Hybrid Hydrological Modeling for Sub-seasonal Droughts Forecasts – A Combination of Traditional Models and Machine Learning Techniques

MSc Thesis Presentation

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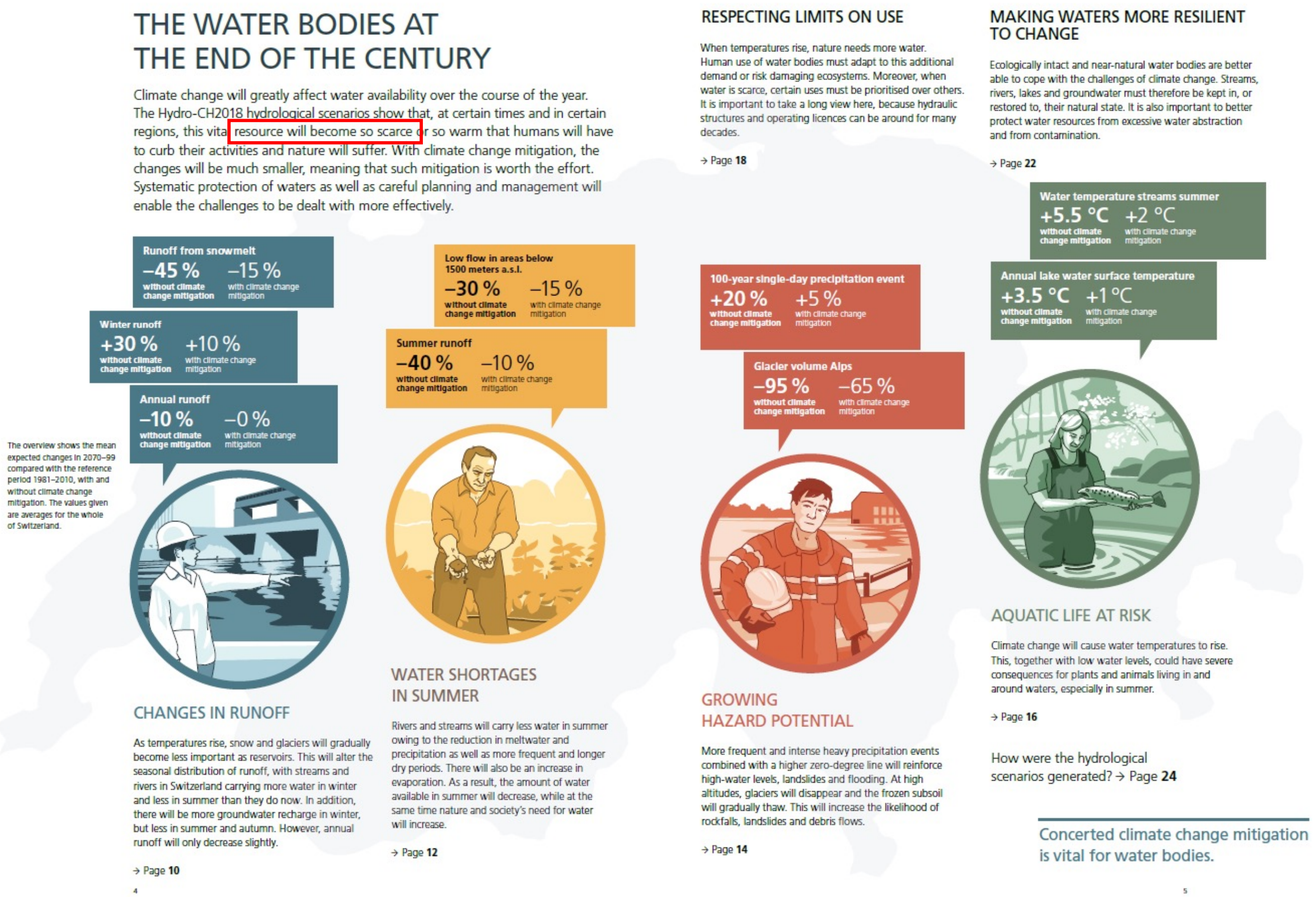
Motivation - Subseasonal Droughts Forecasts



THE WATER BODIES AT THE END OF THE CENTURY

Climate change will greatly affect water availability over the course of the year. The Hydro-CH2018 hydrological scenarios show that, at certain times and in certain regions, this vital resource will become so scarce or so warm that humans will have to curb their activities and nature will suffer. With climate change mitigation, the changes will be much smaller, meaning that such mitigation is worth the effort. Systematic protection of waters as well as careful planning and management will enable the challenges to be dealt with more effectively.

