

Climate Change Effects on Reservoir Inflows and Hydropower Operation

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SCCER-SoE Annual Conference 2019

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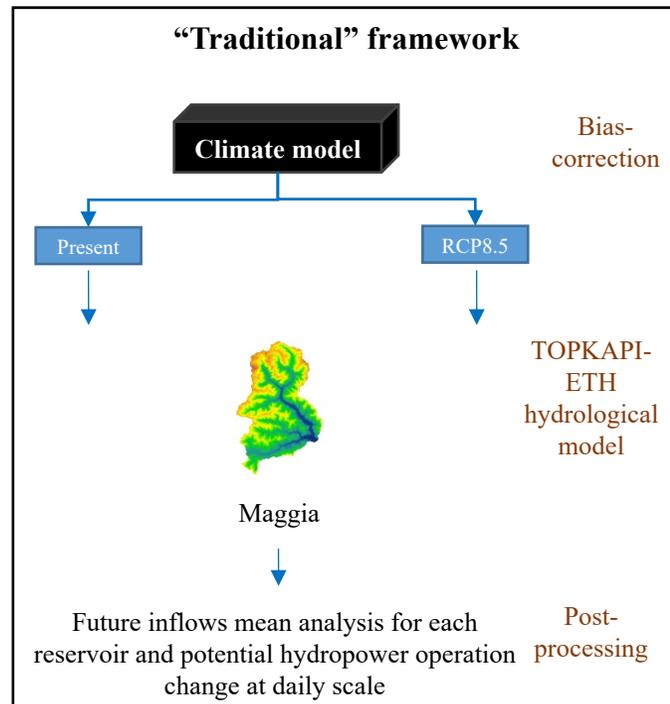
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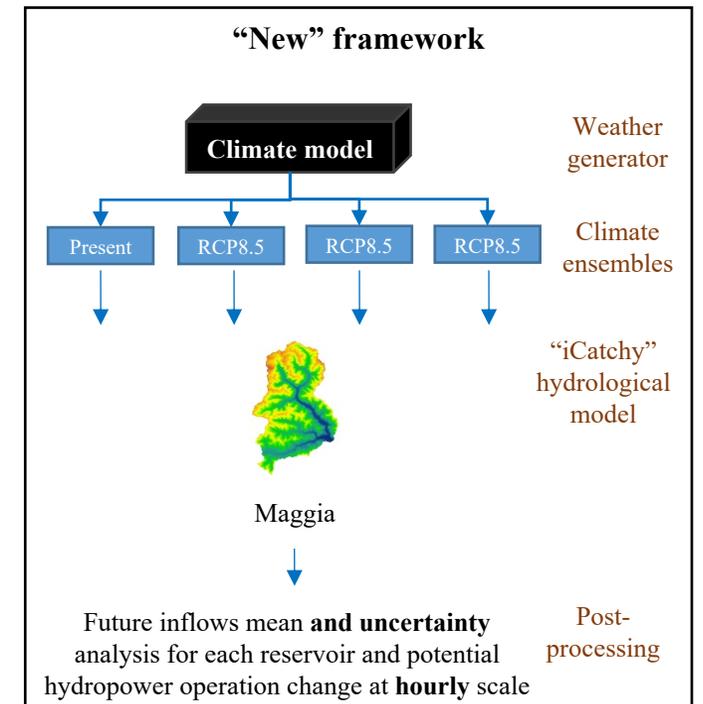
Motivation

1. Estimate climate change effects on reservoir inflows
2. Estimate future hydropower operation strategies



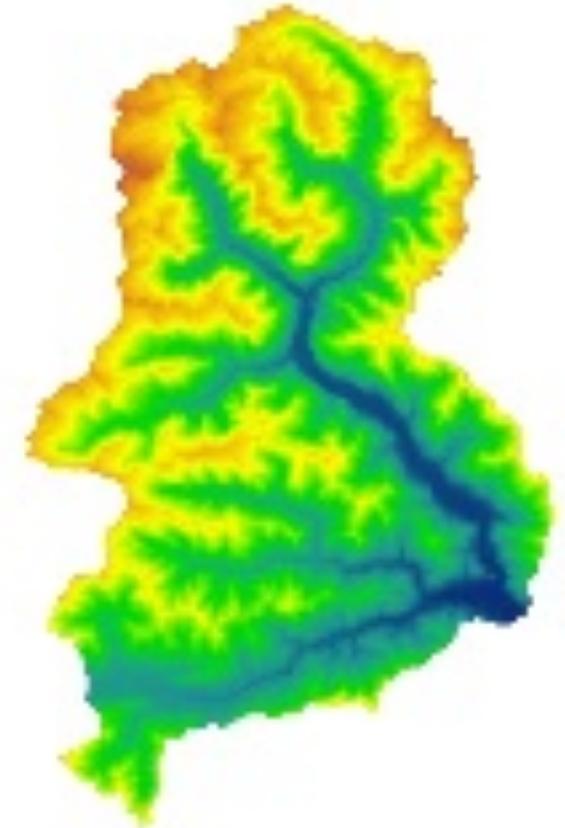
Advantages:

- Retain sub-daily inflow peaks
- Compute inflows for each reservoir/sub-catchment individually
- Embed hydropower policies in the hydrological model

