Task 2.5

Task Title

Integrated simulation of hydropower systems operation

Research Partners

Chair of Hydrology and Water Resources Management (HWRM) at ETH Zurich, Swiss National Institute of Forest, Snow and Landscape Research (WSL), Kraftwerke Mattmark AG (KWM), Axpo, Officine Idroelettriche della Maggia SA (Ofima)

Current Projects (presented on the following pages)

Design of hydropower systems operation under current and future energy market conditions
D. Anghileri, I. Schlecht, A. Castelletti, H. Weigt, P. Burlando

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Impacts of climate change on hydrology and operation of Mattmark reservoir under business-as-usual production targets
D. Anghileri, N. Peleg, A. Castelletti, P. Burlando

Task Objectives

The purpose of Task 2.5 is to develop an advanced modelling framework for the integrated and continuous simulation of hydrological regimes and the operation of hydropower systems. The model allows accounting for climate change scenarios, the corresponding altered streamflow regimes, different energy market conditions (e.g., energy demand and price, increased production by solar and wind powerplants), as well as new boundary conditions for operation (e.g., aquatic ecosystem conservation) and technical solutions (e.g., dam crest heightening or installation of more flexible machines). The modelling framework allows a quantitative assessment of current and future hydropower reservoir operation strategies in terms of energy production and revenue, integration with other power sources, and effects on natural water bodies and ecosystems. The specific objectives are:

- assess impacts of climate change on available water resources at existing and planned HP systems, on their extremes (low and high flows), on floods and sediment transport and, more in general, on any element of change that can affect the hydropower production potential;
- assess the energy production increase achievable by current reservoir operating strategies or ad hoc designed to account for technical improvements and/or adaptations of the hydropower systems to future hydro-climatic and socio-economic forcing;
- analyse the effects of increasingly volatile demand and market conditions (as induced, for instance, by production from other renewable energies) on the production potential and to design more flexible and robust hydropower system operation strategies.

Interaction Between the Partners – Synthesis

Several collaboration has been established with other research partners within the context of the SCCER and other related projects. This represents the first steps towards the integration of the results achieved by different WP2 tasks and activities into a common modelling framework. A strong connection has been built with some industrial partners thanks to periodical meetings, which have the scope of updating the stakeholders of the work results and to include their feedbacks into the research activities, thus collaborating together to shared solutions in view of the energy strategy 2050.

In particular, we are working in collaboration with Task 2.1 to extend our research spatially distributed hydrological model to include a more detailed representation of the glacierised areas. Moreover, we are going to use the high-resolution climate change scenarios developed in Task 2.1 to simulate the effect on hydrological regimes and hydropower system operation across the investigated river basins. The main partners of these activities are: ETH Zurich (Hydrology and Water Resources Management), ETH Zurich (Laboratory of Hydraulics, Hydrology and Glaciology), Center for Climate Systems Modeling (C2SM), and Kraftwerke Mattmark AG / Axpo Power AG.

Further we are working in collaboration with Task 2.2 to assess the impact of different market scenarios on future hydropower operation. We are combining multi-objective optimization techniques and a Swiss electricity market model to design different reservoir operating policies to assess which reservoir operating strategies can lead to maximisation of production to support the 2050 energy strategy. The main partners of these activities are: ETH Zurich (Hydrology and Water Resources Management), Uni Basel (Research Center for Sustainable Energy and Water Management), and Kraftwerke Mattmark AG / Axpo Power AG.

We have established a collaboration with OFIMA to assess future operating strategies also including the effect of different reservoir operating policies on the ecology of downstream river corridors. This activity links to Task 2.4 and to the NRP 70 funded project “HydroEnv”, the purpose of which is to identify key environmental indicators and environmental flow policies to be included in the integrated model as performance metrics to evaluate future hydropower system operation from the ecological point of view.

Finally, we plan to partner with Swiss National Institute of Forest, Snow and Landscape Research (WSL) to develop ensemble streamflow forecasts and explore by means of the integrated model how multi-model forecast uncertainty affects streamflow real-time predictions and their use in hydropower reservoir operation.

Highlights 2015

Several master theses have been conducted to test and develop the modelling framework and produce some preliminary results on two study sites. The students involved come from ETH Zurich as well as from other European universities.

