DTU

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Process control and optimization with stochastic adaptive control algorithms

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

Overview

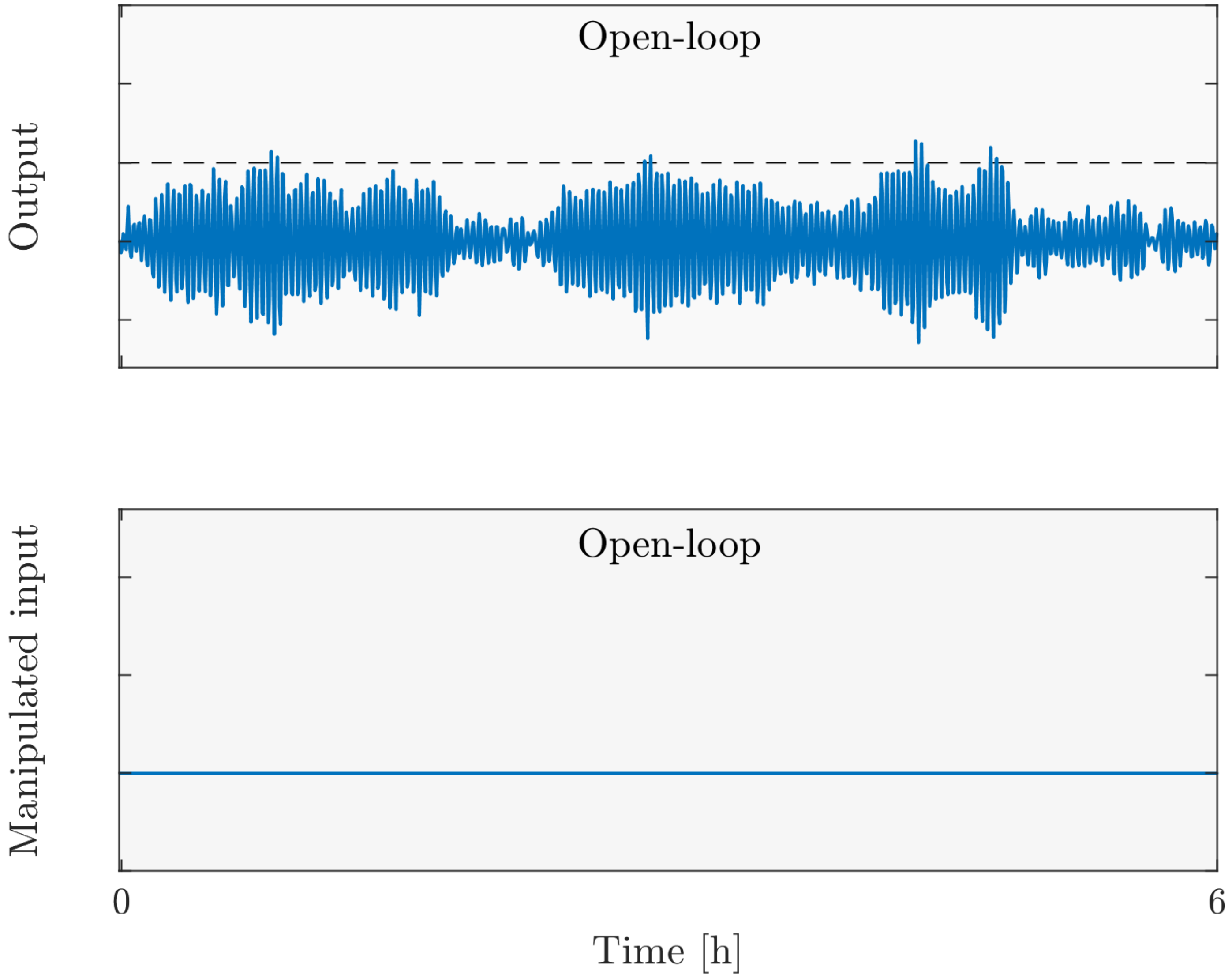
What does adaptivity mean?

What is stochastic adaptive control?

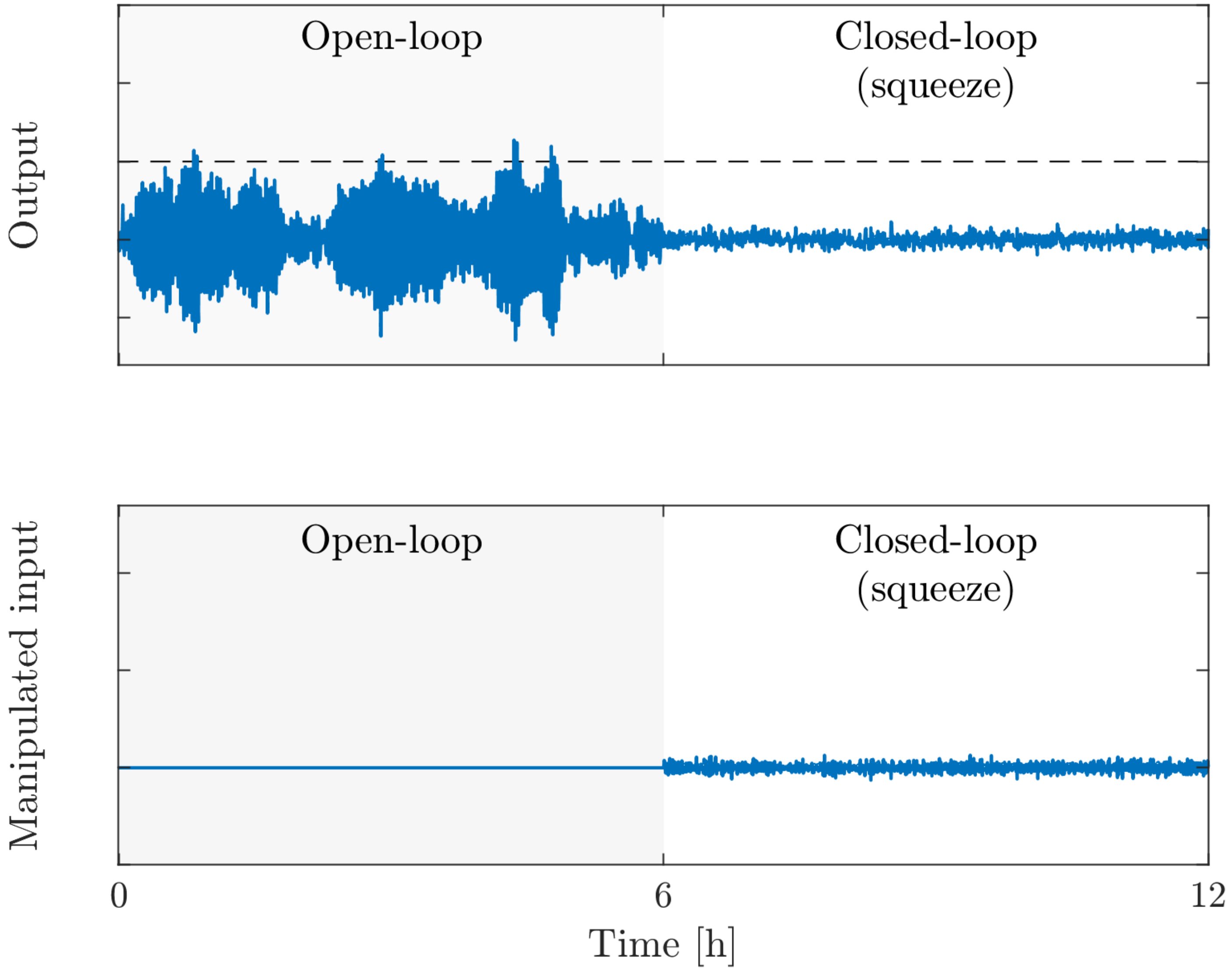
What does it have to do with reservoir engineering?

