Deltares

Methods for addressing uncertainty in reservoir operations under flood conditions

Hydropower scheduling conference 2022 Oslo

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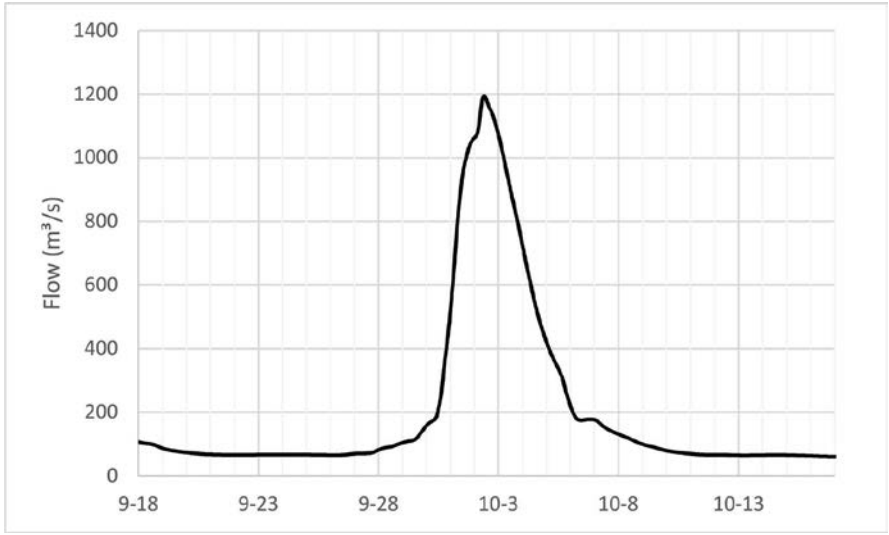
Pre-release from a reservoir for flood management

Observed flow in unregulated Tovdal river



Source:
2019 ICOLD congress proceedings

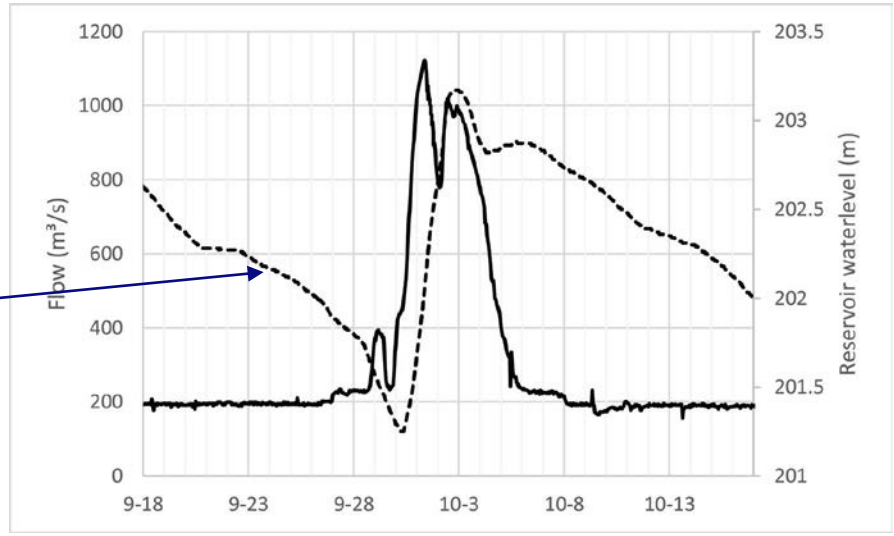
Sustainable and Safe Dams Around the World – Tournier, Bennett & Bibeau (Eds)
© 2019 Canadian Dam Association, ISBN 978-0-367-33422-2

Operation of large Norwegian hydropower reservoirs after quantifying the downstream flood control benefits

B. Glover & K.L. Walløe
Multiconsult, Oslo, Norway

Observed water level (dashed line) at **Byglandsfjord** reservoir and flow (solid line) ca. 60 km downstream of the reservoir.

Pre-release



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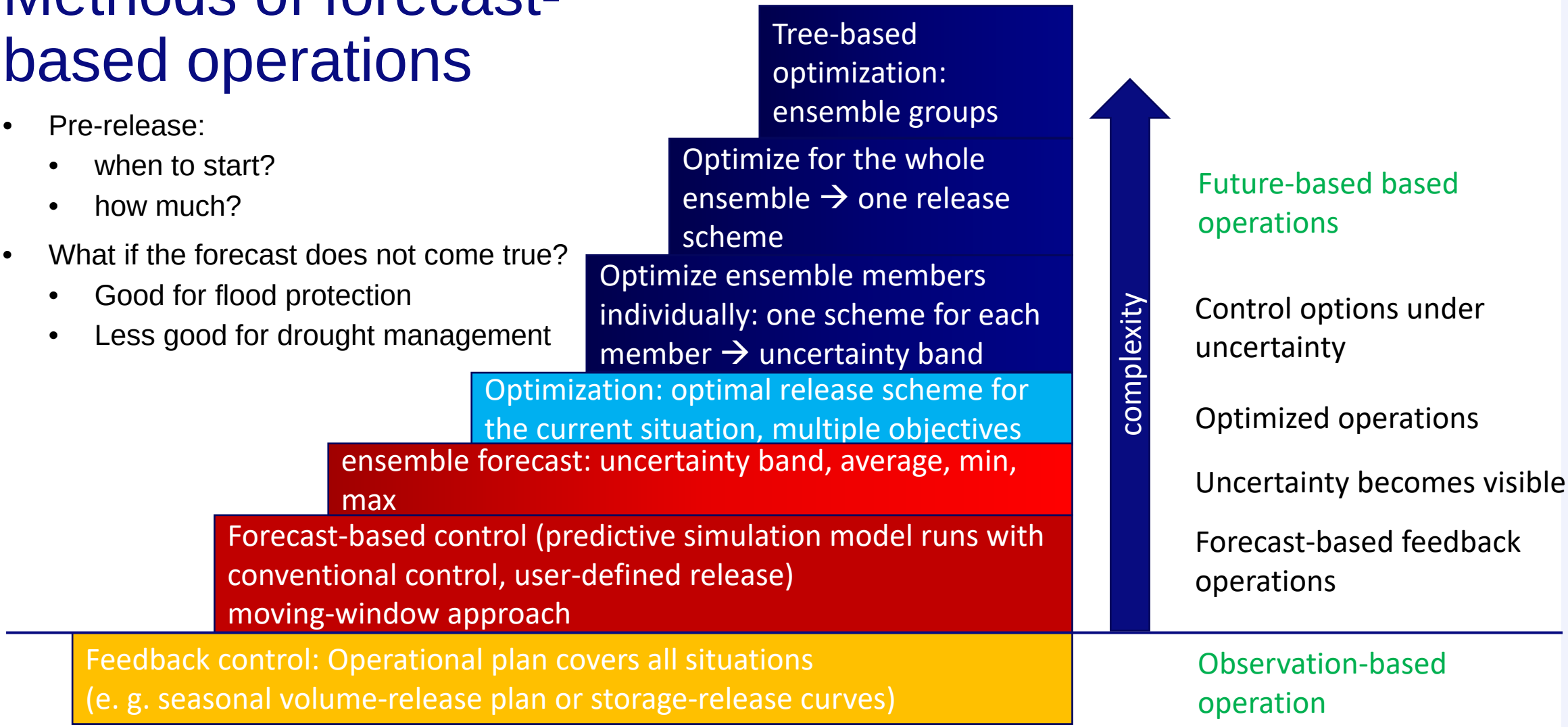
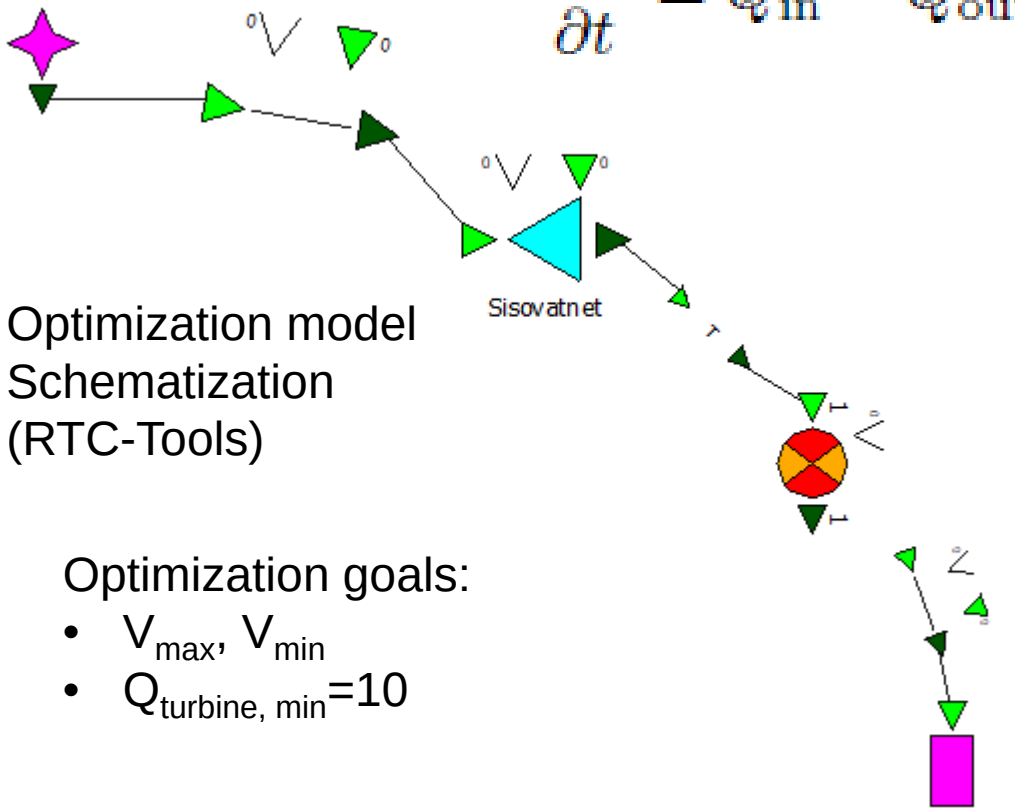
Methods of forecast-based operations

