River discharge extremes in Norwegian regulated catchments: simulations using a hydrologic model including human interventions

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Motivation → Objectives

- Increasing frequency and severity of extreme weather
- Impact prediction requires modelling human interventions

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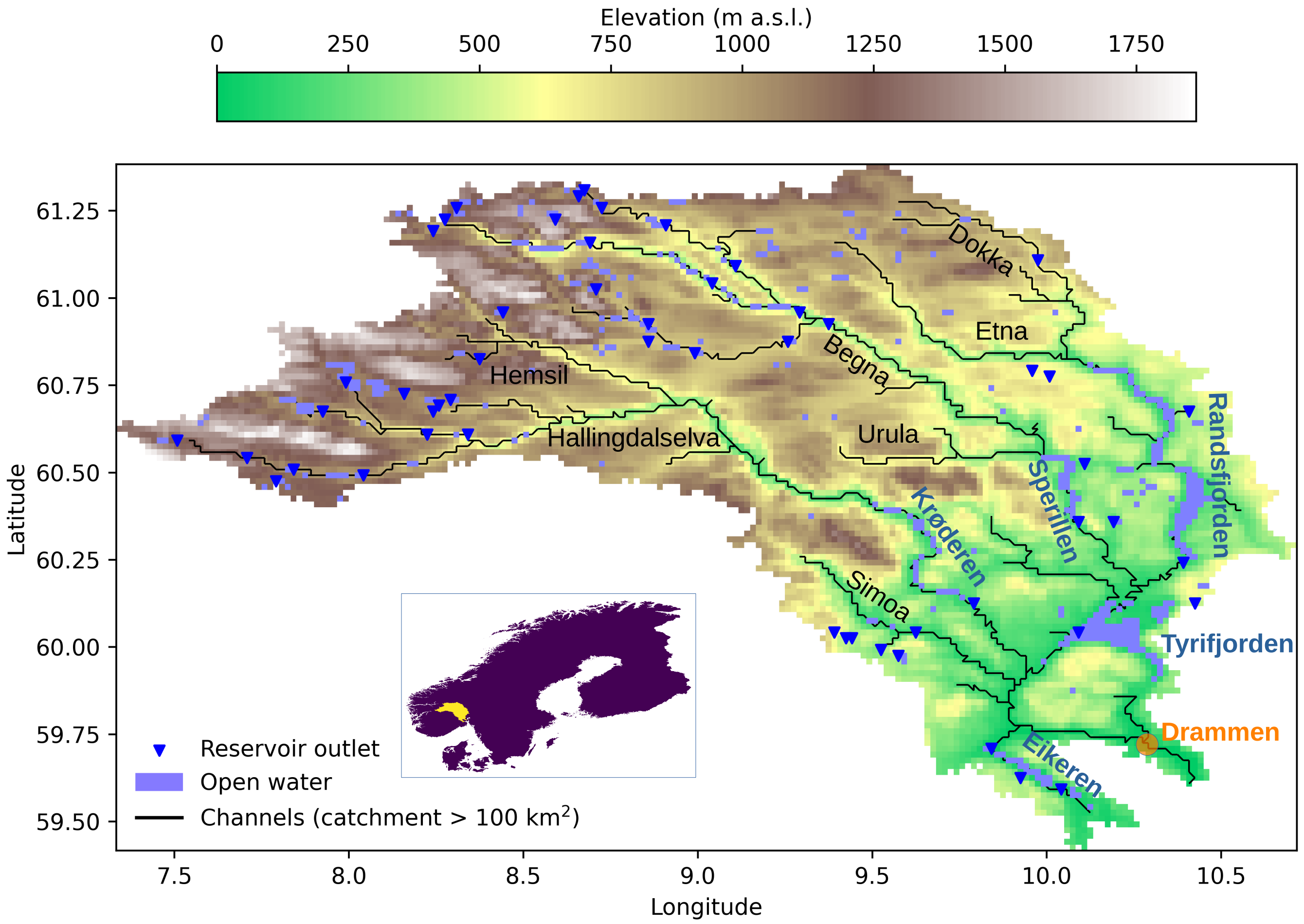
- Evaluate LISFLOOD hydrologic / water resources model in a heavily regulated catchment (Drammen)
- Use local data for model improvement w.r.t. extremes

Outline

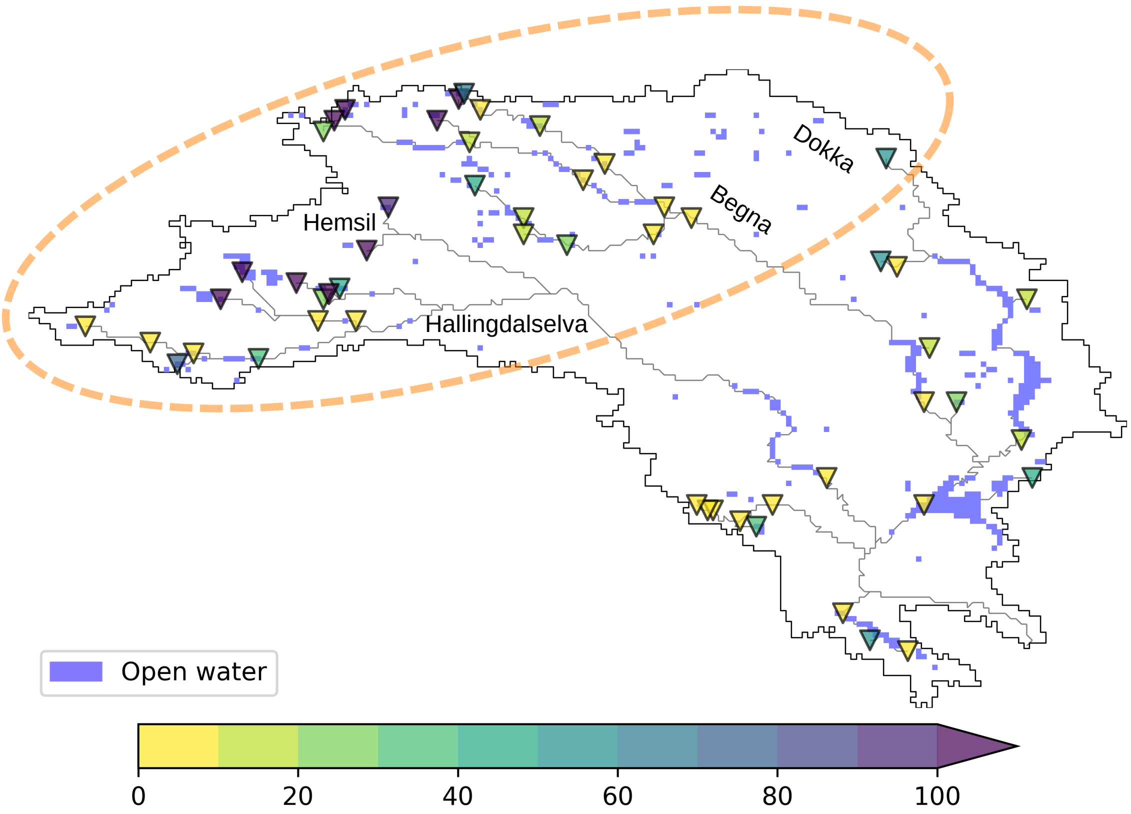
- Drammen catchment
- LISFLOOD hydrologic and water resources model
- Model input and calibration
- Results
- Conclusions and way forward

Drammen catchment



- Seasonal hydrologic regime dominated by snowmelt
- 54 reservoirs (only 4 in European LISFLOOD setup)
- Active storage ~ 35% of average annual streamflow
- Reservoirs crucial to reduce flood damage, especially when large snowmelt is predicted