Runoff from snowmelt
−45 % without climate change mitigation
−15 % with climate change mitigation

Winter runoff
+30 % without climate change mitigation
+10 % with climate change mitigation

Annual runoff
−10 % without climate change mitigation
−0 % with climate change mitigation

The overview shows the mean expected changes in 2070–99 compared with the reference period 1981–2010, with and without climate change mitigation. The values given are averages for the whole of Switzerland.

CHANGES IN RUNOFF

As temperatures rise, snow and glaciers will gradually become less important as reservoirs. This will alter the seasonal distribution of runoff, with streams and rivers in Switzerland carrying more water in winter and less in summer than they do now. In addition, there will be more groundwater recharge in winter, but less in summer and autumn. However, annual runoff will only decrease slightly.

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Low flow in areas below 1500 meters a.s.l.
−30 % without climate change mitigation
−15 % with climate change mitigation

Summer runoff
−40 % without climate change mitigation
−10 % with climate change mitigation

WATER SHORTAGES IN SUMMER

Rivers and streams will carry less water in summer owing to the reduction in meltwater and precipitation as well as more frequent and longer dry periods. There will also be an increase in evaporation. As a result, the amount of water available in summer will decrease, while at the same time nature and society's need for water will increase.

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RESPECTING LIMITS ON USE

When temperatures rise, nature needs more water. Human use of water bodies must adapt to this additional demand or risk damaging ecosystems. Moreover, when water is scarce, certain uses must be prioritised over others. It is important to take a long view here, because hydraulic structures and operating licences can be around for many decades.

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100-year single-day precipitation event
+20 % without climate change mitigation
+5 % with climate change mitigation

Glacier volume Alps
−95 % without climate change mitigation
−65 % with climate change mitigation

GROWING HAZARD POTENTIAL

More frequent and intense heavy precipitation events combined with a higher zero-degree line will reinforce high-water levels, landslides and flooding. At high altitudes, glaciers will disappear and the frozen subsoil will gradually thaw. This will increase the likelihood of rockfalls, landslides and debris flows.

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MAKING WATERS MORE RESILIENT TO CHANGE

Ecologically intact and near-natural water bodies are better able to cope with the challenges of climate change. Streams, rivers, lakes and groundwater must therefore be kept in, or restored to, their natural state. It is also important to better protect water resources from excessive water abstraction and from contamination.

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Water temperature streams summer
+5.5 °C without climate change mitigation
+2 °C with climate change mitigation

Annual lake water surface temperature
+3.5 °C without climate change mitigation
+1 °C with climate change mitigation

AQUATIC LIFE AT RISK

Climate change will cause water temperatures to rise. This, together with low water levels, could have severe consequences for plants and animals living in and around waters, especially in summer.

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How were the hydrological scenarios generated? → Page 24

Concerted climate change mitigation is vital for water bodies.

