



TECHNIEK
EN MANAGEMENT

Internationale RTC- toepassingen

Dr. Dirk Schwanenberg (Deltares)





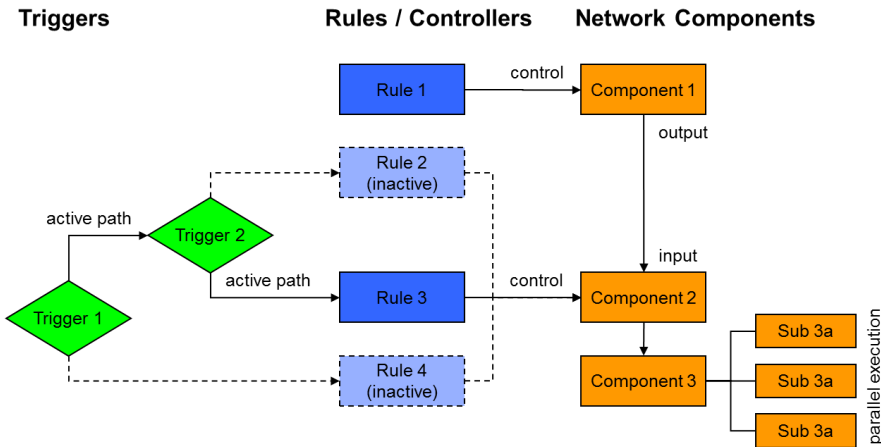
RTC Applications Abroad

- Control of hydraulic structures in hydraulic models
- Simulation of reservoirs and reservoir systems by operating rules (feedback / feed-forward based on observed data)
- Short-term management of multi-objective reservoir systems by deterministic and stochastic optimization as decision-support for
 - hydropower,
 - flood mitigation,
 - water supply and irrigation,
 - recreation, etc.

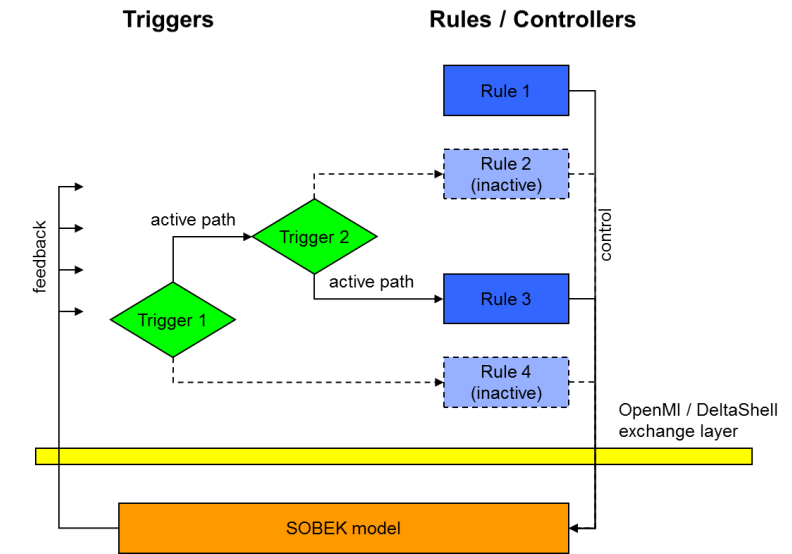
Control of hydraulic structures in hydraulic models

- Novel technical framework at Deltares: D-RTC with the core RTC-Tools as control module for hydraulic models (SOBEK, Delft3D Flexible Mesh)
- Applications
 - Cascades of run-of-the-river hydropower plants and related weirs, e.g. Rhine tributaries such as Mosel, Nahe and Main
 - Intake structures for irrigation and water supply
 - Control of flood detention polders
 - Control of hydraulic structures in urban water systems including sewers

Control of hydraulic structures in hydraulic models (2)