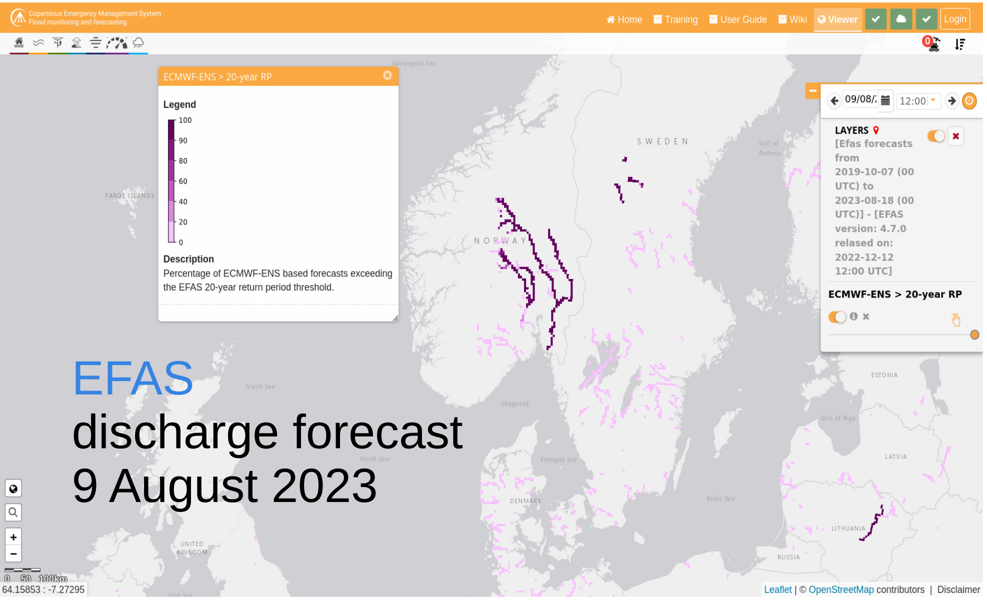
Active storage (% annual precipitation)

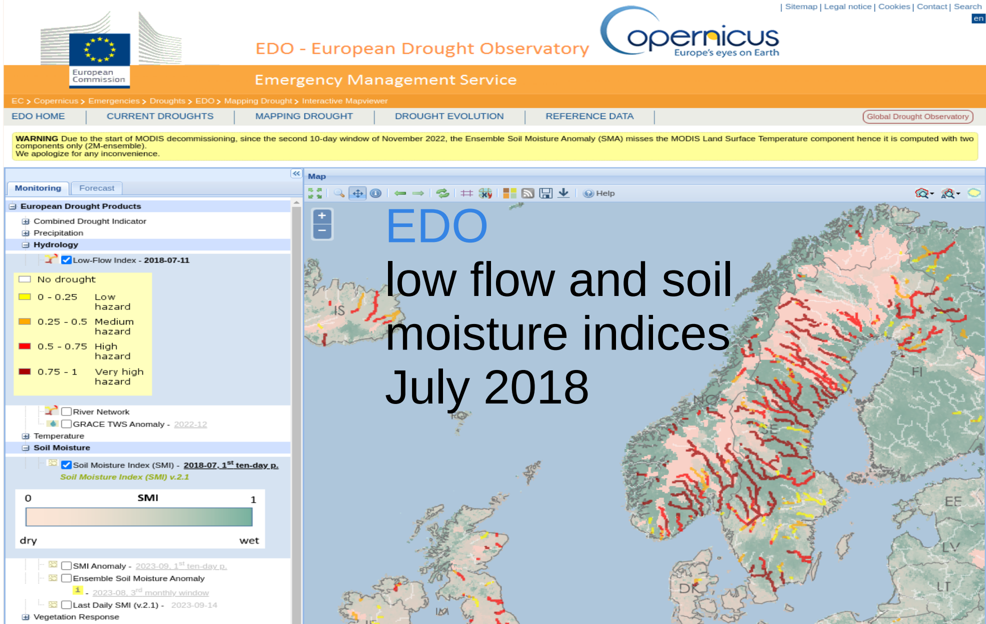


Most regulating capacity (active storage / annual precipitation) is upstreams, where precipitation is also largest

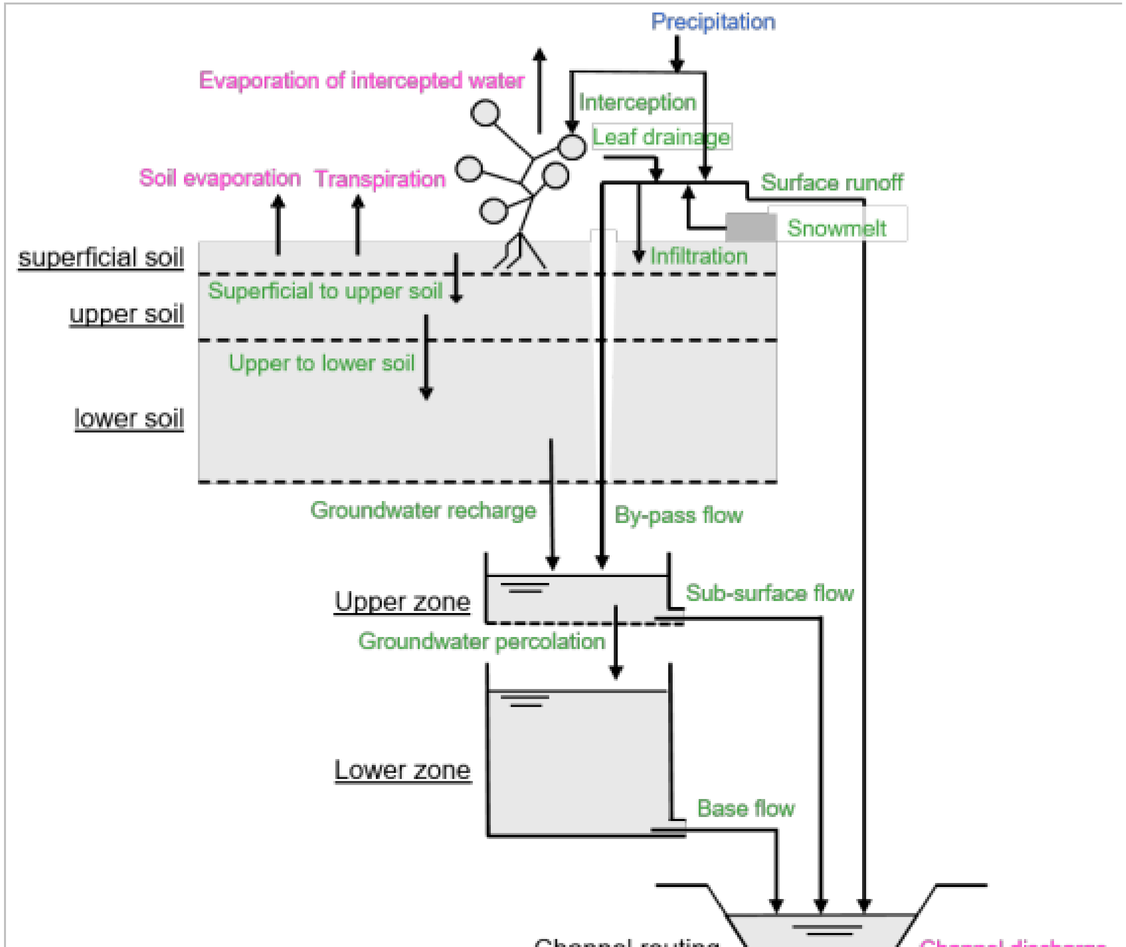
LISFLOOD hydrologic and water resources model