The activities on Task 2.5 were presented in two international conferences thanks to two oral contributions:

- Operation of hydropower generation systems in the Alps under future climate and socio-economic drivers. European Geosciences Union General Assembly 2015 - Vienna (Austria)
- The role of hydropower operation to contribute to the future electricity supply of Switzerland: aim and experience of the Swiss Competence Center on Energy Research - Supply of Electricity (SCCER-SoE). EWRI (World Environmental and Water Resources Congress) - Austin, Texas (U.S.A.)

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Design of hydropower systems operation under current and future energy market conditions

Daniela Anghileri, Ingmar Schlecht, Andrea Castelletti, Hannes Weigt, and Paolo Burlando

Abstract

Future Swiss hydropower (HP) production may be threatened by unprecedented challenges: a decreasing water availability, due to climate change, an increased energy demand, due to nuclear plant phase out, and uncertain operating conditions, due to highly fluctuating conditions on the energy market.

In this work, we analyse the tradeoff between adequate energy supply and profitable operation under current and future energy market conditions.

We combine multi-objective optimization techniques and a Swiss electricity market model to design different reservoir operating policies.

Results inform to which extent hydropower production can cope with both secure energy supply and profitable operation for the power companies.

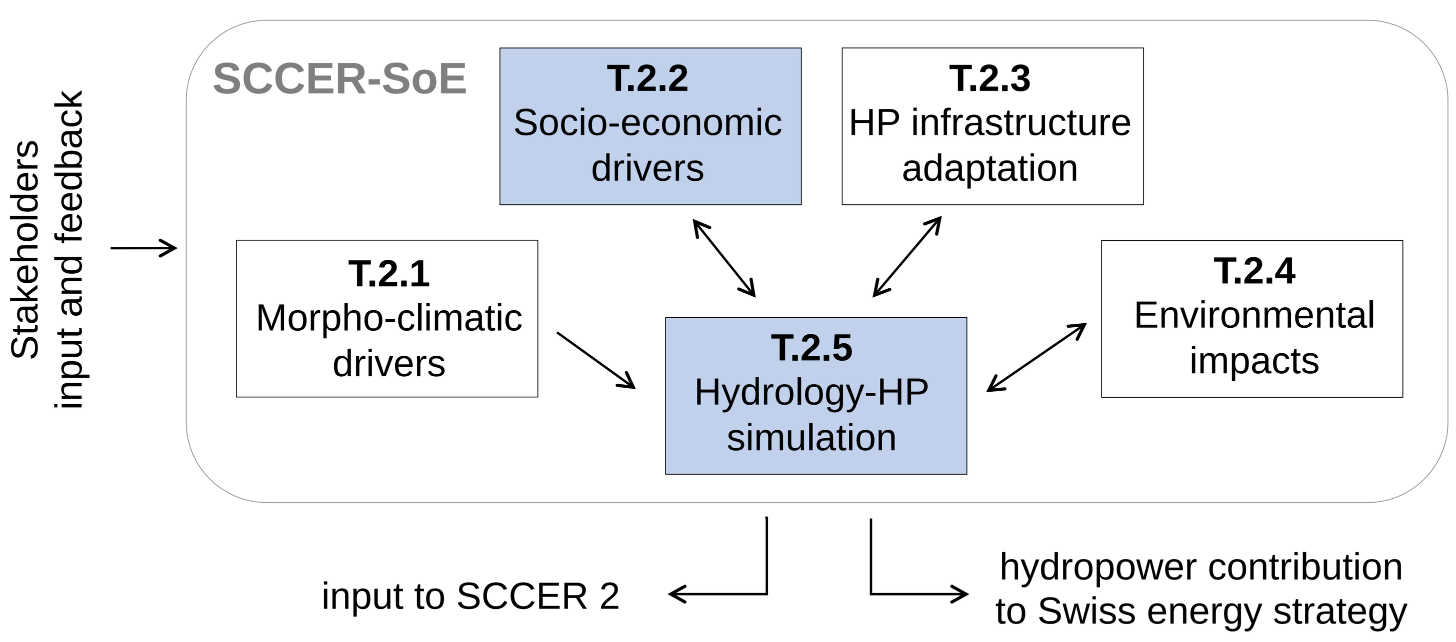
1. Objectives and relevance of the work

- Evaluate different hydropower operation policies under future climate, demand and market scenarios.
- Assess which reservoir operating policies lead to maximisation of production to support the 2050 energy strategy.
- Analyze the profitability of such policies under different future market conditions.

Results inform on the impacts of future climate and energy market conditions on hydropower generation and provide insights to future reservoir operating policies and energy market design.