What does adaptivity mean?

Open-loop (no process control)

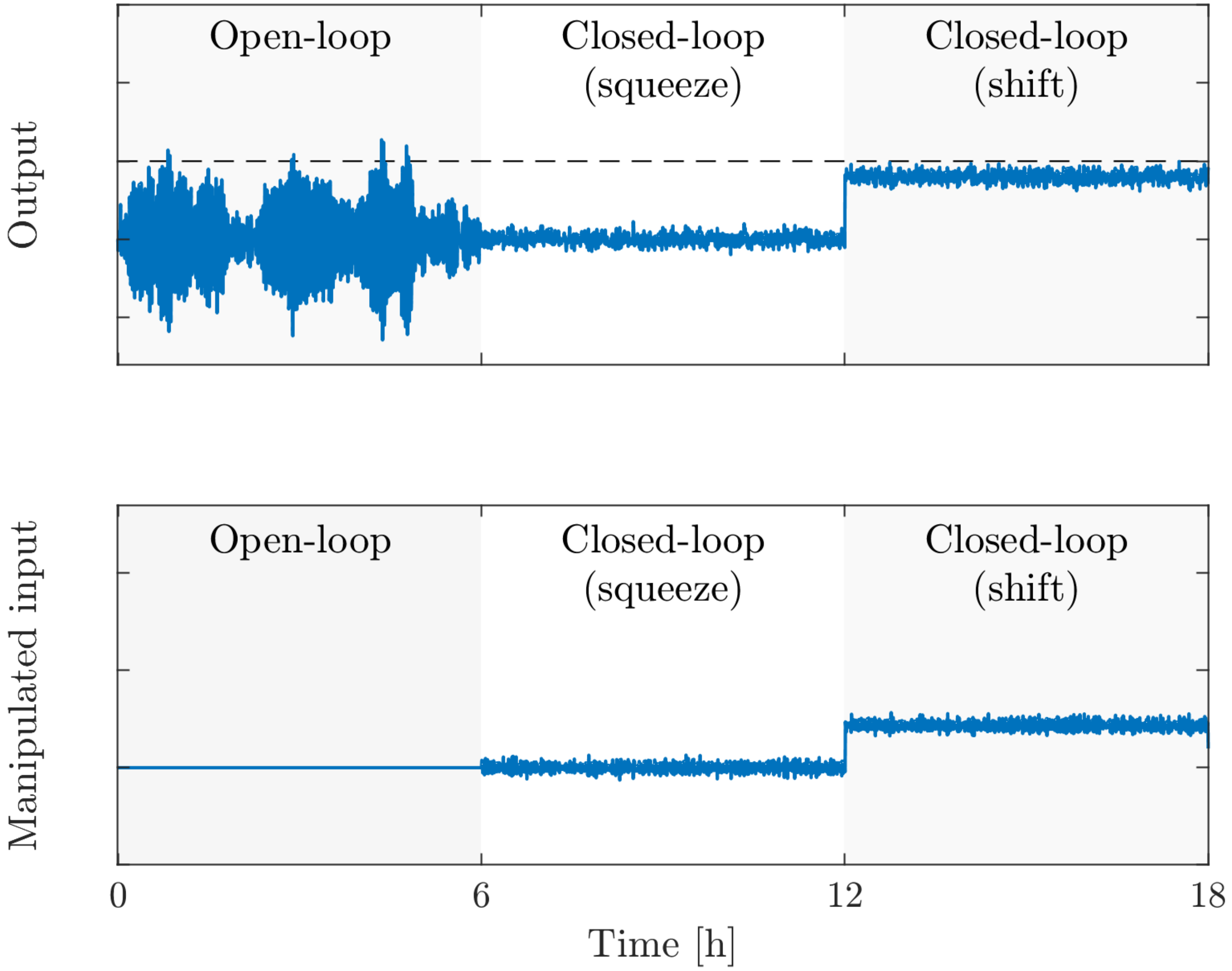


Squeeze



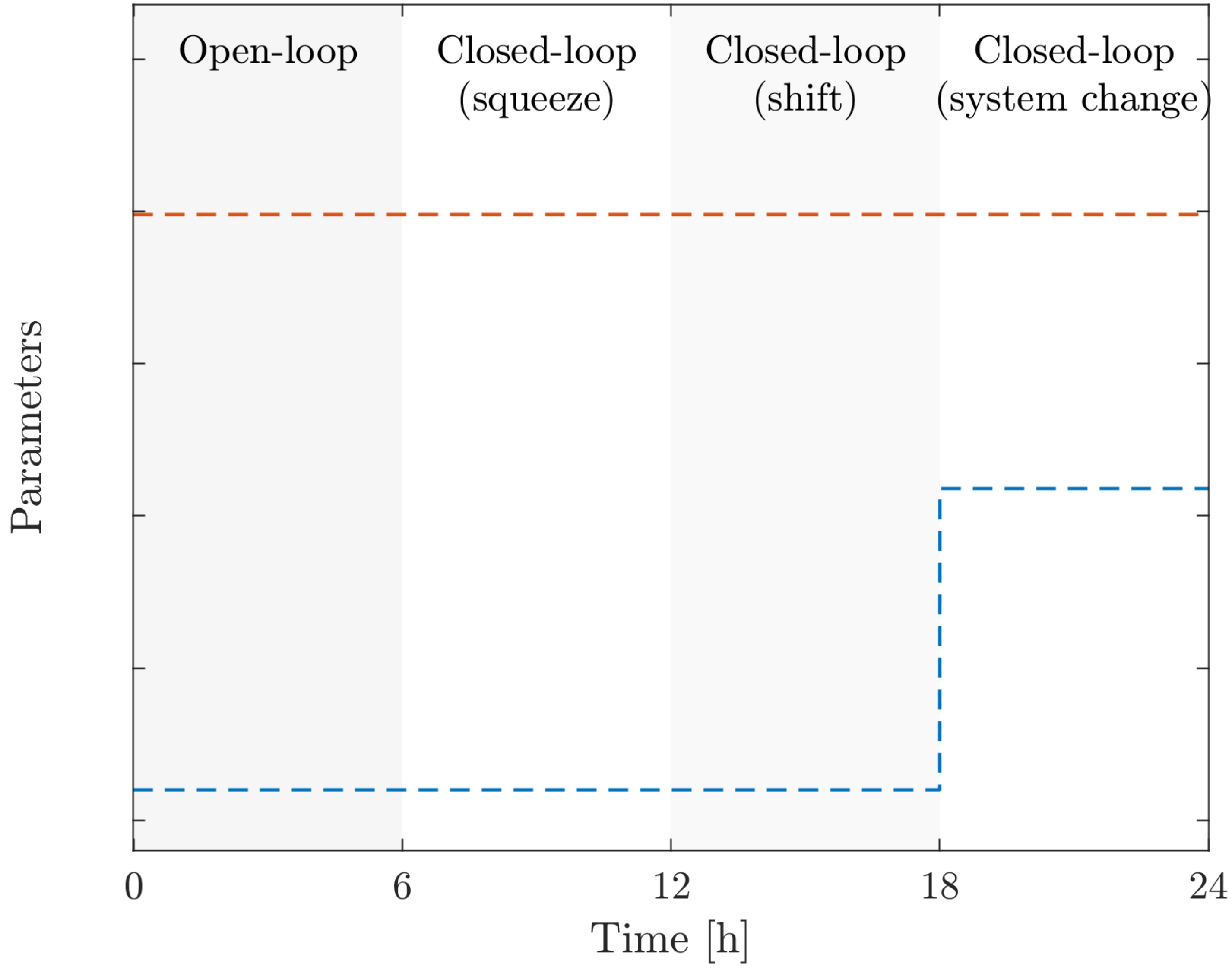
Open-loop
Closed-loop
(squeeze)
Output
Open-loop
Closed-loop
(squeeze)
Manipulated input
0
6
12
Time [h]