- Developed by European Commission's JRC and ECMWF
- Operational use in flood prediction (EFAS) and drought monitoring (EDO)
- Recent applications in Water-Energy-Food-Ecosystem Nexus assessments





LISFLOOD: hydrology



(from LISFLOOD documentation)

Space resolution:

- Gridded: now 1'
- Sub-grid land cover tiles

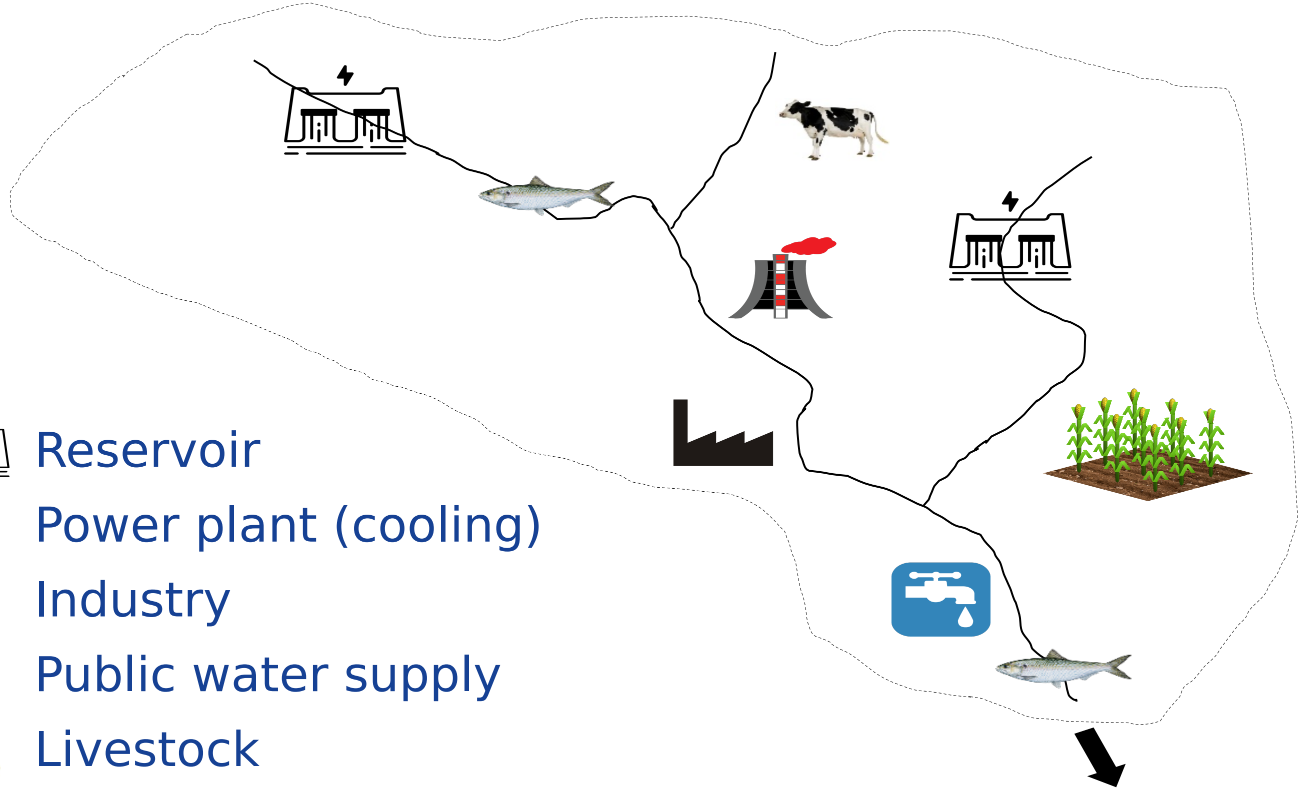
Time resolution:

- Input & water balance: daily
- River routing: hourly

River routing:

- 1D kinematic wave: channel, floodplain
- Lakes
- Regulated reservoirs
- Human water use

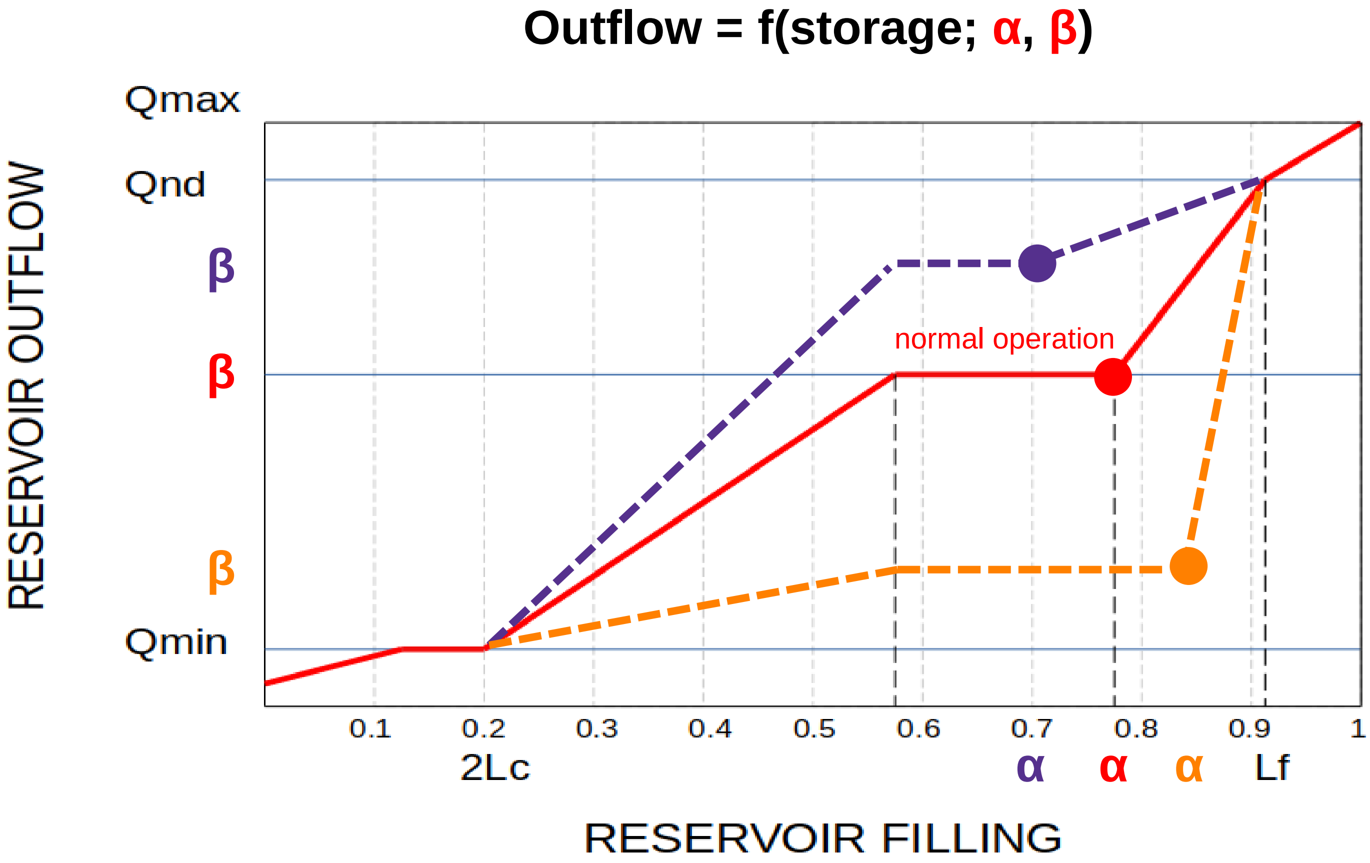
LISFLOOD: water resources



- Reservoir
- Power plant (cooling)
- Industry
- Public water supply
- Livestock
- Irrigation
- Environmental flow requirement