2. Context within SCCER – SoE

This work represents a joint effort of task T2.2 and T2.5



Main partners involved in this work:

- ETH Zurich (Hydrology and Water Resources Management)
- Uni Basel (Research Center for Sustainable Energy and Water Management)
- Kraftwerke Mattmark AG c/o Axpo Power AG

3. Methods and contributions

We develop a decision analytic framework composed of a coupled hydrological and hydropower operation model.

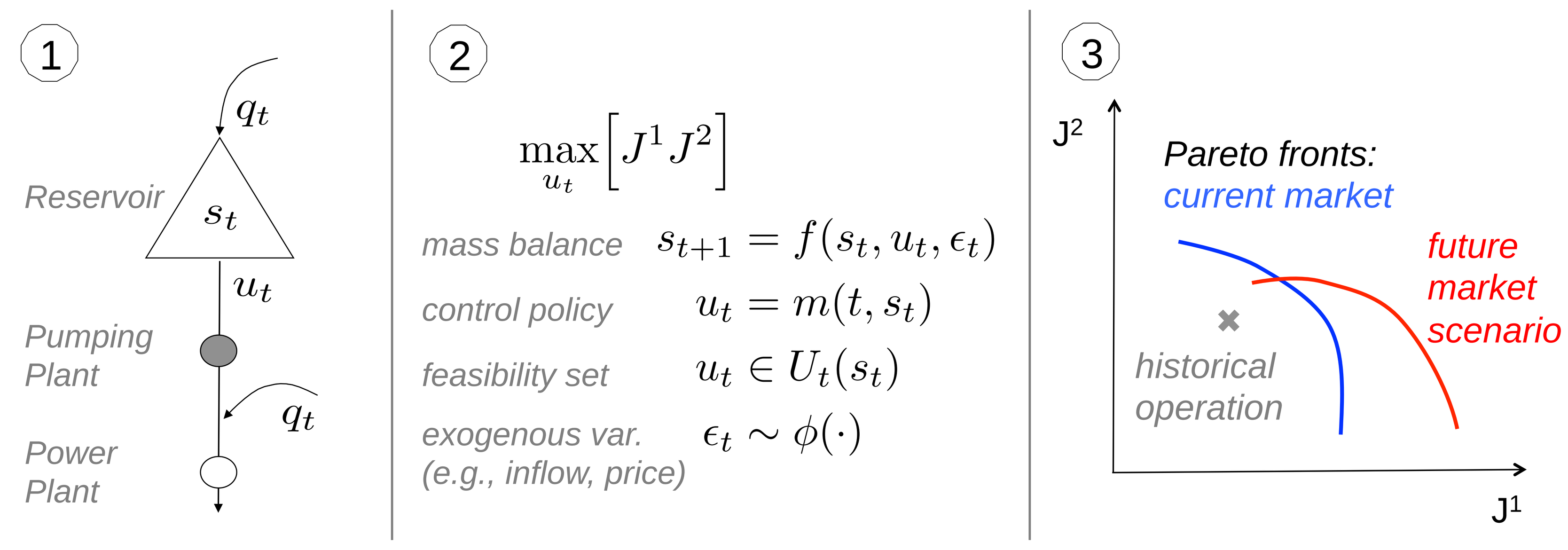
We use multi-objective optimization techniques to design different hydropower reservoir operating alternatives and to explore different tradeoffs between profitability and secure supply.

We investigate how these tradeoffs may evolve in time under different energy market scenarios, derived using the Swissmod[1] model of the Swiss electricity market using the DC load flow approach.