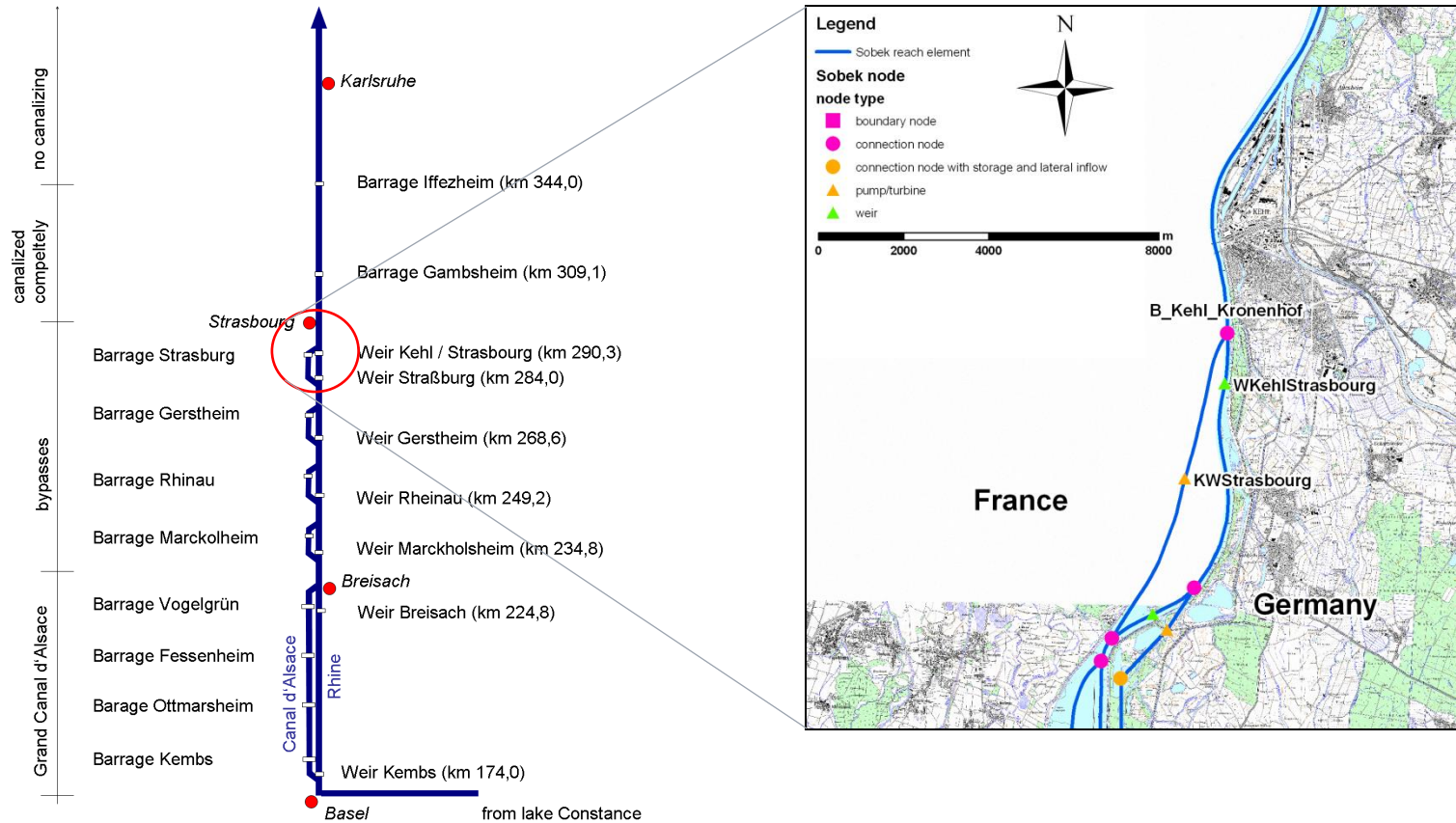


RTC of embedded model



RTC of coupled model

Case: Rule-based Control of the Upper Rhine along the German-French Border

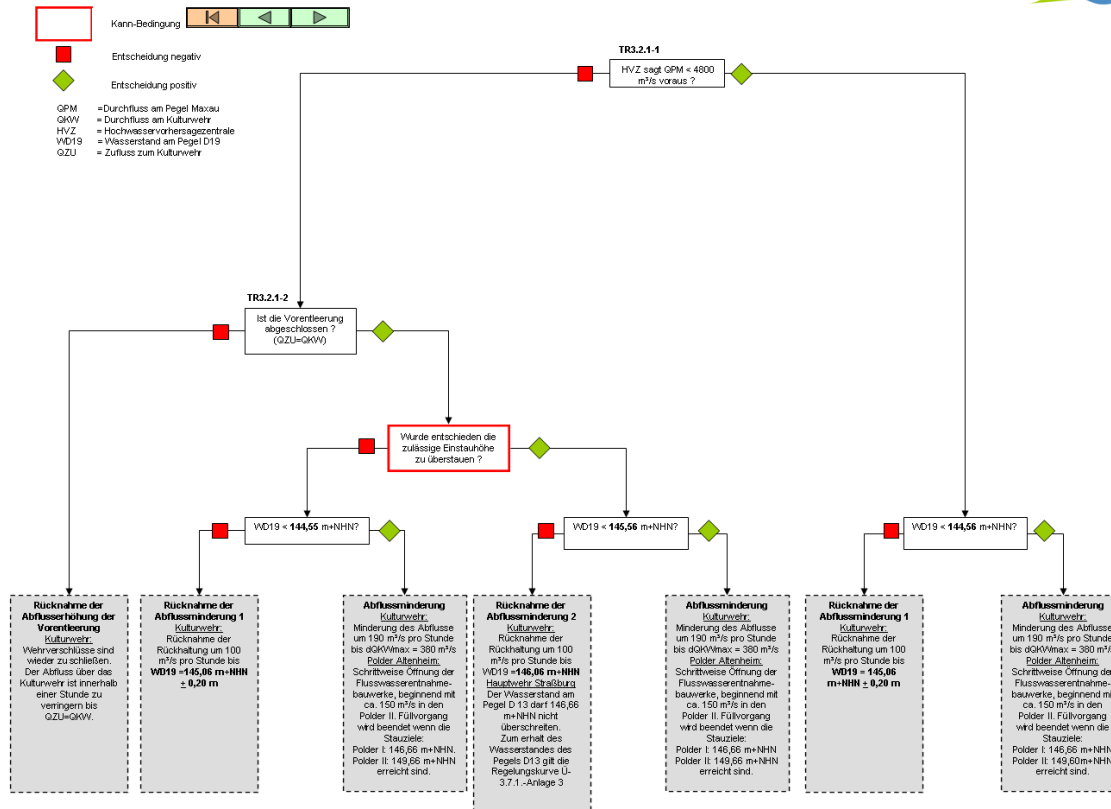


Case: Rule-based Control of the Upper Rhine along the German-French Border (2)

- Heavily-modified reach of River Rhine between the cities of Basel and Karlsruhe
- Main objectives of river training measures have been navigation and hydropower generation
- Major ongoing efforts to construct controlled flood mitigation polders to compensate negative aspects of the training measures
- Sophisticated operation procedure developed by the German and French authorities and stakeholders
- OpenMI-coupled pilot model of SOBEK 2 and RTC-Tools to model the operating rules by approx. 150 triggers and 400 controllers for German Federal Institute of Hydrology

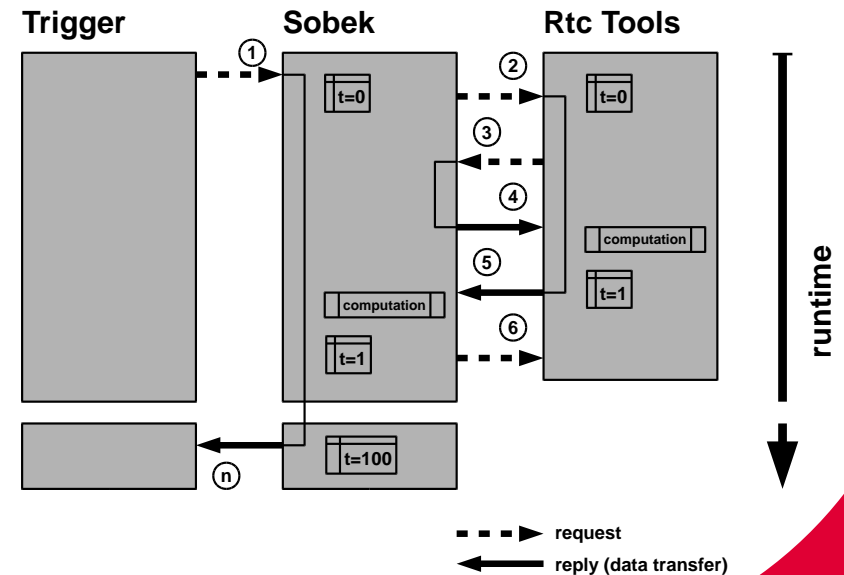
Case: Rule-based Control of the Upper Rhine along the German-French Border (3)

EB 3.2.1 Entscheidungsbaum HWR-Betrieb Kulturwehr Kehl/Straßburg

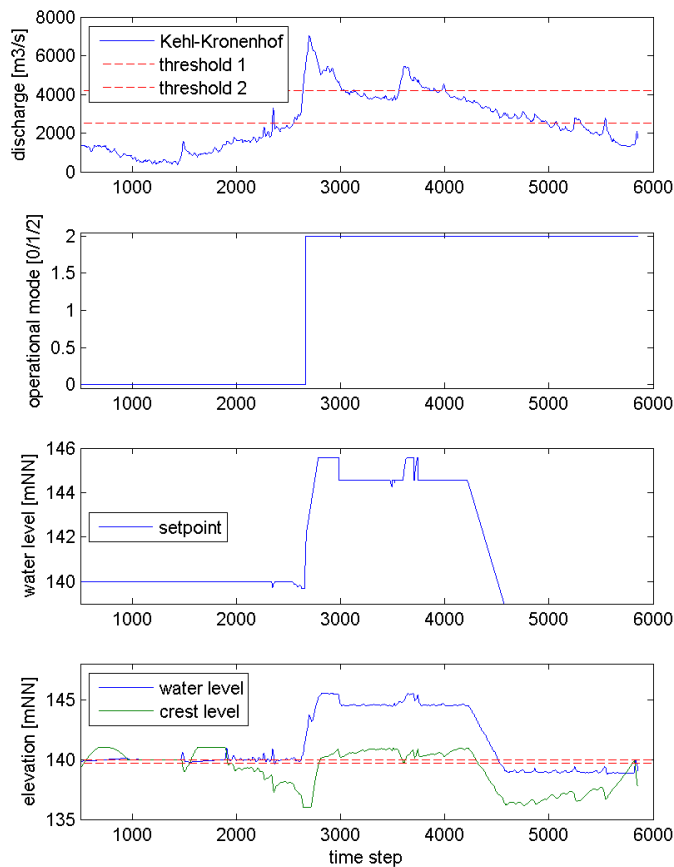


Case: Rule-based Control of the Upper Rhine along the German-French Border (4)

- OpenMI coupling of Sobek 2 and RTC-Tools makes all feedback feature of RTC-Tools available in Sobek
- D-RTC in Sobek 3 currently supports only a subset of the available features
- GUI / D-RTC support of additional features will be made available in the future (on user request)