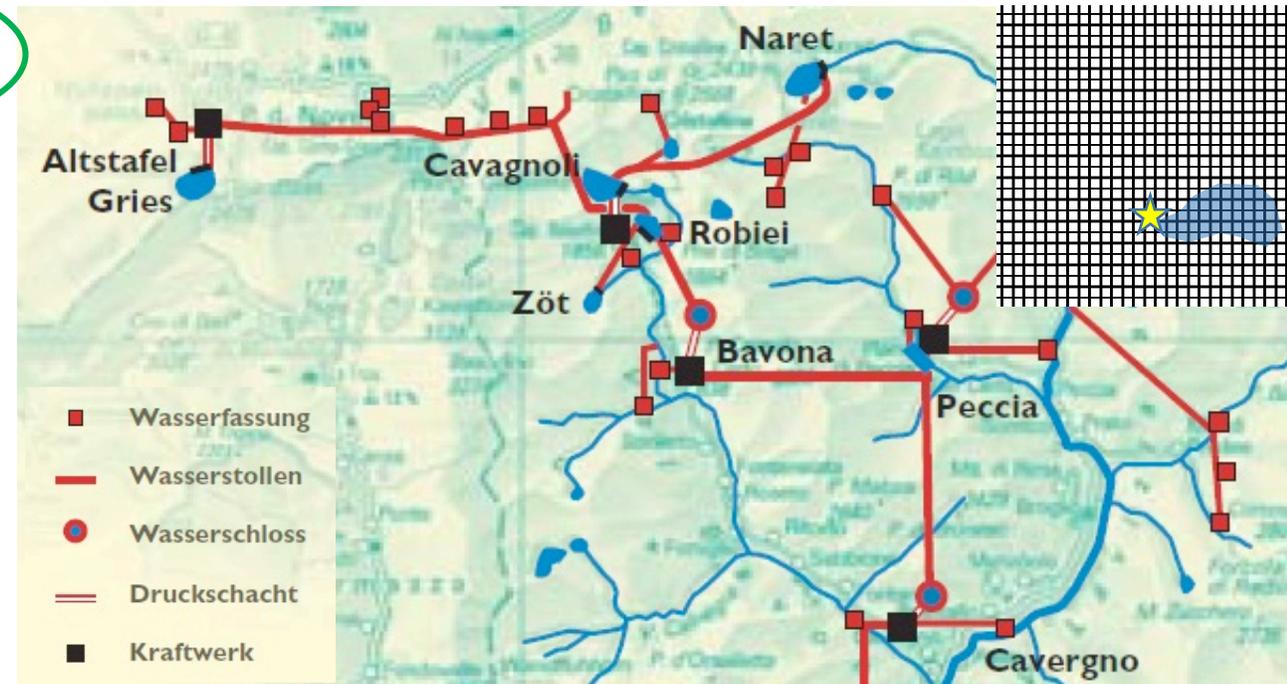
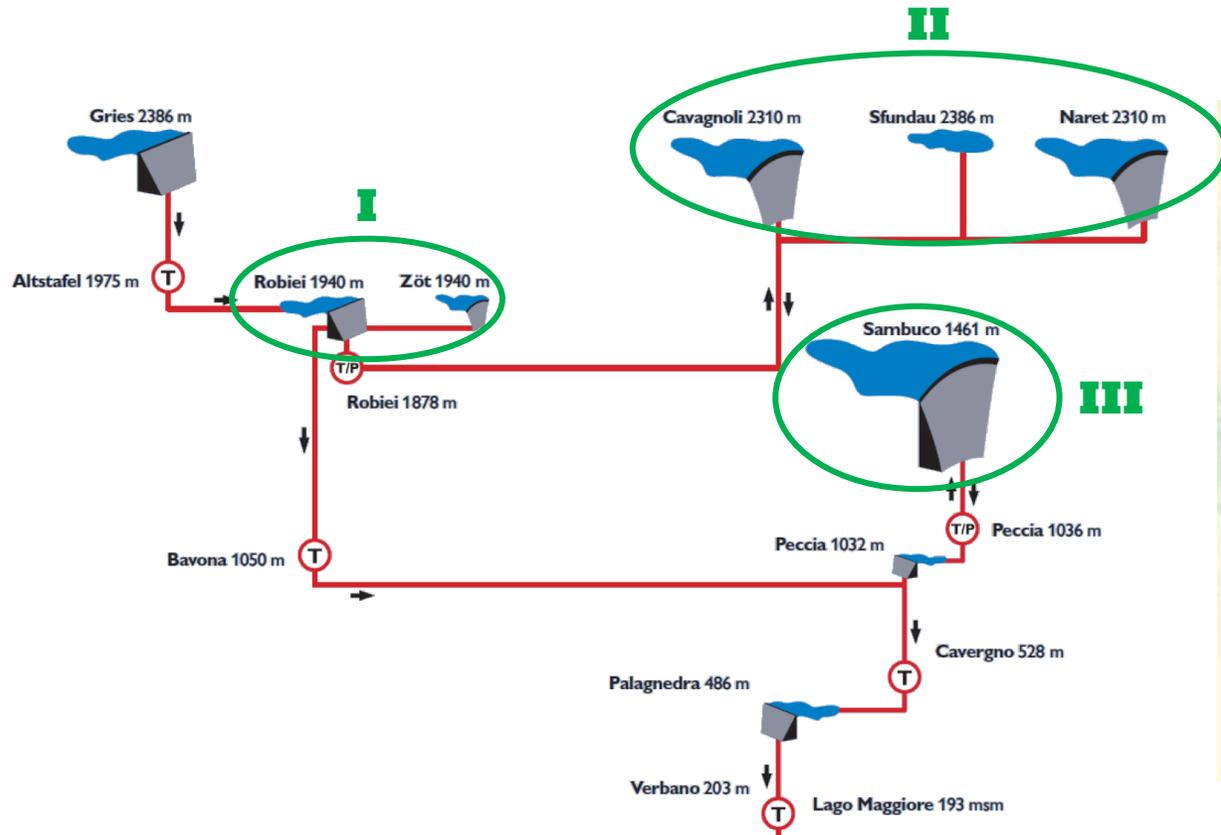