- Pre-release:
  - when to start?
  - how much?
- What if the forecast does not come true?
  - Good for flood protection
  - Less good for drought management



Sisovatnet: RTC-Tools optimization model

$$\frac{\partial V}{\partial t} = Q_{\text{in}} - Q_{\text{out}}$$

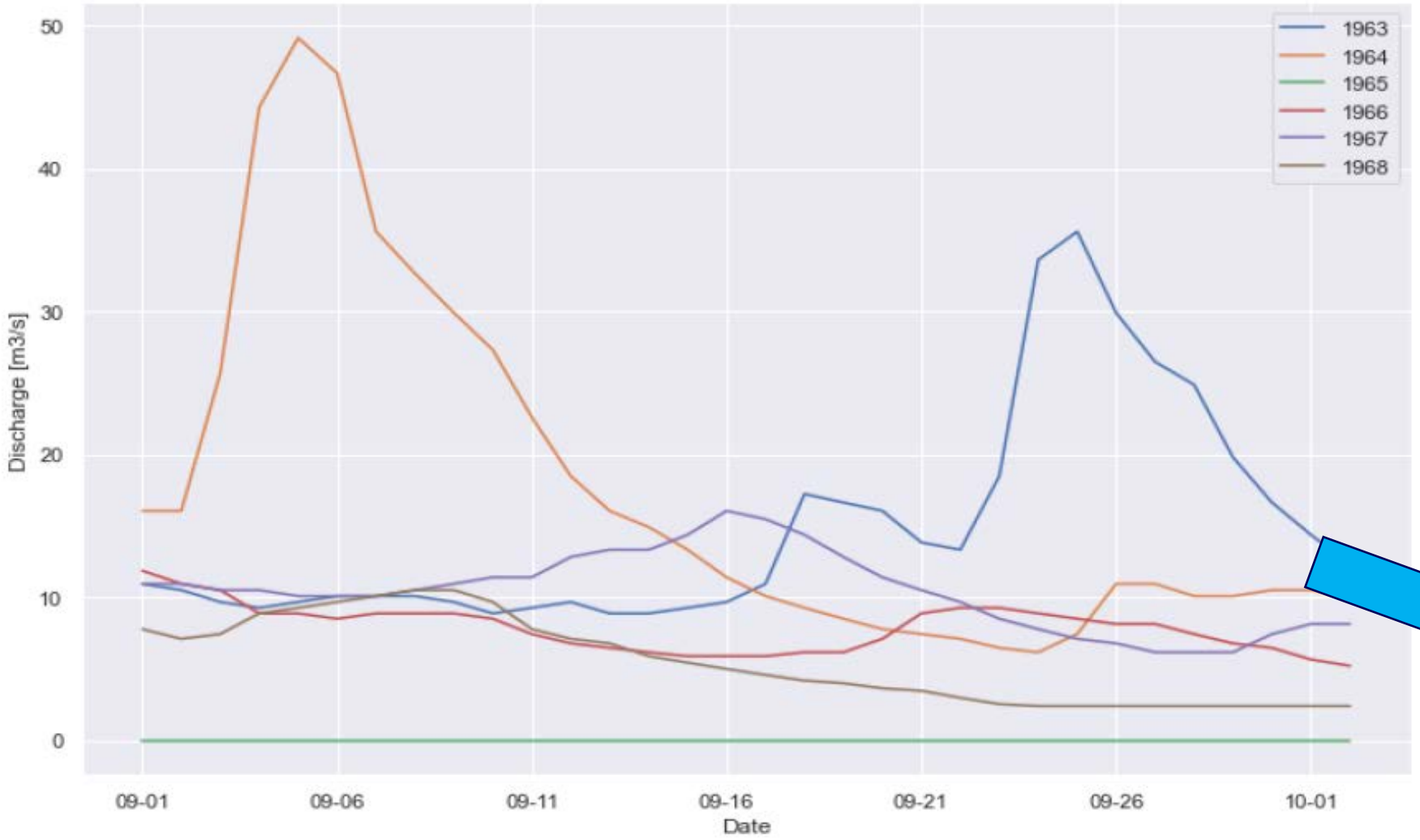


Optimization model Schematization (RTC-Tools)

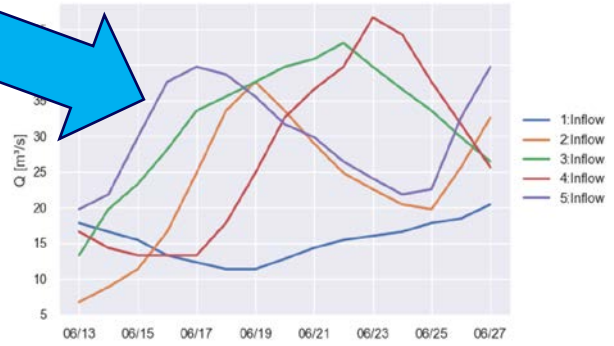
Optimization goals:

- V_{max}, V_{min}
- $Q_{turbine,\ min}$=10

Input data



- Historic discharge data from 6 years
- Rescaled, combined and treated as ensemble



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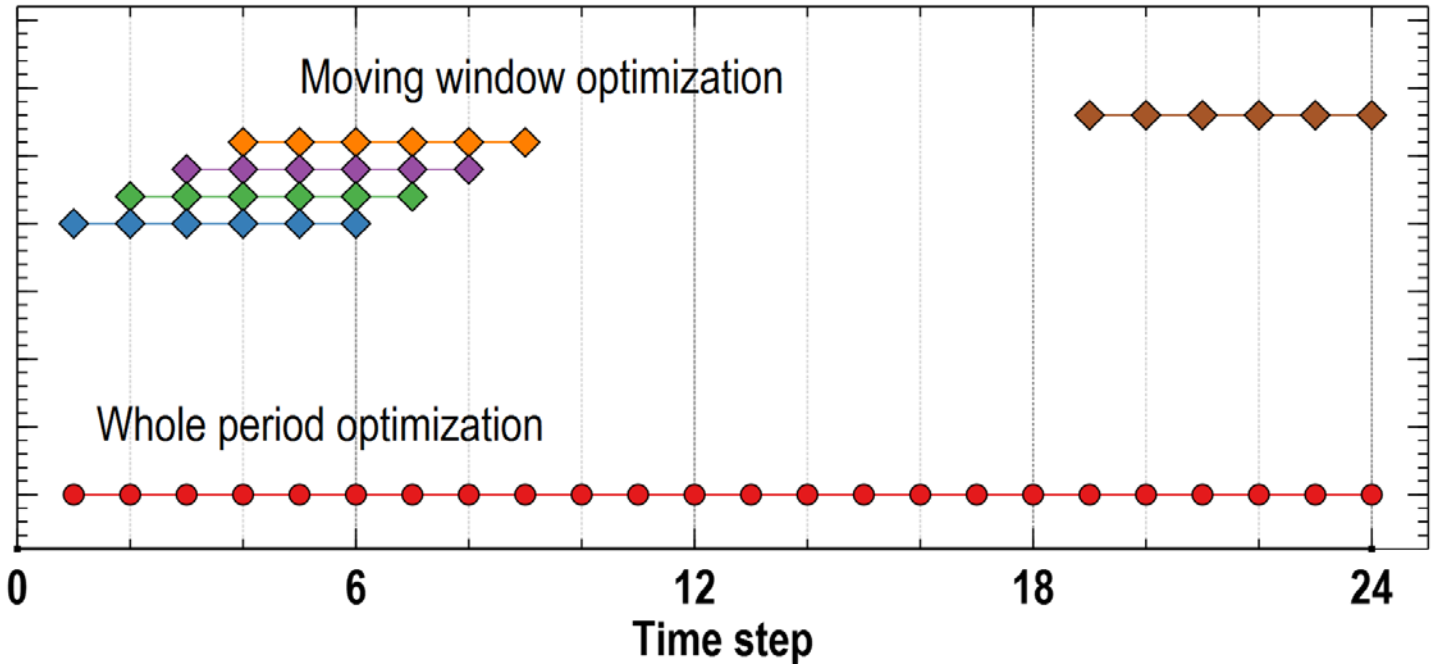
Moving window optimization