Case: Rule-based Control of the Upper Rhine along the German-French Border (5)



- Feasibility study approves the validity of the modeling concept
- Post-processing and visualization is still based on dedicated scripts
- Further integration into DeltaShell and related scripting support will facilitate those developments in the future

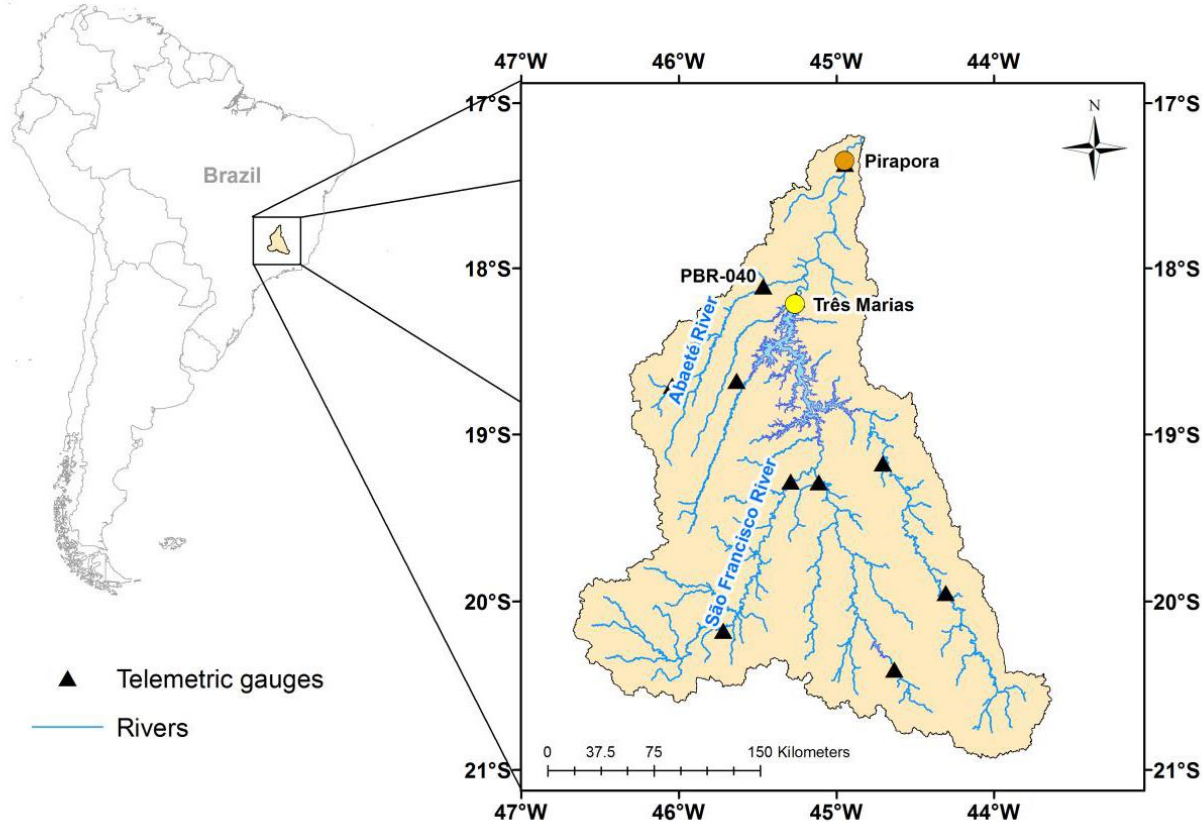
Case: Flood Mitigation in Reservoirs

Tres Marias Reservoir in Brazil

- Multi-purpose reservoir in the Brazilian state of Minas Gerais
- Power generation / release trajectories by the national grid coordinator ONS during normal operating conditions
- Reservoir operation by the owner CEMIG during flood events to mitigate flood damages downstream of the reservoir, in particular in the city of Pirapora
- Hydrological model and decision support component for Tres Marias reservoir are part of the operational forecasting system of CEMIG
- Special attention on forecast uncertainty and robust decision making by stochastic optimization

Case: Flood Mitigation in Reservoirs

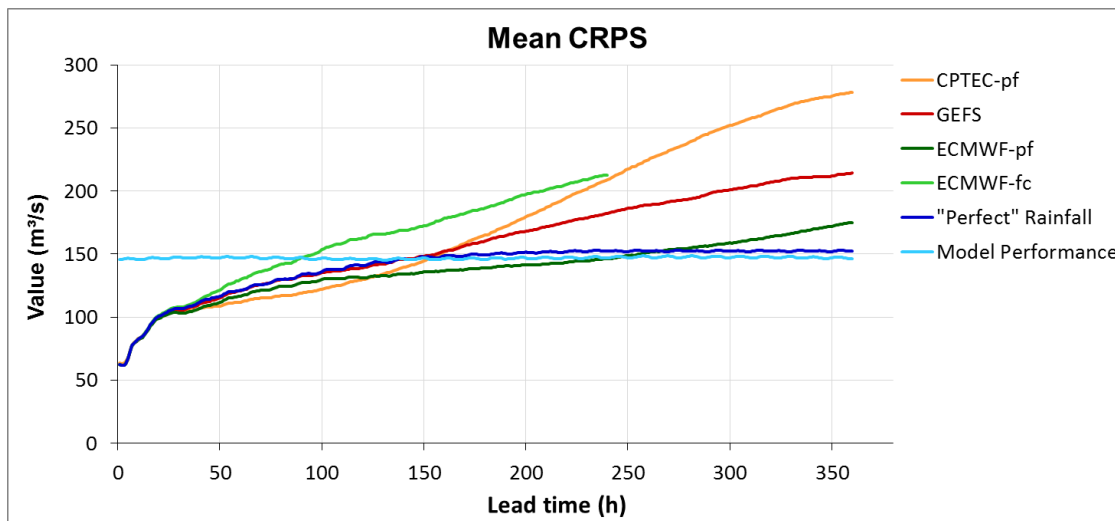
Tres Marias Reservoir in Brazil (2)



Case: Flood Mitigation in Reservoirs

Tres Marias Reservoir in Brazil (3)