Shift

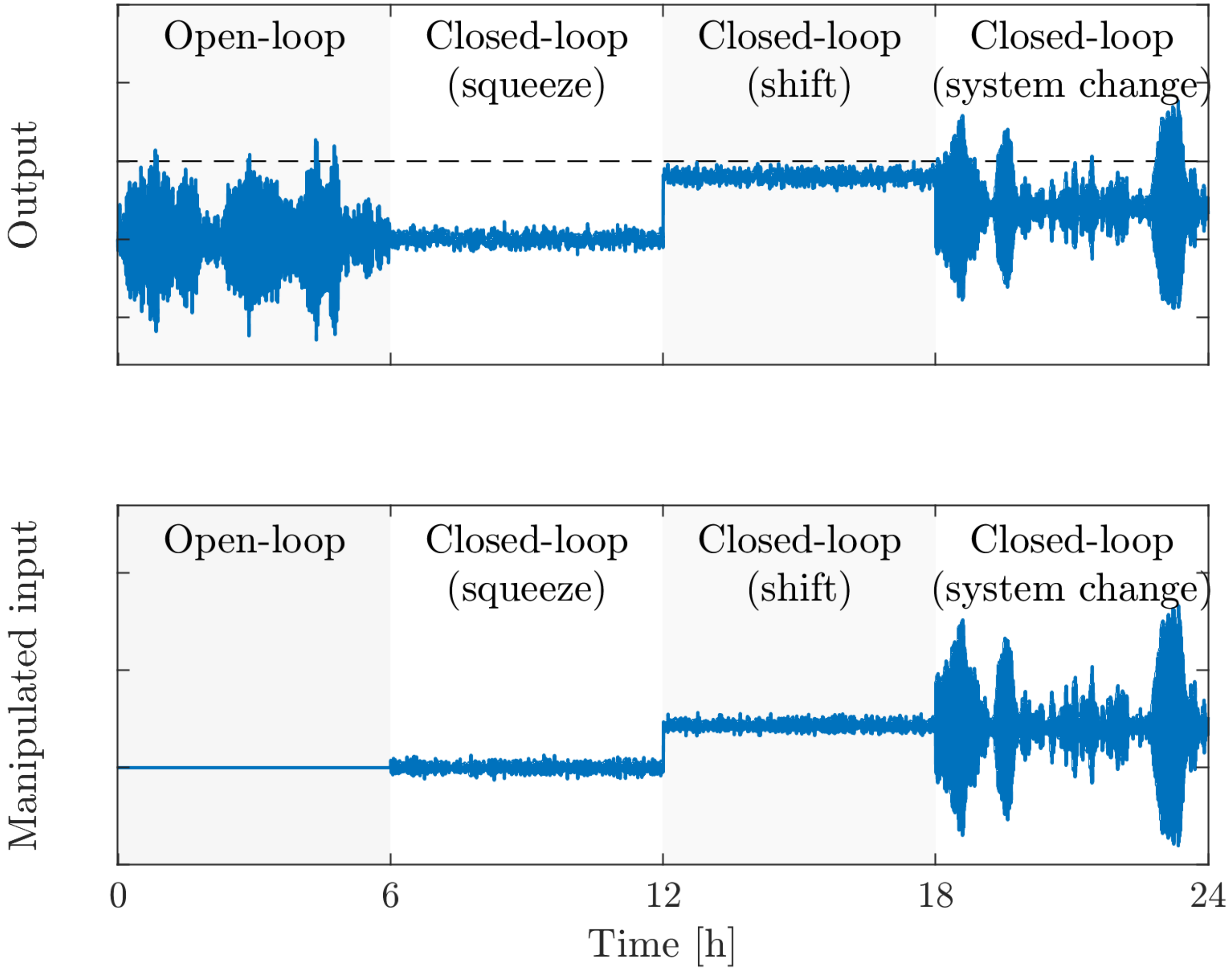


Open-loop
Closed-loop (squeeze)
Closed-loop (shift)
Output
Open-loop
Closed-loop (squeeze)
Closed-loop (shift)
Manipulated input
0
6
12
18
Time [h]