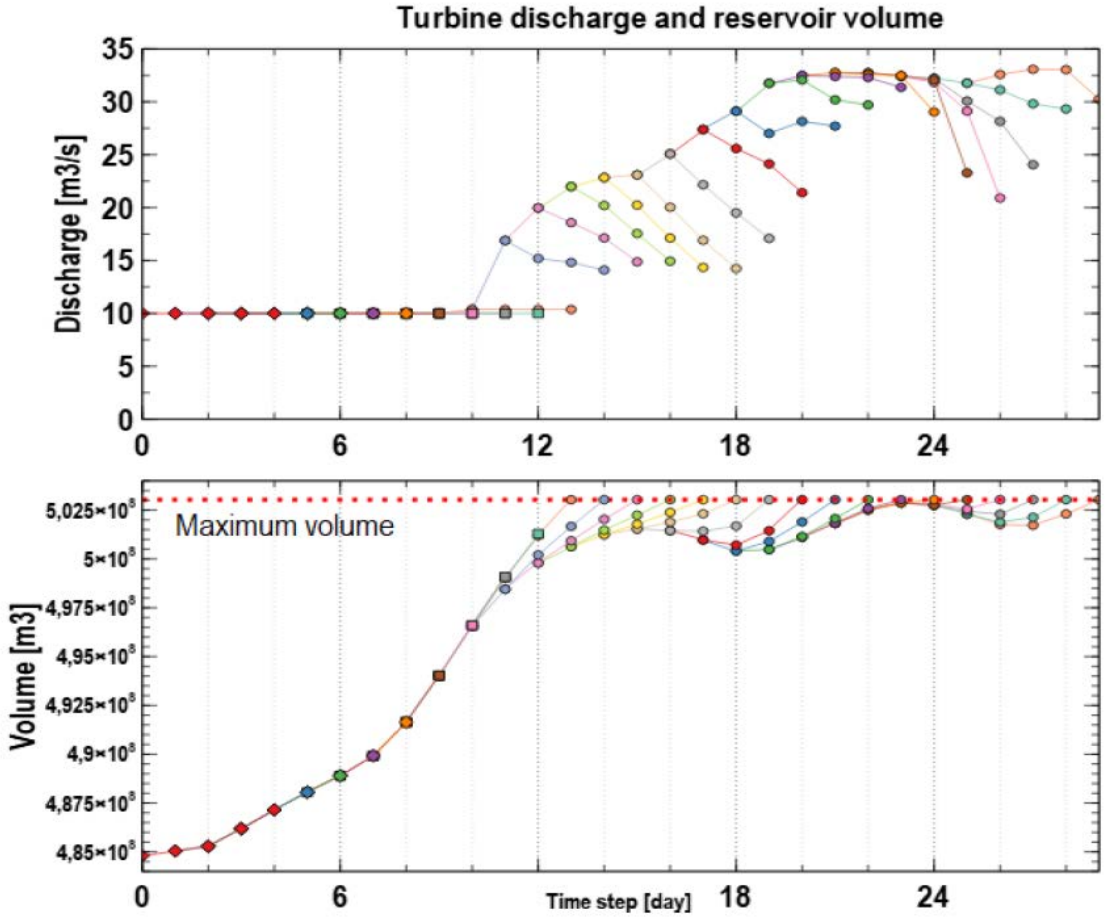
Optimization for al time steps

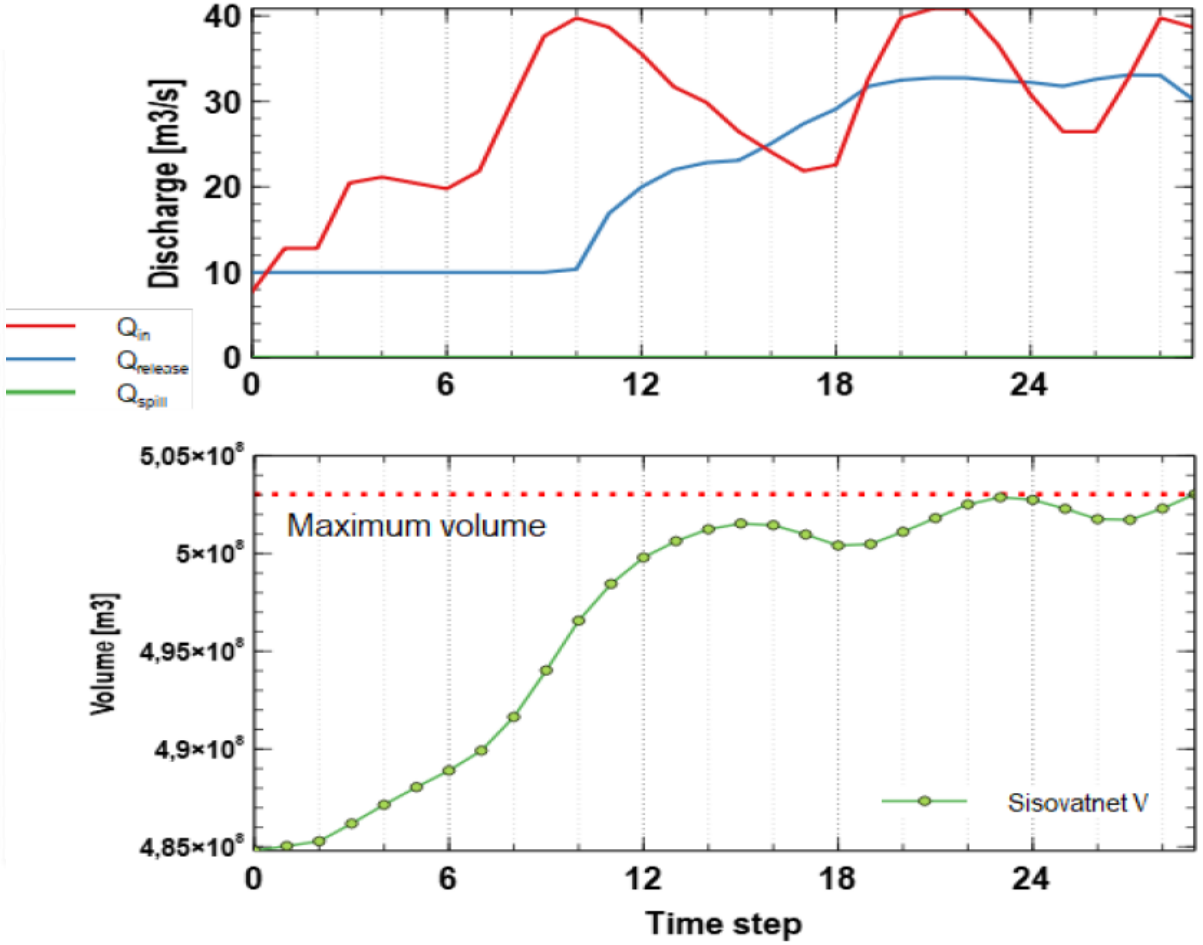
- Scenario analysis
- Full forecast window (“perfect forecast”)
- Applied for the results in previous slides

Moving window, closed loop

- Optimize for a limited forecast window
- Apply optimization result (reservoir release) for time step 1
- Move one time step forward