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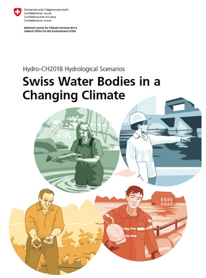
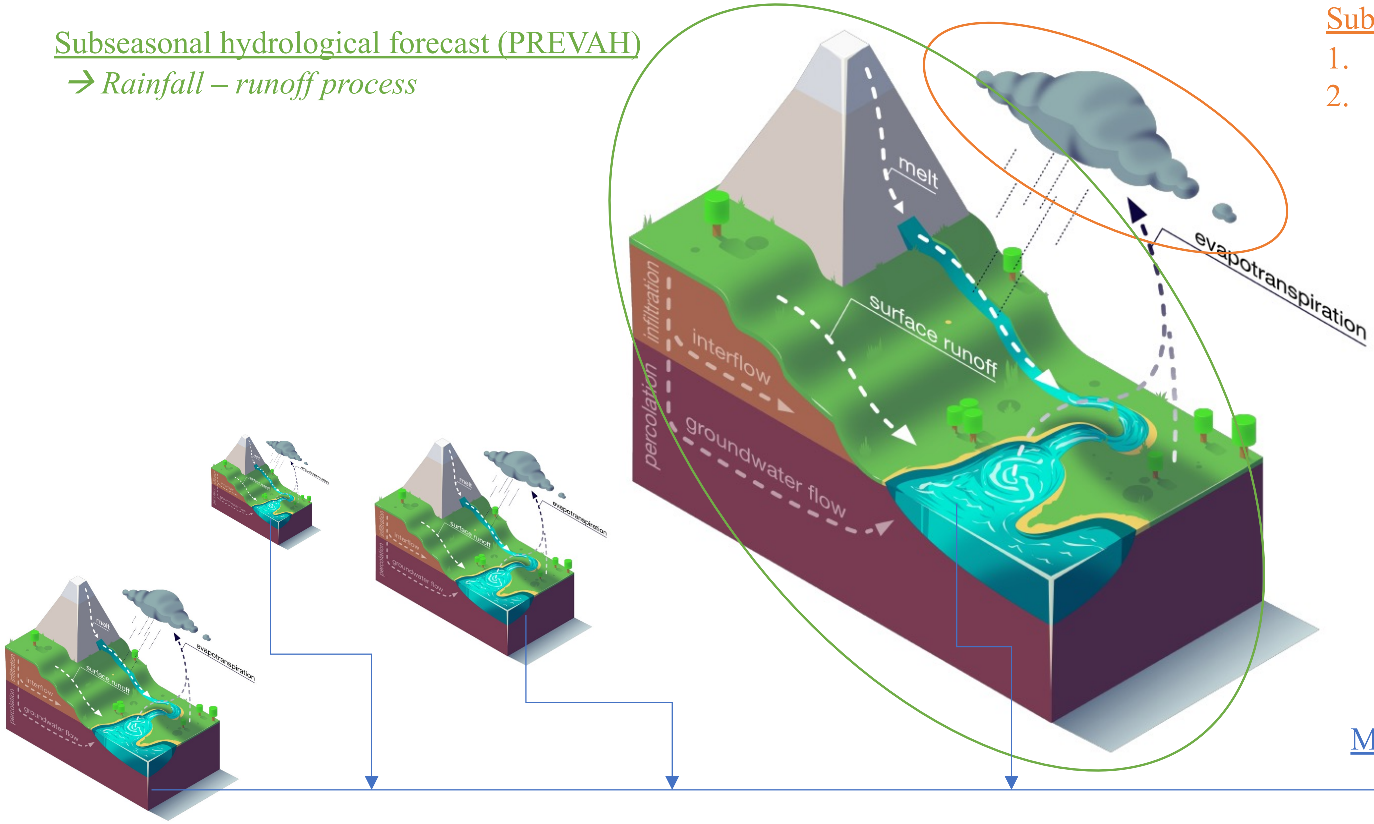


Methods - Combining traditional and machine learning models

Subseasonal hydrological forecast (PREVAH)
→ *Rainfall – runoff process*

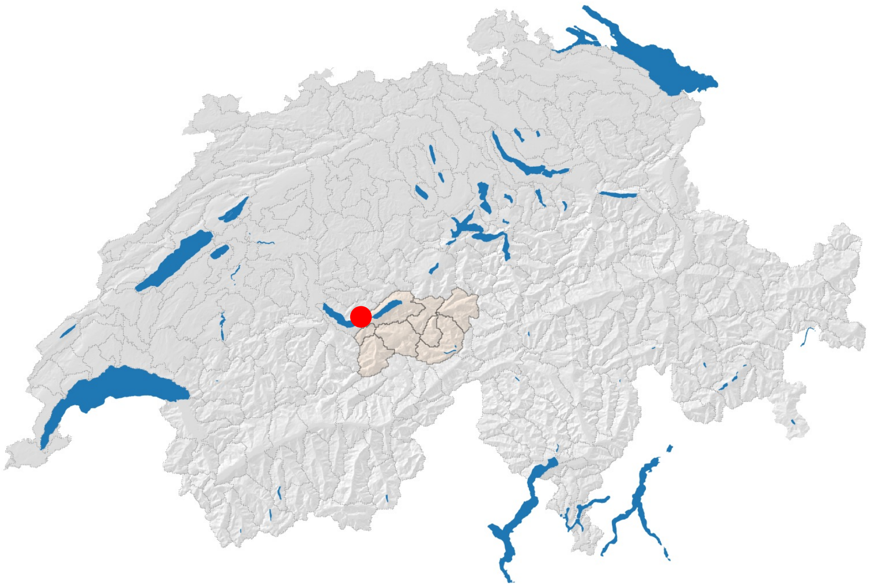
Subseasonal meteorological forecasts
1. Raw meteorological forecasts
2. Pre – processed meteorological forecasts