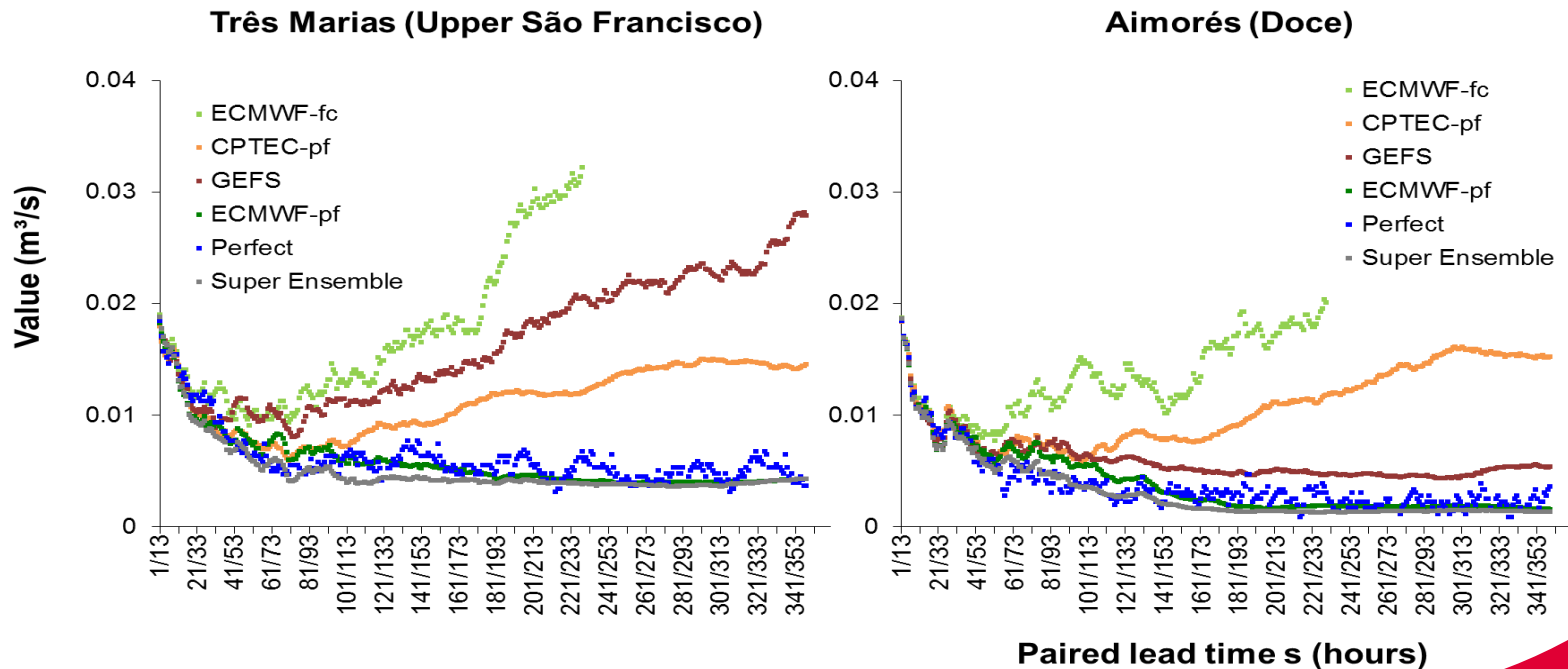
- Assessment of the forecast skill of several meteorological products in combination with the hydrological model MGB-IPH
- Assumption: better and longer forecast leads to better decisions



Case: Flood Mitigation in Reservoirs

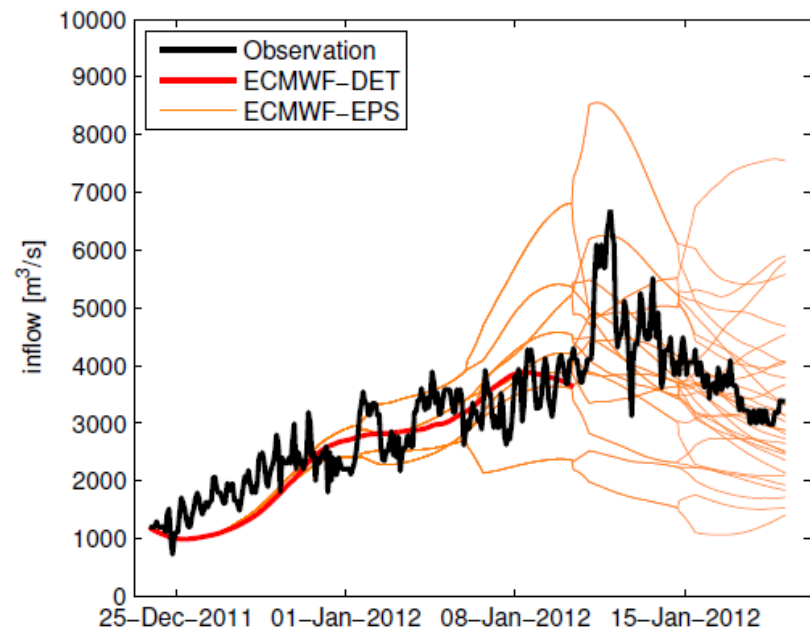
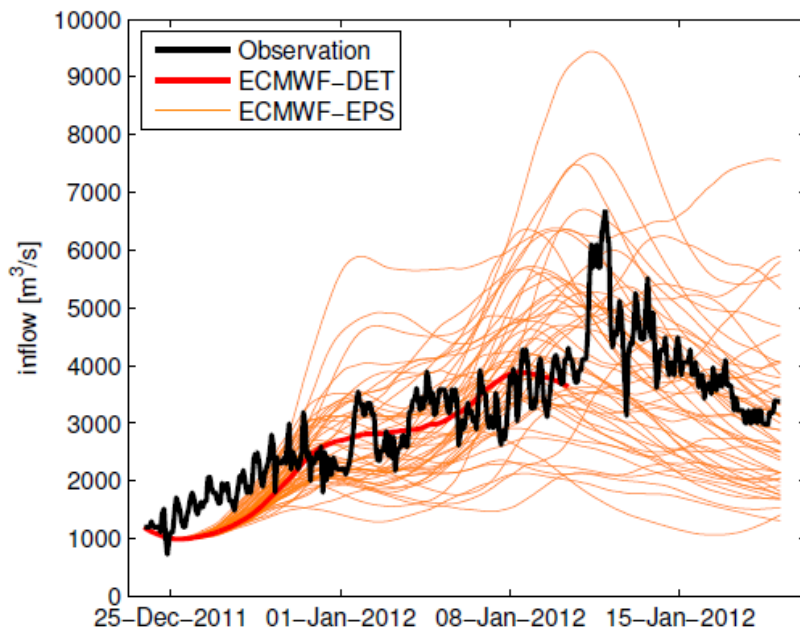
Tres Marias Reservoir in Brazil (4)

- Forecast Convergence Score addresses the stability of subsequent forecasts leading to more stable decisions



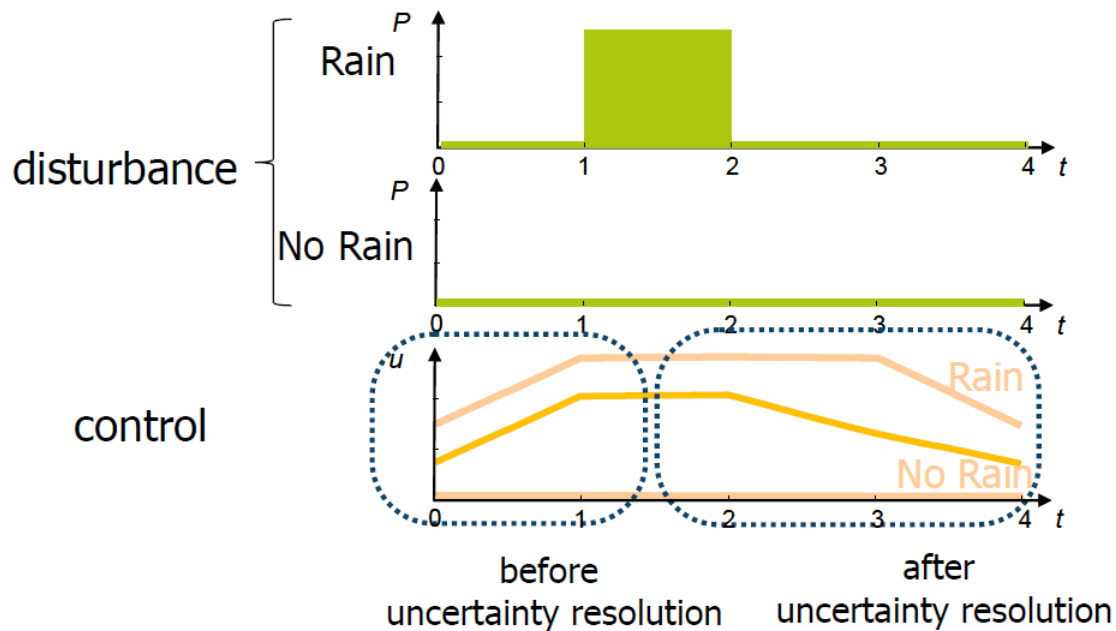
Case: Flood Mitigation in Reservoirs Tres Marias Reservoir in Brazil (5)

