HYDROMETEOROLOGICAL ENSEMBLE PREDICTIONS IN SWITZERLAND: USING STREAMFLOW FORECASTS TO IMPROVE HYDROPOWER RESERVOIR OPERATIONS

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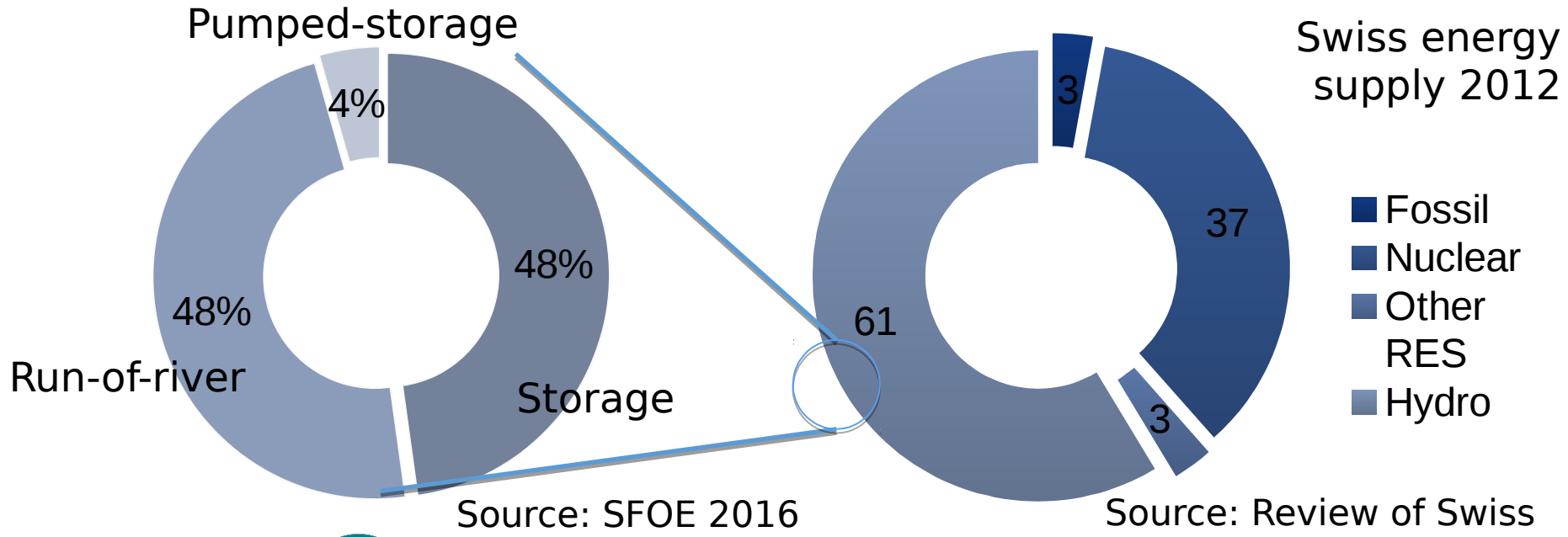
• Energy background in Switzerland

- Energy strategy 2050
  - *nuclear phase out ✉ towards renewable energy system*
- Innovative approaches to address energy consumption
  - *ensure energy supply and increase efficiency*
- 8 Swiss Competence Centers for Energy Research:
  - *Energy supply, Mobility, Storage, Biofuels, Infrastructure, Buildings, industrial processes, energy consumption*

✉Can we increase the efficiency of hydropower plants by providing sub-seasonal ensemble hydrometeorological forecasts?

Hydropower in Switzerland

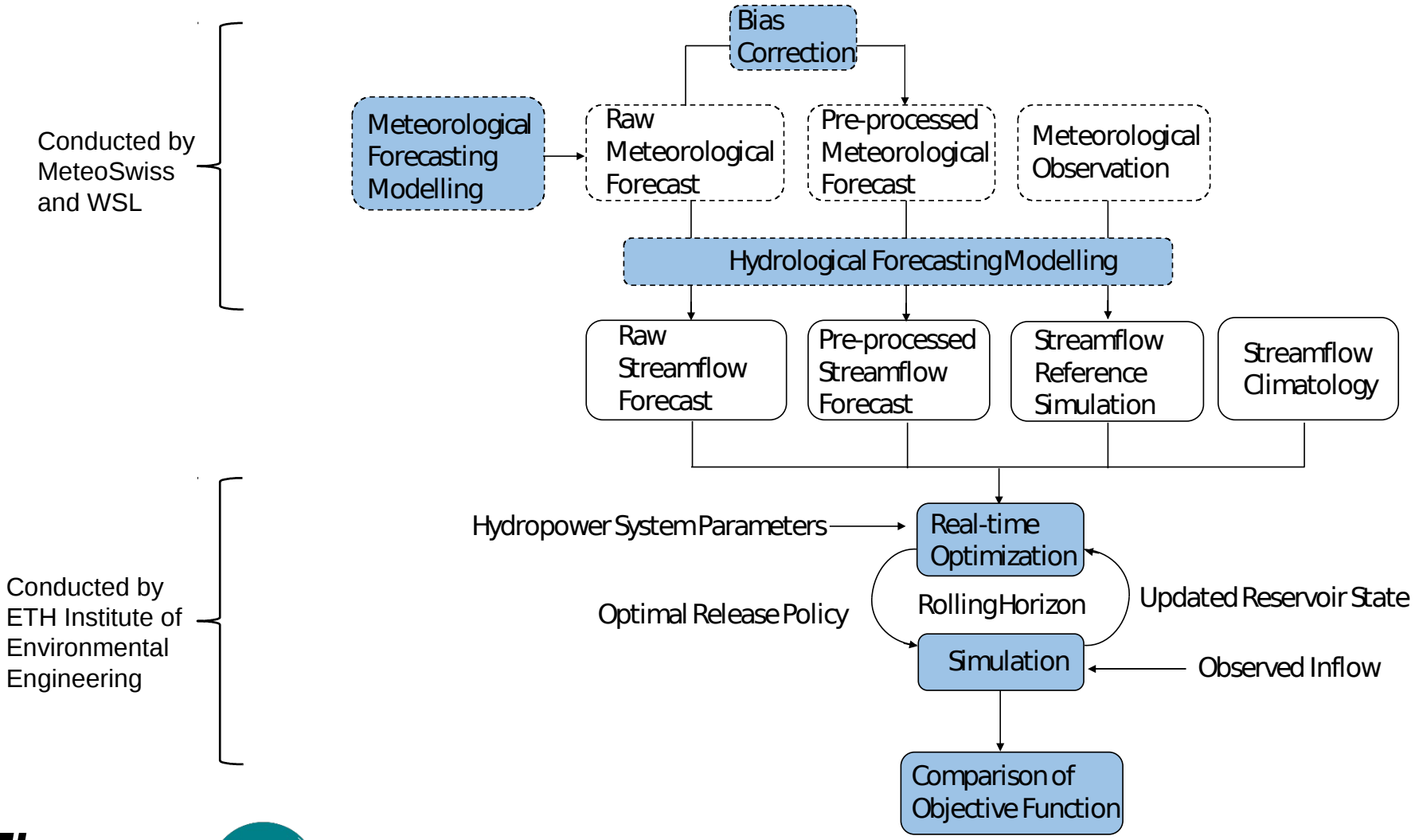
- Hydropower is the most important domestic source of renewable energy in Switzerland
- Hydropower accounts for about 61% of domestic electricity production in Switzerland (SFOE, 2016[1])



Research Interest

- Can we use extended-range hydrometerological forecast to increase the efficiency of existing storage hydropower plants?
- Does pre-processing & post-processing have an impact on streamflow **forecast quality** and **forecast value** hydropower operation optimization?
- What is the impact of pre-processing & post-processing on forecast value with respect to forecast quality?

