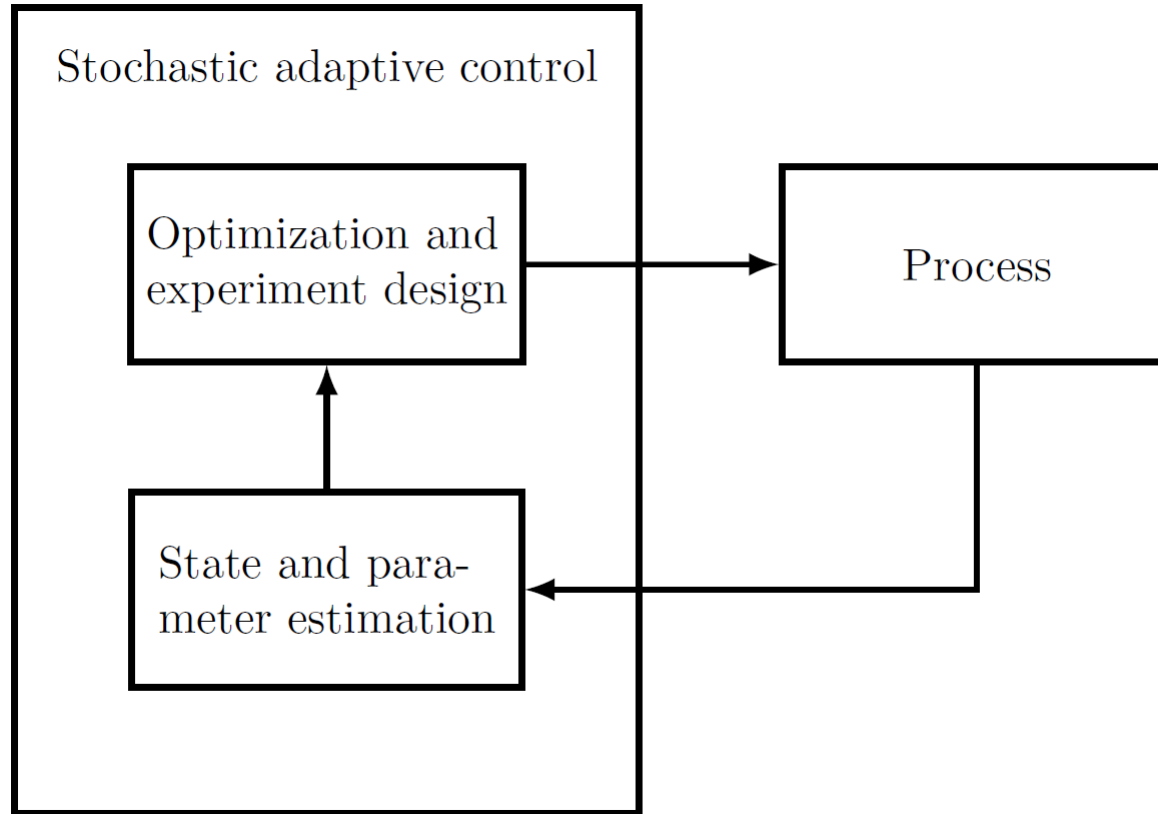
- *max. profit + min. uncertainty*



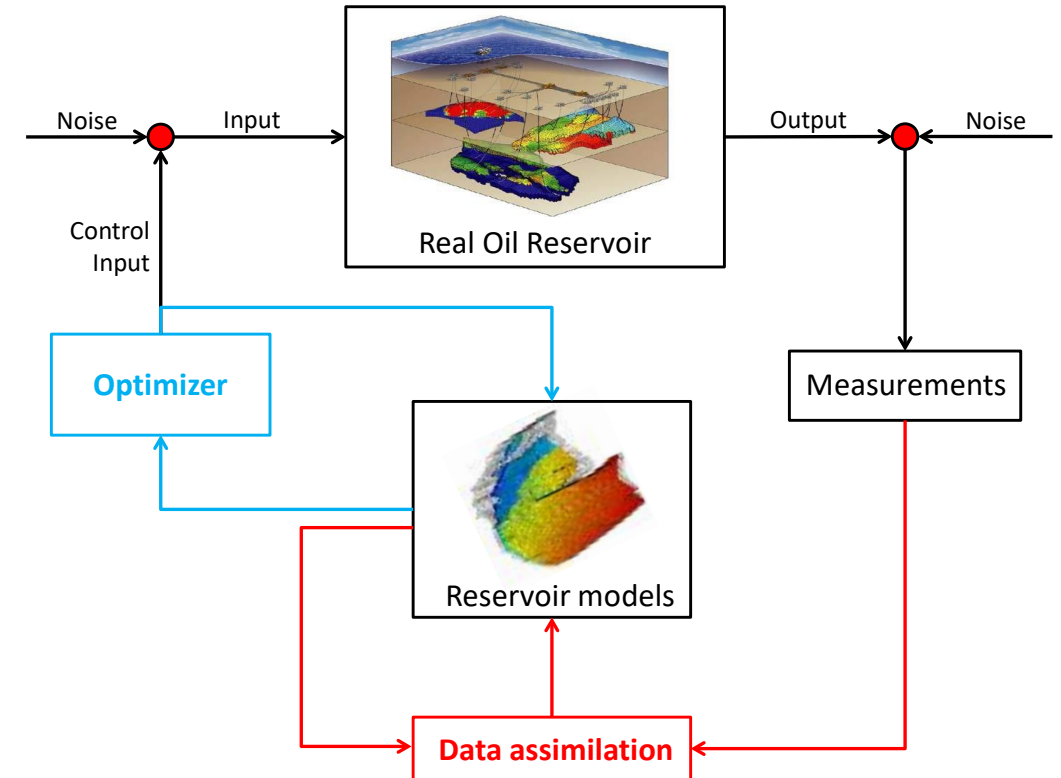
Examples of optimization:

- Maximize CO₂ storage
- Minimize CO₂ leaks
- Max. residual + min. structural trapping

Stochastic adaptive control



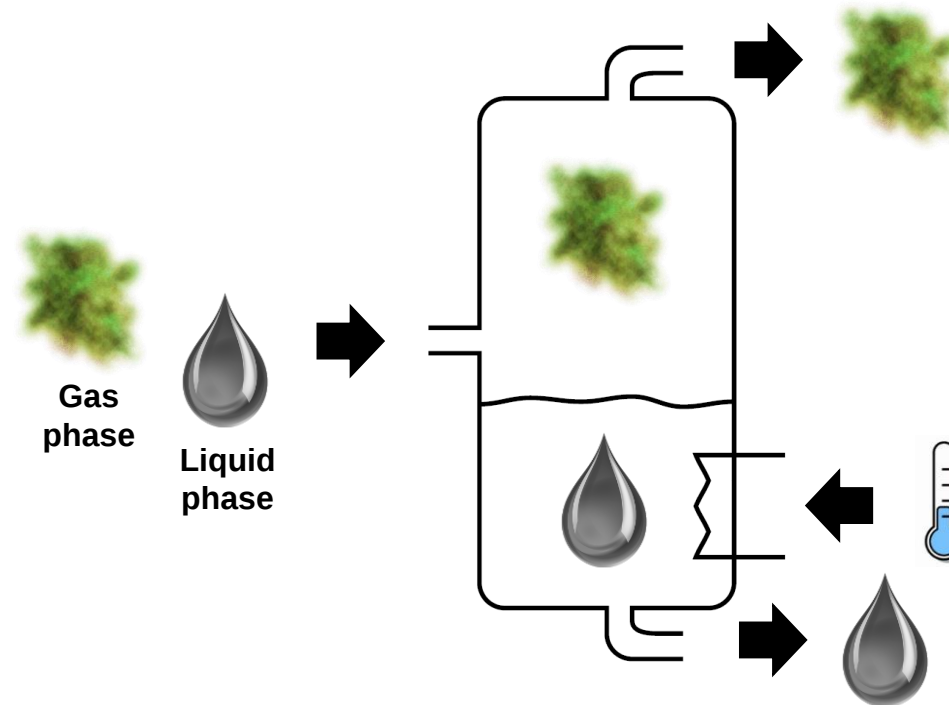
Closed-loop reservoir management (CLRM)



Flash separator example (UV flash)

Details

- 8 h of operation
- Measure temperature and pressure every 5. min
- Minimize energy consumption
- Upper bound on H_2S vapor mole fraction (2%)
- Upper bound on pressure (7.5 MPa)
- Unknown feed temperature increase of 5 K after 2 h
- Adaptive nonlinear model predictive control algorithm