Study area – Maggia valley (OFIMA)

- Total drained area of 840 km²
- Elevation ranges between 204 and 3208 m
- Present climate precipitation are 1840 mm
- Hydrological data available for pre-dam and post-dam periods



Study area – Maggia valley (OFIMA)

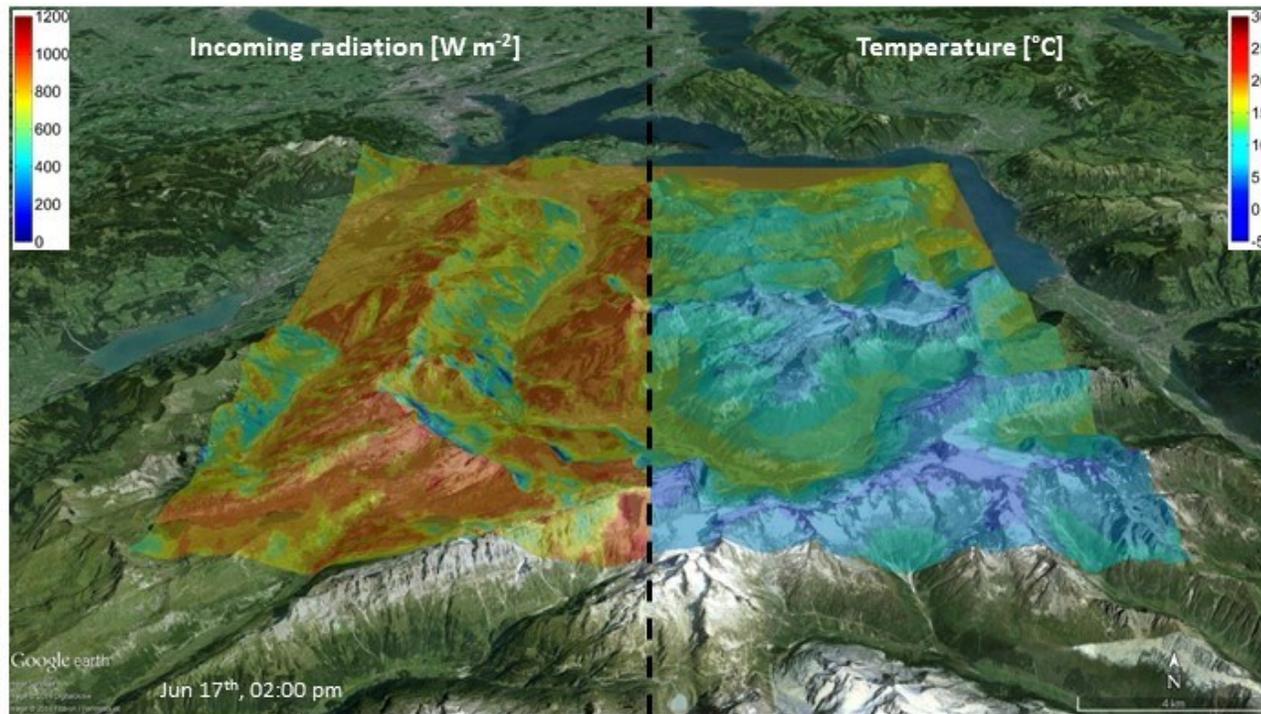


Methods

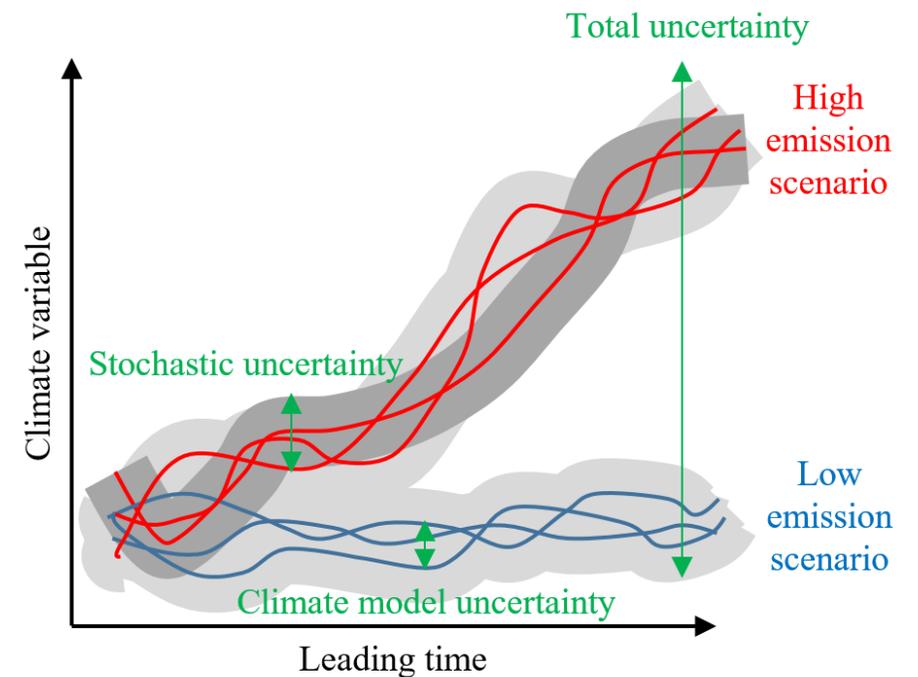
1. Climate downscaling
2. Hydrological simulations
3. Hydropwer operation optimization