Moving window optimization, 5 days





Forecast length 5 days: higher volume

Inflow scenario 1968

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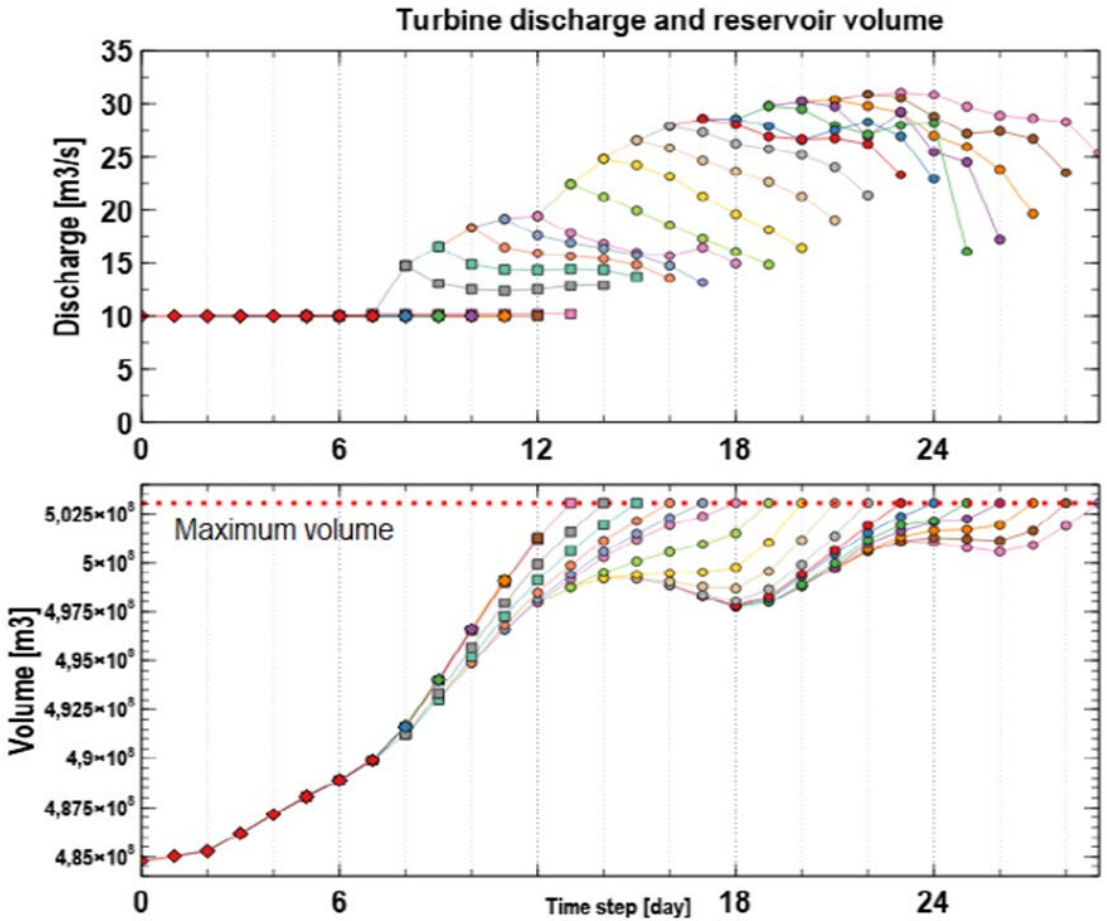
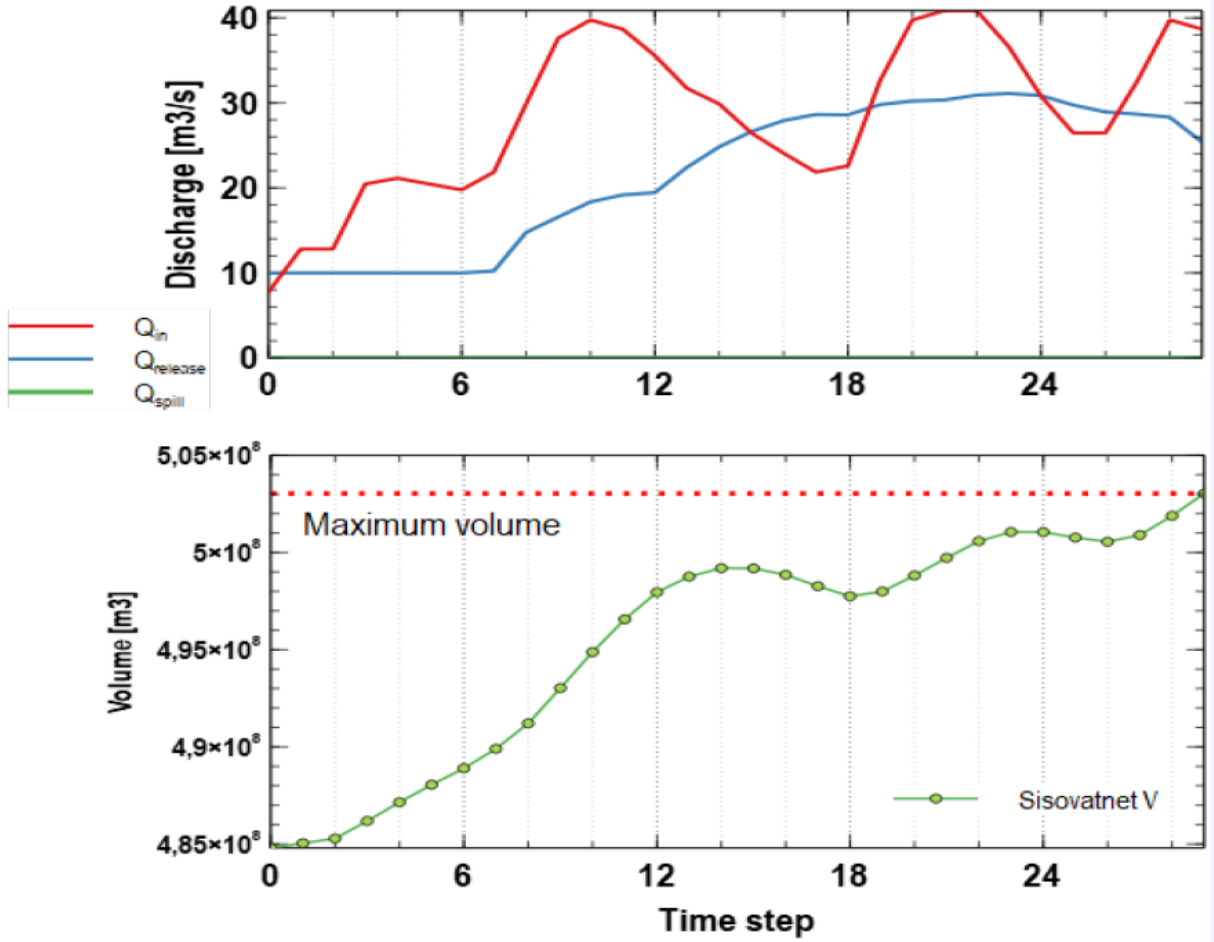
Moving window optimization, 8 days





Forecast length 8 days: max. volume, release starts earlier

Inflow scenario 1968

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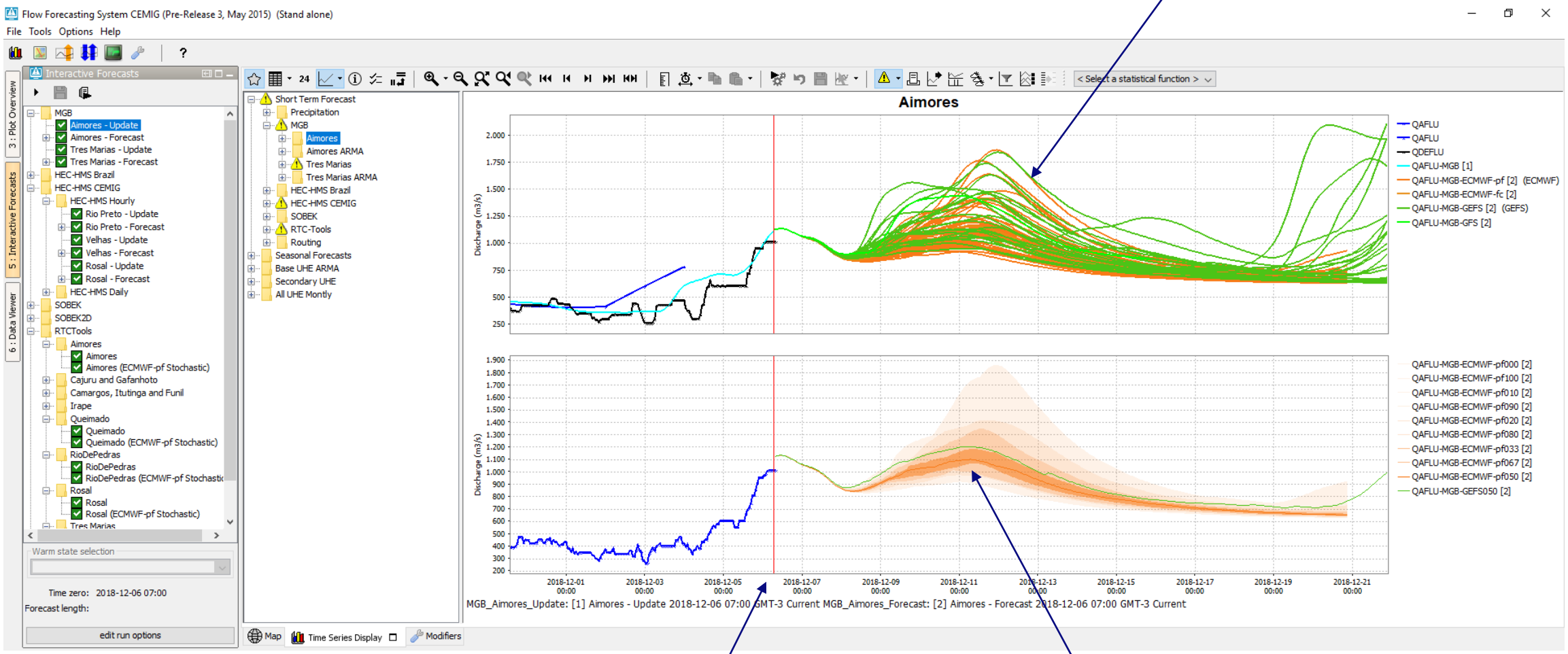
Ensemble forecast for reservoir inflow and moving window

Inflow forecast (ensemble members)