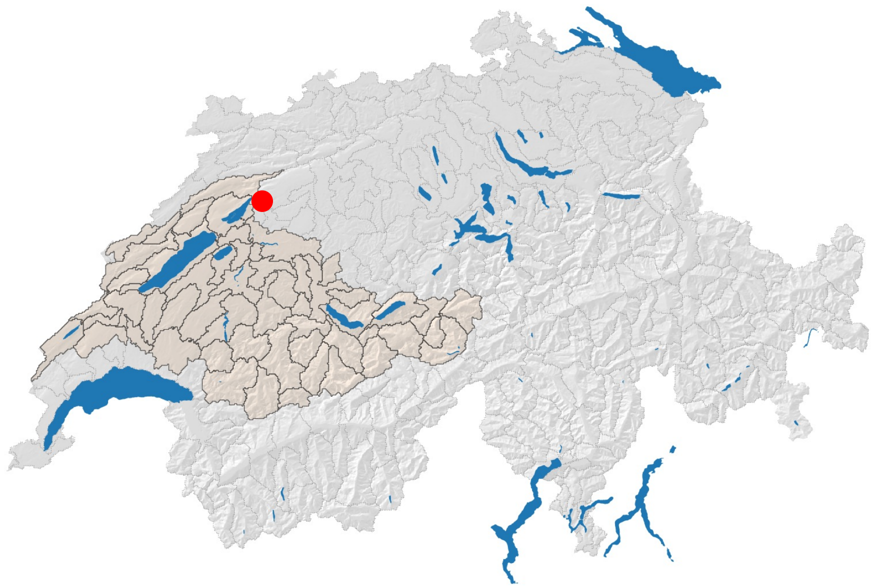
Machine Learning (ML)

Region of interest - Alpine Aare Basin

Brienz Basin
- Contributing catchments: 8
- Area: 1’200 km^2

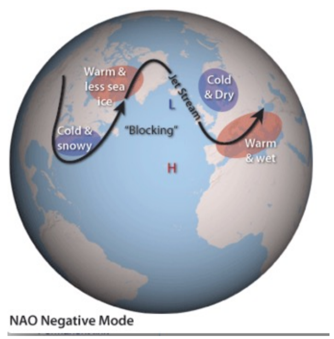


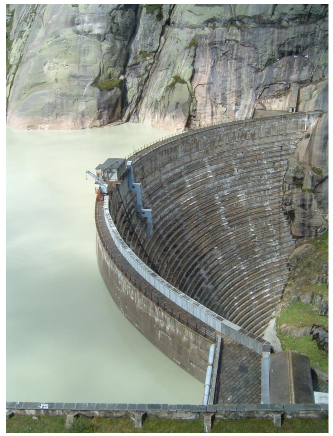
Biel Basin
- Contributing catchments: 54
- Area: 8’000 km^2



Better informed ML

1. Basic state:
   - PREVAH forecast only
2. Catchment control:
   - Initial conditions (Fundel et al. 2013)
3. Meteorological control:
   - Weather regimes (Chang et al. 2020)
4. Human control:
   - Hydropower proxy (Bogner et al. 2019)