- Probabilistic forecasts get reduced to scenario trees as input for multi-stage stochastic optimization algorithms



Intermezzo: Robust Decisions by Stochastic Optimization

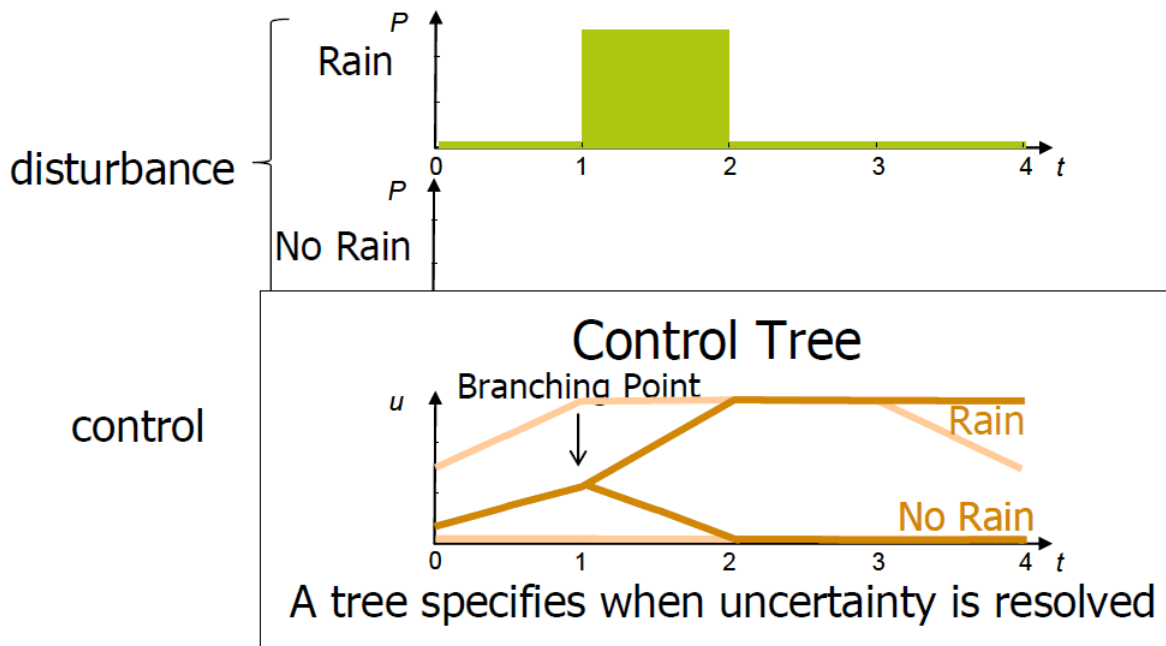
Decision Uncertainty Resolution Decision



Once uncertainty is resolved, it is possible to adopt the control strategy optimal to the remaining scenario !!!

Intermezzo: Robust Decisions by Stochastic Optimization (2)

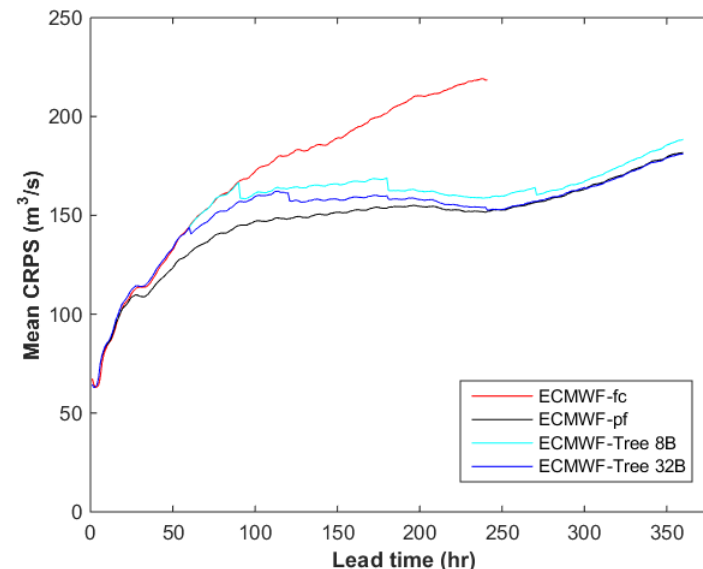
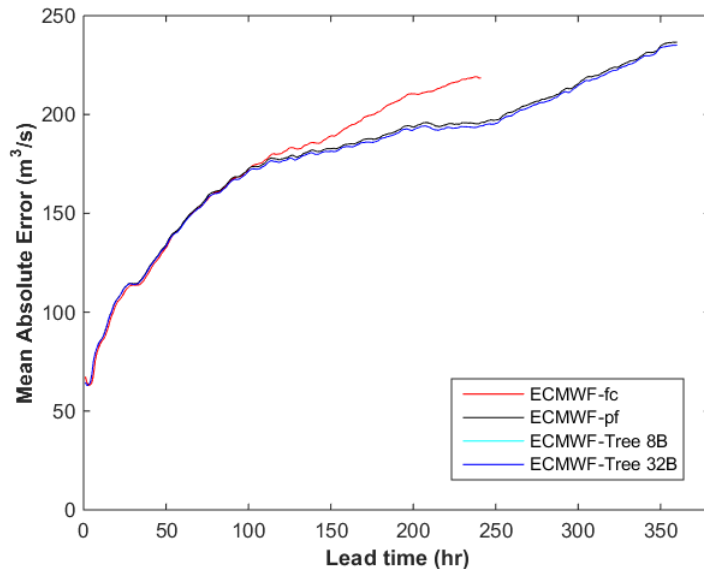
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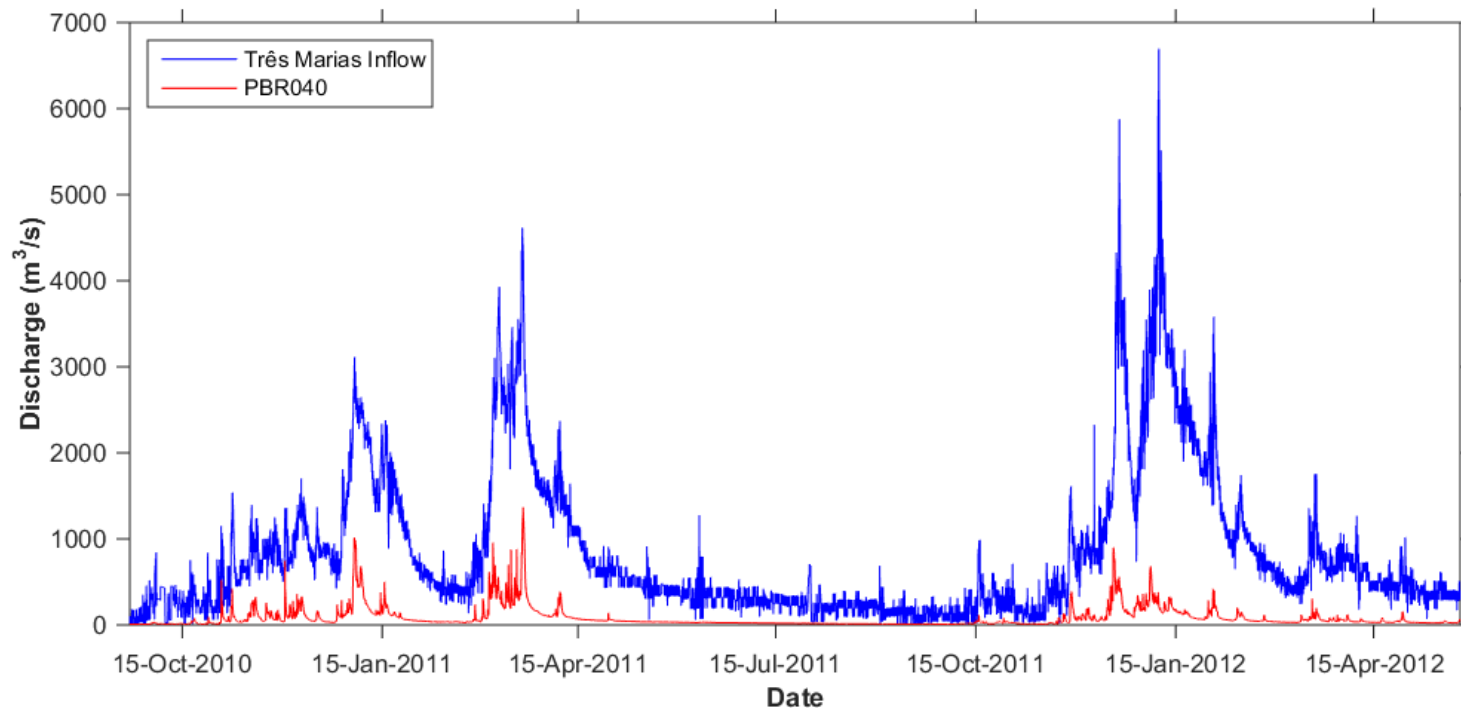
Case: Flood Mitigation in Reservoirs Tres Marias Reservoir in Brazil (6)