- Water demands from multiple sectors
- Water abstractions based on water demand, availability and ecological flow requirements
- Sources: groundwater, rivers, lakes and reservoirs
- Simple reservoir model

LISFLOOD: reservoirs

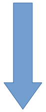


Simple model (+)

- Useful for large data-scarce domains

Limitations (–)

- Real operation purposes (e.g. hydropower) not included
- Reservoirs are independent



- Cannot exploit detailed data

Model input

- **Land surface** (vegetation, land cover, soil, river network, etc.): EFAS maps at 1’ resolution

- **Atmospheric forcing** 1978-2020 (1 km): seNorge_2018 (precipitation, temperature), HySN5 (radiation, humidity) and Klinogrid (wind)

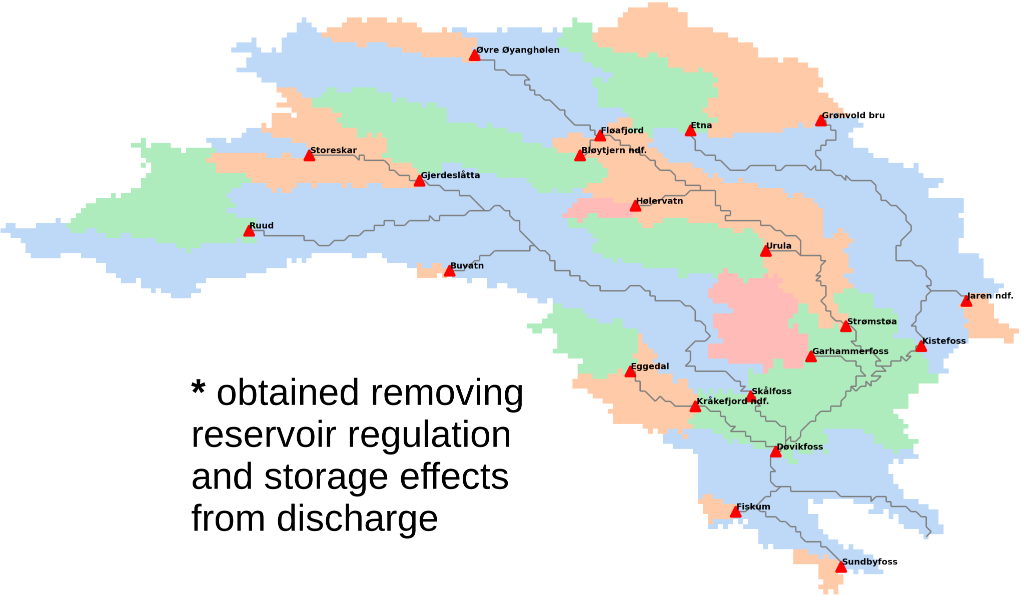
- **Reservoir active storage**: NVE

Model calibration: 2 steps

To avoid compensation errors arising when calibrating all parameters simultaneously

1

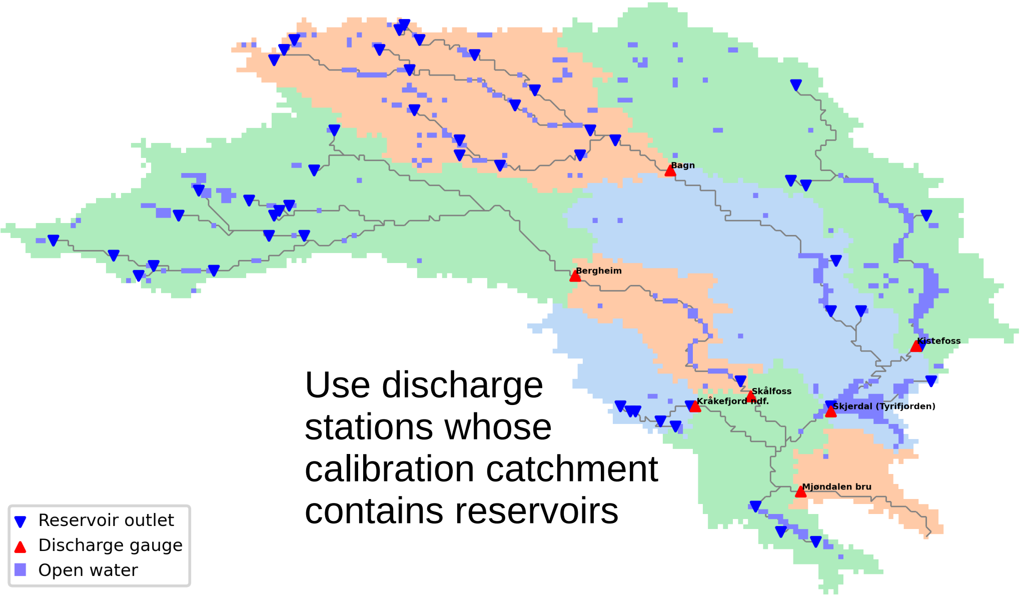
Calibrate 7 hydrologic parameters against naturalised streamflow*