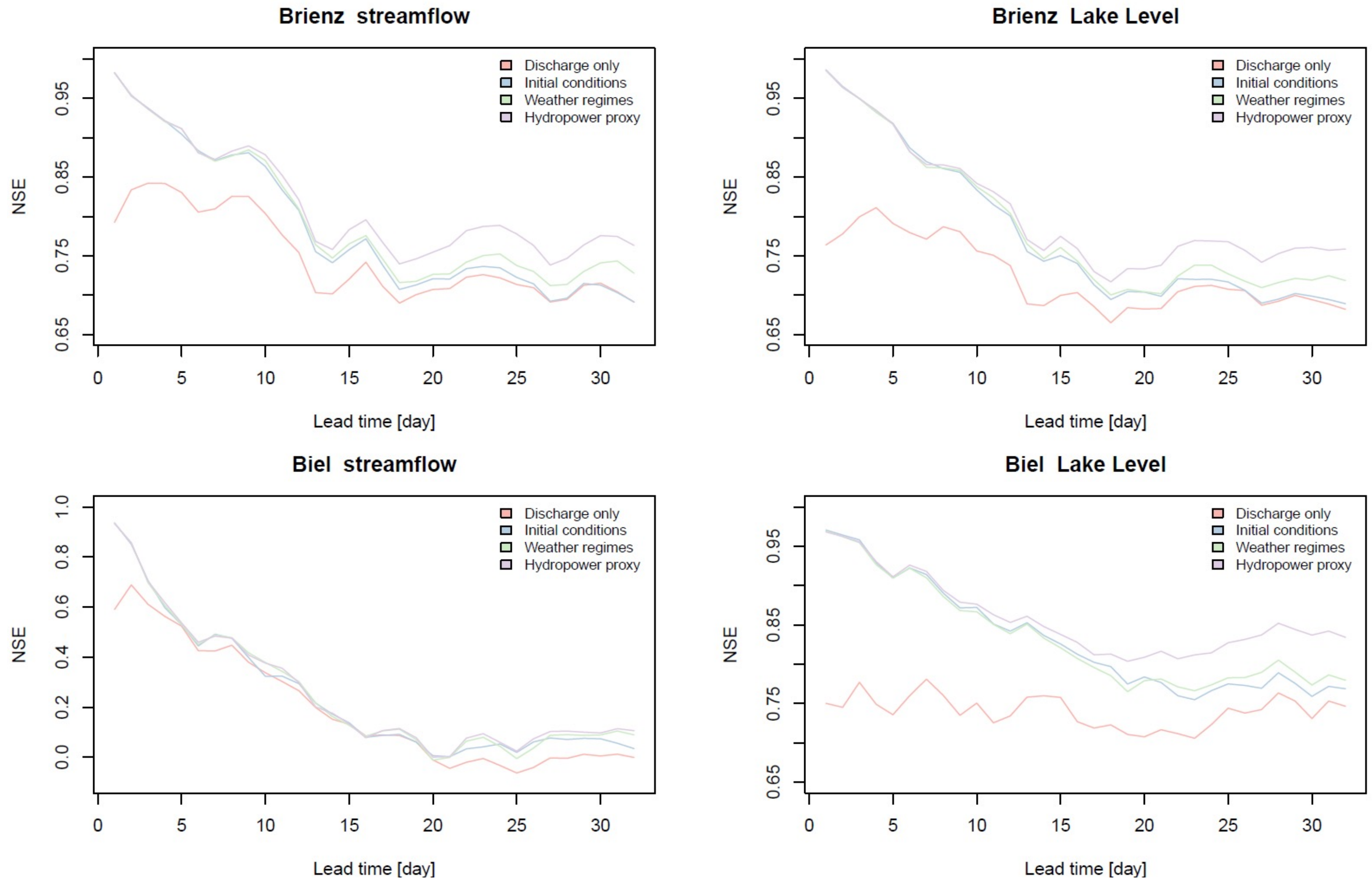




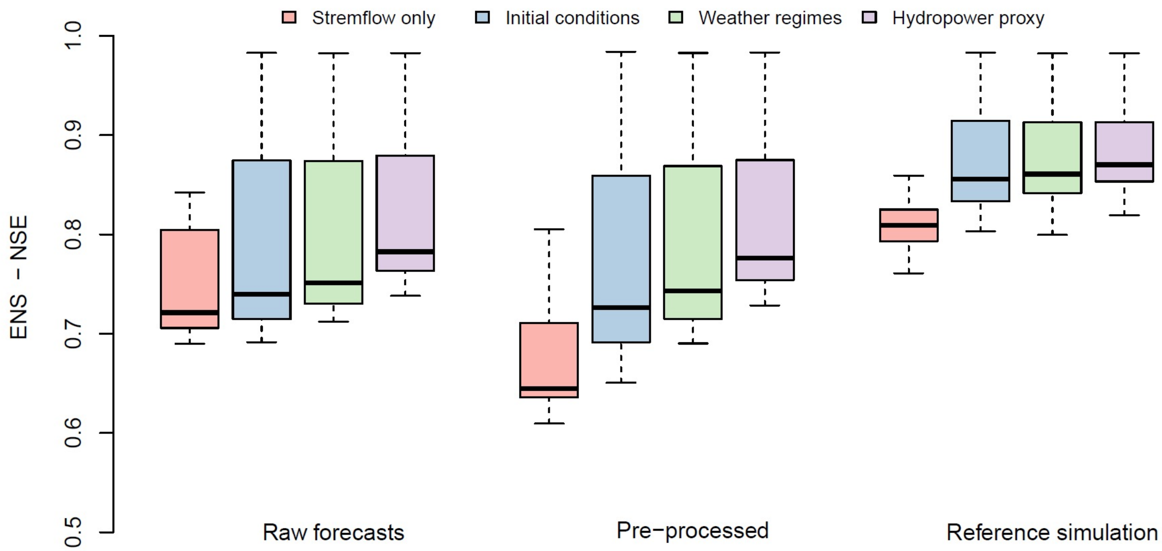
Questions

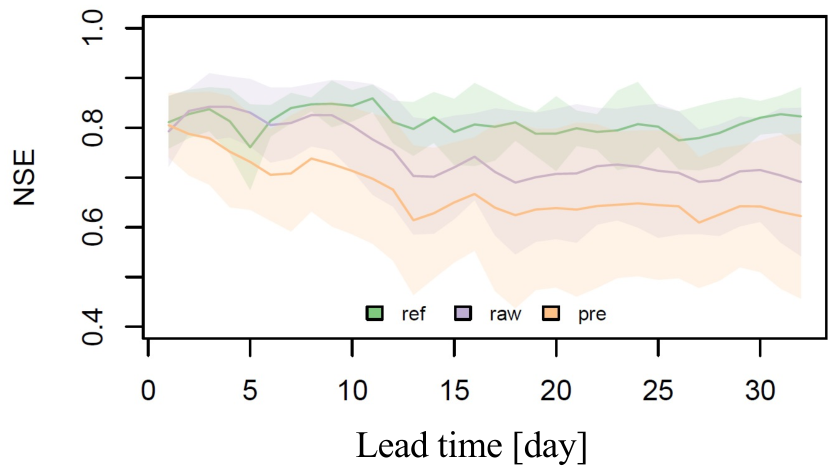
1. Can added information provide any performance improvement to ML?
2. Are pre-processed meteorological forecasts a better input compared to raw forecasts?
3. How the model perform in extreme low flow situations?