Climate downscaling

- The **AWE-GEN-2d** (**A**dvanced **WE**ather **GEN**erator for **2-D**imensional grid) model

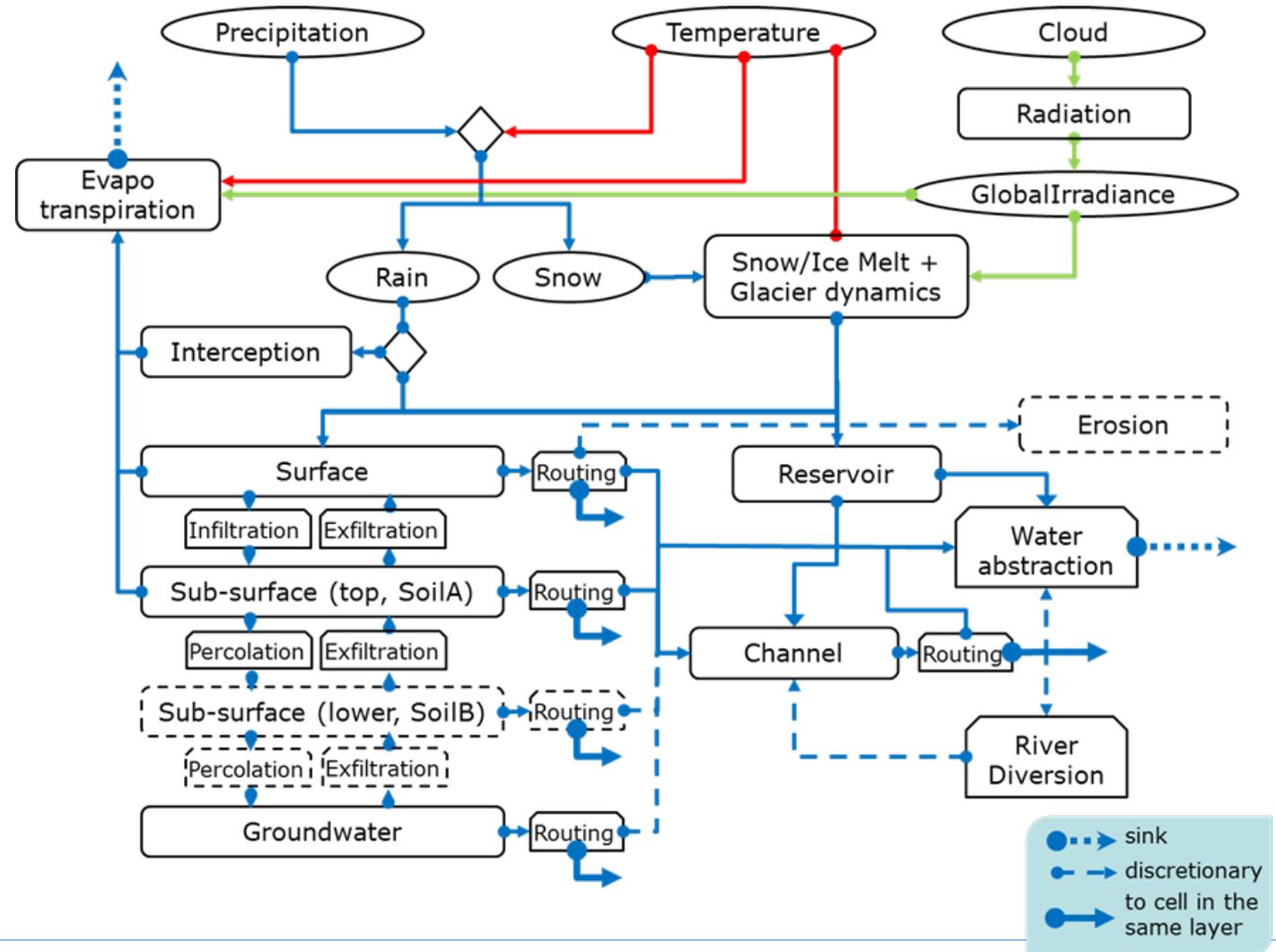
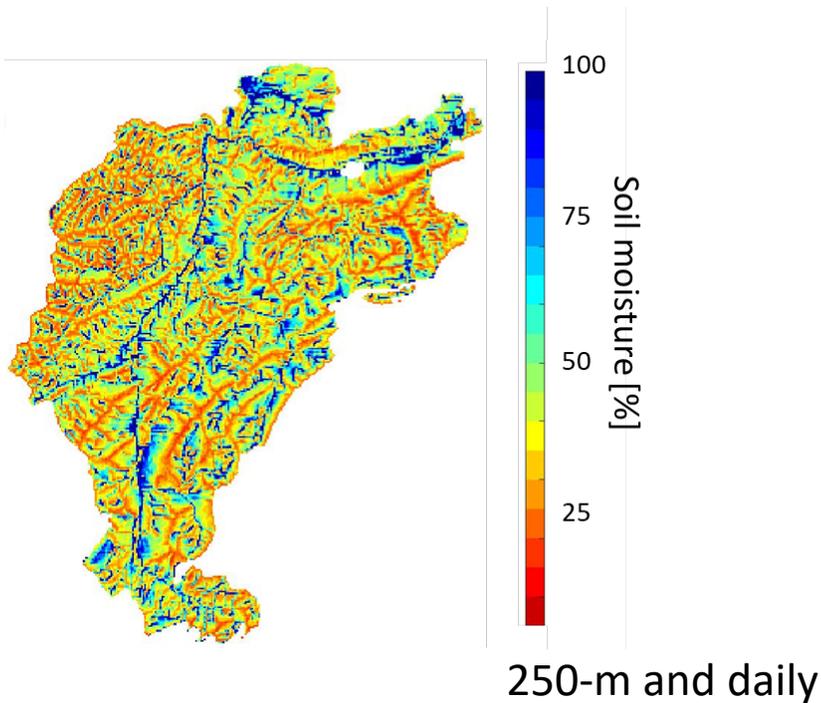