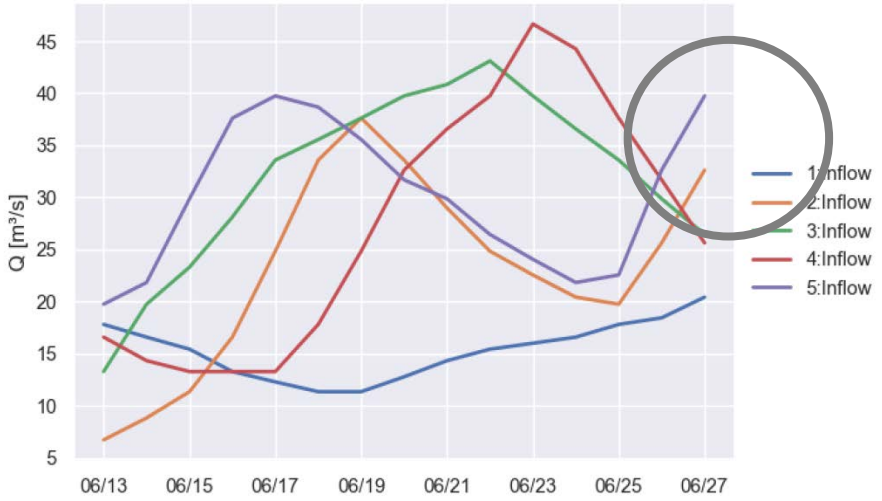
Moving window: t0

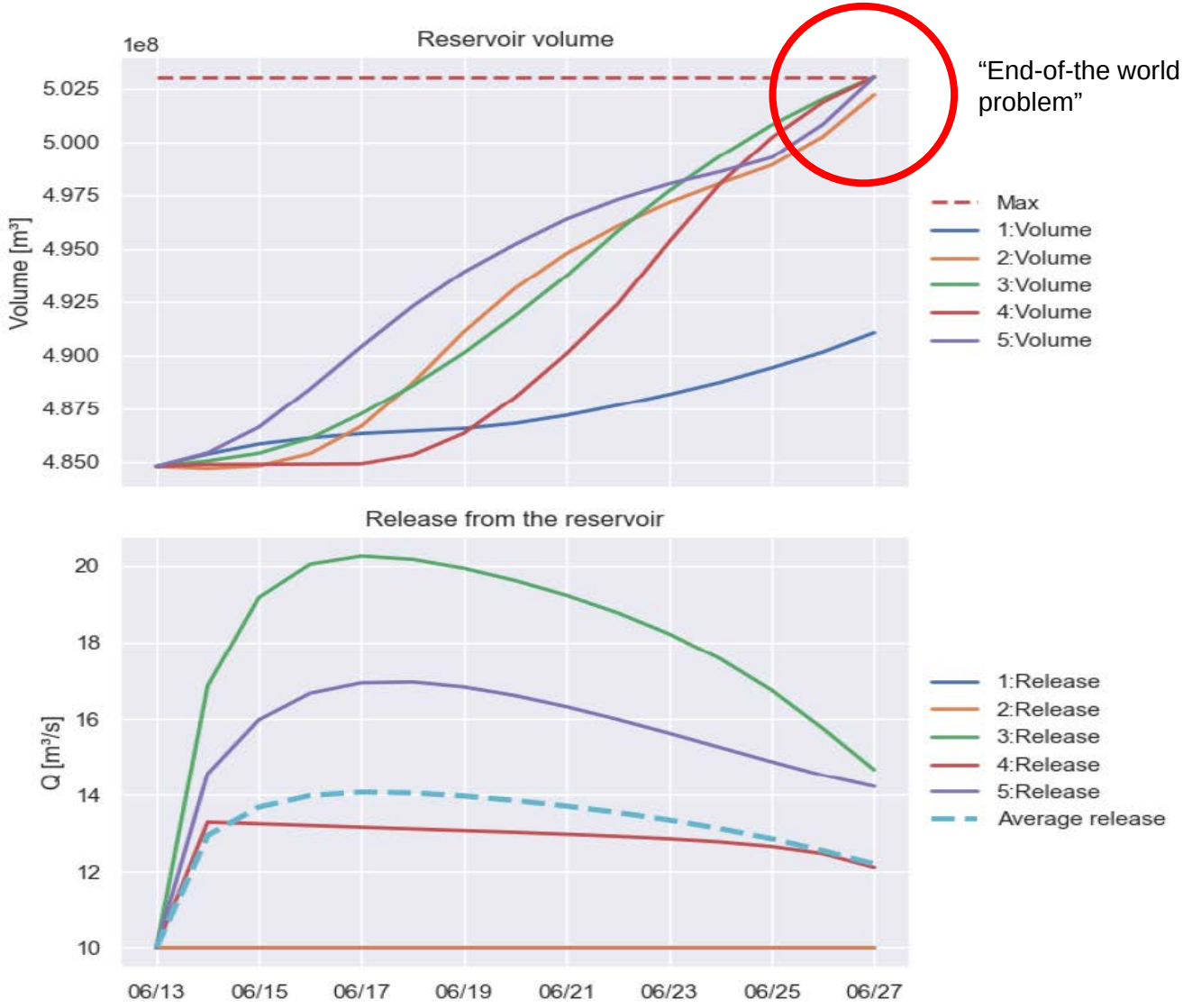
Uncertainty band

Automatic update with new ensemble forecast when available

Automatic simulation/optimization runs with new forecast

Ensemble forecast: Individual optimization





"End-of-the world problem"

- Decision support: Which release scheme to choose?
  - Average?
  - Min?
  - Max?
- Illustrates uncertainty and worst cases
- Points to possible bottle necks

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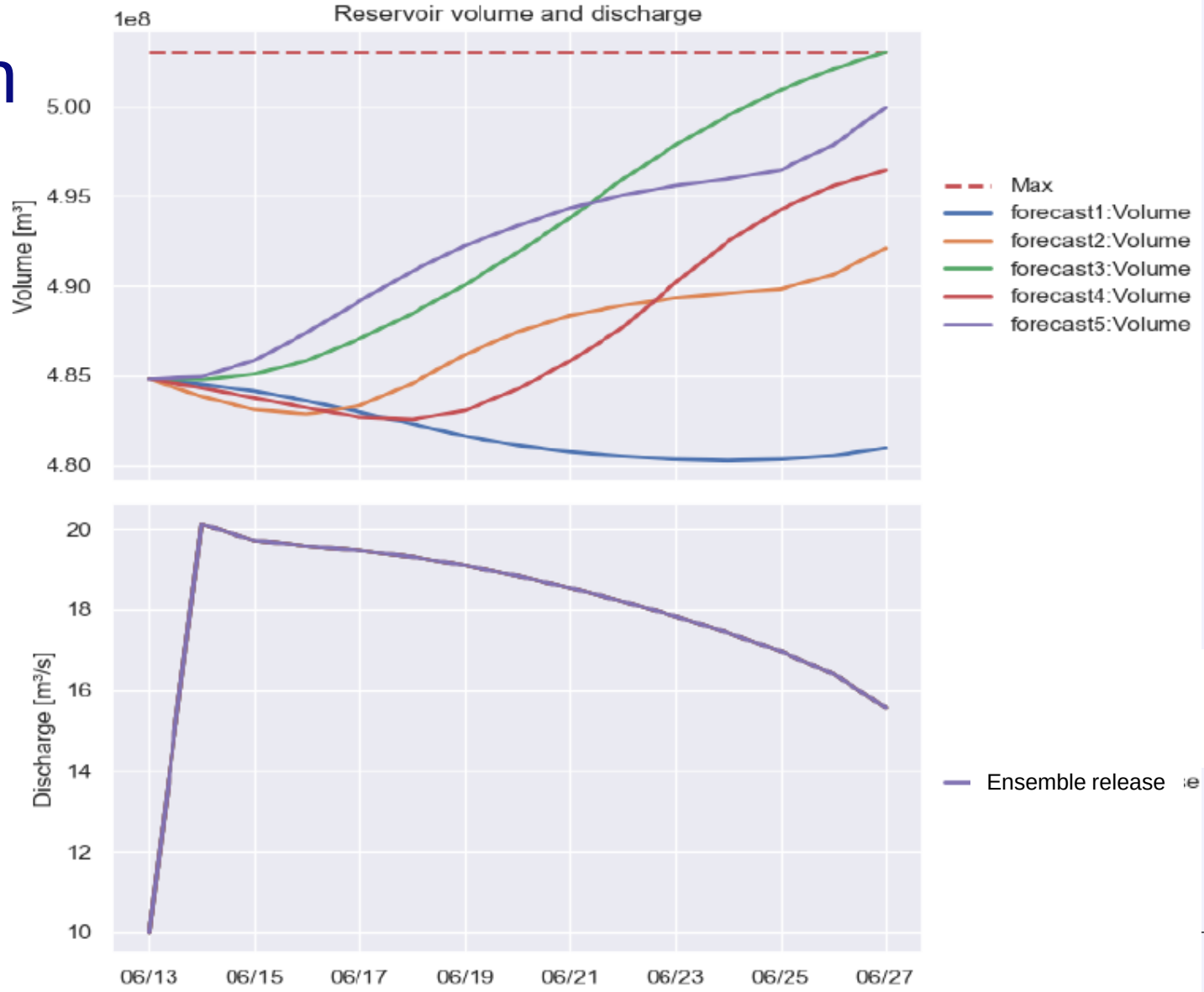
Ensemble forecast: Ensemble optimization

Functional principle:

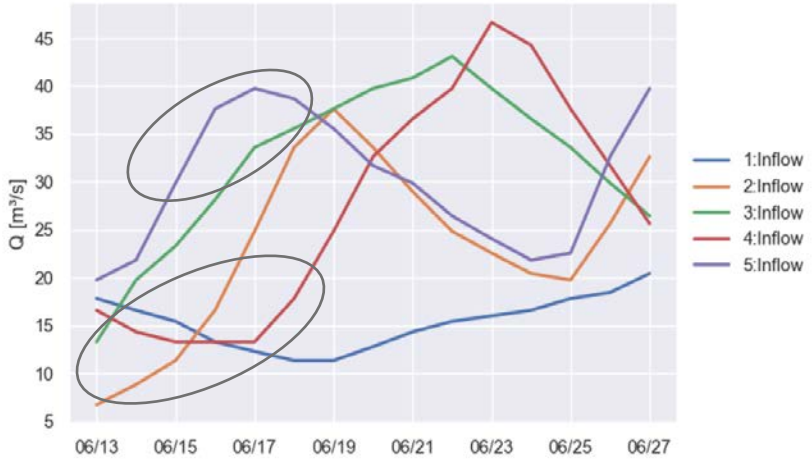
- Find a release scheme that fits for all ensemble members
- Optimal release for the (whole) ensemble