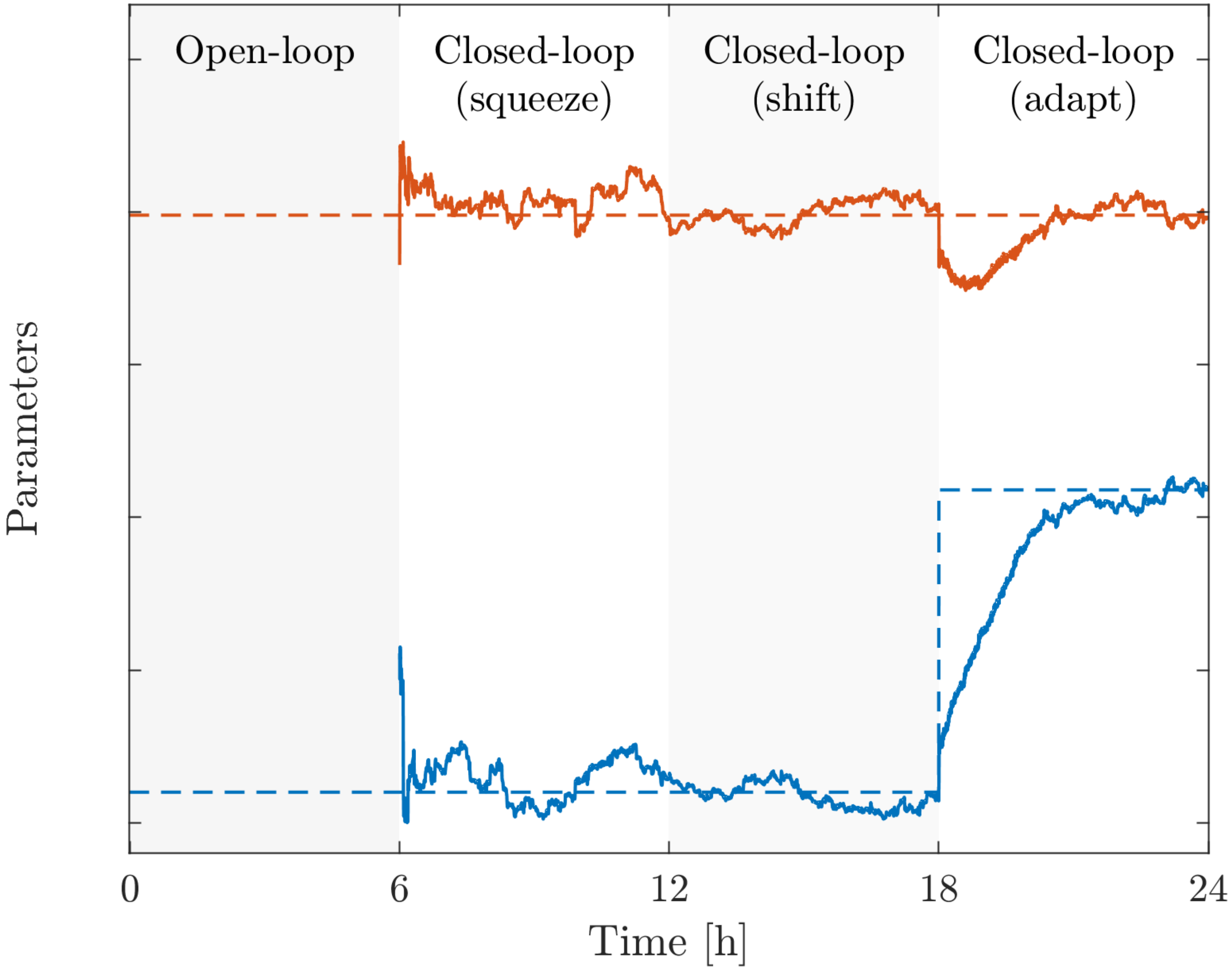
System change



System change

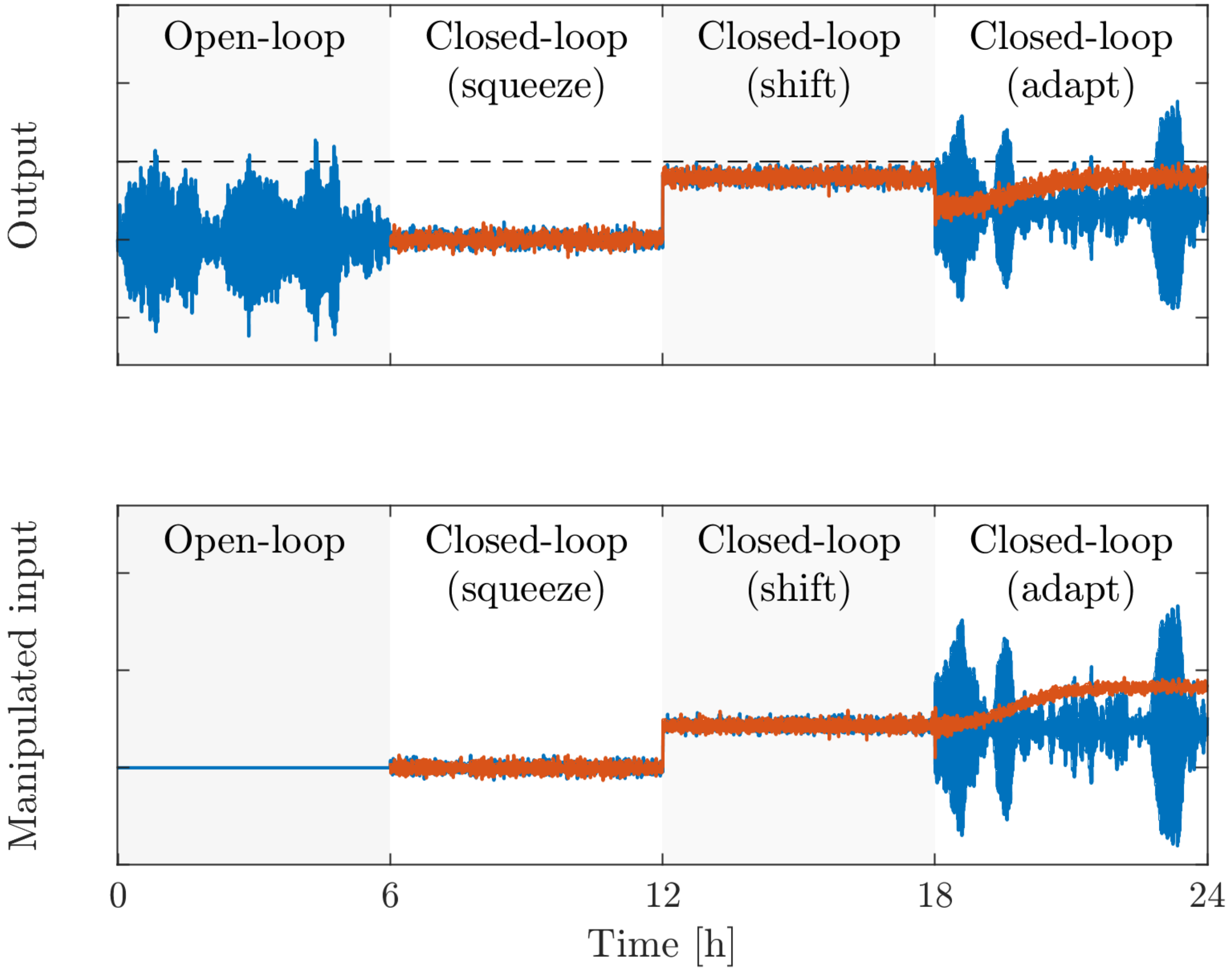


Adapt



Open-loop
Closed-loop (squeeze)
Closed-loop (shift)
Closed-loop (adapt)
Parameters
0
6
12
18
24
Time [h]

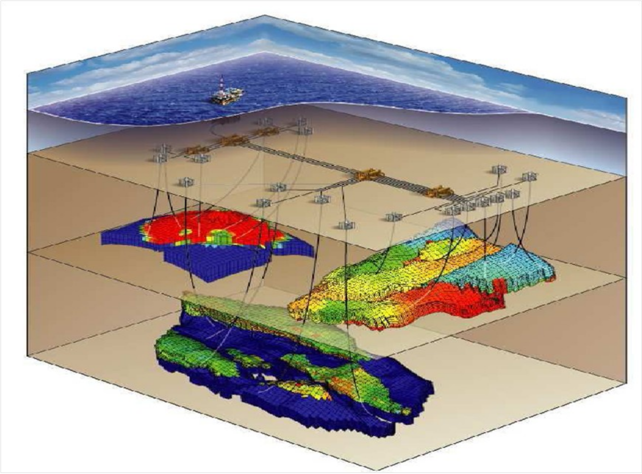
Adapt


Open-loop