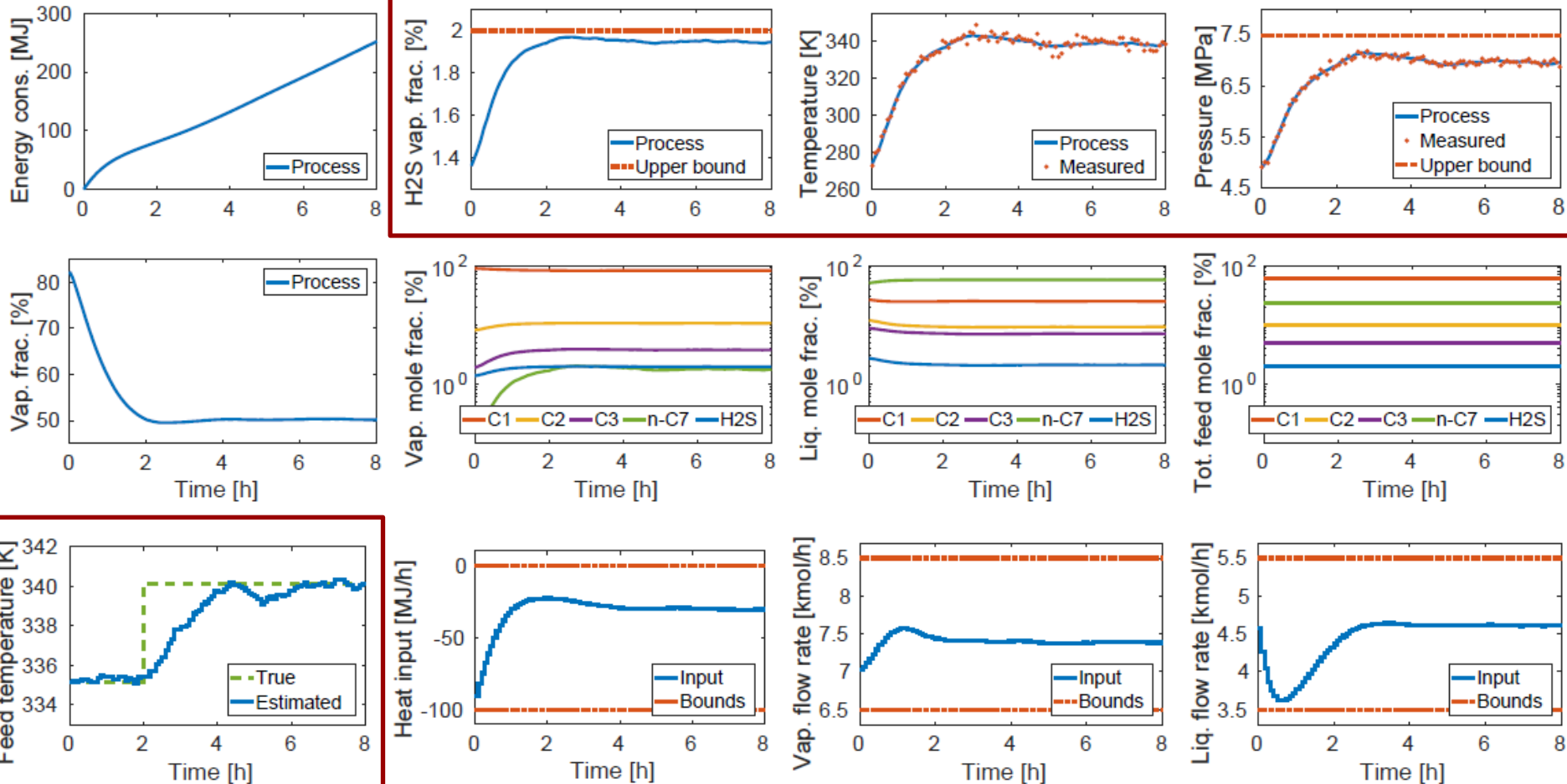


Feed (1 kmol/h)

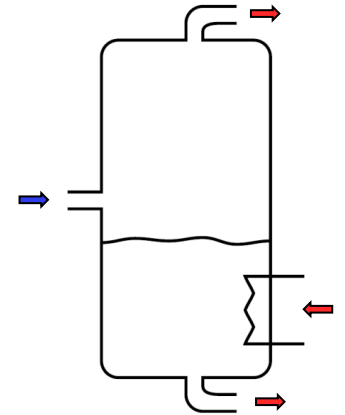
Composition:

C_1	60%
C_2	10%
C_3	5%
n-C ₇	23%
H_2S	2%

Flash separation example

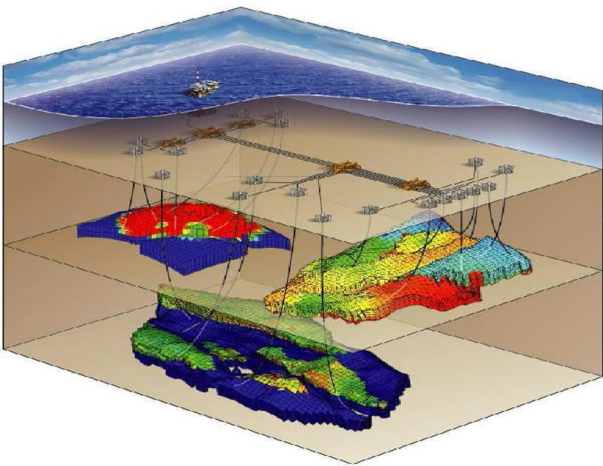


- Minimize heat input
- Satisfy bounds
- Estimate feed temperature

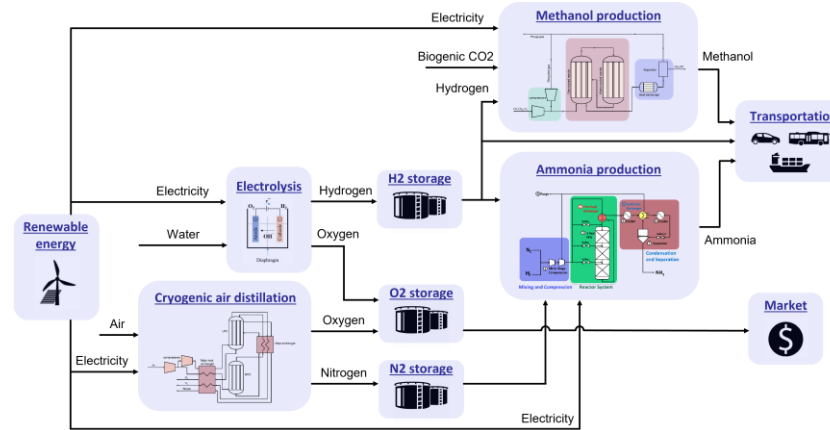


Other processes I aim to work with

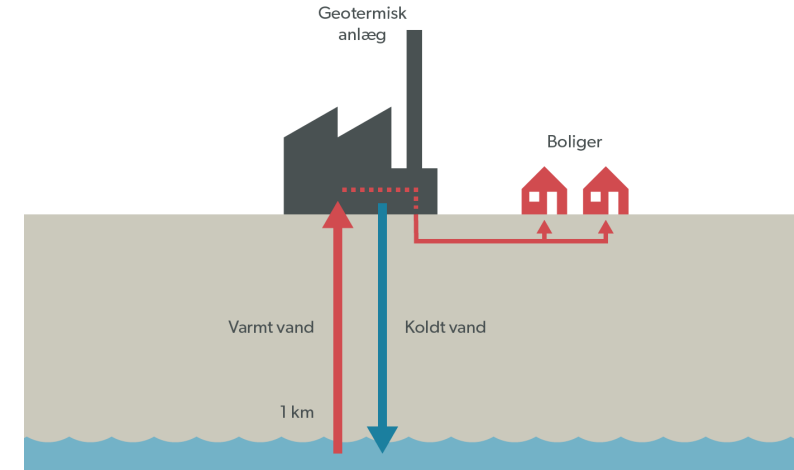
CO₂ storage



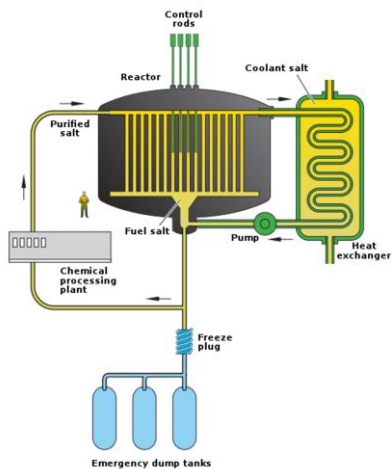
Power-to-X



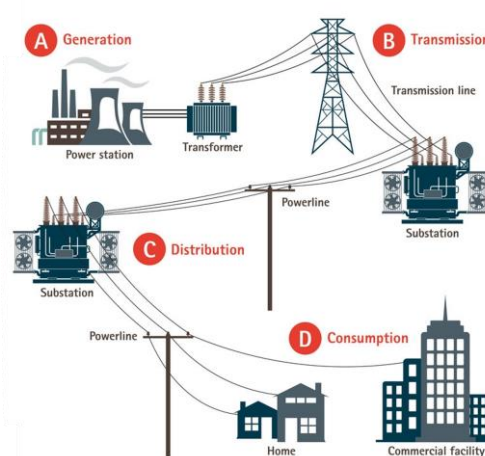
Geothermal energy



Nuclear power



Power grids



Thermal storage



Summary

Squeeze-shift-adapt

Stochastic adaptive control in reservoir engineering: Quantify and mitigate risk

**Numerical example of flash separation
w. unknown feed temperature change**

Thank you