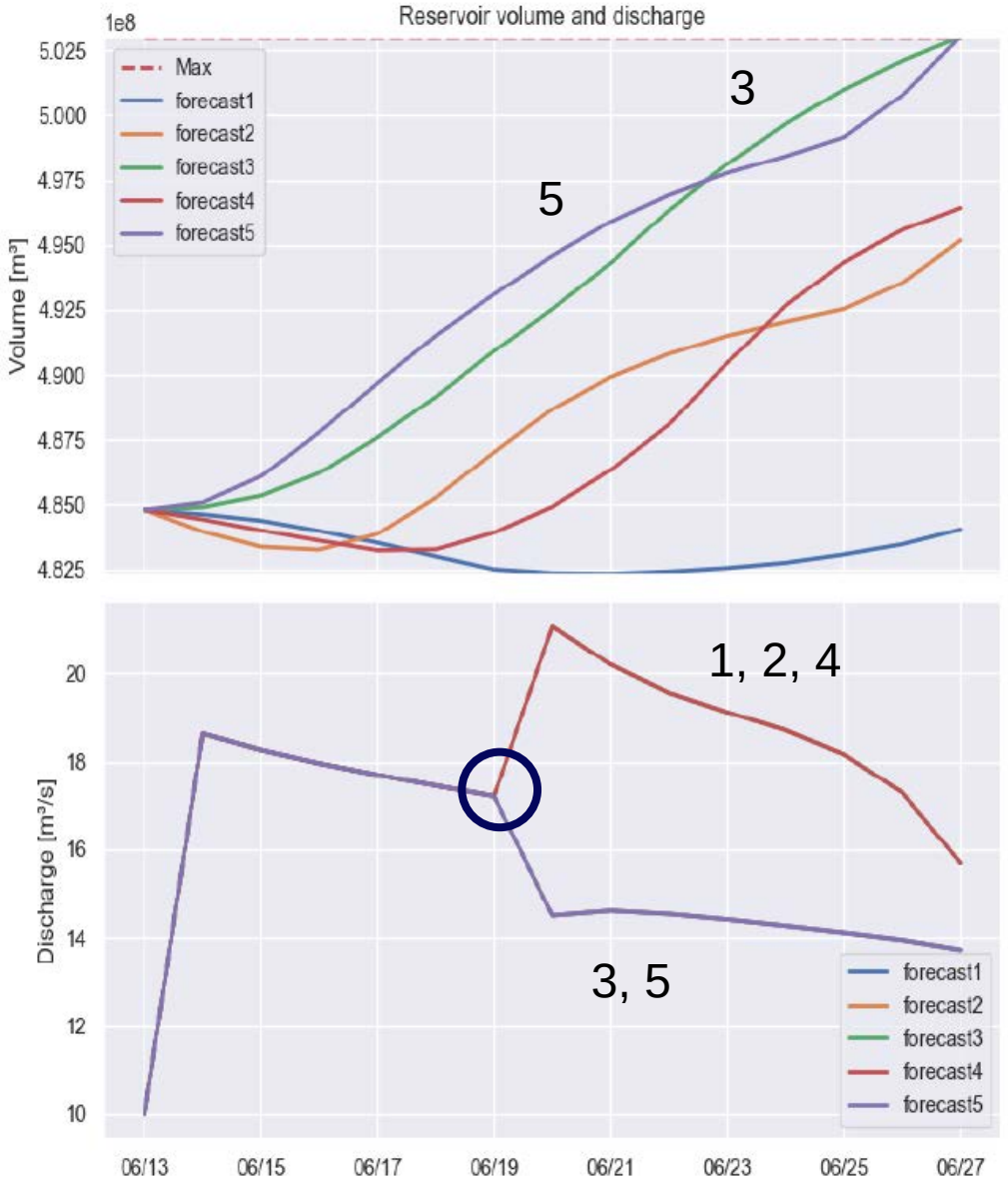
Output:

- One release scheme (decision support)
- Driven by the cumulative extremes (envelope) from the ensemble
- Conservative (“on the safe side”)



Ensemble tree optimization





Functional principle:

- Group similar ensemble members
- Optimize grouped ensemble members together until the next branching point

Output:

- One release scheme until the first branching point, different options for after the branching point
- Allows to postpone decisions while staying track with respect to operational goals and limits

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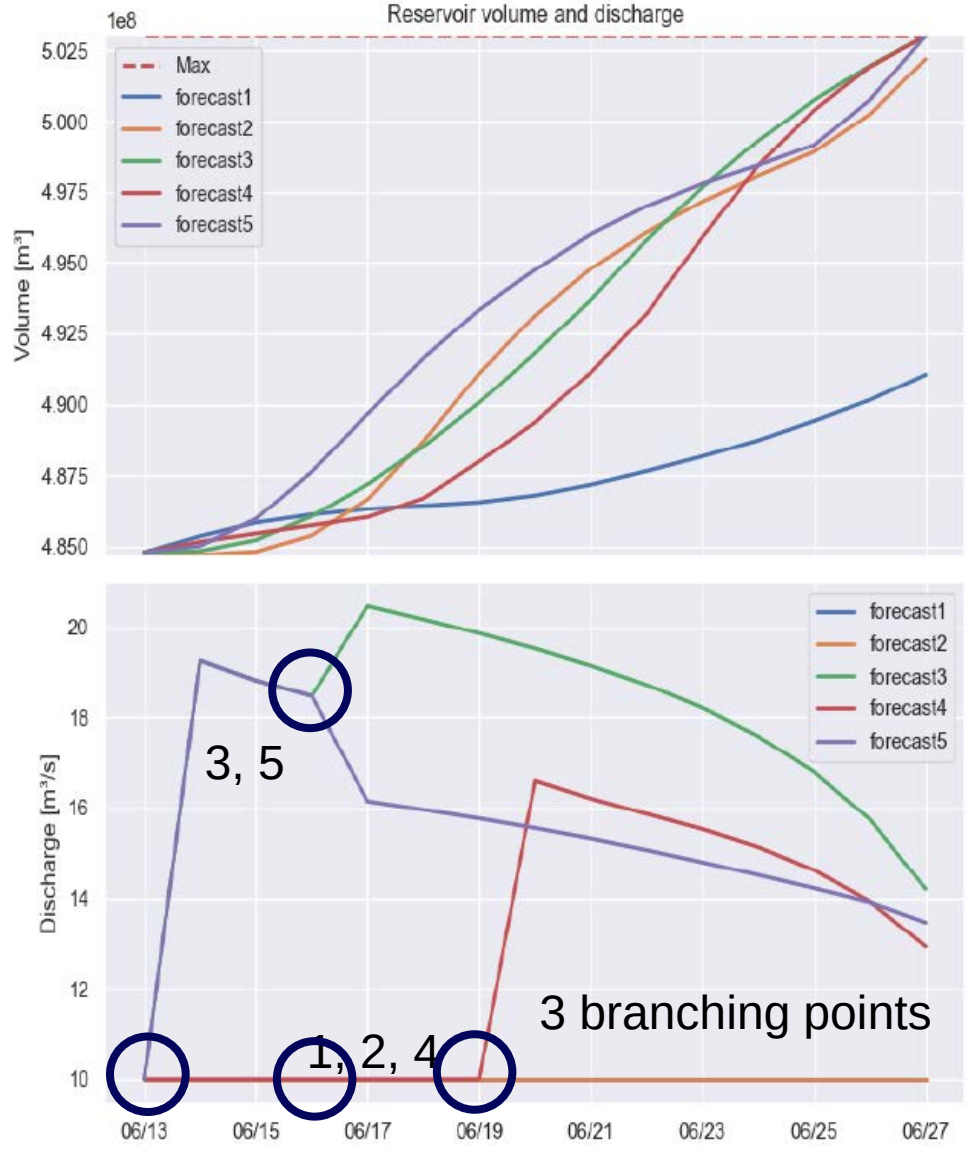
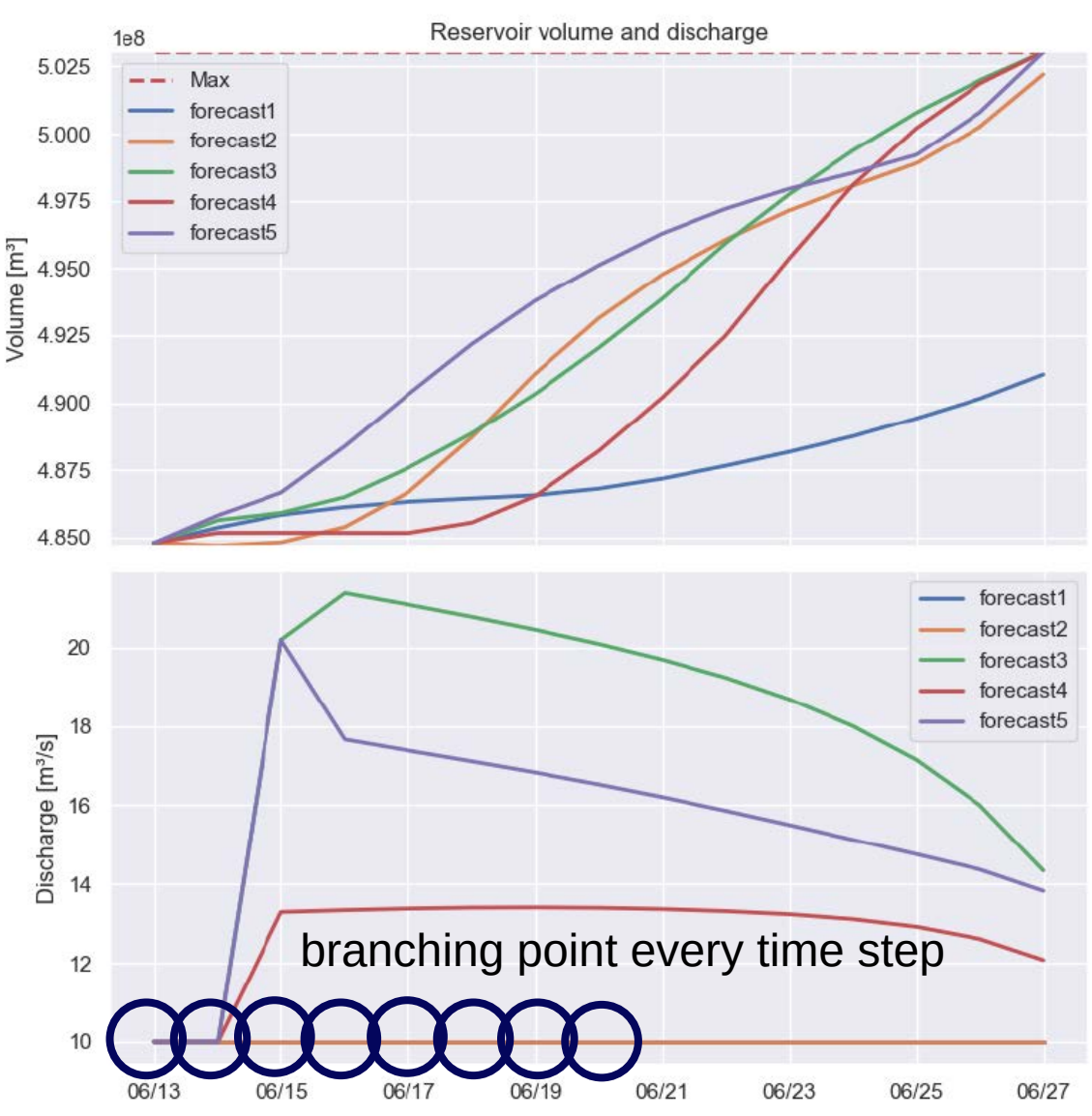
Ensemble tree optimization: more branching points