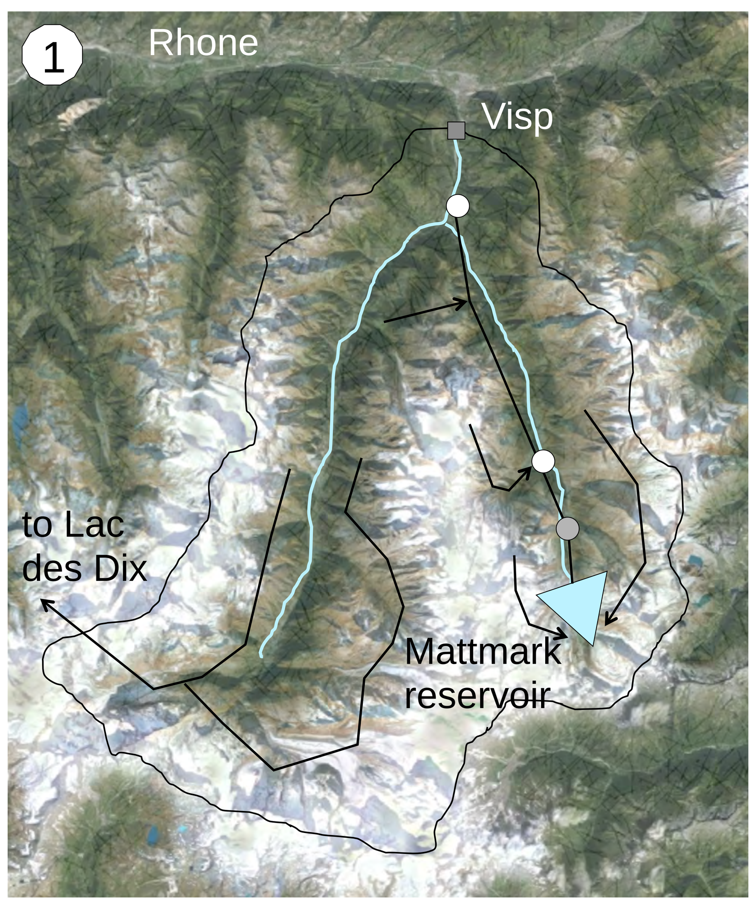
[1] Schlecht and Weigt "Swissmod - A Model of the Swiss Electricity Market" FoNEW Discussion Paper 2014/01

Methods: multi-objective optimization

1. Detailed modelling of the HP system
2. Definition of the control problem (multiple objectives, e.g., maximisation of revenue, production, reliability and flexibility of supply)
3. Analysis of the tradeoffs between objectives under different market scenarios



4. Application to pilot study and preliminary results



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two objectives:

- maximise production
- maximise revenue

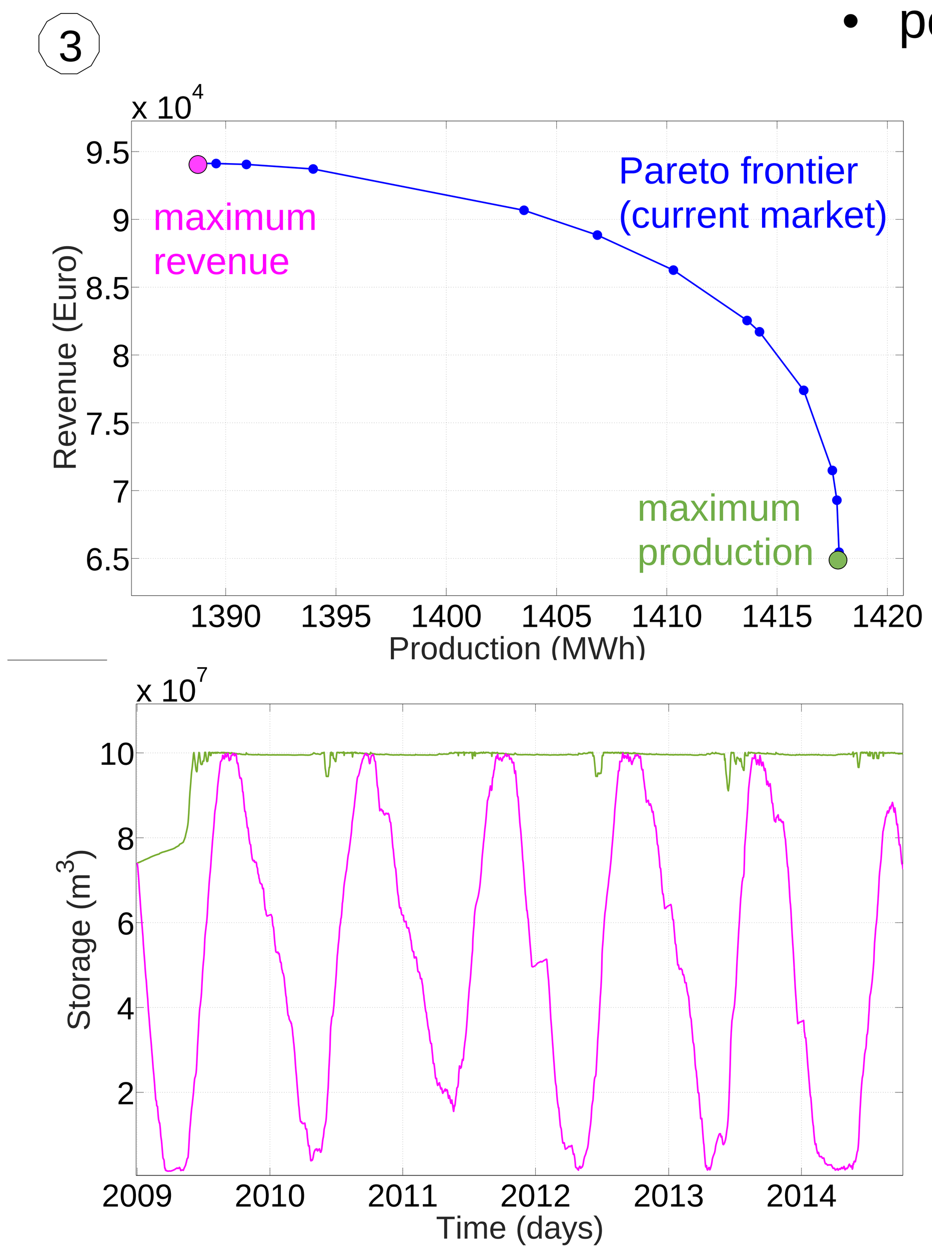
subject to physical constraints (mass balance, spillway capacity, …)