Methodology Framework



Hydro-meteorological Forecast Chain

Meteorological

- ECMWF IFS extended-range forecasts (CY40r1)
- 2014-2015 ✉ hindcasts period 1994-2014
- 32 days lead time, once per week, 5 hindcast members
- Gridded observational data of precipitation, temperature for bias correction

Hydrological

- Hydrological model PREVAH
- Historical level, release and inflow data (2000 – 2016, daily aggregation) provided by the hydropower operator Verzasca SA
- Historical electricity wholesale price (Dec. 2006 – Dec. 2016, hourly), Open source EPEX SPOT SE (http://www.epexspot.com/en/)
- Climatological and reference forecasts used as lower / upper boundary (reference run = hydrological simulation with observed meteorological input)

Bias Correction: Pre-processing

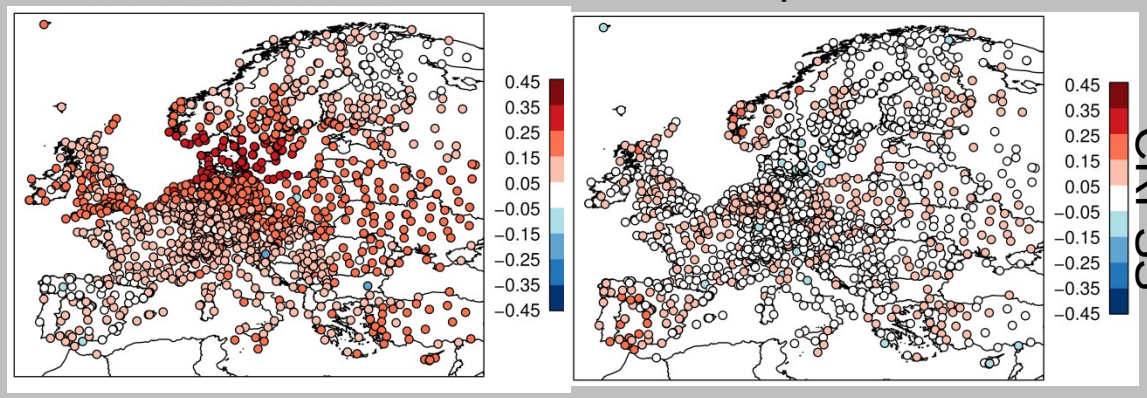
- Systematic bias, coarse resolution of the forecast
- Downscaling and systematic bias correction in meteorological forcing (precipitation and temperature)
- Quantile Mapping (QM) approach: day and lead-time dependent correction
  (✉More information: Poster by Monhart et al.)
- Leave-one-year-out cross-calibration framework

Bias Correction: Pre-processing, Short excursion:

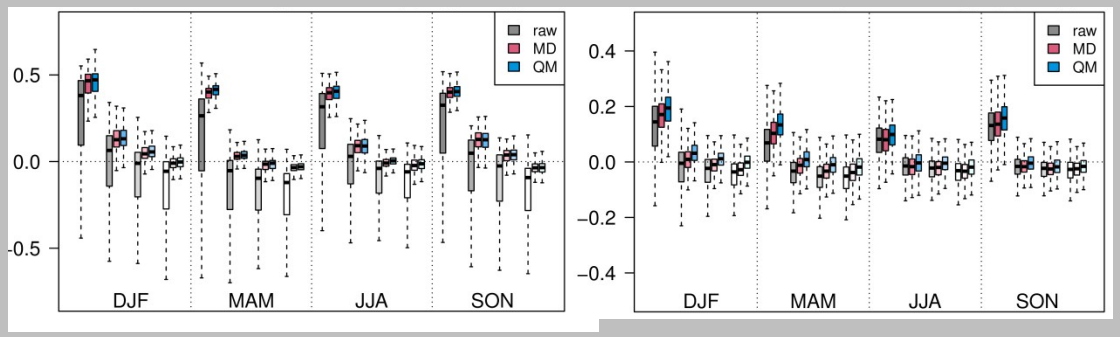
(✉More information:
Meteorological Verification: Skill of Sub-seasonal Forecasts in Europe: Effect of Bias Correction and Downscaling Using Surface Observations, in Review, JGR: Atmospheres,
Hydrological verification: Poster by Monhart et al.)