1. Better informed ML



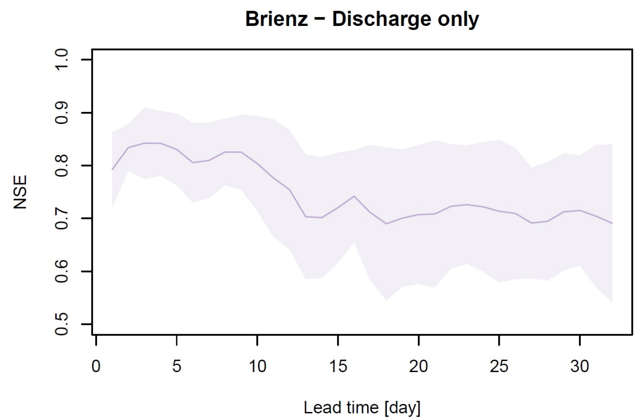
2. Meteorological input

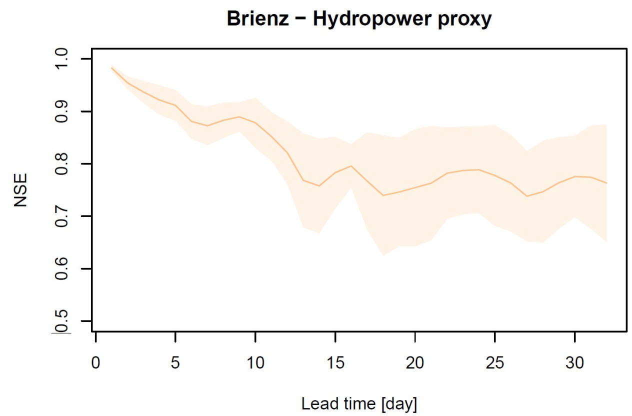




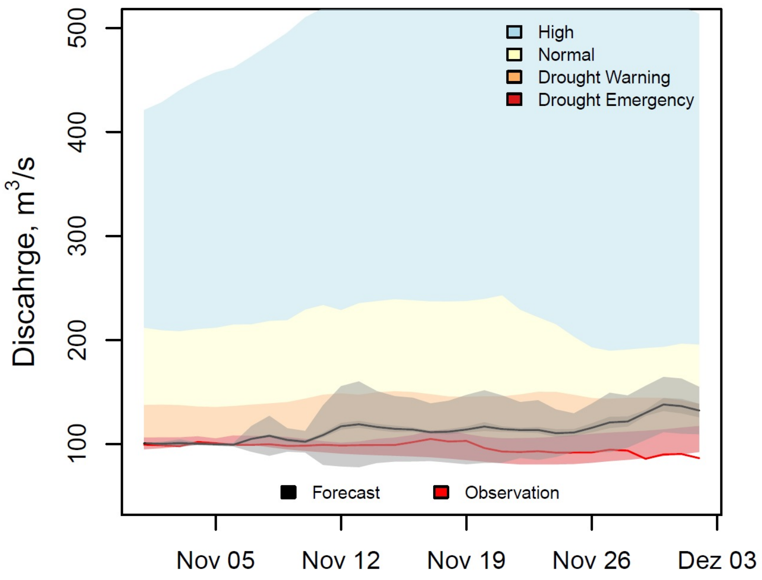
Hydrological and ML ensemble

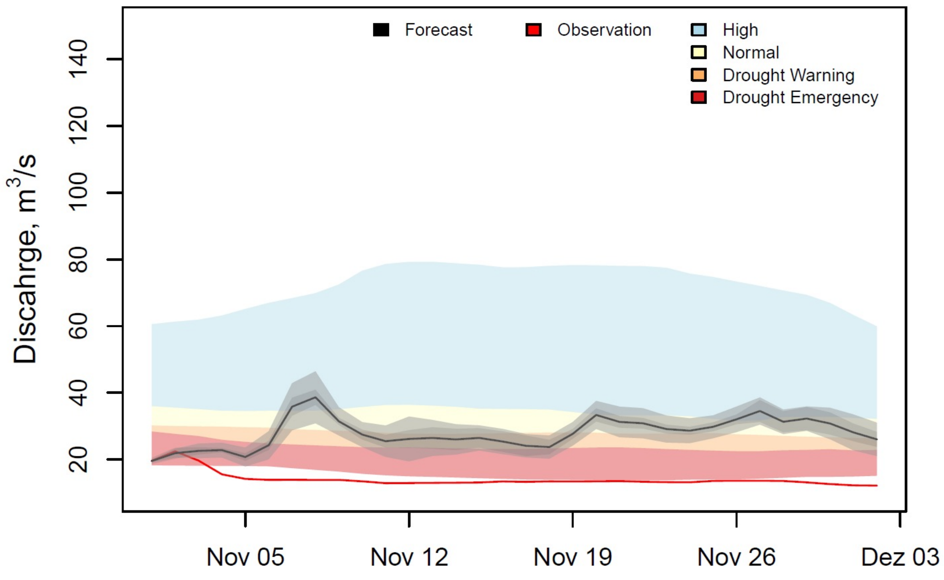
- Hydrological ensemble
  - 51 members
- Machine learning
  - ML ensemble: 6 algorithms
  - ML uncertainty: 5 train-test data sets
- In total
  - 325’000 simulations
  - 1’400 hours = 58 days