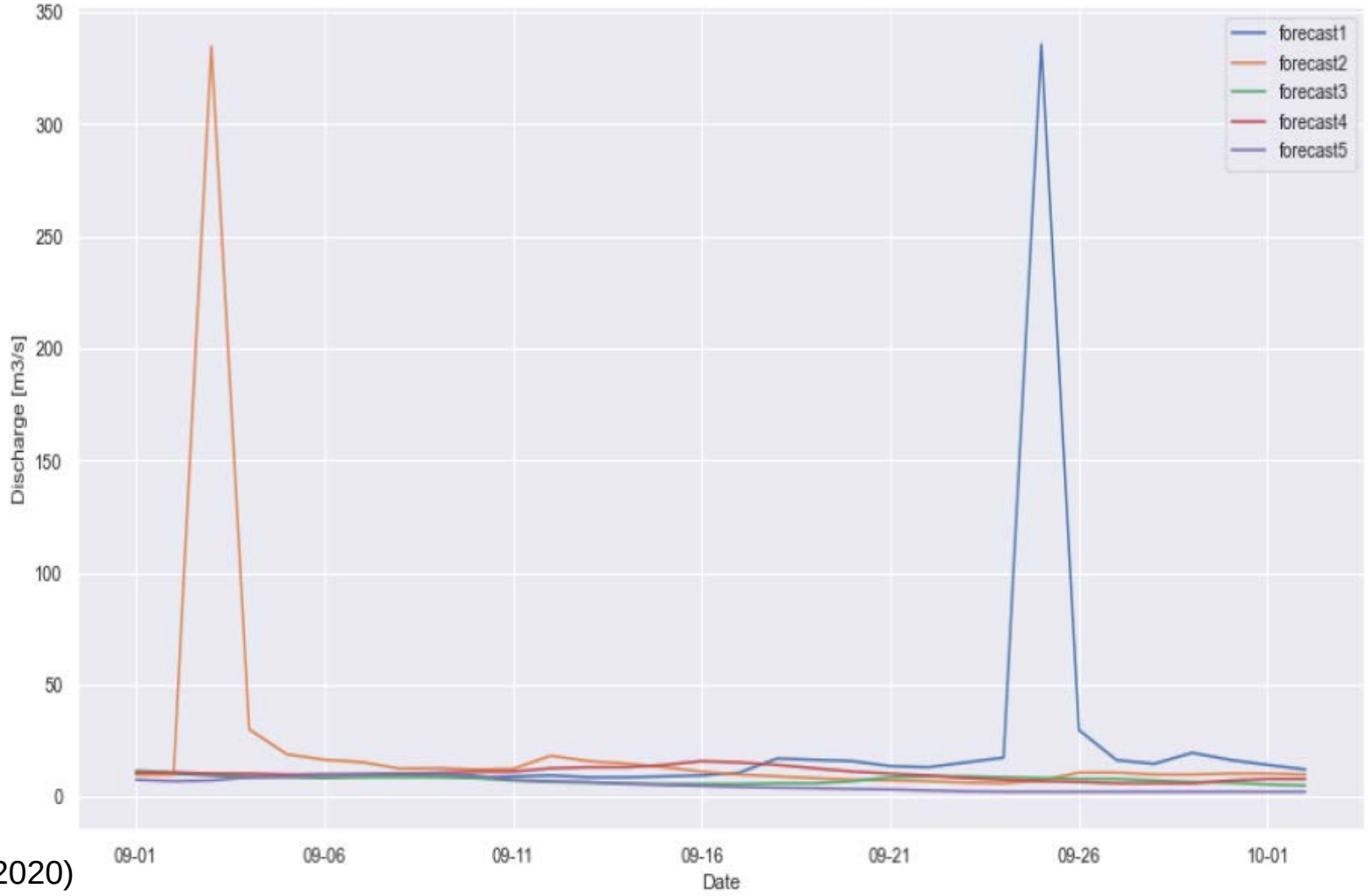




Jøkulhlaup: ensemble with ice-burst scenario

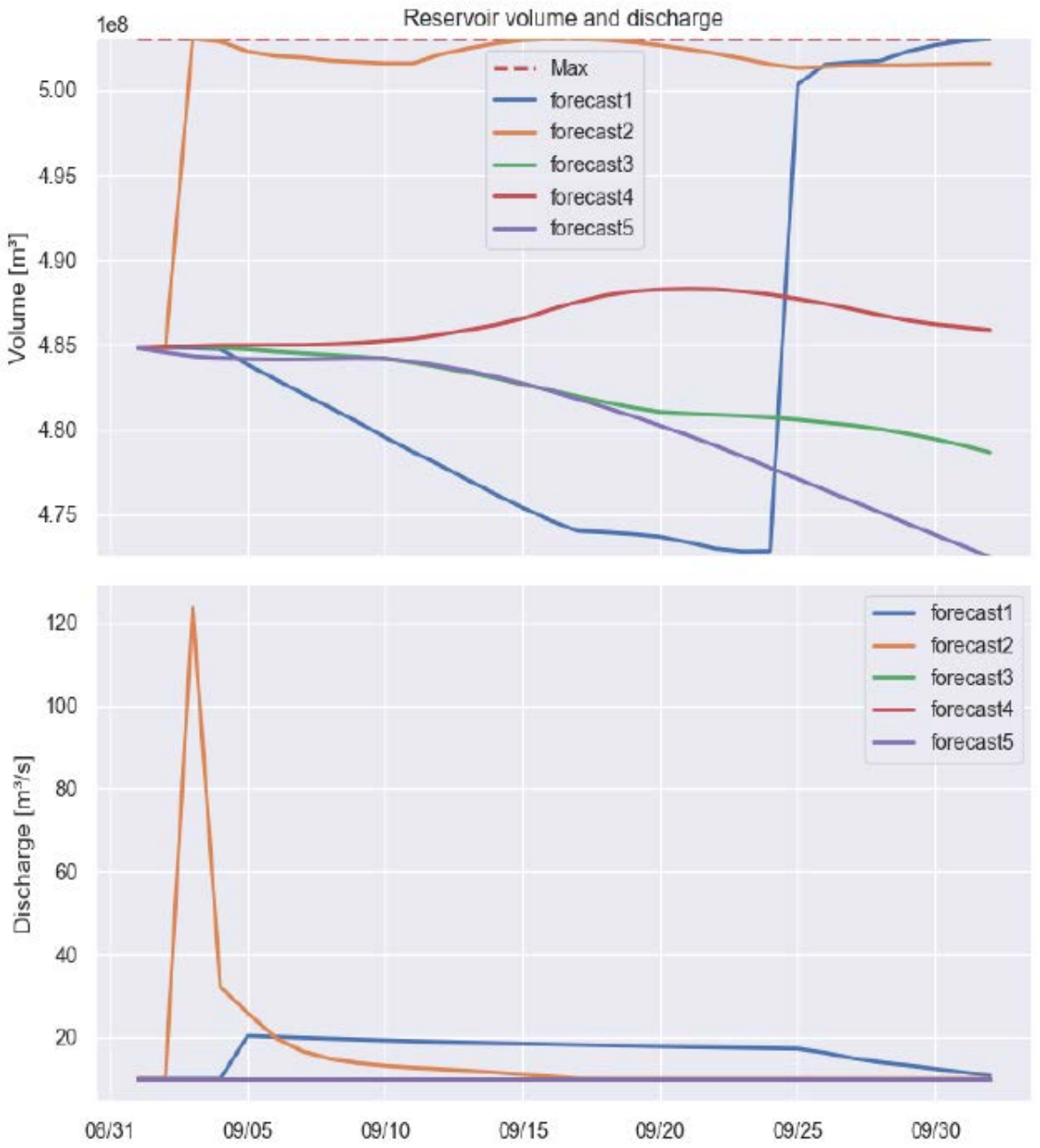
- Ensemble with 5 members
  - Three members with hydrological flood only
  - Two ice bursts
    - Early
    - Late