Temperature

Precipitation

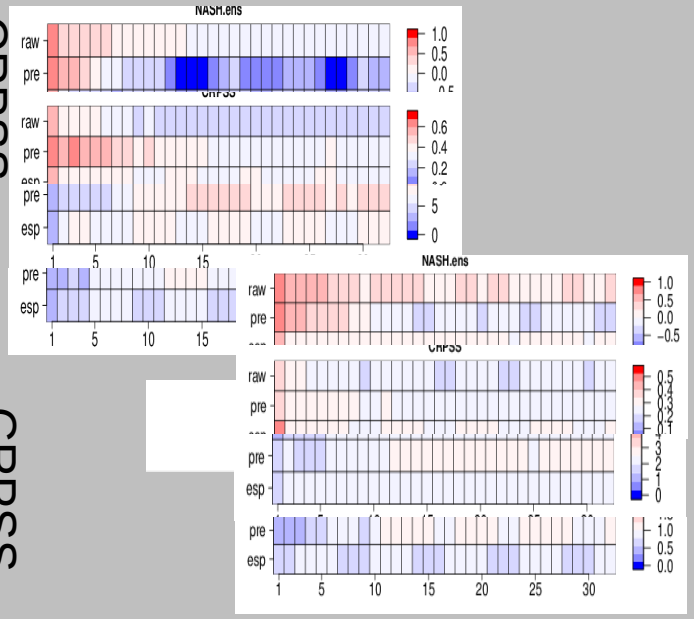


CRPSS



CRPSS

Hydrological Verification
For 3 different catchents, different skill metrics…



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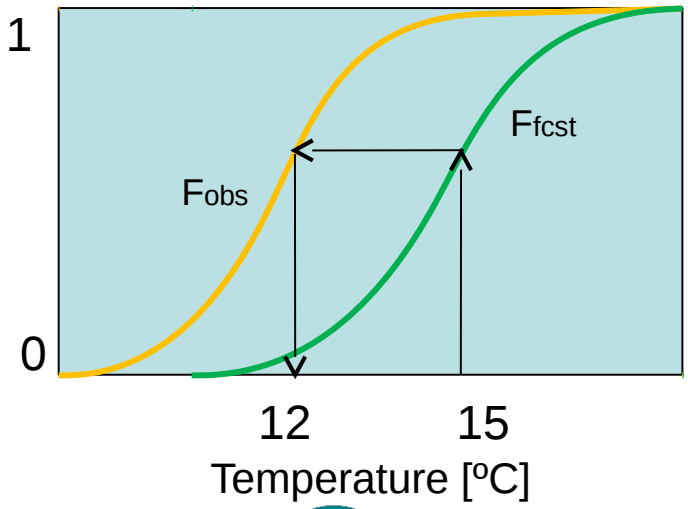
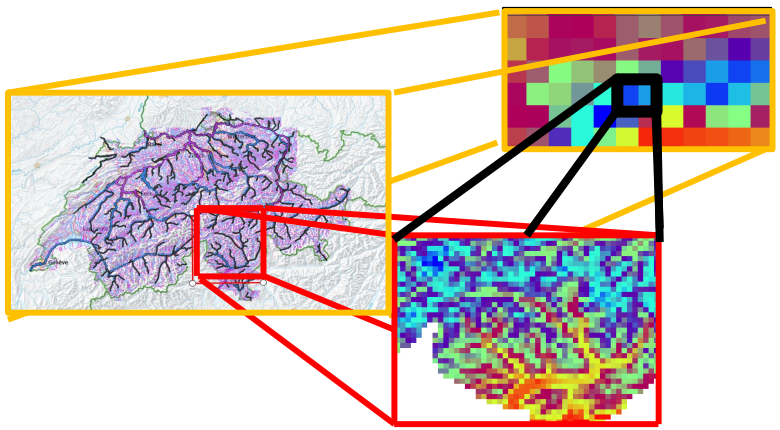
Post-processing:

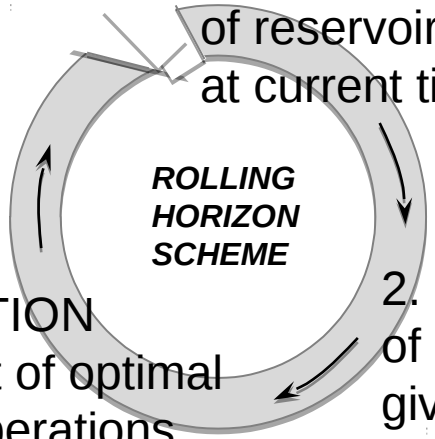
- Wavelet VectorAutoRegressive model (waveVARX)





Optimization

- Deterministic Dynamic Programming on rolling horizon

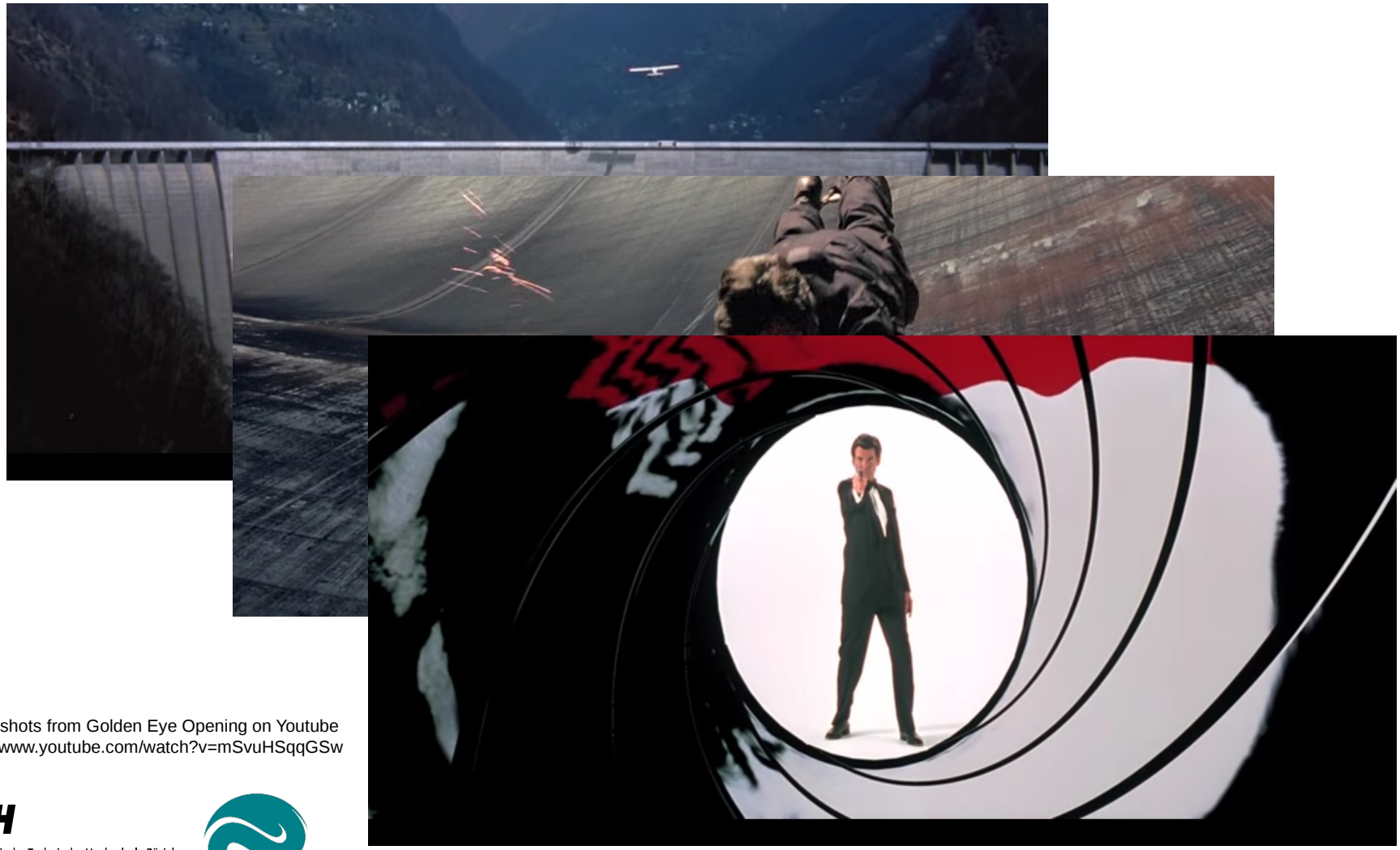


- Median of ensemble members (on cumulative basis to mimic natural streamflow signature)
- Objective function: maximization of the revenues using an average price reference trajectory (hourly resolution)
- The forecast horizon is artificially extended to 365 days by adding climatology data (to avoid premature emptying of the reservoir)