* obtained removing reservoir regulation and storage effects from discharge

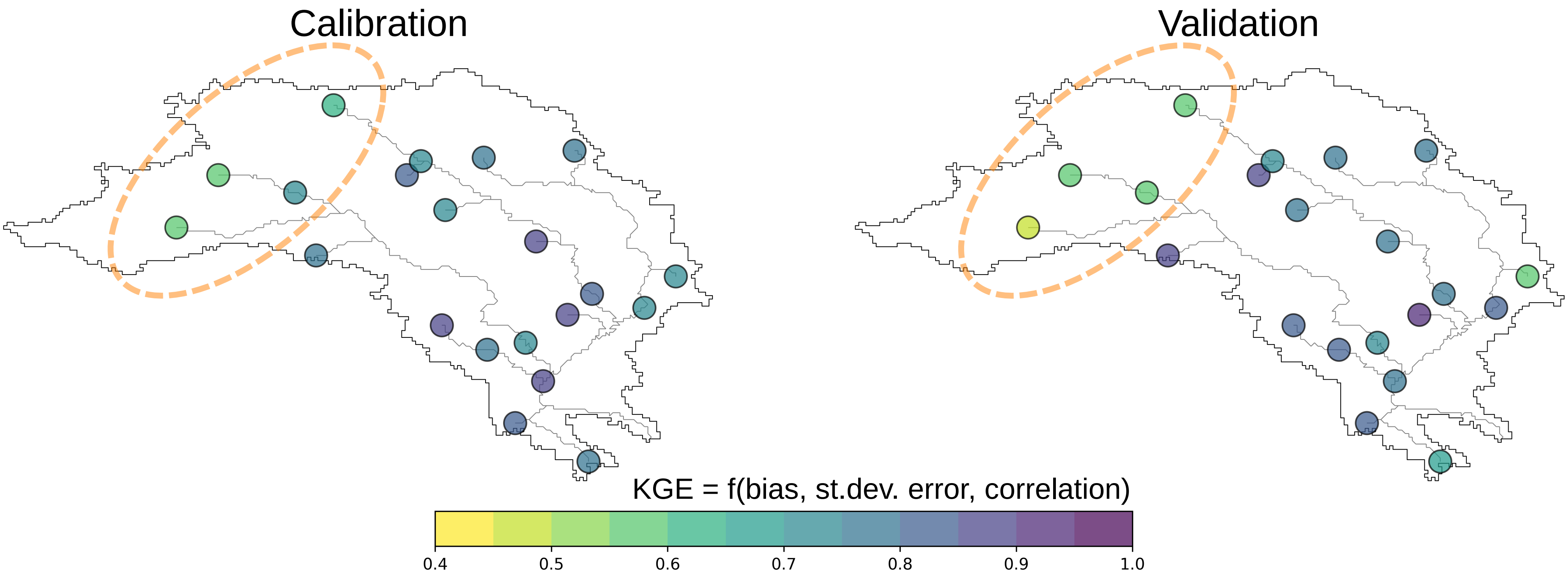
2

Calibrate 2 reservoir parameters against river discharge



Use discharge stations whose calibration catchment contains reservoirs

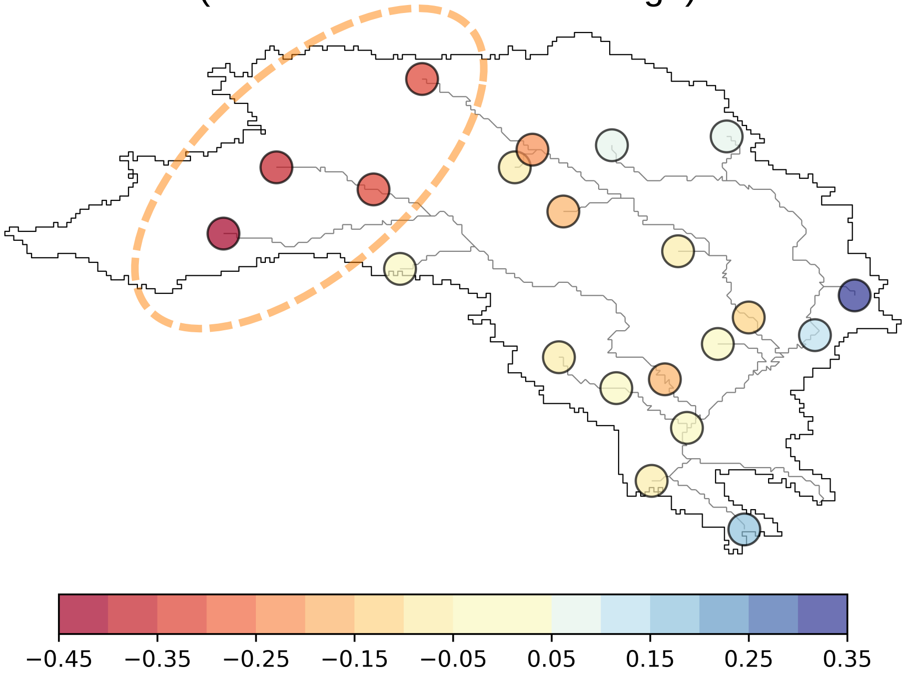
Naturalised streamflow calibration



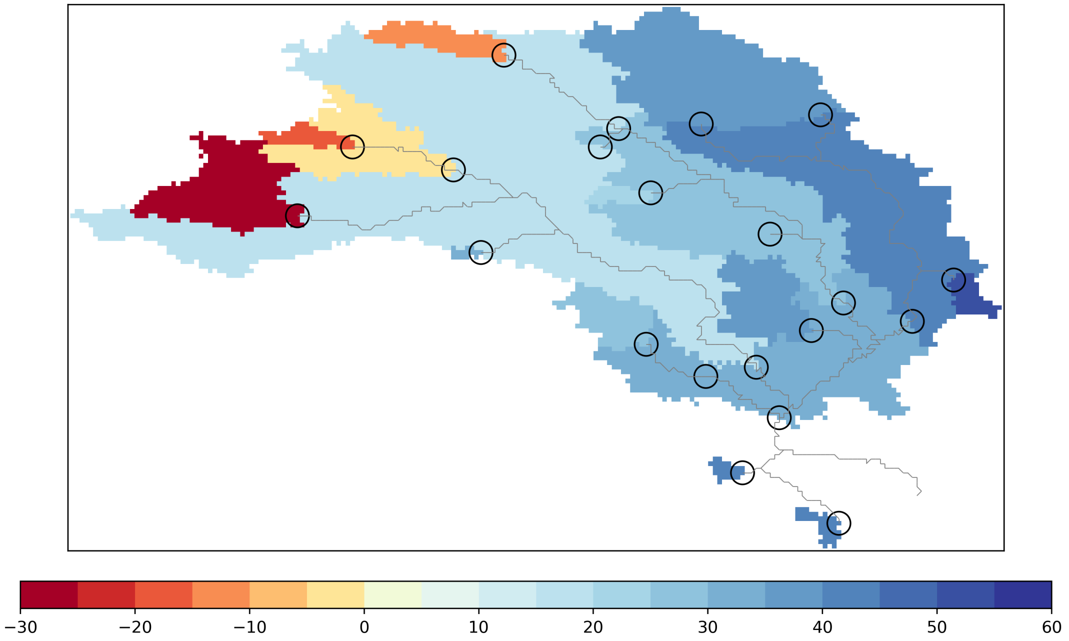
- Relatively high and robust KGE (> 0.75 at 60% stations) and correlation (> 0.8)
- North-western headwaters: lower KGE due to large negative bias

Streamflow underestimation

Bias (fraction of observed average)

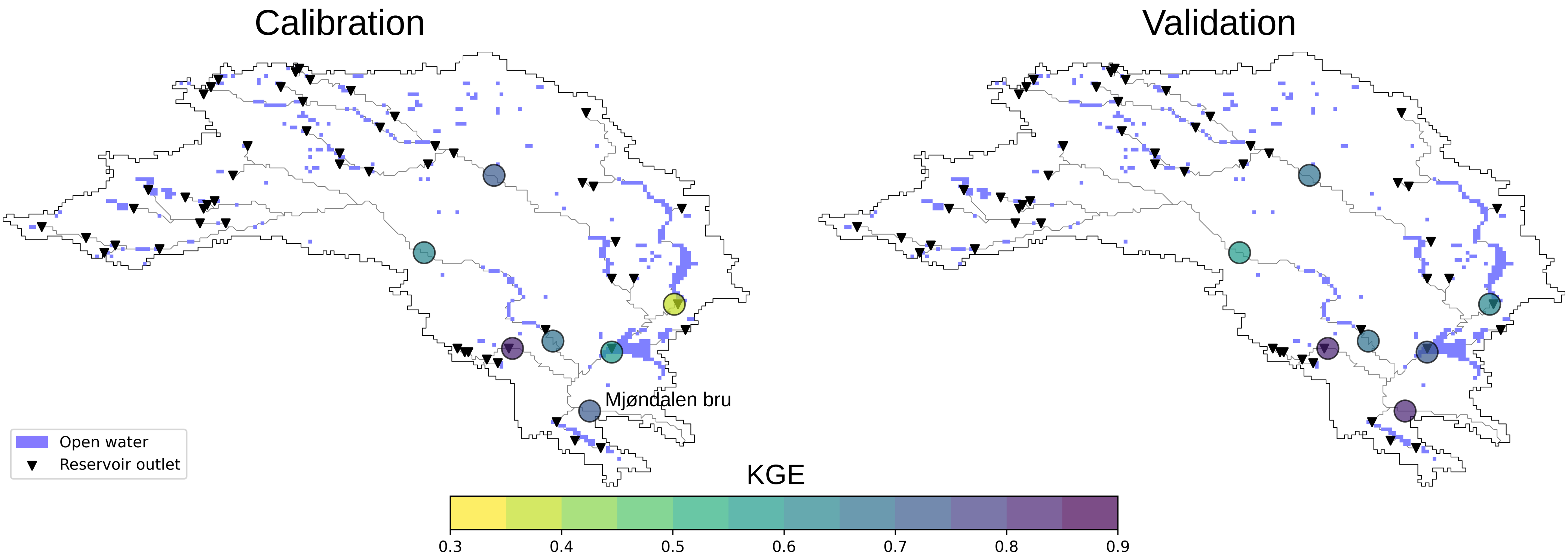


Precipitation – measured streamflow (% precipitation)