100-m and hourly



Hydrological simulations

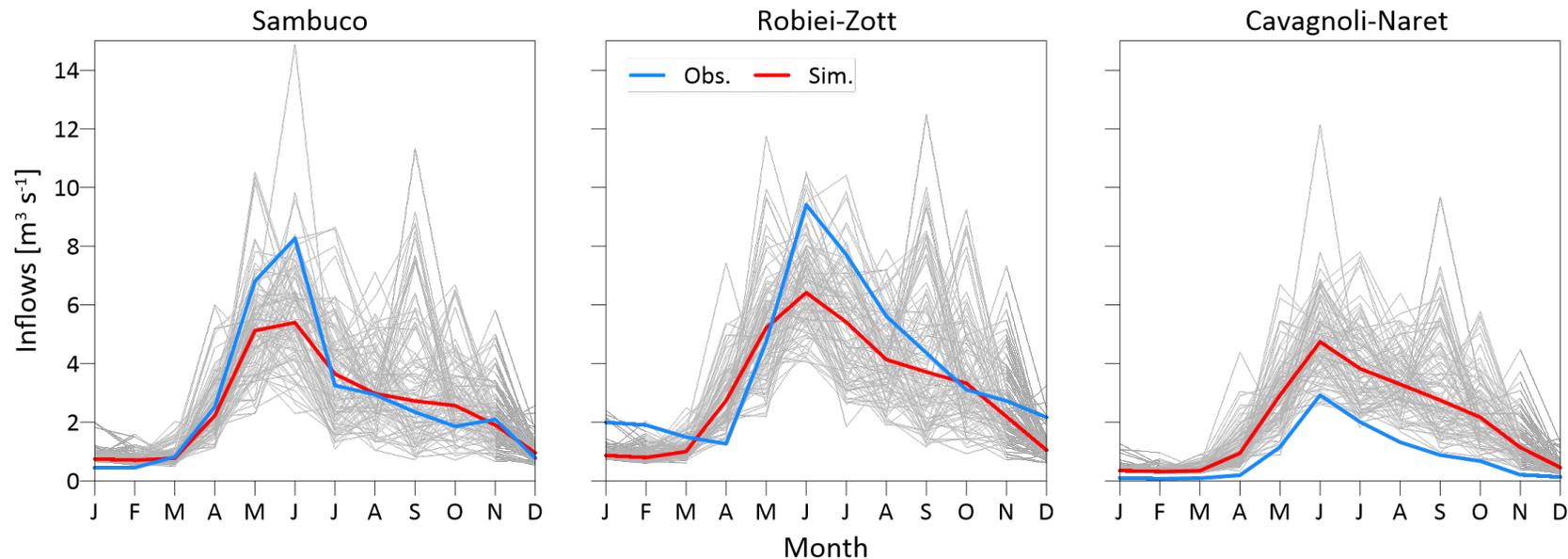
- The TOPKAPI-ETH model.
- To be replaced with iCatchy.



(see SCCER-SoE annual conference 2018; Anghileri et al.)