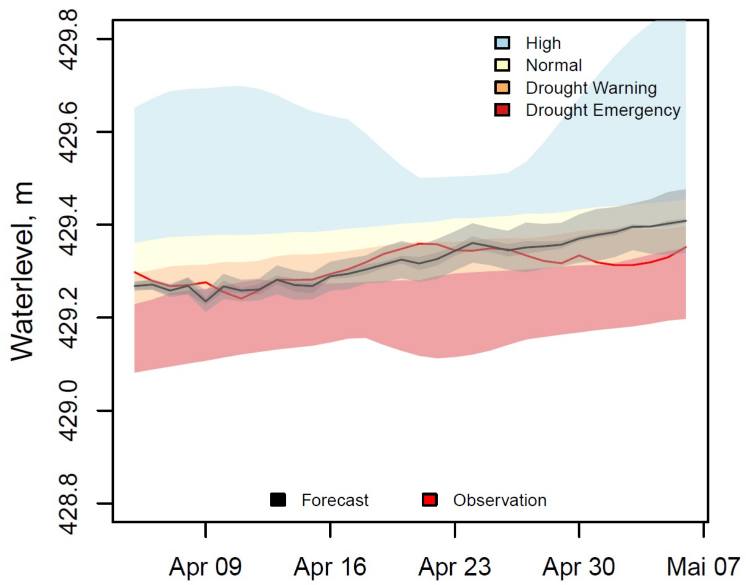


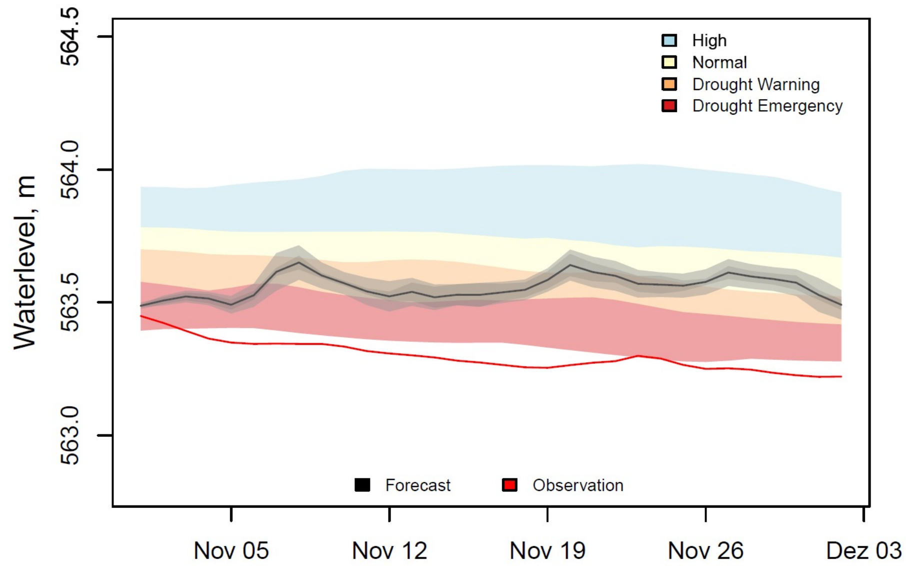
3. Low flow forecasting - Streamflow





Low flow forecasting – Lake level





Take home messages

1. **Hybrid modeling outperform traditional approach to forecast streamflow and lake level.**
2. **Lake levels** are sub-seasonally accurately forecasted, regardless the basin size
3. **Streamflow** forecasts have shown basin-size skill dependency
4. **Pre-processed meteorological** inputs do not exceed those obtained via the **raw forecasts**.
5. **Informed ML** produces better forecasts than those obtained using hydrological model outputs only.
   - **Initial conditions** provide the most useful piece of information
   - **Weather regimes** improve the skill especially in the second half of the forecast period.
   - **Hydropower regulation proxy** is generally the second most informing features.