Arkhangelsk Chemical Weapons Facility -- USSR

Screenshots from Youtube
https://www.youtube.com/watch?v=mSvuHSqqGSw

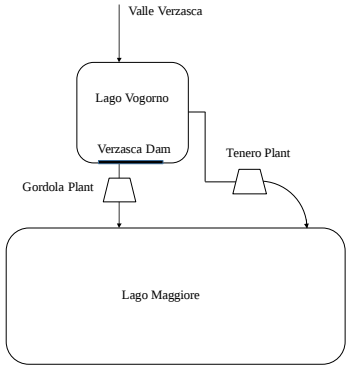
Arkhangelsk Chemical Weapons Facility – USSR Verzasca Dam in Switzerland



Screenshots from Golden Eye Opening on Youtube
https://www.youtube.com/watch?v=mSvuHSqqGSw

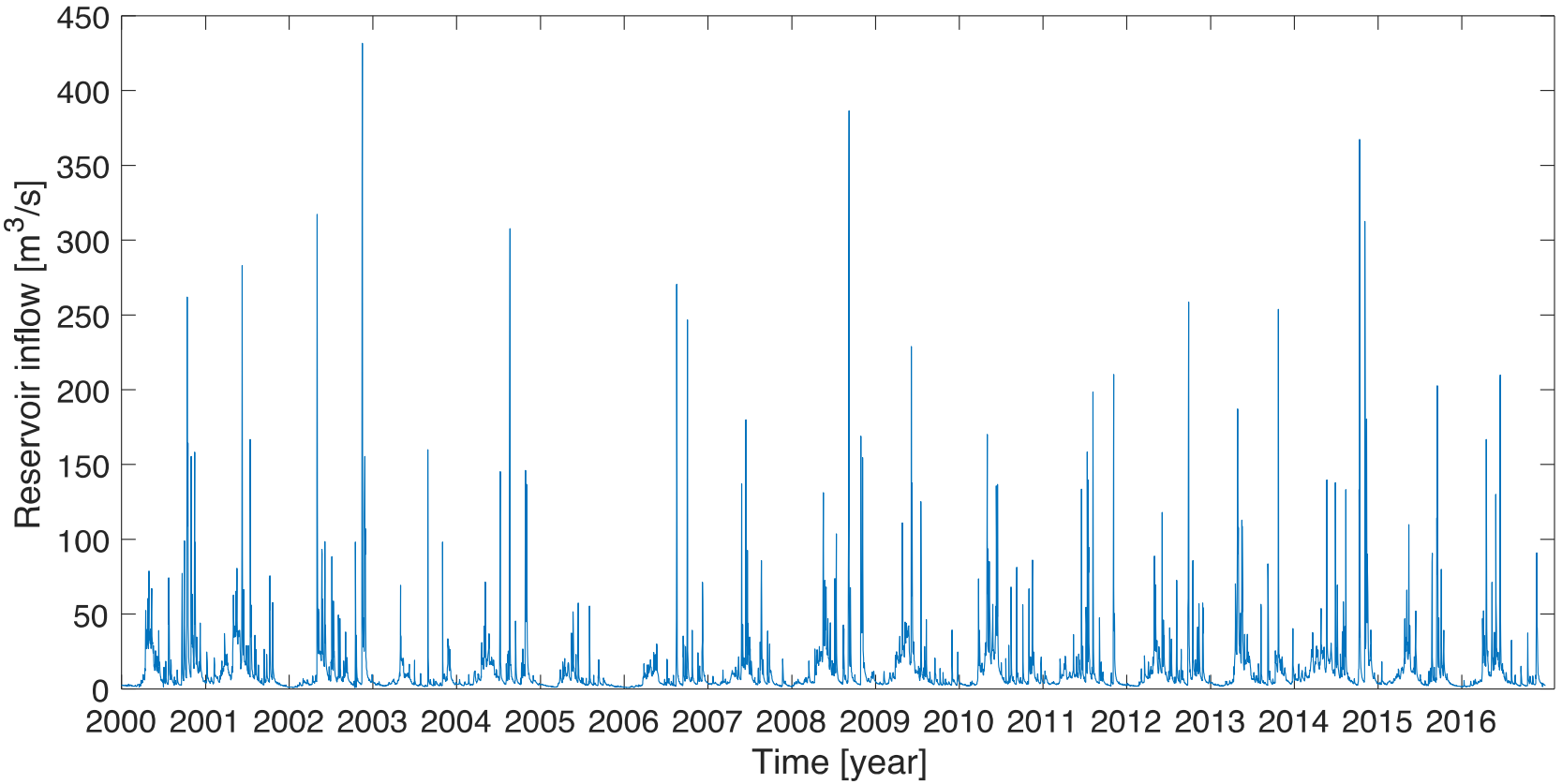
Verzasca Reservoir – Back to the real world

Source: Google Map



Area of the Catchment [km^2]	230
Reservoir active storage [10^6 m^3]	85
Height of Dam [m]	220
Installed capacity [MW]	105
Annual generation [MWh]	234
Annual inflow [10^6 m^3]	407
Inflow type	Snow/Rain

Historical Inflow



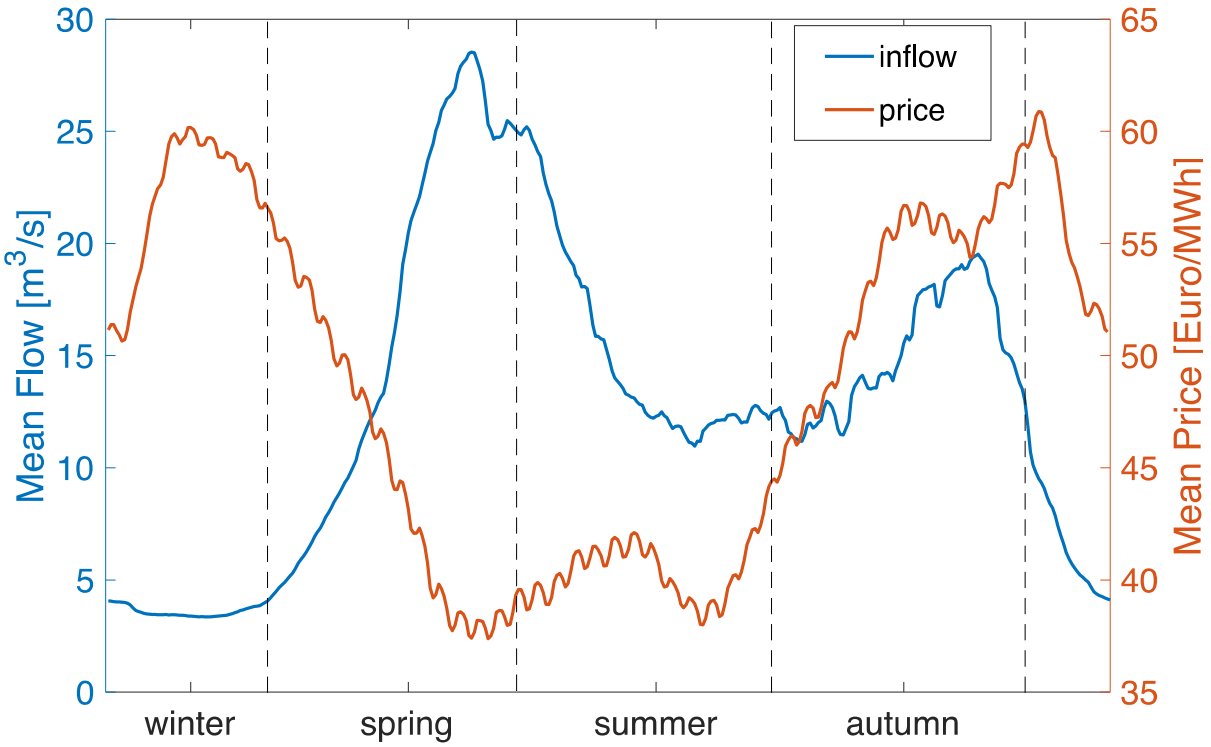
- High variability with flash flows up to 400 m³/s