Closed-loop (squeeze)
Closed-loop (shift)
Closed-loop (adapt)
Output
Open-loop
Closed-loop (squeeze)
Closed-loop (shift)
Closed-loop (adapt)
Manipulated input
0
6
12
18
24
Time [h]

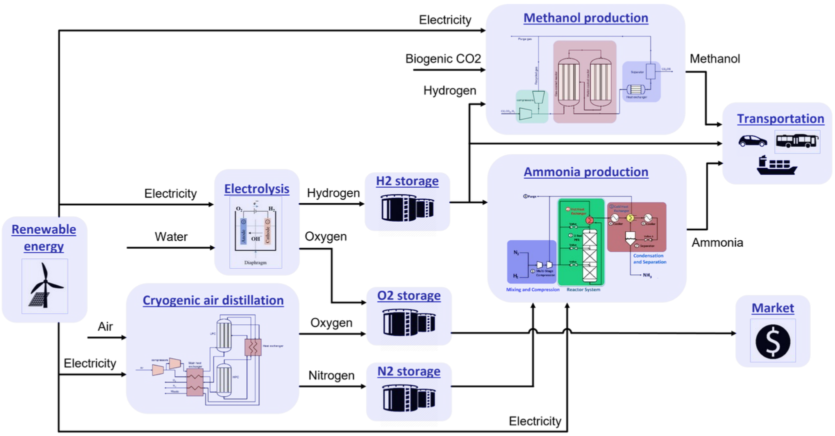
Subproblems in stochastic adaptive control and relation to reservoir engineering