- Forecast skill of the ECMWF/MGB streamflow forecast: comparison of deterministic and probabilistic (ensemble) forecast and the derived scenario tree with 8 and 32 branches

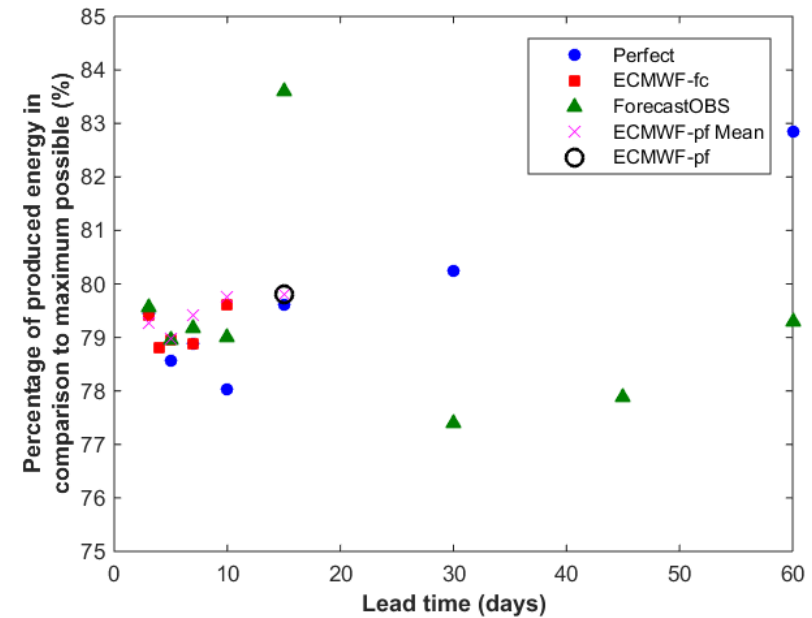
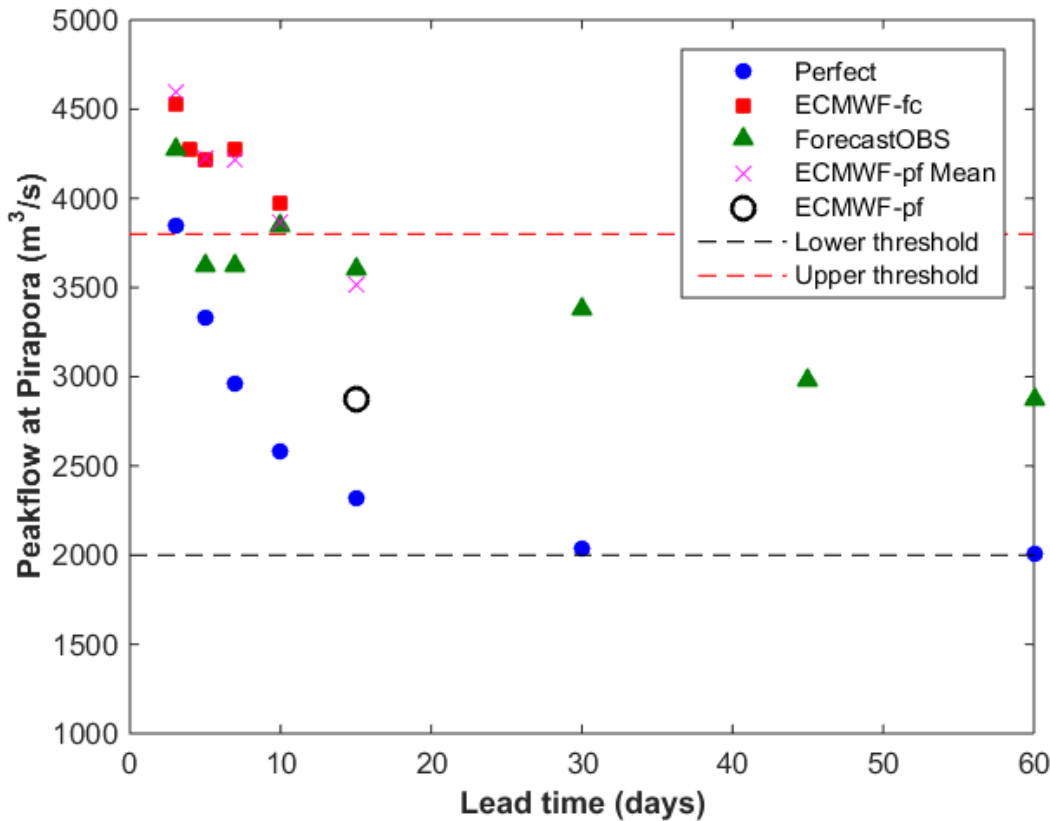


Case: Flood Mitigation in Reservoirs Tres Marias Reservoir in Brazil (7)

- Hydrograph of Tres Marias inflow and main downstream tributary (PBR040) in the reach to Pirapora



Case: Flood Mitigation in Reservoirs Tres Marias Reservoir in Brazil (8)



Case: Flood Mitigation in Reservoirs Tres Marias Reservoir in Brazil (9)