→ difficult to forecasts (effect on forecast quality)

→ difficult to buffer (effect on forecast value)

Historical Inflow and Price

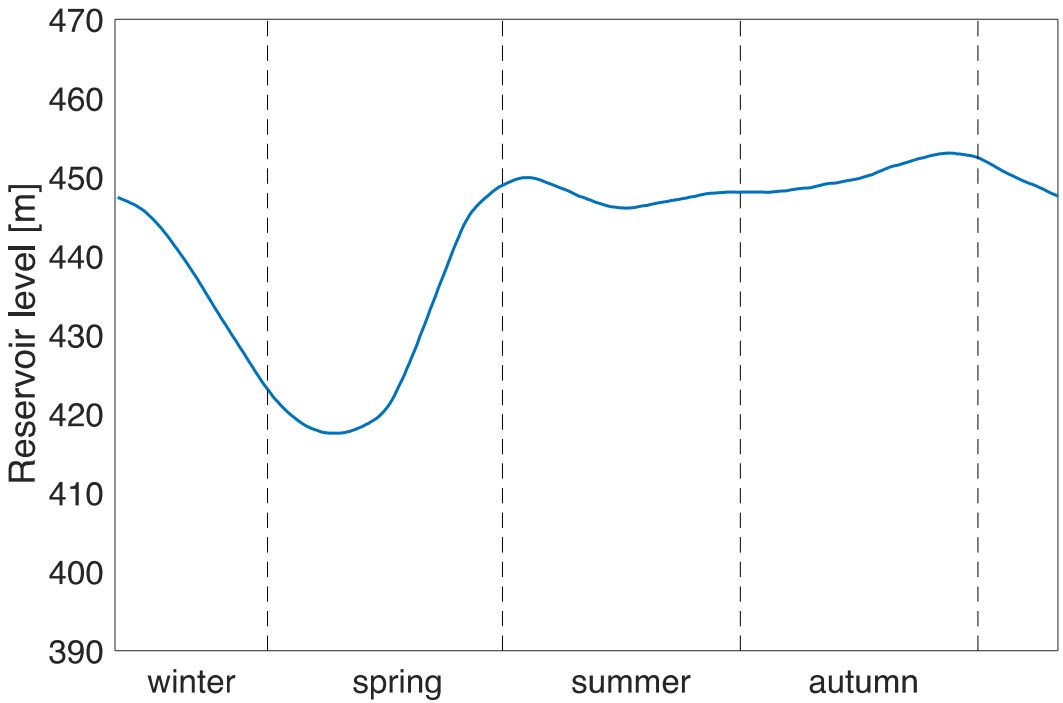
Yearly averaged



- Inflow peaks in spring and autumn
- Price and Inflow show nearly opposite fluctuations

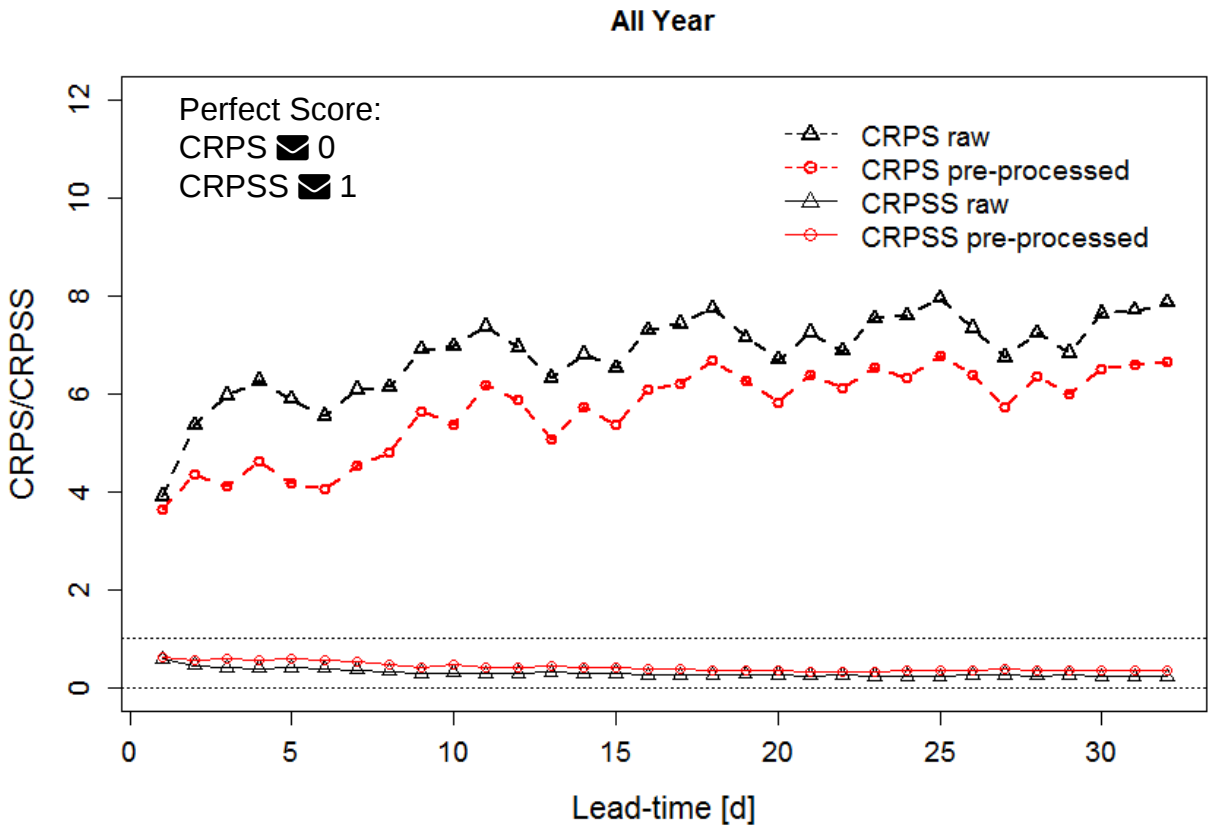
  ✉ reservoir operations can (partially) shift water volumes from summer/autumn to winter to meet higher electricity prices