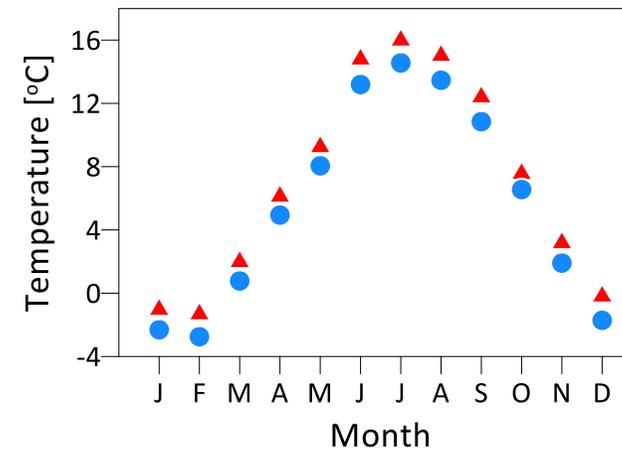
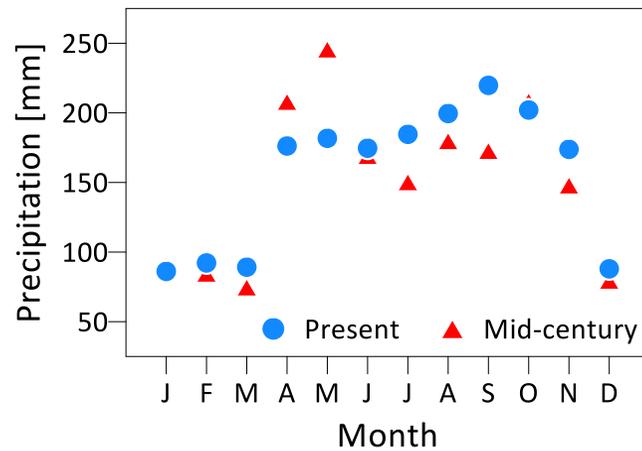
Present inflows to the reservoirs

- Inflow data were obtained from OFIMA for the period of 2005-2015.
- Outputs (100 simulations, daily runs) from a preliminary set-up of the Topkapi-ETH model, accounting only for the main diversions and intakes.

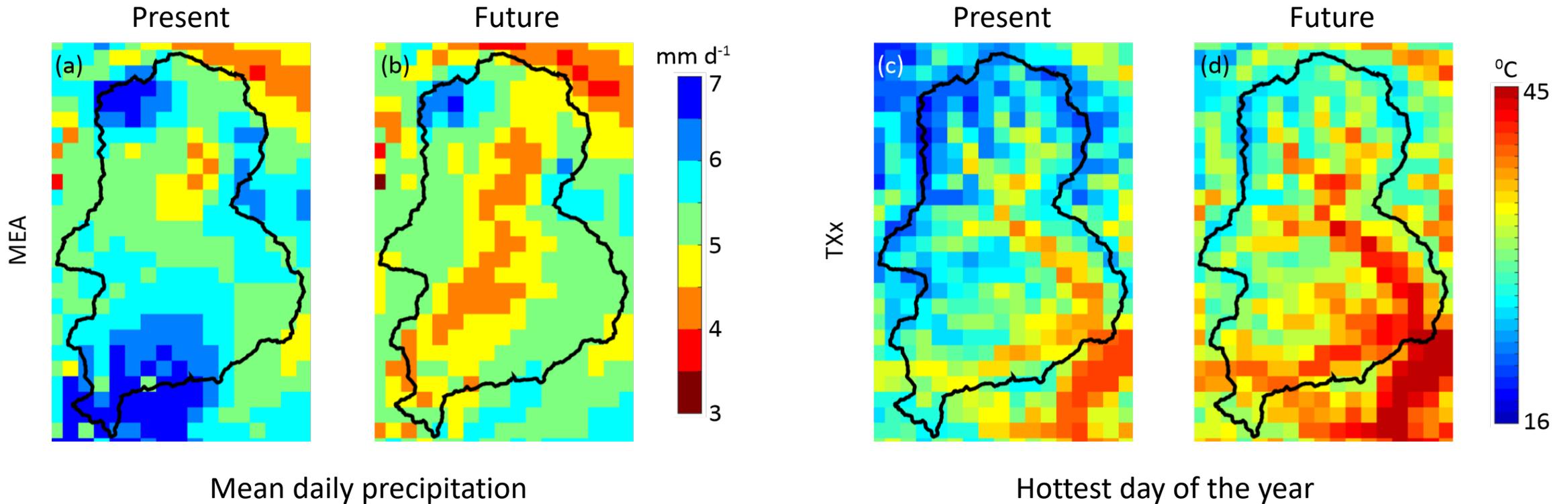


Climate change

- 9 climate models from the CH2018 official climate scenarios for Switzerland
- RCP8.5
- Period of interest 2030-2059