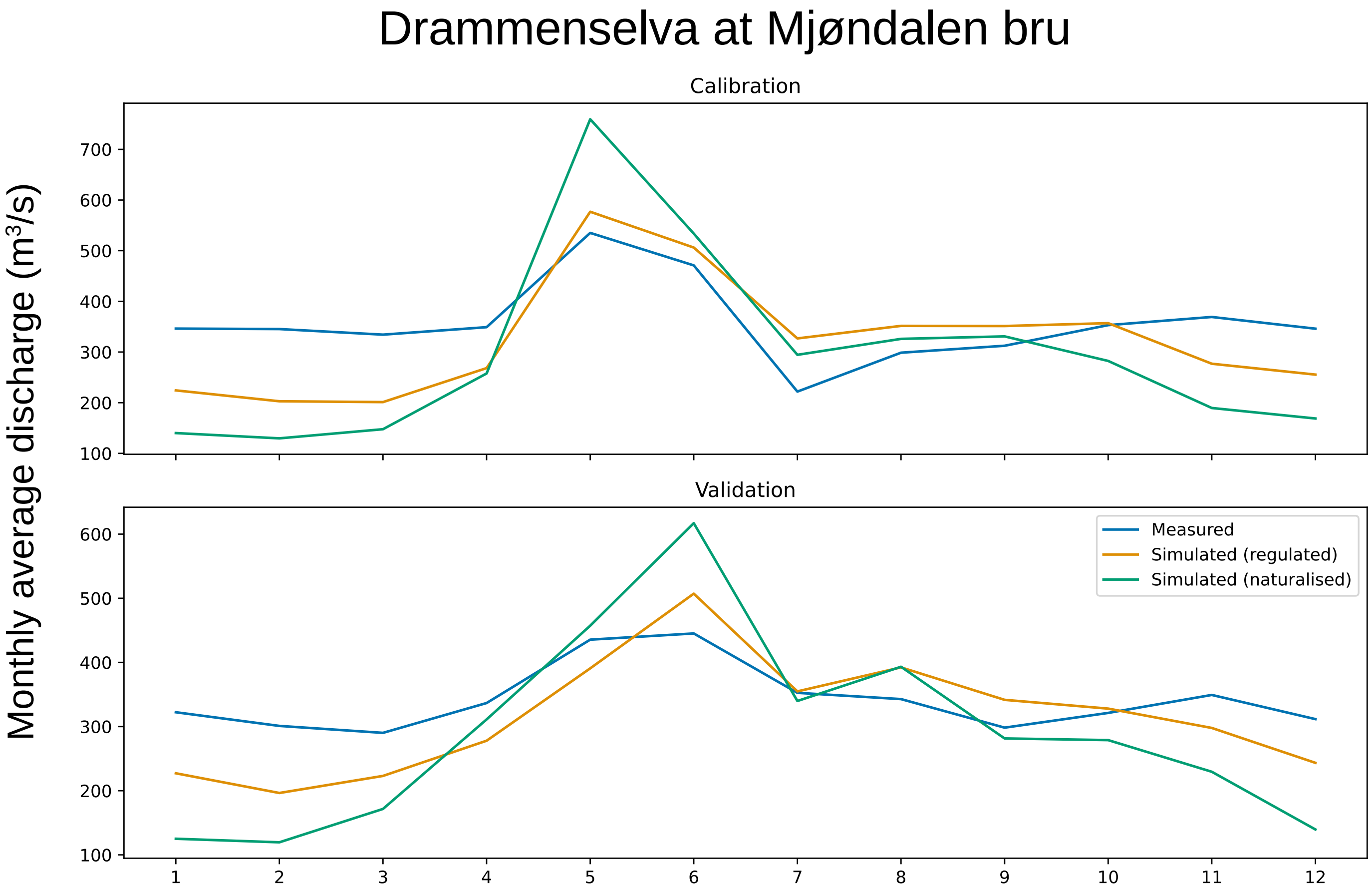
- Average measured streamflow exceeds precipitation by up to 270 mm/year
- Negative model bias partly due to underestimated precipitation input

Reservoir calibration



- Lower KGE than naturalised calibration, due to simplistic reservoir model
- Robust under validation