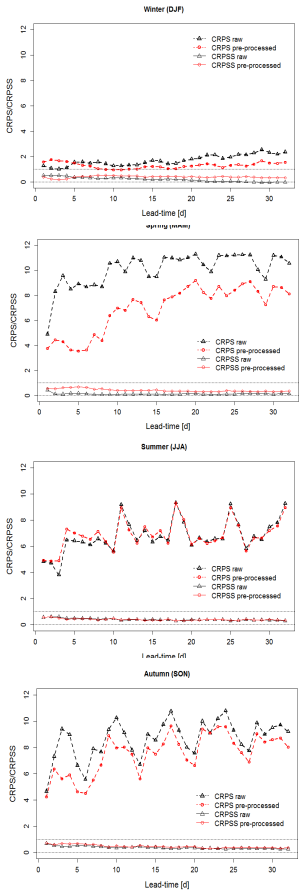
Observed climatological storage level



- Reservoir drawdown in winter (to meet high price and make room for snowmelt flows)
- High and relatively constant levels in summer and autumn

Streamflow Forecast Verification: Pre-processing





Winter

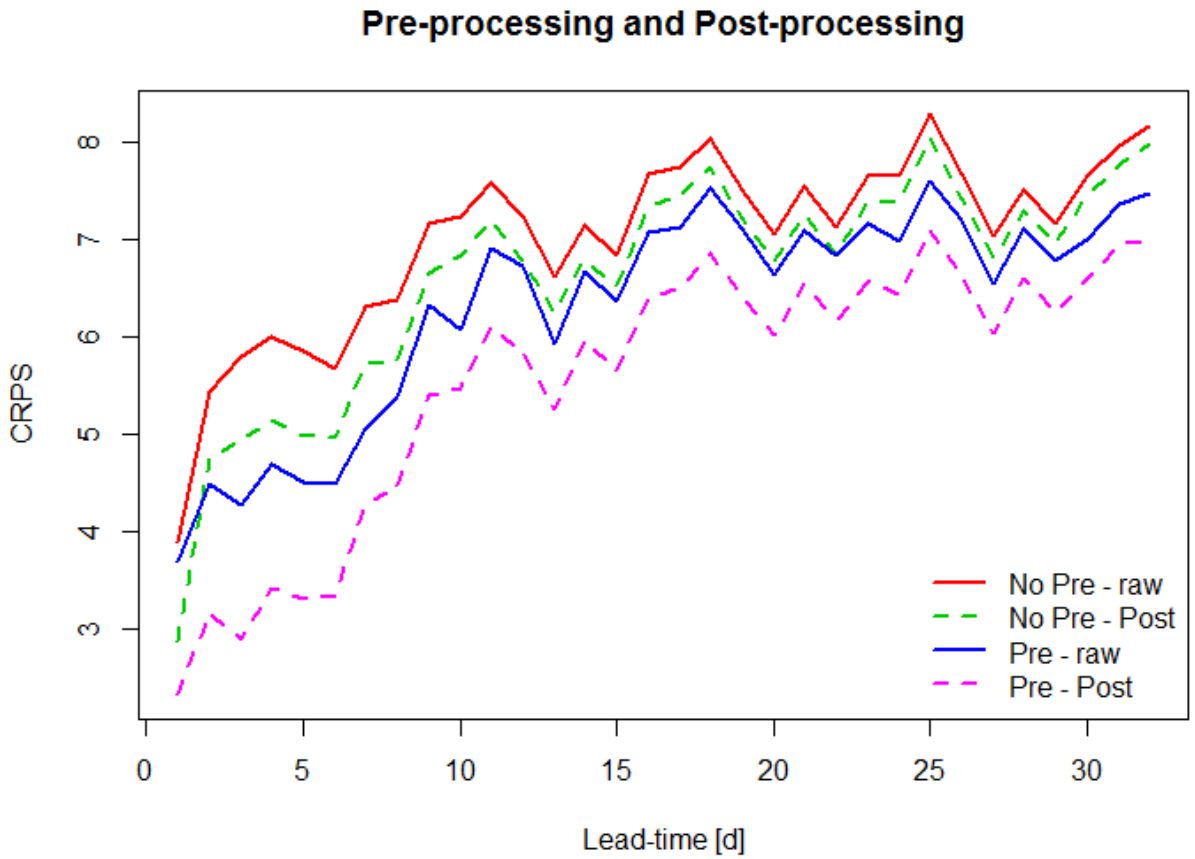
Spring

Summer

Autumn

- Pre-processing improves forecast quality depening on season

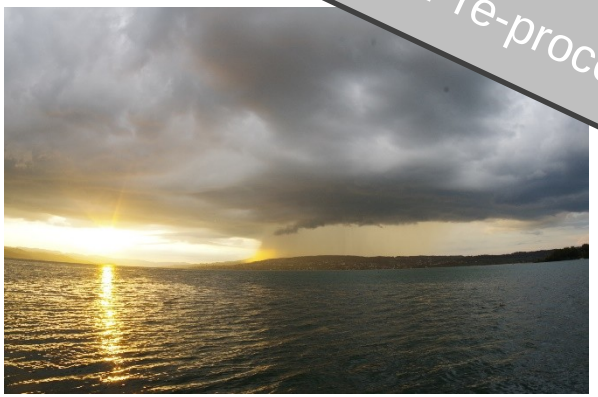
Streamflow Forecast Verification: Post-processing