one control variable:
daily reservoir release

two exogenous variables:
inflow to Mattmark reservoir, energy price

Modeling simplifications so far:

- pumping is not considered
- perfect knowledge of inflow
- perfect knowledge of energy price



The Pareto frontier is the solution of the control problem on the historical period 2009-2014 (top panel).

It considers current market conditions ('energy-only' market) and shows a conflict between maximization of energy production and maximization of revenue, which produce totally different reservoir dynamics (bottom figure).

The analysis informs on the maximum achievable production and the tradeoff in terms of power company income.

5. Future developments

- Analyse the evolution of tradeoff under different market scenarios and portfolios of power sources
- Evaluate the role of pumped storage (added value in current and future operation)
- Assess the joint effects of hydro-climatic and socio-economic drivers on hydropower system operation
- Upscale the analysis to regional/national scale

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Impacts of climate change on hydrology and operation of Mattmark reservoir under business-as-usual production targets

Daniela Anghileri, Nadav Peleg, Andrea Castelletti, Paolo Burlando

Abstract

Future water availability in the Alps is expected to vary considerably due to climate change and the associated glacier retreat. The potential change in hydrological processes may challenge hydropower (HP) production and the rules currently adopted to operate the reservoirs.

In this work we explore the impacts of climate change on the Mattmark hydropower system in the Visp Valley.

We develop an advanced modelling framework for the integrated simulation of the operation of hydropower plants, which accounts for high resolution climate change scenarios, the corresponding altered streamflow regimes, energy demand and price, as well as new boundary conditions for operation (e.g., aquatic ecosystem conservation).