Other processes I aim to work with

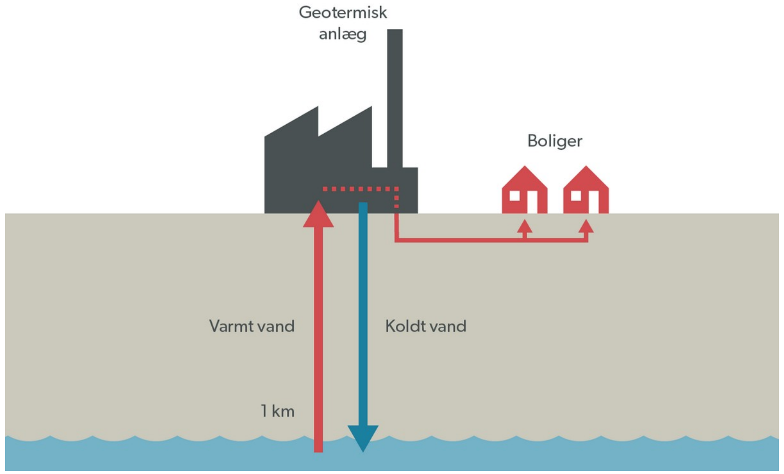
CO_2 storage



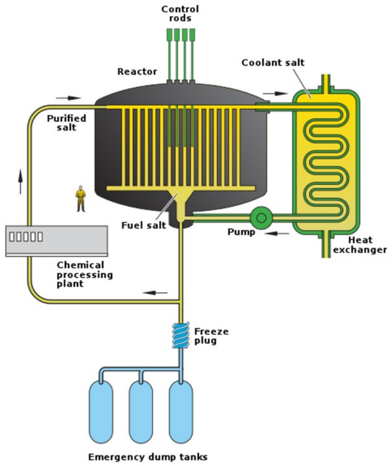
Power-to-X



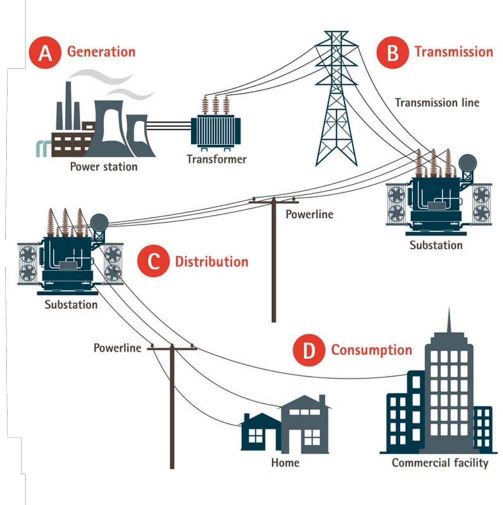
Geothermal energy



Nuclear power



Power grids

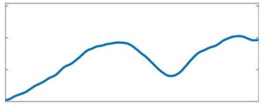


Thermal storage

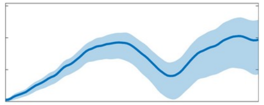
Uncertainty

Uncertainty modeling

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



$$\mathrm{d}x = f(x, u, d, p)\mathrm{d}t + \sigma(x, u, d, p)\mathrm{d}w$$

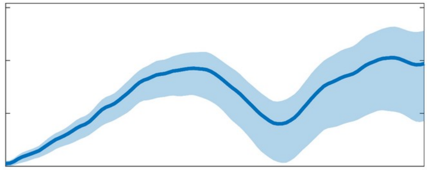


Examples of uncertainty:

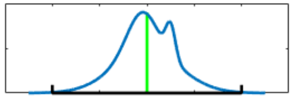
- **permeabilities (*parameters, p*)**
- **Injection/borehole completion (*manipulated inputs, u*)**
- **aquifer support/water drive (*disturbances, d*)**

Uncertainty quantification (UQ)

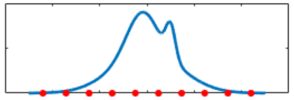
- predict by stochastic simulation



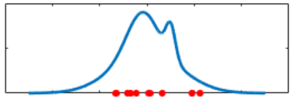
- **Linearization**



- **Unscented transformation**



- **Monte Carlo simulation**



Examples of UQ:

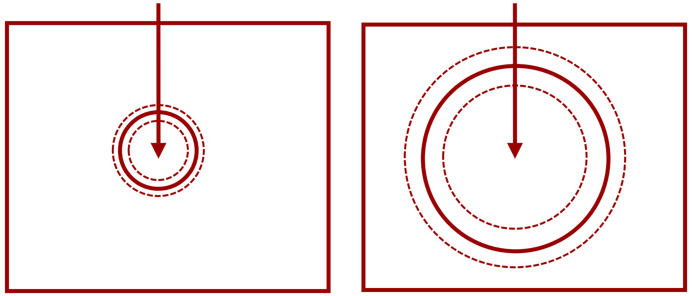
- **CO_2 plume location**
- **Risk/amount of CO_2 leaks**
- **Residual/structural trapping**

State estimation

- Integrate UQ and measurements

$$\mathrm{d}x = f(x, u, d, p)\mathrm{d}t + \sigma(x, u, d, p)\mathrm{d}w$$
$$y(t_k) = g(x(t_k), p) + v_k$$

For transport processes, uncertainty grows over time

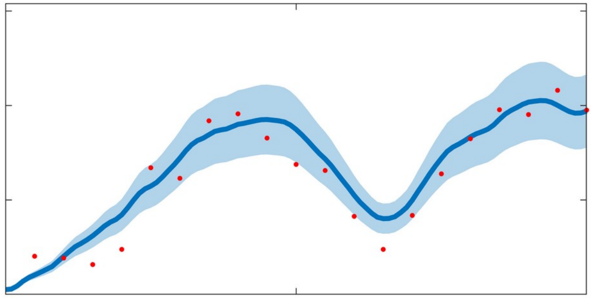


- **Extended, unscented, and ensemble Kalman filters + particle filters**

Adaptivity

Parameter estimation

$$\mathrm{d}x = f(x, u, d, p)\mathrm{d}t + \sigma(x, u, d, p)\mathrm{d}w$$
$$y(t_k) = g(x(t_k), p) + v_k$$