Regulated vs naturalised simulations

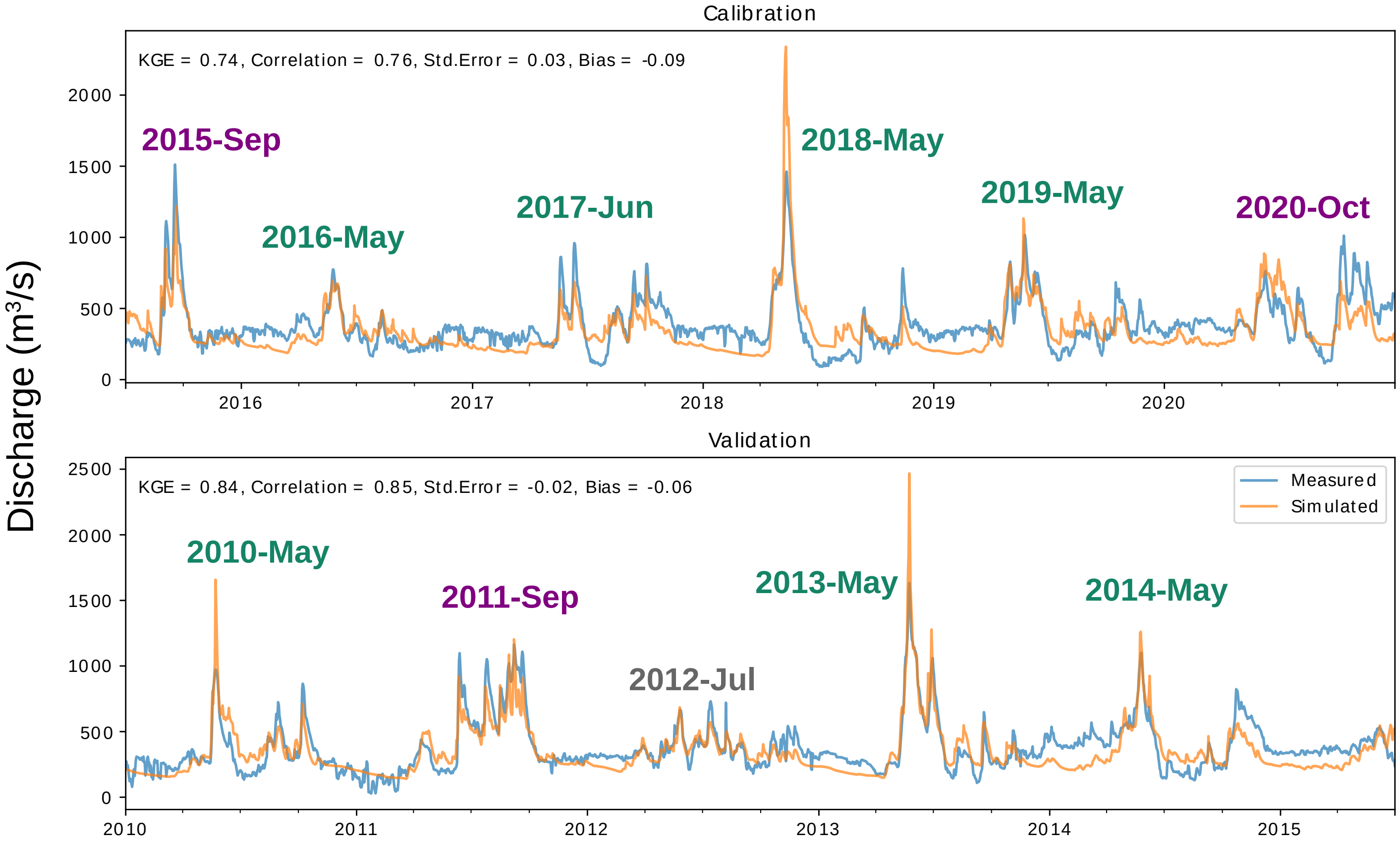


Comparison of naturalised and regulated (reservoirs) simulations against measured discharge:

- Reservoirs improve reproduction of discharge seasonality
- Improvement due to storage buffering effect rather than simplistic regulation model
- Naturalised simulation is a low benchmark

Regulated calibration: extremes

Drammenselva at Mjøndalen bru



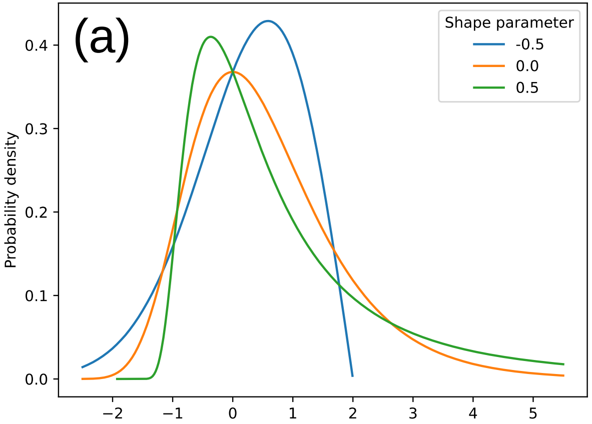
- Underestimation during most low flow periods.
- Overestimation of most **spring annual maxima**, especially the largest ones (2013, 2018)
- Underestimation of 2015 and 2020 **autumn maxima**
- Fair reproduction of several flow peaks (2011, 2014, 2019)

Extremes: annual maxima

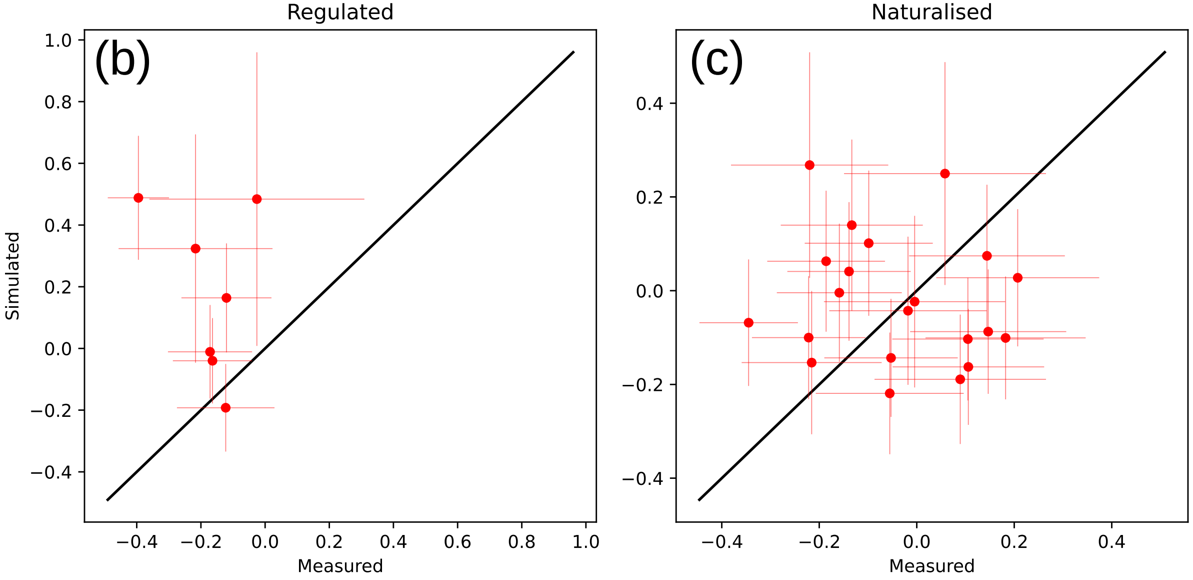
Generalised extreme value (GEV) distribution fitted to annual maxima:

- Shape parameter determines upper tail thickness (a)
- Regulated (reservoirs) simulation vs discharge: general overestimation (b)
- Naturalised simulation vs naturalised streamflow: no clear pattern (c)

Example: GEV shape parameter and tail



GEV shape parameter estimates with 90% confidence intervals



Conclusions

- Promising 2-step calibration approach:
    1. Hydrologic parameters using naturalised streamflow
    2. Reservoirs parameters using discharge
- Representation of extremes to be improved

- Future work:

  - Precipitation correction

  - Develop a more realistic reservoir model

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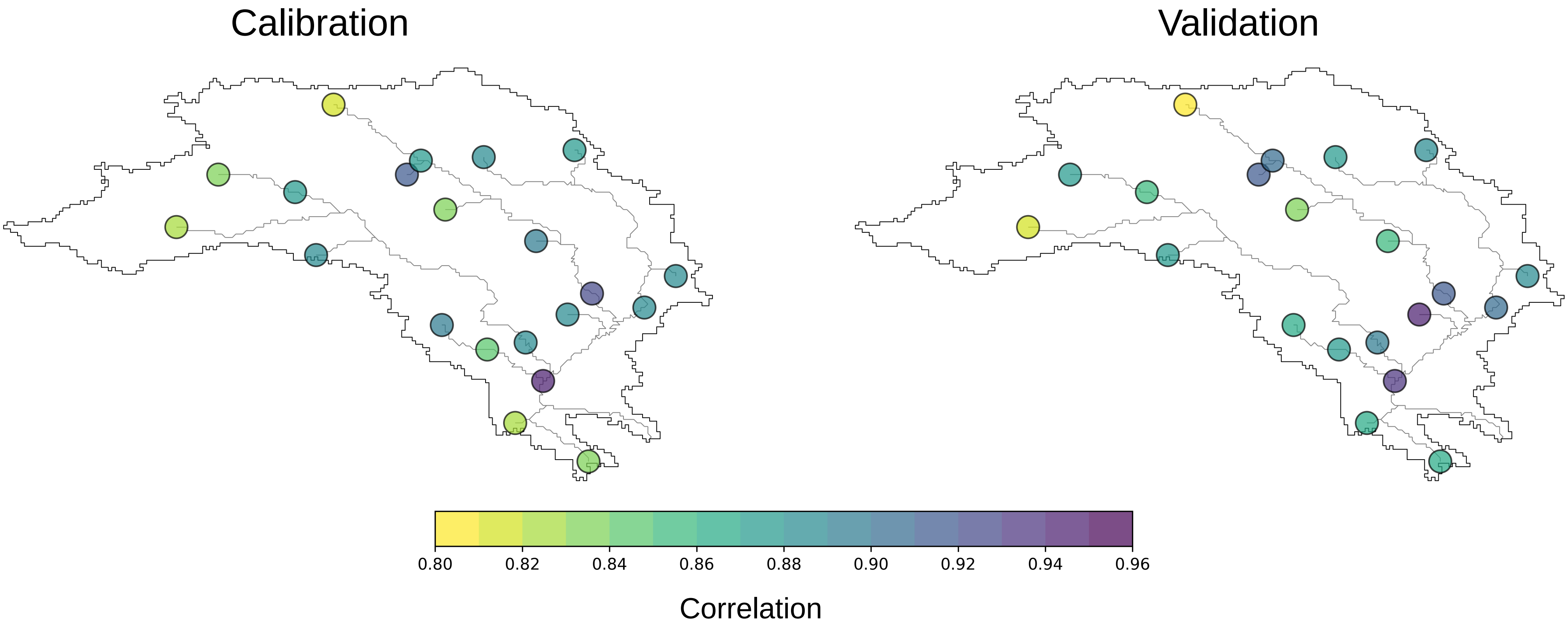
- LISFLOOD group at JRC