- Non-linear performance gain when pre- and post-processing is combined

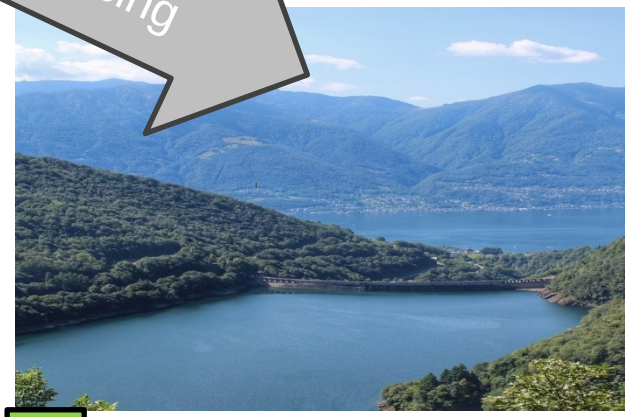
Data and Methodology

70 NFP Energiewende
Nationales Forschungsprogramm



Pre-processing

Post-processing



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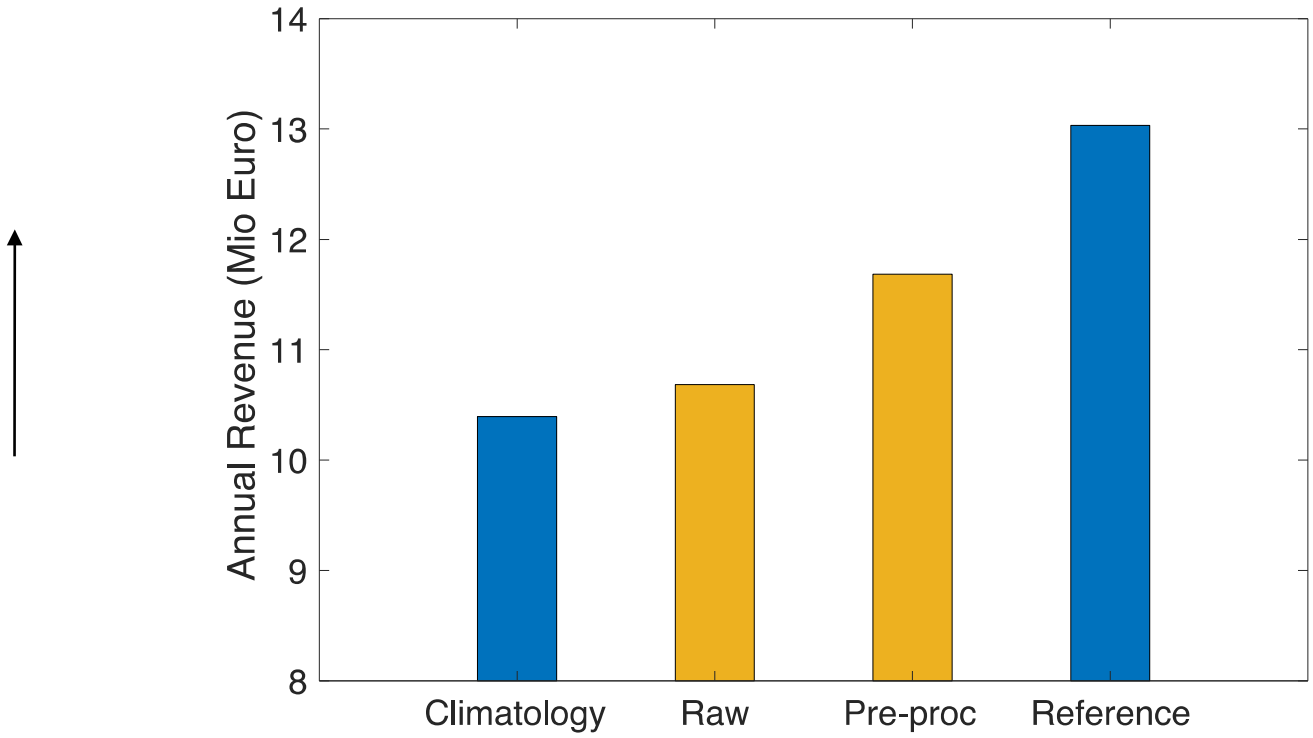
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology
MeteoSwiss

WSL Swiss Federal Institute for Forest, Snow and Landscape Research WSL

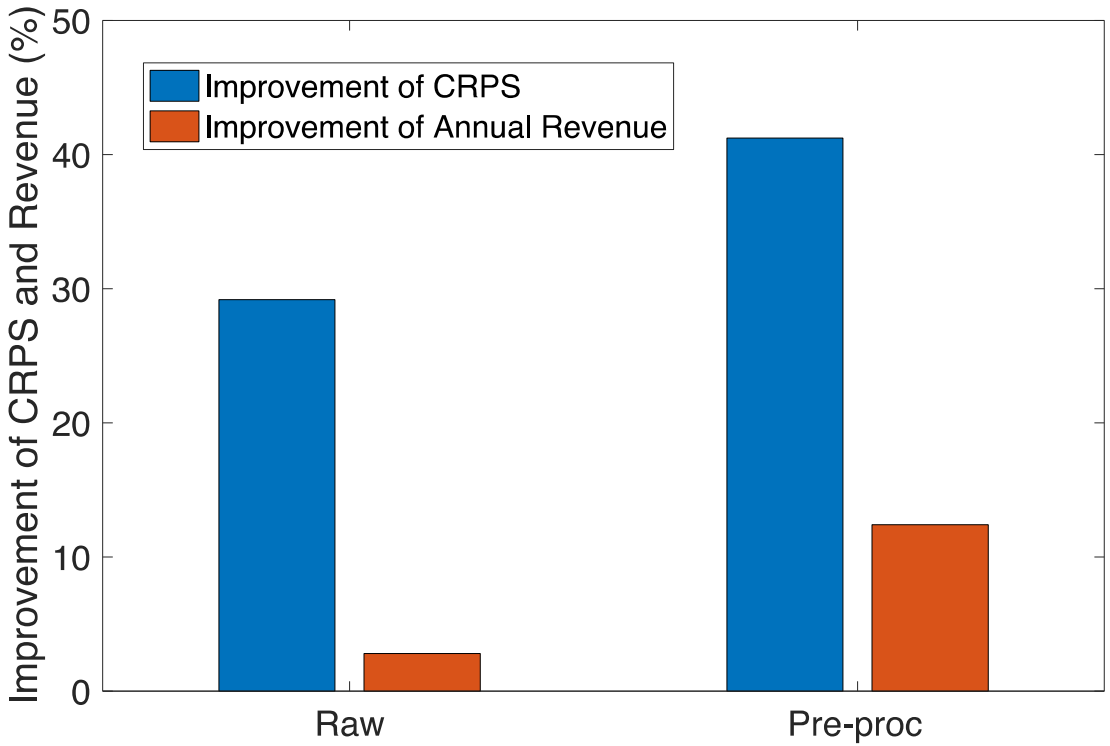
ETH zürich
Institute of Environmental Engineering