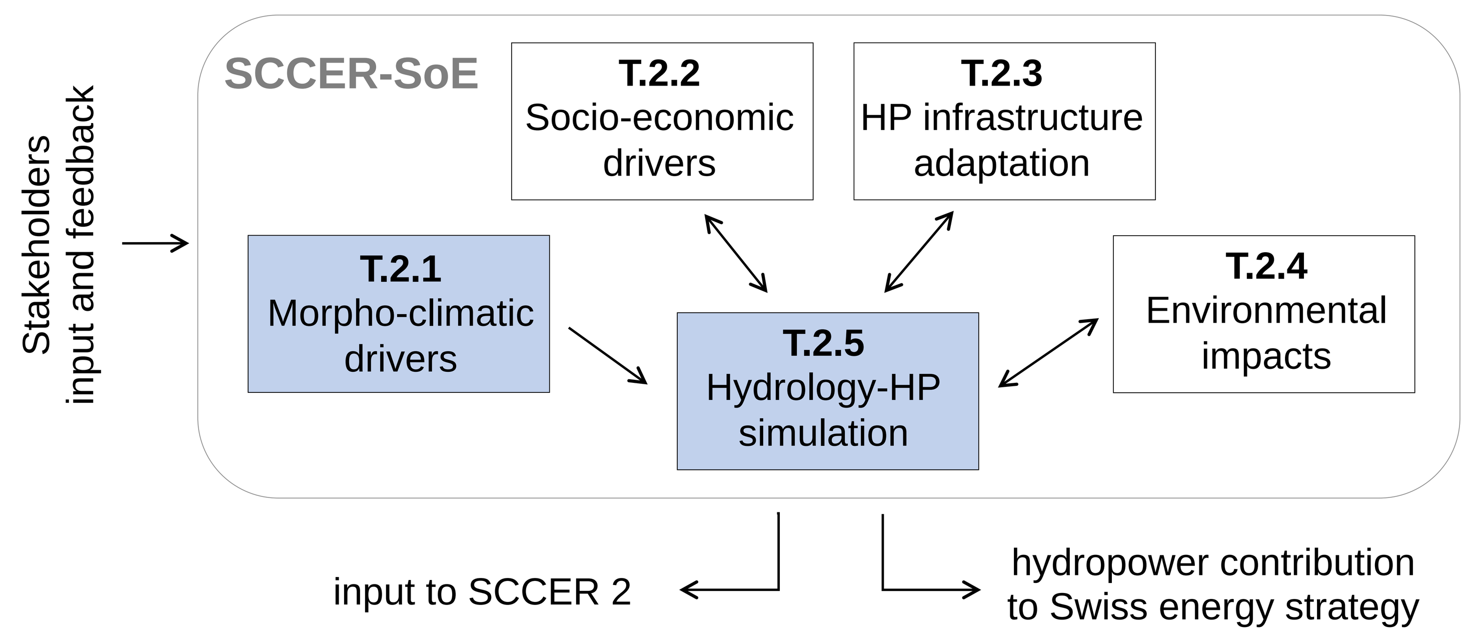
1. Objectives and relevance of the work

- Produce ensemble of high resolution climate change scenarios downscaled to the spatial scale relevant for hydropower operation
- Assess the impacts of climate change on water system functioning both in terms of power production and environment conservation
- Evaluate the sustainability of current hydropower operating policies under future climate scenarios
- Design adaptation strategies for reservoir operation to counteract the effects of climate change

Results represent a detailed projection of future water resource availability and allow for the design of reservoir operating policies robust to climate change uncertainty in support the 2050 energy strategy.

2. Context within SCCER – SoE

This work represents a joint effort of task T2.1 and T2.5.

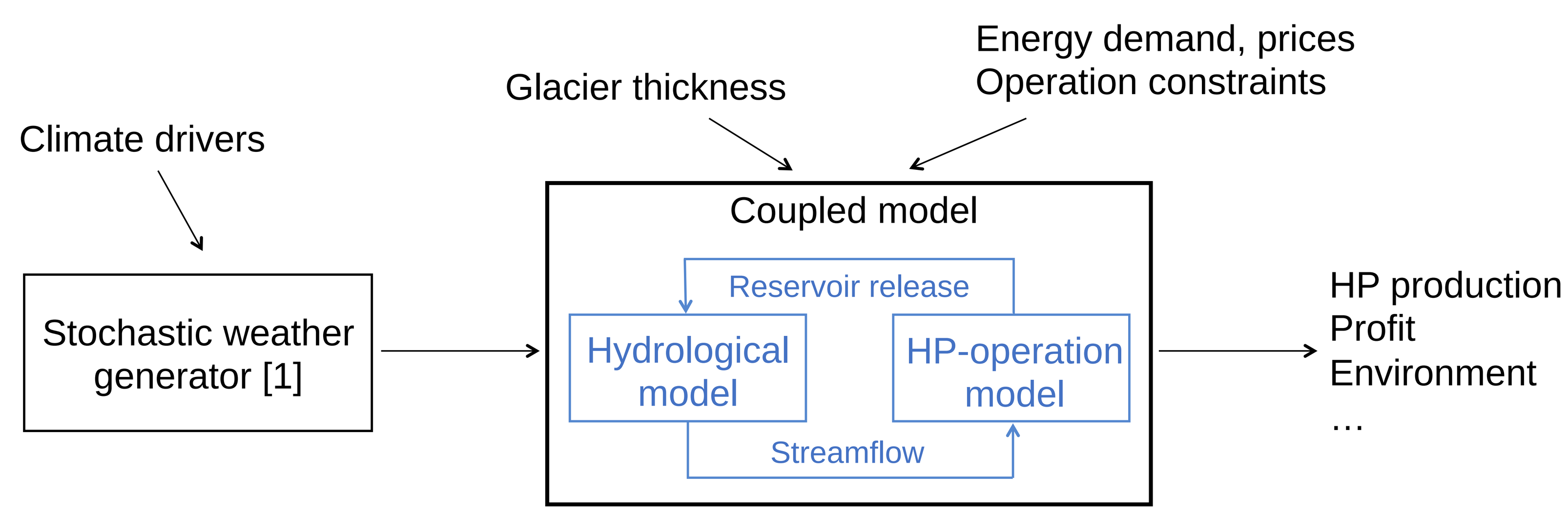


Main partners:

- ETH Zurich (Hydrology and Water Resources Management)
- ETH Zurich (Laboratory of Hydraulics, Hydrology and Glaciology)
- Center for Climate Systems Modeling (C2SM)
- Kraftwerke Mattmark AG c/o Axpo Power AG

3. Methods and contributions

We combine high resolution statistical downscaling techniques, spatially distributed hydrological model, and advanced water resources management techniques.



Methods … continuation

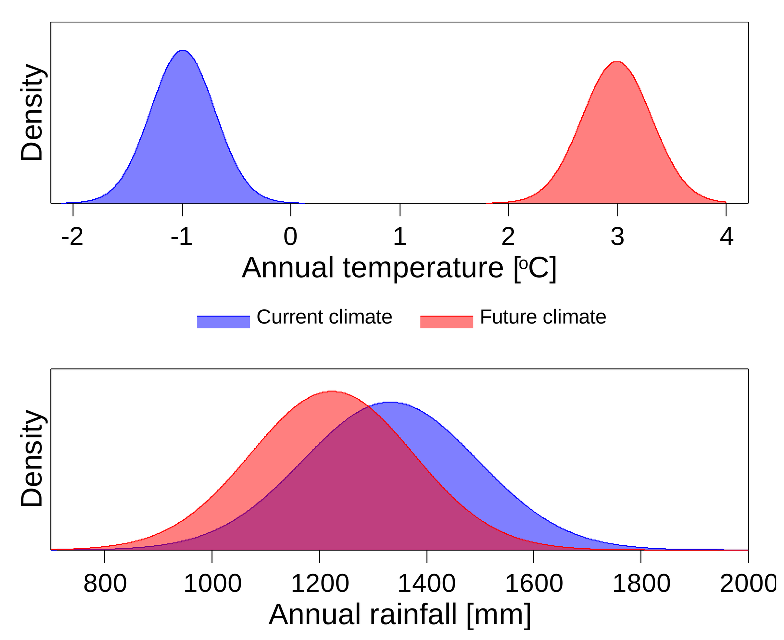
The AWE-GEN-2d (Advanced WEather GENerator for 2-Dimension grid) is used for the statistical downscaling to formulate a high spatio-temporal resolution fields of rainfall and temperature. For more details refer to [1].

The hydrological model Topkapi-ETH is a fully distributed and physically explicit model allowing for the simulation of snow accumulation, glacier dynamic, and geomorphological processes.

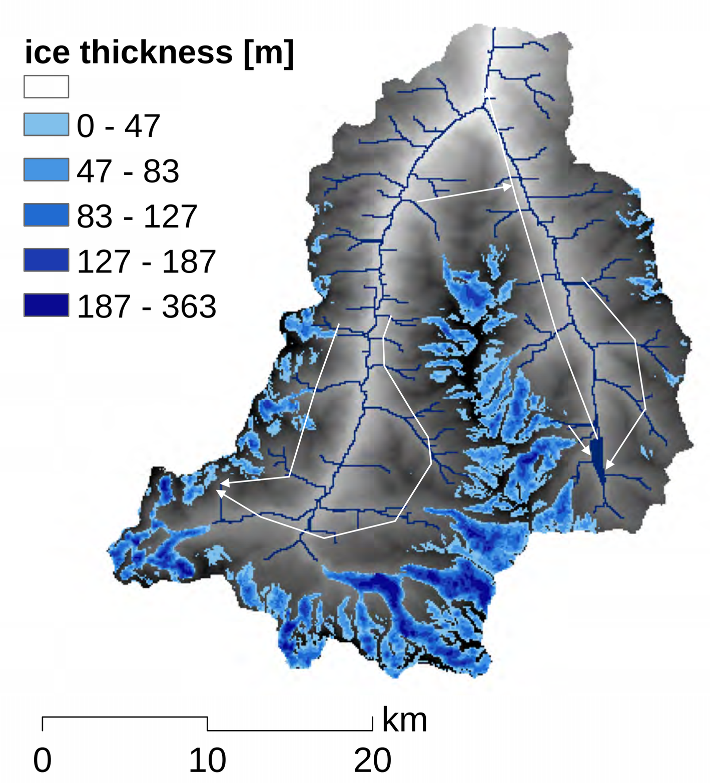
The hydropower operation model can account for historical operating rules as well as data-driven or optimization based operating policies.