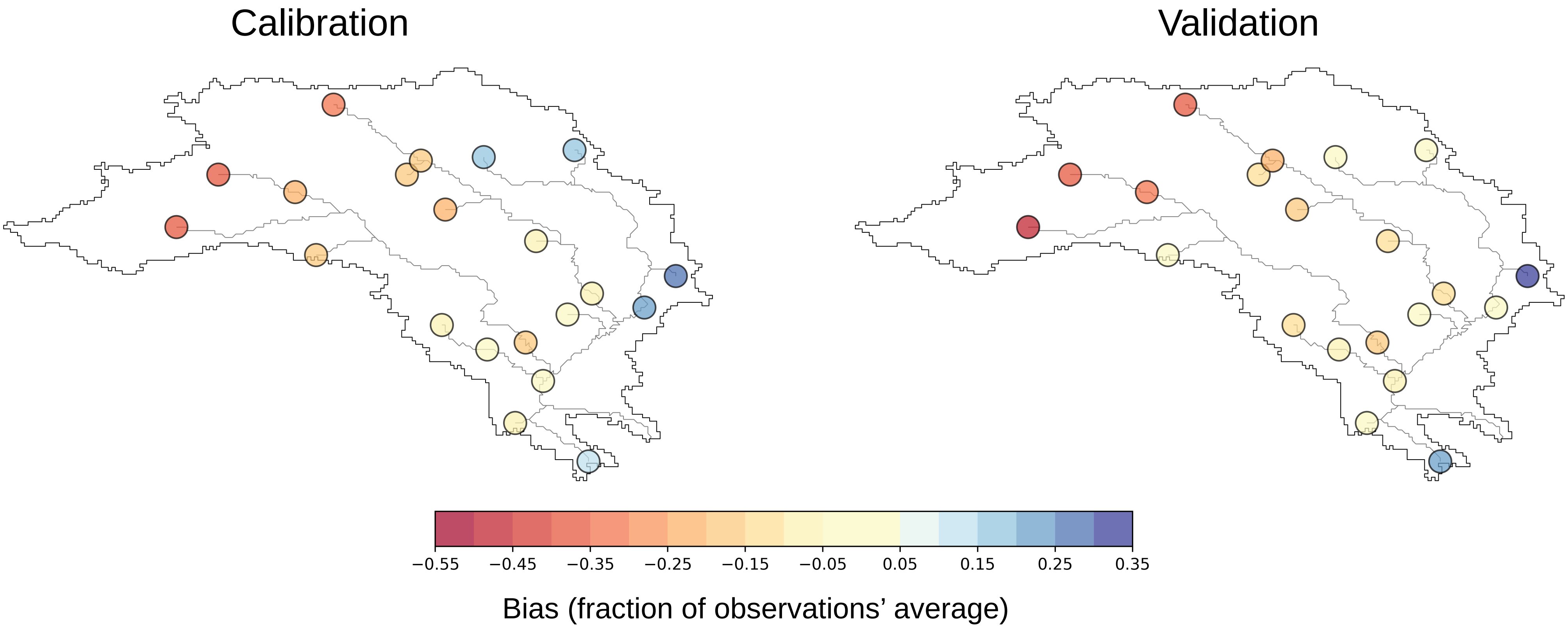
Thank you

Extra slides

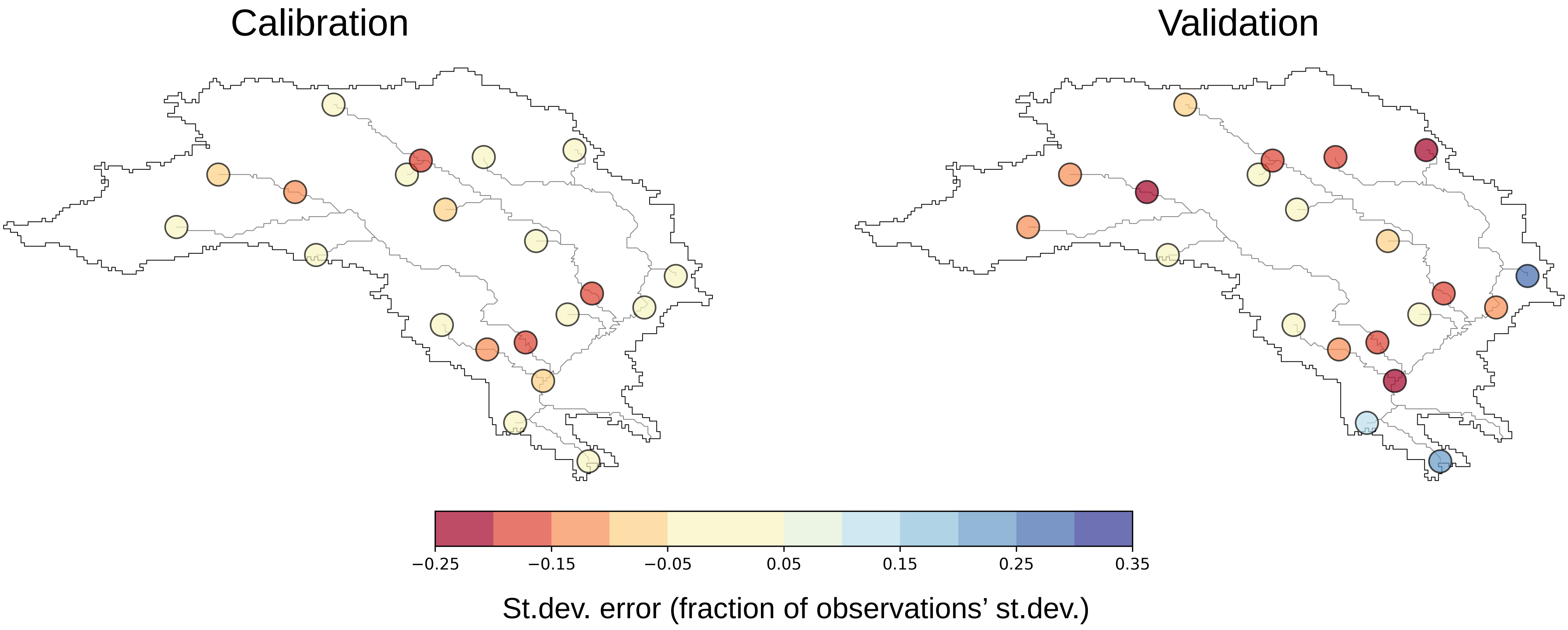
Naturalised streamflow results



Naturalised streamflow results



Naturalised streamflow results



Calibrated vs uncalibrated reservoirs