Streamflow forecasts value: Annual Revenue



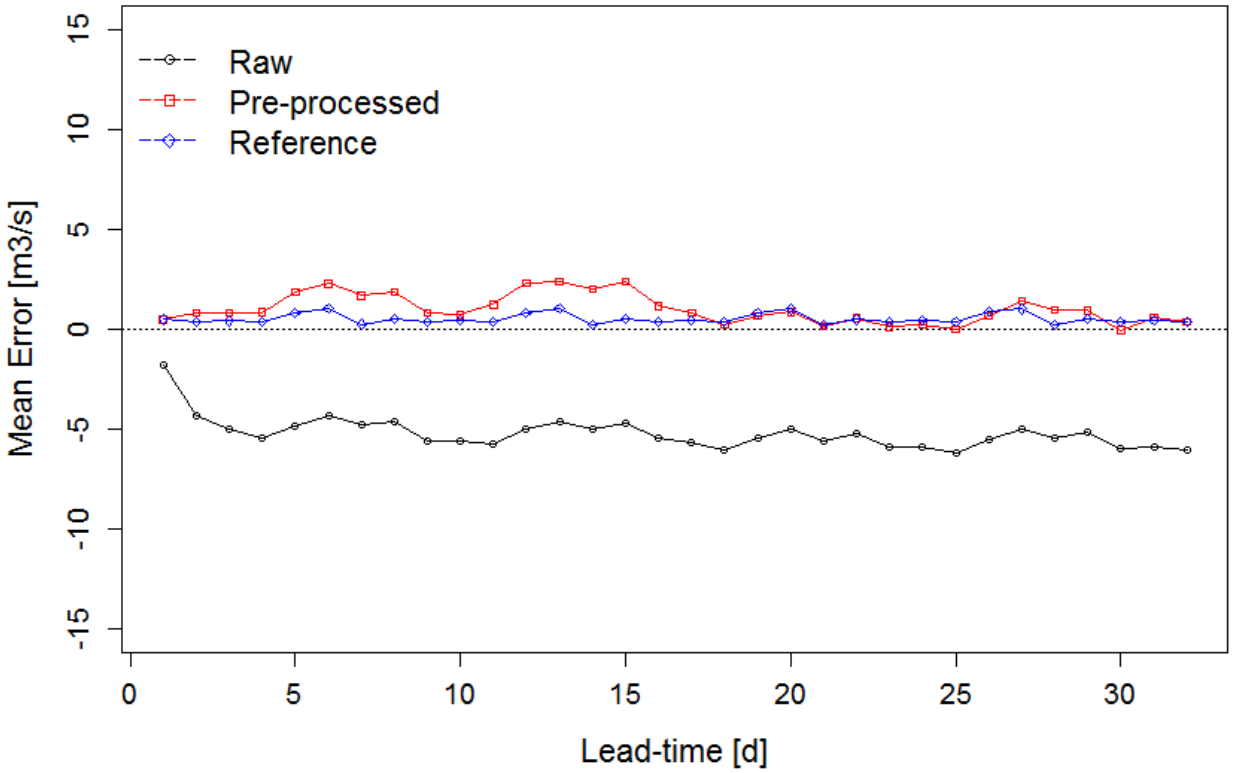
- Adopting raw forecast in the optimization improves slightly the annual revenue
- Pre-processing further improves the forecast performance

Optimization: Quality v.s. Value



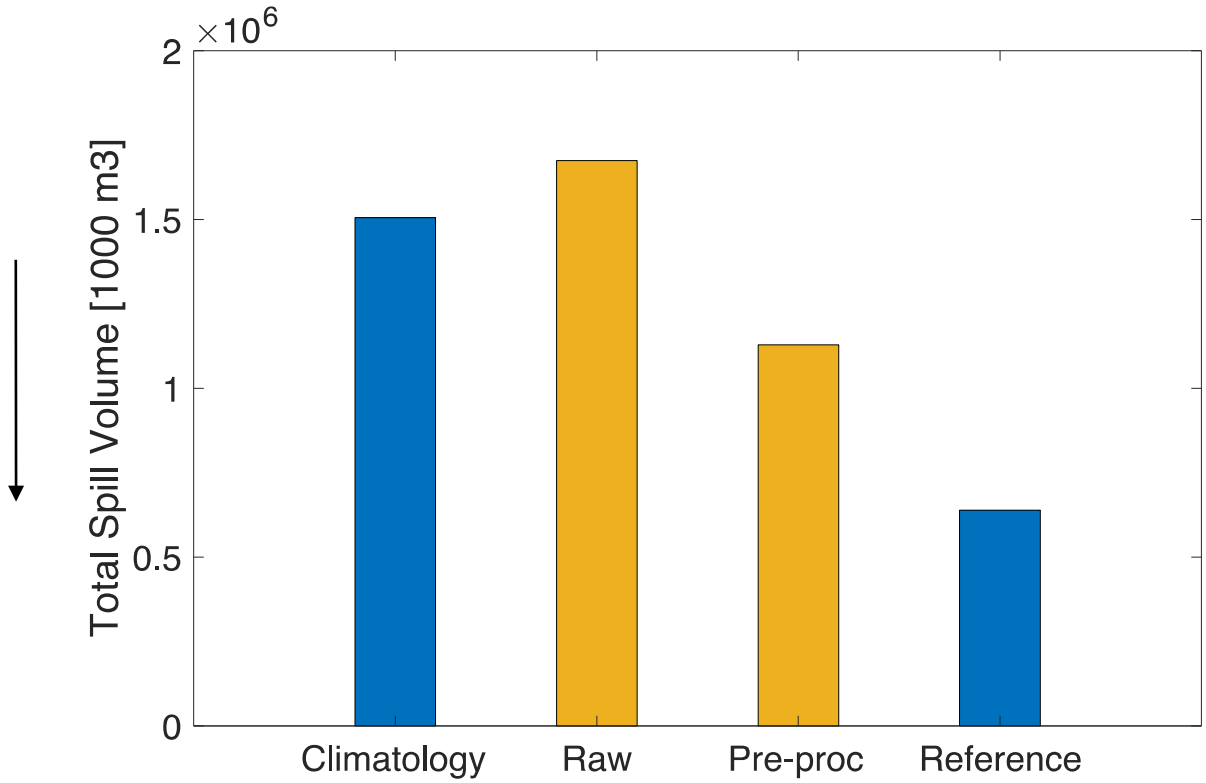
- Improvement of forecast quality does not propagate completely to forecast value
- Pre-processing improves both forecast quality and forecast value

Optimization: Mean Error



- Negative bias in raw forecasts
- Underestimated streamflows can lead to too much spill / not enough release

Optimization: Spill



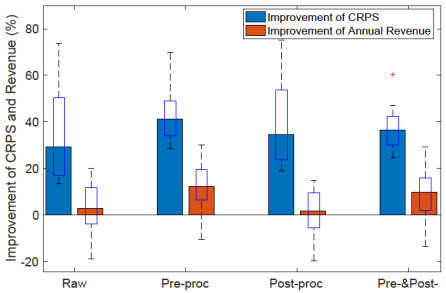
Conclusion

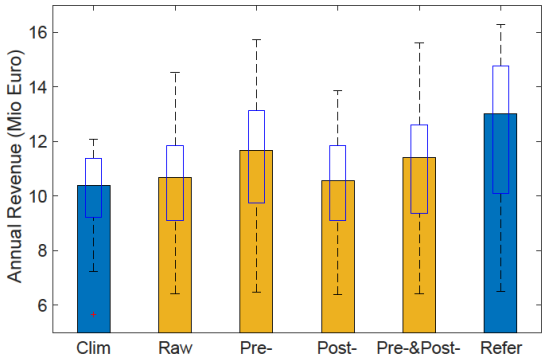
- **Does bias correction in the meteorological forcing forecasts have an impact on streamflow forecast quality and its value?**
  - Bias correction greatly improves the forecast quality in spring and autumn, when snow contributes to the inflow
  - The quality of forecasts has significant impacts on the operation optimization. Better forecasts provide better optimization results.

- **How much is the impact of bias correction on forecast value with respect to forecast quality?**
  - Improvement of forecast quality does not completely propagate to the improvement of forecast value, i.e. the propagation is most likely diminished

Outlook

- Stochastic optimization: to account for forecast uncertainty and to exploit the information contained in the Ensemble Forecasts
- Apply post-processing technique to raw and pre-processed forecasts
  - Systematic bias correction in hydrological modelling
  - Further improvement of forecast quality? Is it really worth it?
  - Behavior in different catchments





Thank you!