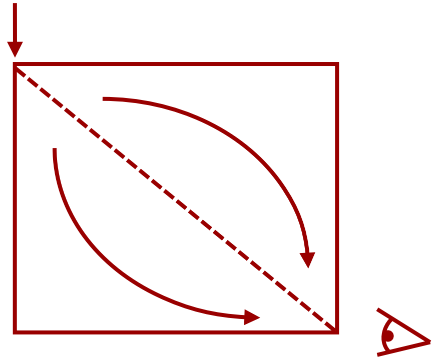


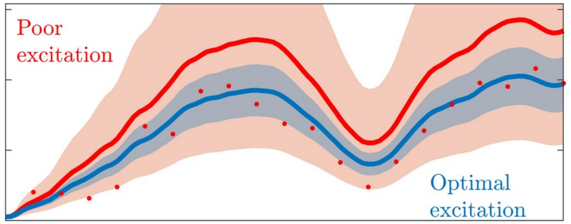
Examples:

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

Optimal experiment design

- generate informative data



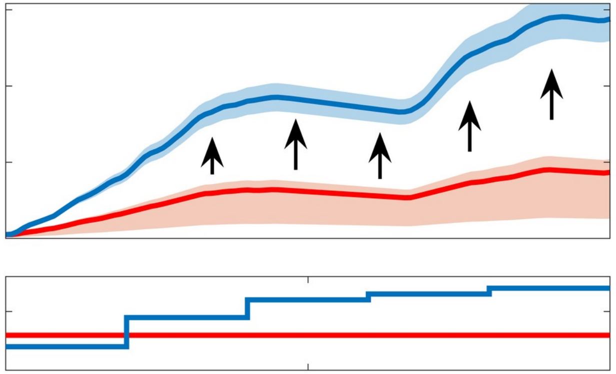


Examples:

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

Optimization under uncertainty

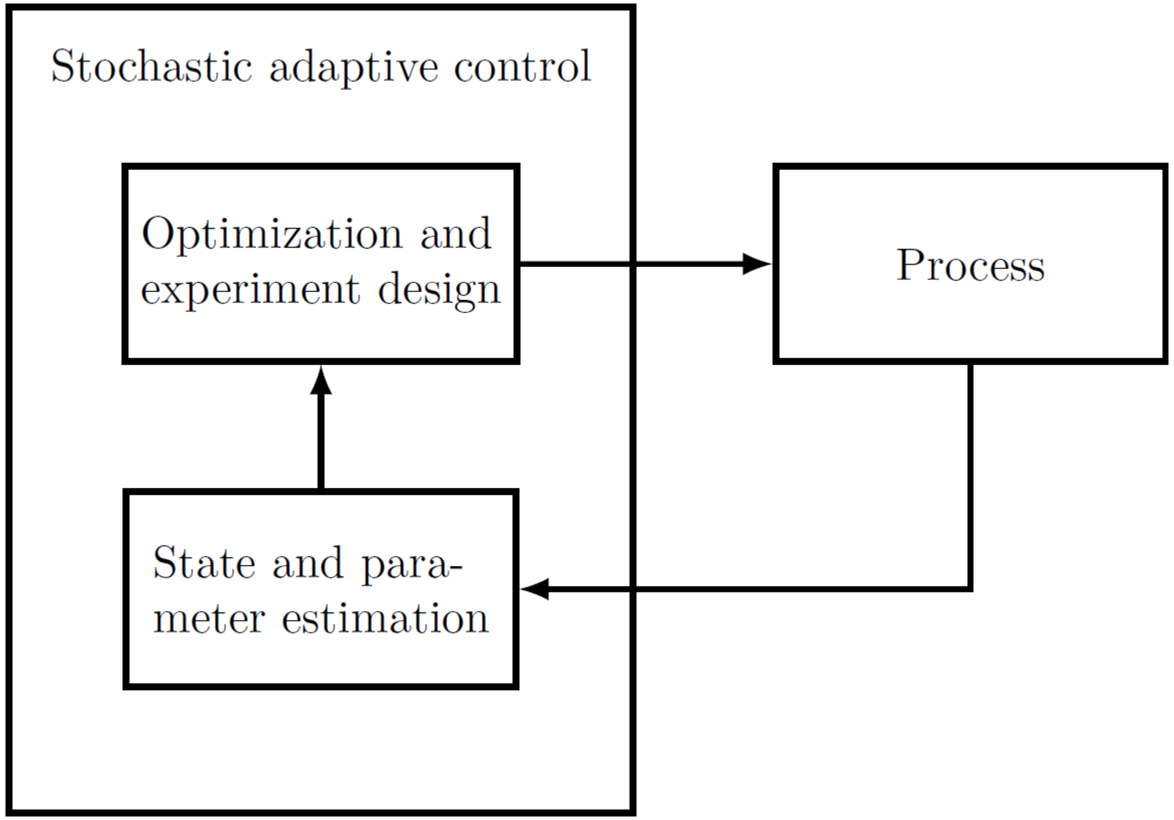
- max. profit + min. uncertainty



Examples of optimization:

- **Maximize CO_2 storage**
- **Minimize CO_2 leaks**
- **Max. residual + min. structural trapping**