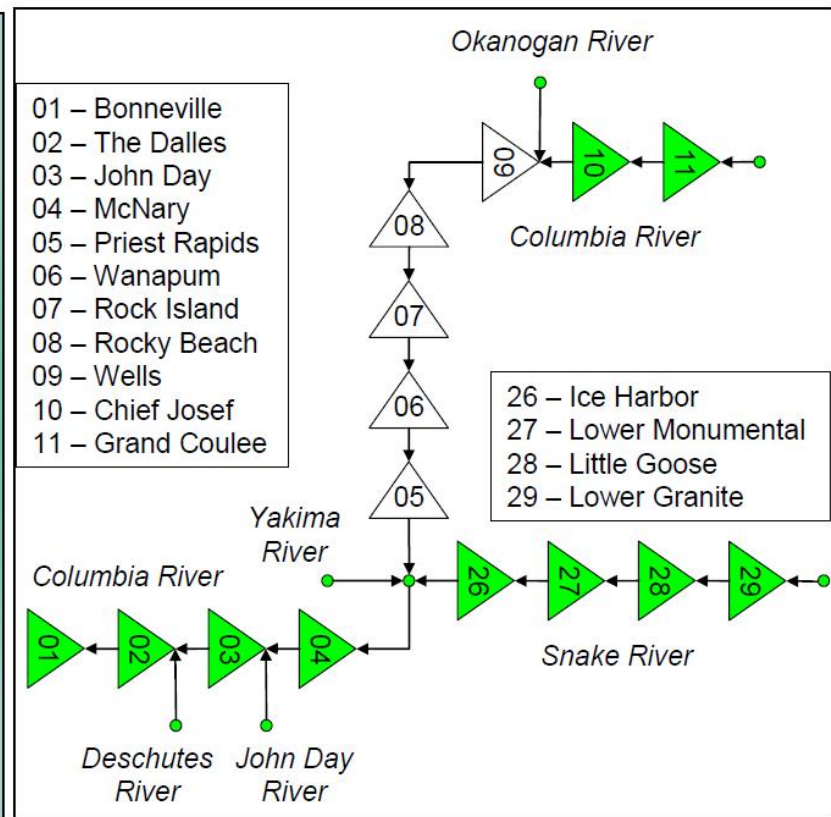
- Significant benefit of the probabilistic forecast in combination with a stochastic optimization
 - Much better flood protection
 - Almost no impact on power generation
- Decision support runs in production mode at CEMIG since early 2016 for 12 reservoirs of which 5 of the single reservoirs operate in stochastic optimization mode
- Further research will focus on the bias correction of the meteorological forecasts and the roll-out of the stochastic optimization approach



Case: Short-term Management of Hydropower Projects (HYPRM)

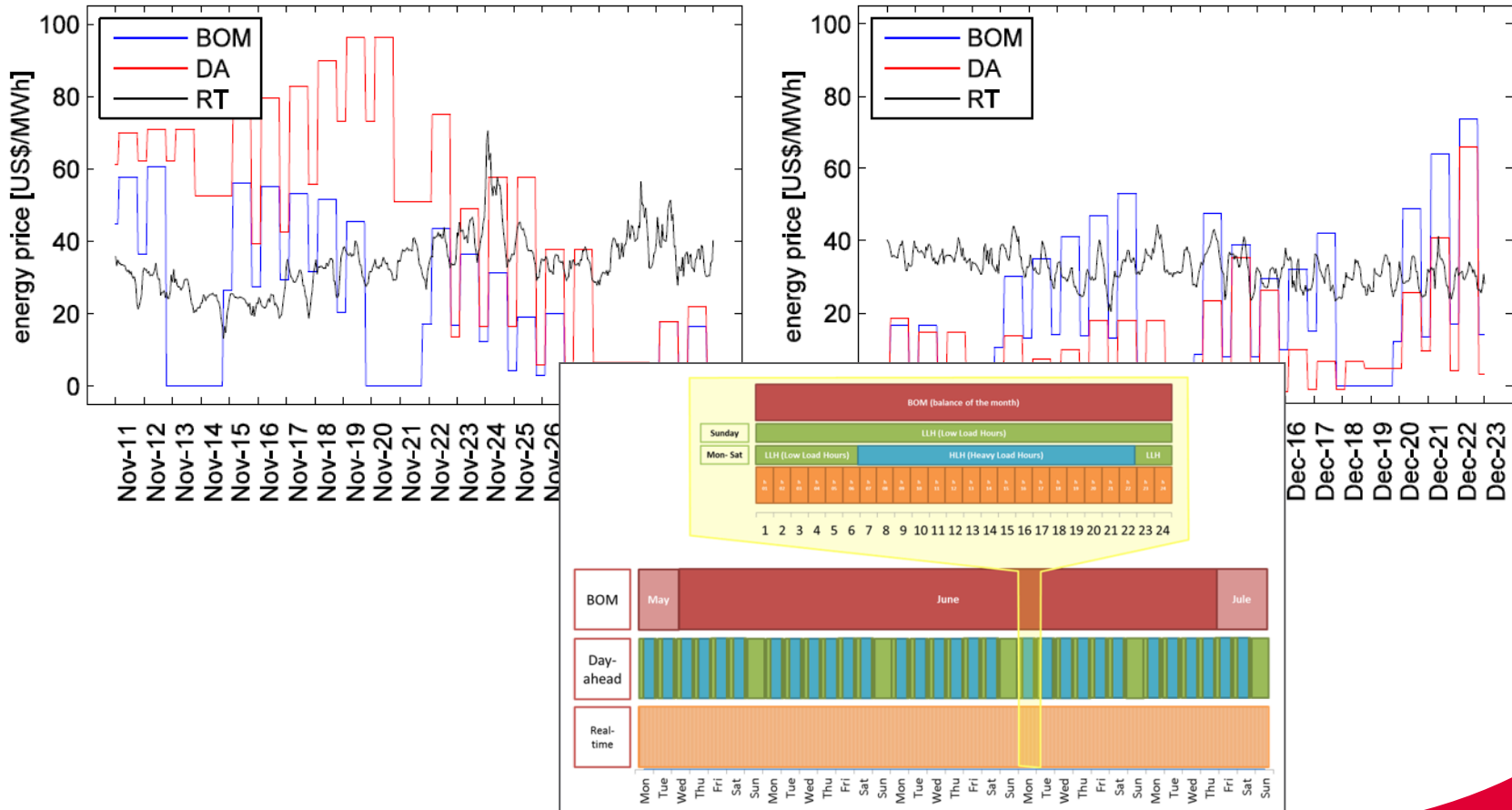
- Short-Term Hydropower Production and Marketing Optimization (HyProM), Technology Innovation project for Bonneville Power Administration (BPA)
- BPA manages an installed hydropower capacity of 22,000 MW in the Pacific northwest of the USA
- Innovations:
 - Integrated short-term management of hydropower production and marketing over a forecast horizon of 21 days
 - Evolution from deterministic to stochastic optimization
 - Development of tools for integrated management of scenarios of streamflow, wind generation and load and meteo-related uncertainty

Case: Short-term Management of Hydropower Projects (2)