Inflow to Sisovatn (Photo: C. R. Amundsen, 2020)



Ensemble tree optimization with ice burst

- Branching point every time step
- Immediate action needed for scenario “early ice burst” (branch at first time step)
  - Large spill
  - Loss of water if the ice burst does not occur
- Late ice-burst provides a short lead time before decision for pre-release
- Pre-release moderate for late ice-burst
  - Comparatively low spill (hydropower)
- Here: ice burst probability 0.4 (2 in 5)



Summary

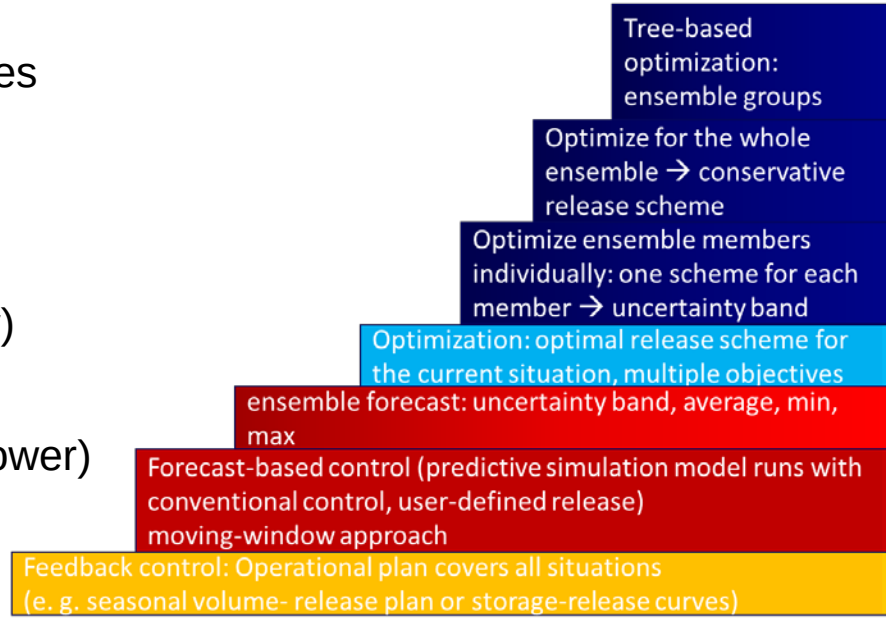
Methods for taking uncertainty into account in reservoir operations under flood conditions

- Moving window optimization
  - Accounts for limited forecast periods (5-14 days)
    - The longer the forecast horizon the better
- Ensemble optimization
  - Individual ensemble member simulation/optimization illustrates uncertainty, but does not suggest a clear decision
    - Proven technology
  - Ensemble optimization produces a conservative result
  - Tree-based optimization provides a decision support until a future point in time (branching point)
    - Number and position of branching points are important

Note: Optimization results shown are based on hindcast with historic values (assumption: forecast becomes truth, as forecasted)

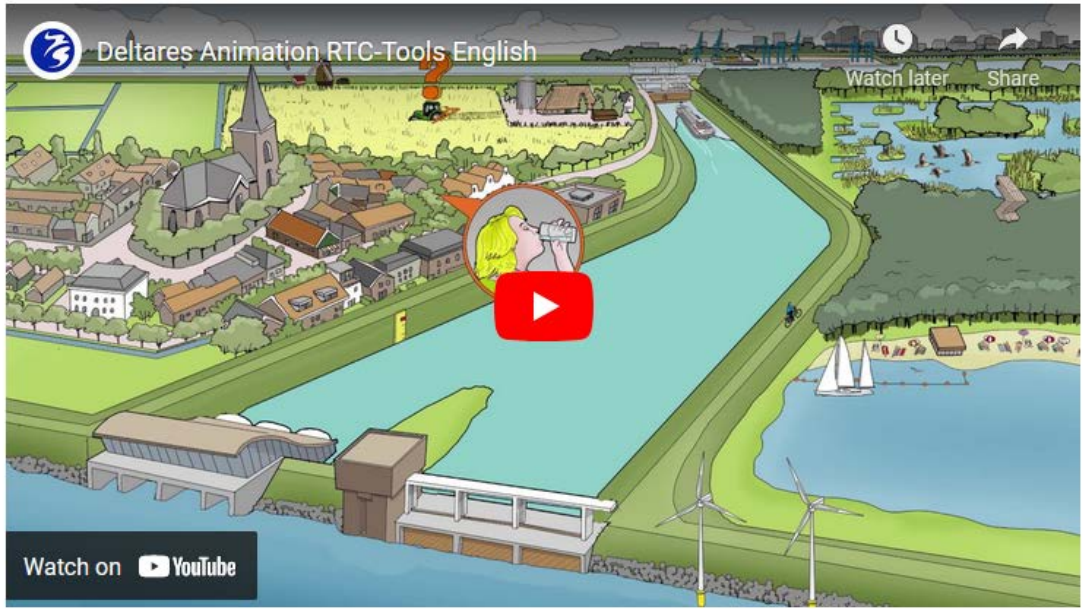
Outlook:

- Ice burst scenario
  - Can help for pre-release decision (loss of water versus dam safety)
  - Prediction/forecast of the ice burst?
- Added value of ensemble optimization for normal operations (hydropower) or low flow situations?

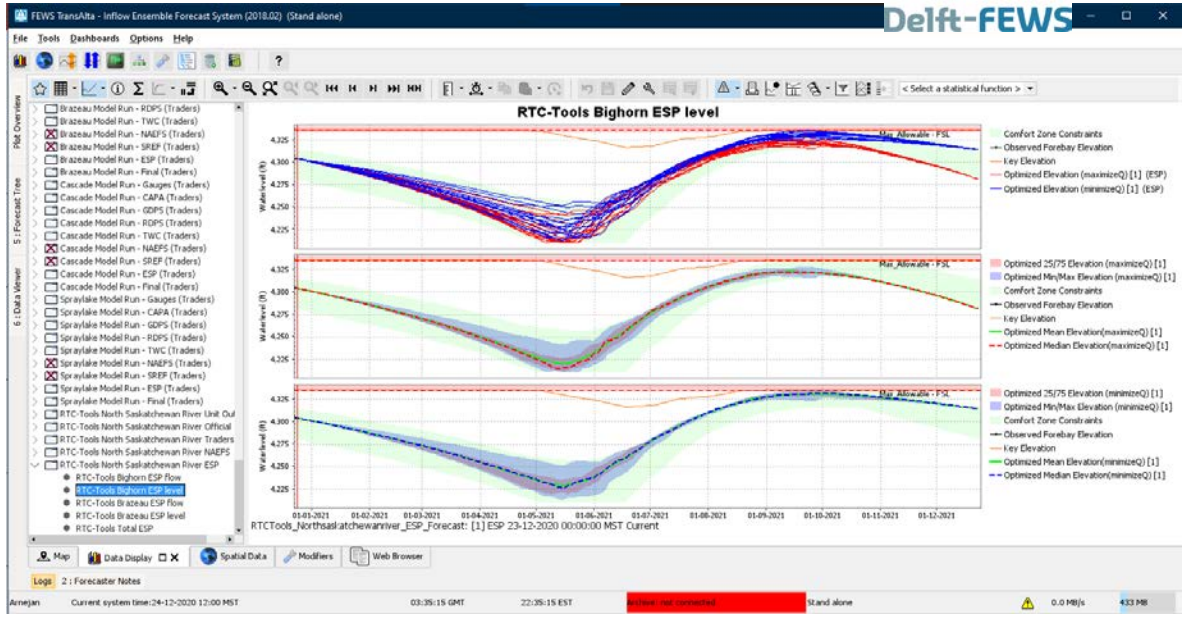


RTC-Tools

- A toolbox for (**r**eal-**t**ime) **c**ontrol and optimization of water systems
- Websites
  - https://www.deltares.nl/en/software/rtc-tools/
  - https://oss.deltares.nl/web/rtc-tools



- Open source
- Modelica-library with various flow equations
- Comes as Python package
- Conflict resolution with goal programming and weighting factors
- Ensemble optimization
- Integrates in Delft-FEWS for operational use



RTC-Tools optimization results in Delft-FEWS TransAlta (van Loenen & Fru, CEATI conference 2021)

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