4. Application to pilot study and preliminary results

	DJF	MAM	JJA	SON	
Temperature	3.83	3.65	4.83	3.81	[◦C]
Rainfall	22.7	-10.1	-27	-8.9	[%]



Two ensembles were generated using the AWE-GEN-2d model, representing the current climate (2004-2014) and the future climate (2071-2100). Each ensemble consists of multiple realizations of 30-years data. The ensembles rainfall and temperature statistics presented to the left.
The factors of change used for this study (summarized in the Table to the left) are derived from the official CH2011 climate scenarios, using the median predictions for the end-of-the-century with the A2 emission scenario.

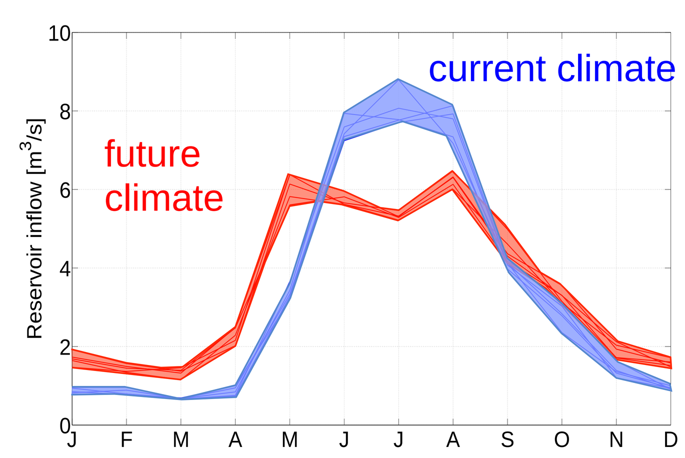


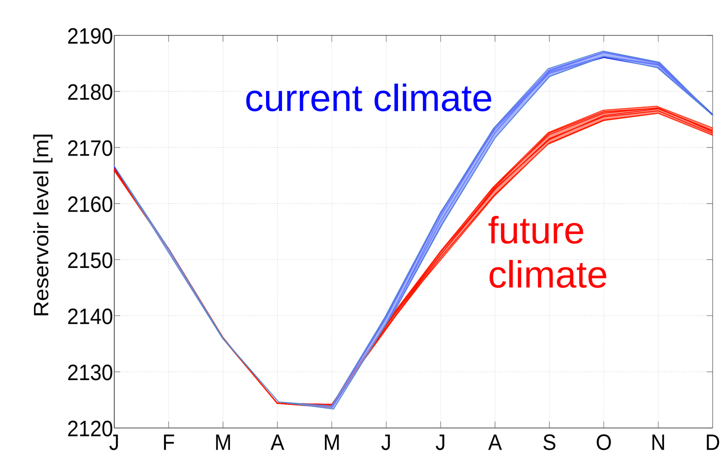
The Topkapi-ETH hydrological model main features are:

- spatial resolution: 100 m regular grid
- temporal resolution: hourly
- glacier thickness maps as in [2, 3]

Calibration on historical inflow (1994-2014) showed NSE = 0.80 (computed on the daily resolution).

The bottom panels show preliminary results of the seasonal average trajectories of reservoir inflow and reservoir level resulting from the simulations of the ensembles for the current and future climate.





5. Future developments

- Fully characterize climate change uncertainty on streamflow regimes
- Assess the resilience of hydropower system to future changes by design of new reservoir operating policies intended to adapt to future water availability
- Assess the combined effect of climate change and reservoir operation on environment
- Design robust reservoir operating policies to future system uncertainty
- Upscale the analysis to regional scale

References

[1] see poster "*Generation of very high resolution scenarios to investigate climate change impact on hydropower operation*" (Task 2.1) by Peleg et al.

[2] Huss and Farinotti (2012). Distributed ice thickness and volume of all glaciers around the globe. Journal of Geophysical Research, 117,

[3] Fischer et al. (2014). The new Swiss Glacier Inventory SGI2010. Arctic, Antarctic and Alpine Research, 46(4), 933-945.