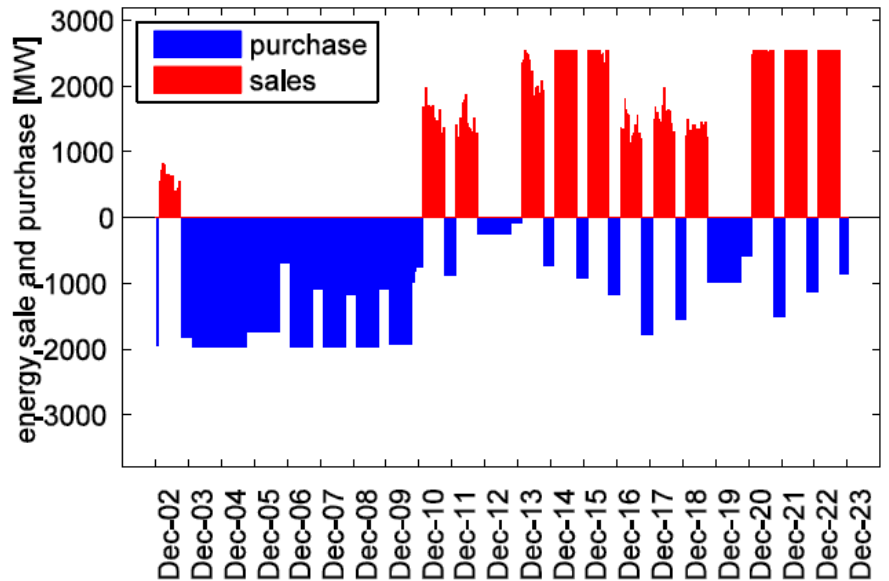
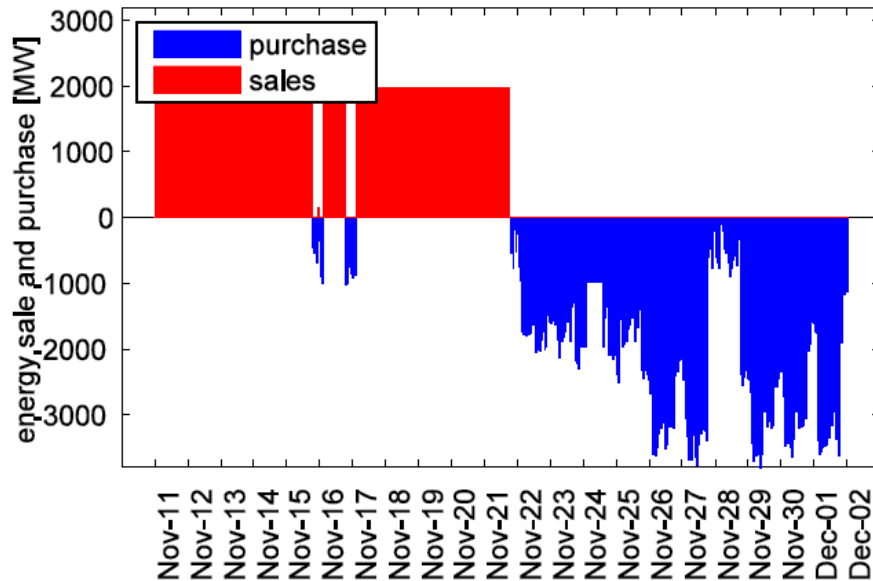


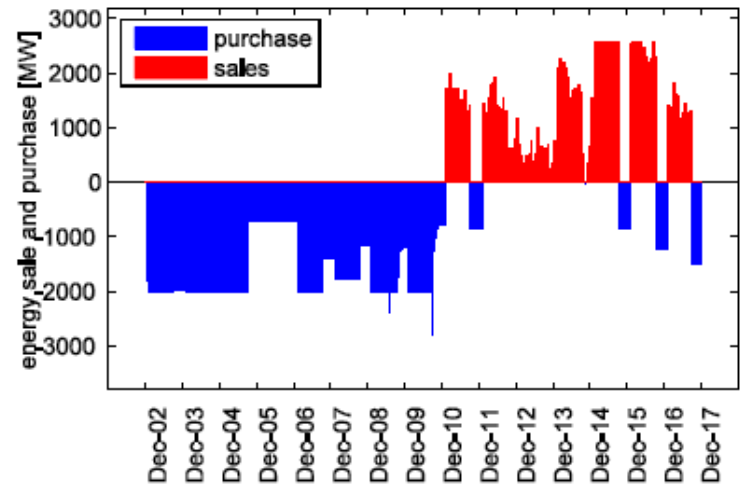
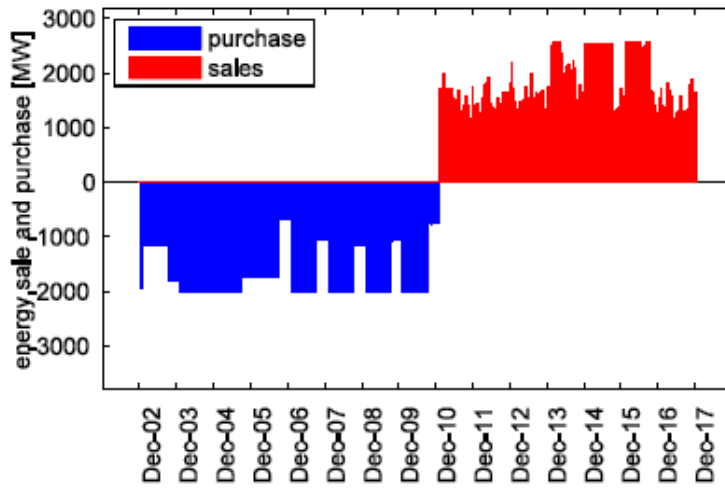


Case: Short-term Management of Hydropower Projects (3)



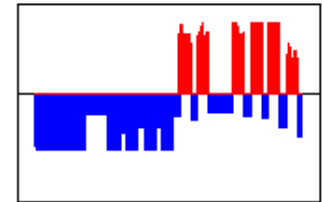
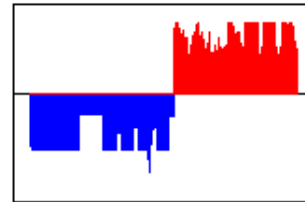
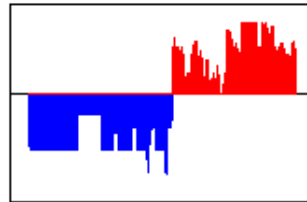
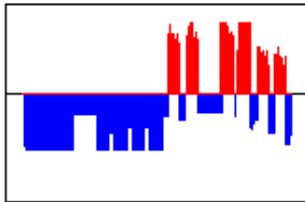
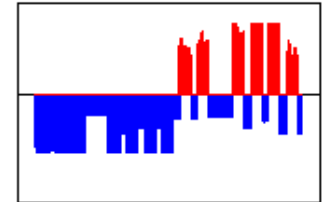
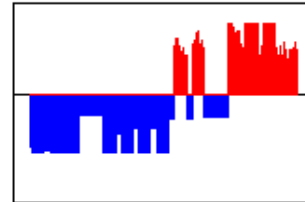
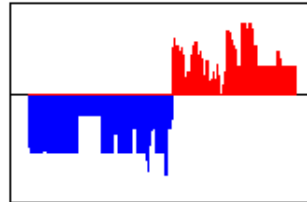
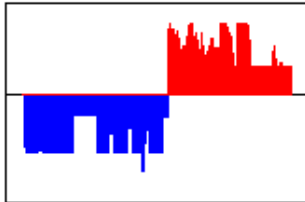
Case: Short-term Management of Hydropower Projects (4)





a)

b)





Case: Short-term Management of Hydropower Projects (6)

- Scenario tree propagates the meteorological uncertainty through the hydropower reservoir system
- Constraints enable the user to direct the uncertainty to
 - the reservoir system (variability appears as spread of forebay elevations)
 - or to the energy market.

Outlook NL

Hoe profiteren NL waterbeheerders hiervan?

- Breed gebruik van Deltares software → meer robuustheid
- Uitbreiding van model bibliotheek en RTC functionaliteiten
- Performance verbeteringen: HSL solver, hard constraints, 2^e order afgeleiden (binnenkort)
- Ontwikkeling nieuwe technieken als *multi-stage stochastic optimization* en *multi-objective optimization*

Actuele innovatieprojecten in NL

- TKI project “Multi-stage Stochastic and Robust Optimization of Flood Mitigation Measures under Forecast Uncertainty” (Dirk Schwanenberg): Fundamenteel onderzoek naar onzekerheid in voorspellen en getrapte optimalisatie
- TKI project “Rekenen aan Slim Water Management” (Klaas-Jan van Heeringen): vervolg op bovenstaande, brede toepassing van korte termijn optimalisatie bij 4 waterbeheerders
- “Water-Energy-eXchange” (WEX) (Ivo Pothof + KJvH): optimalisatie van energieverbruik (CO₂ en kosten) in NL waterbeheer, in samenwerking met energieleveranciers