Stochastic adaptive control

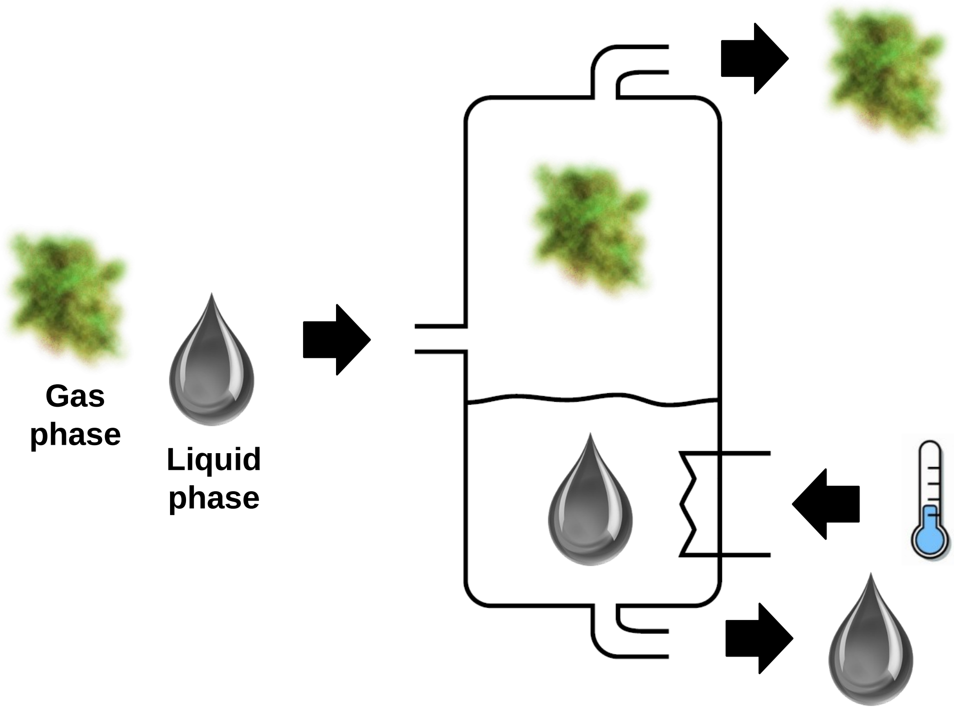


Closed-loop reservoir management (CLRM)

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



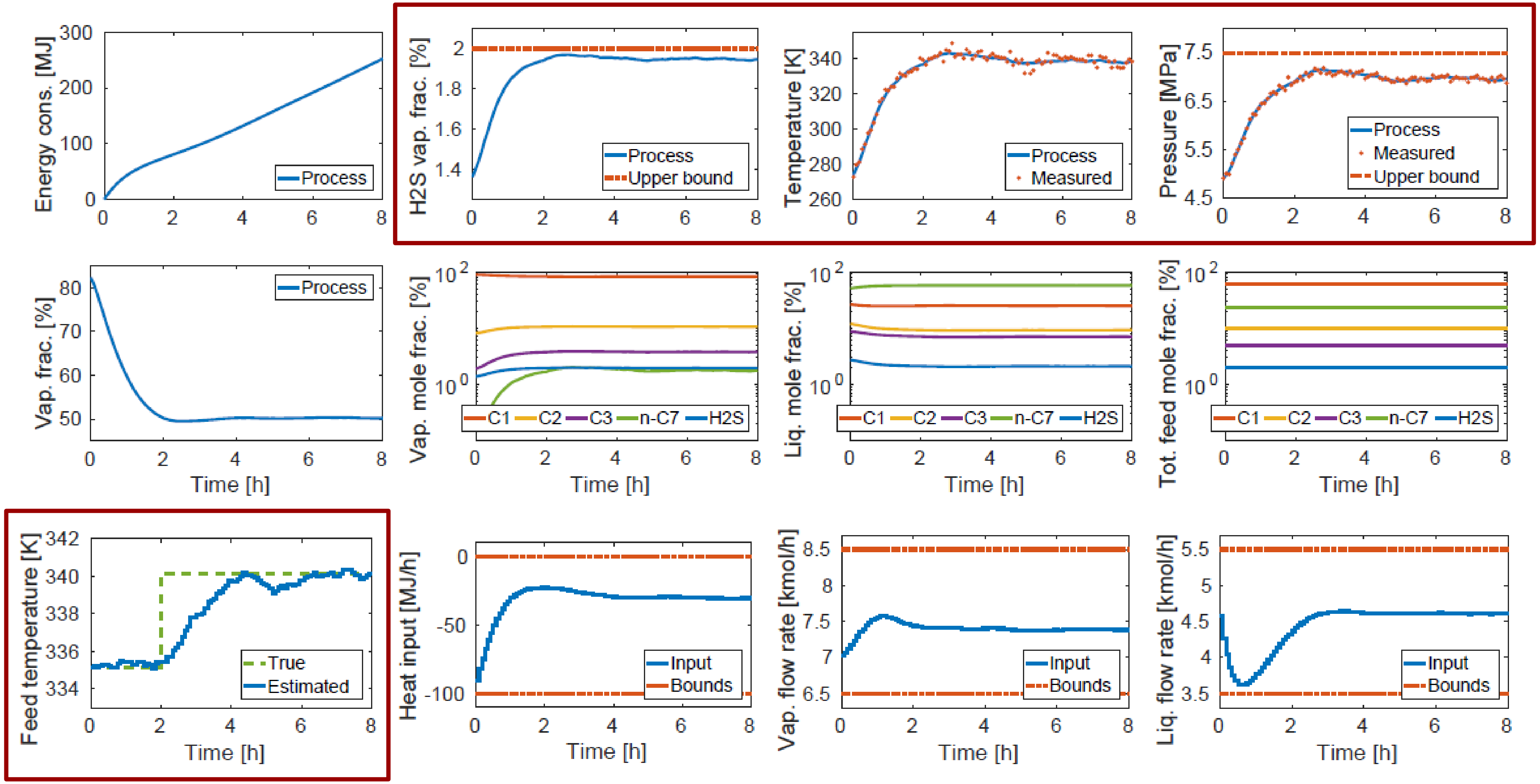
Feed (1 kmol/h)

Composition:

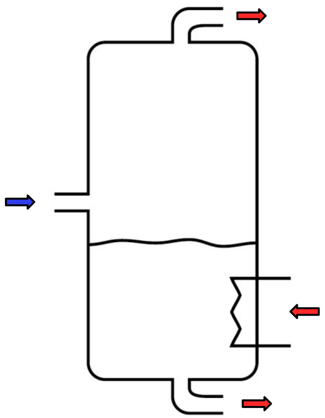
C_1	60%
C_2	10%
C_3	5%
n-C_7	23%
H_2S	2%

Ritschel, T.K.S., Jørgensen, J.B., 2019. Nonlinear Model Predictive Control for Disturbance Rejection in Isoenergetic-isochoric Flash Processes. IFAC-PapersOnLine 52(1), pp. 796–801. DOI: 10.1016/j.ifacol.2019.06.159.

Flash separation example



- Minimize heat input
- Satisfy bounds
- Estimate feed temperature



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