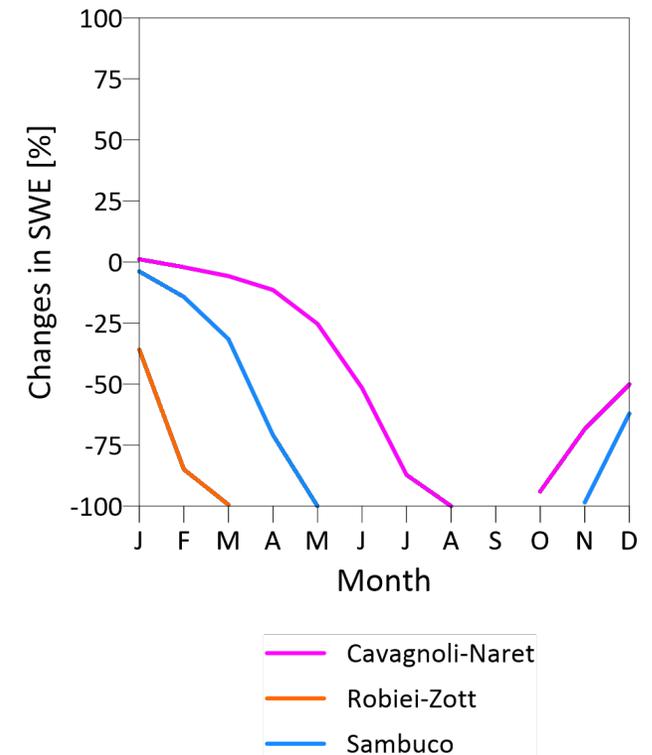


Climate change



Future inflows to the reservoirs

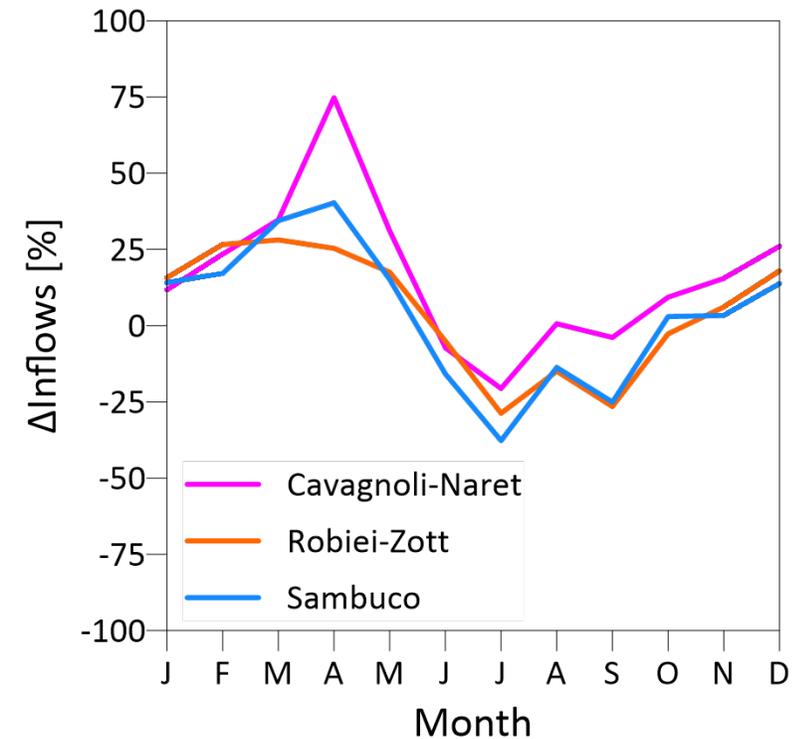
- 200 simulations were conducted to analyze the impacts of climate change on the hydrology for the mid of the century.
- The hydrological system is sensitive to the changes in climate, particularly with respect to the contribution of snow water equivalent, which declines significantly in all reservoirs in the future simulations.



Future inflows to the reservoirs

Results point at a reduction in the total inflows into the reservoirs, with a clear seasonal pattern:

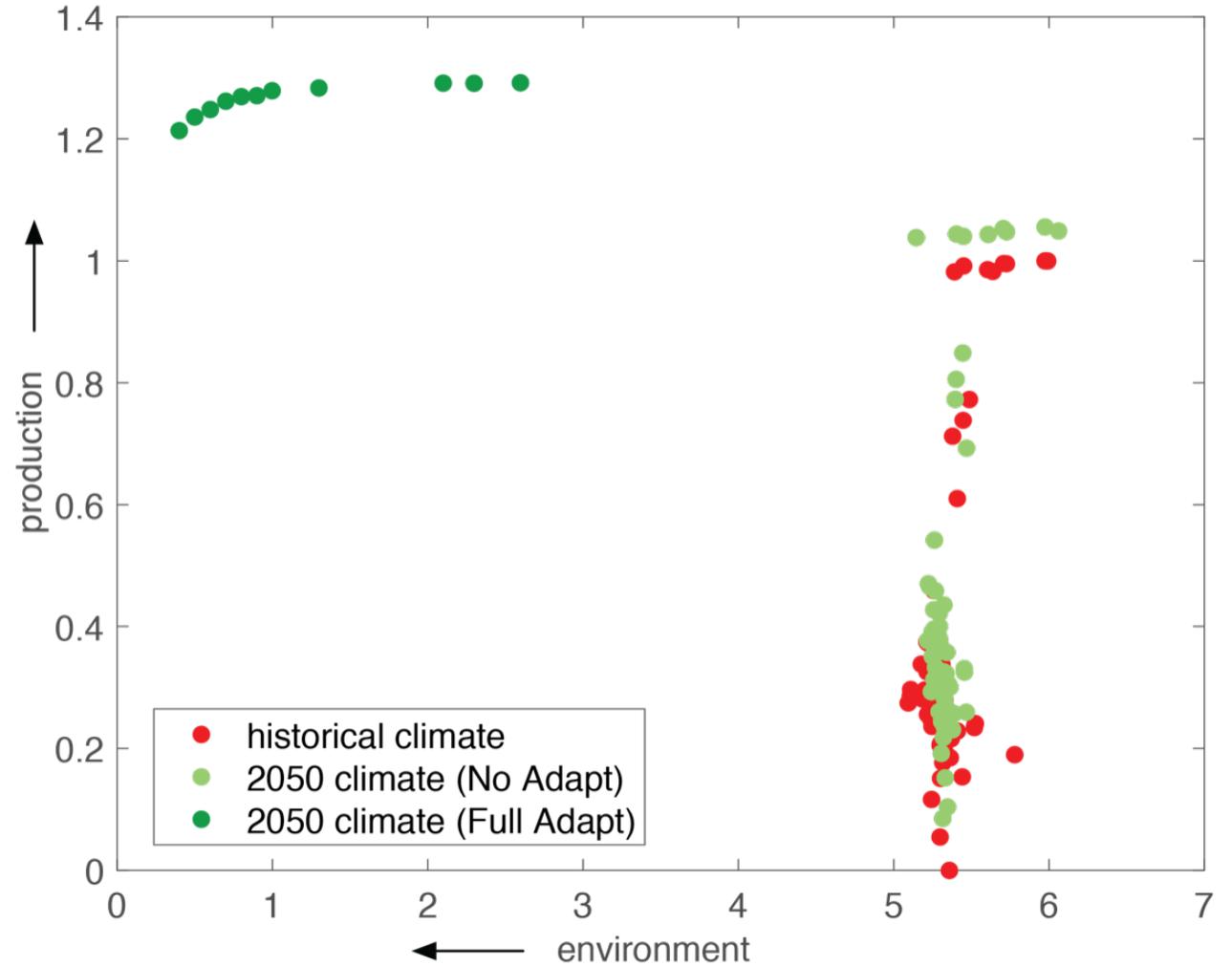
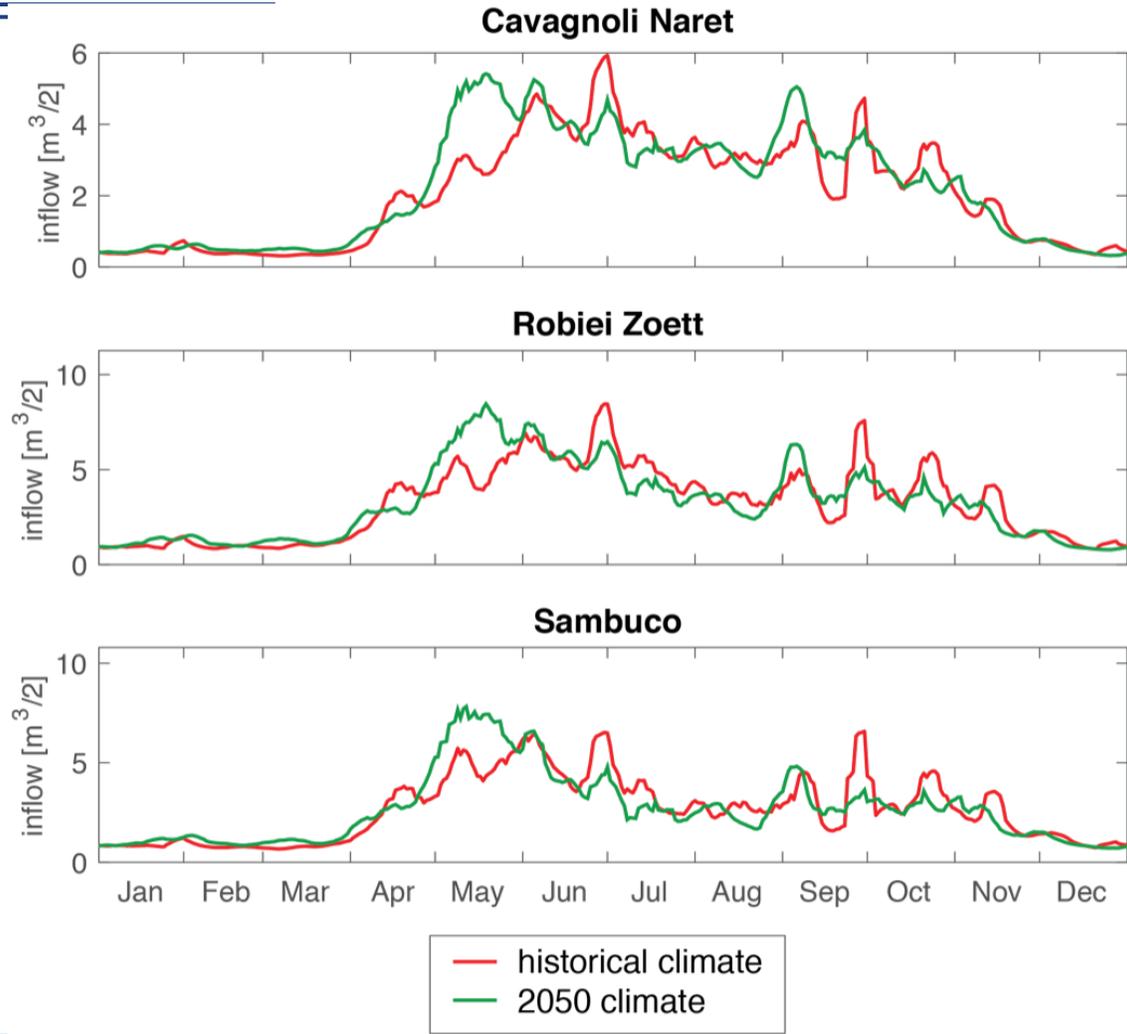
- Increase during April-May (reduction in SWE, but increase of rainfall → total precipitation increases)
- Decrease between June and October (reduction in both SWE and rainfall).



Future work

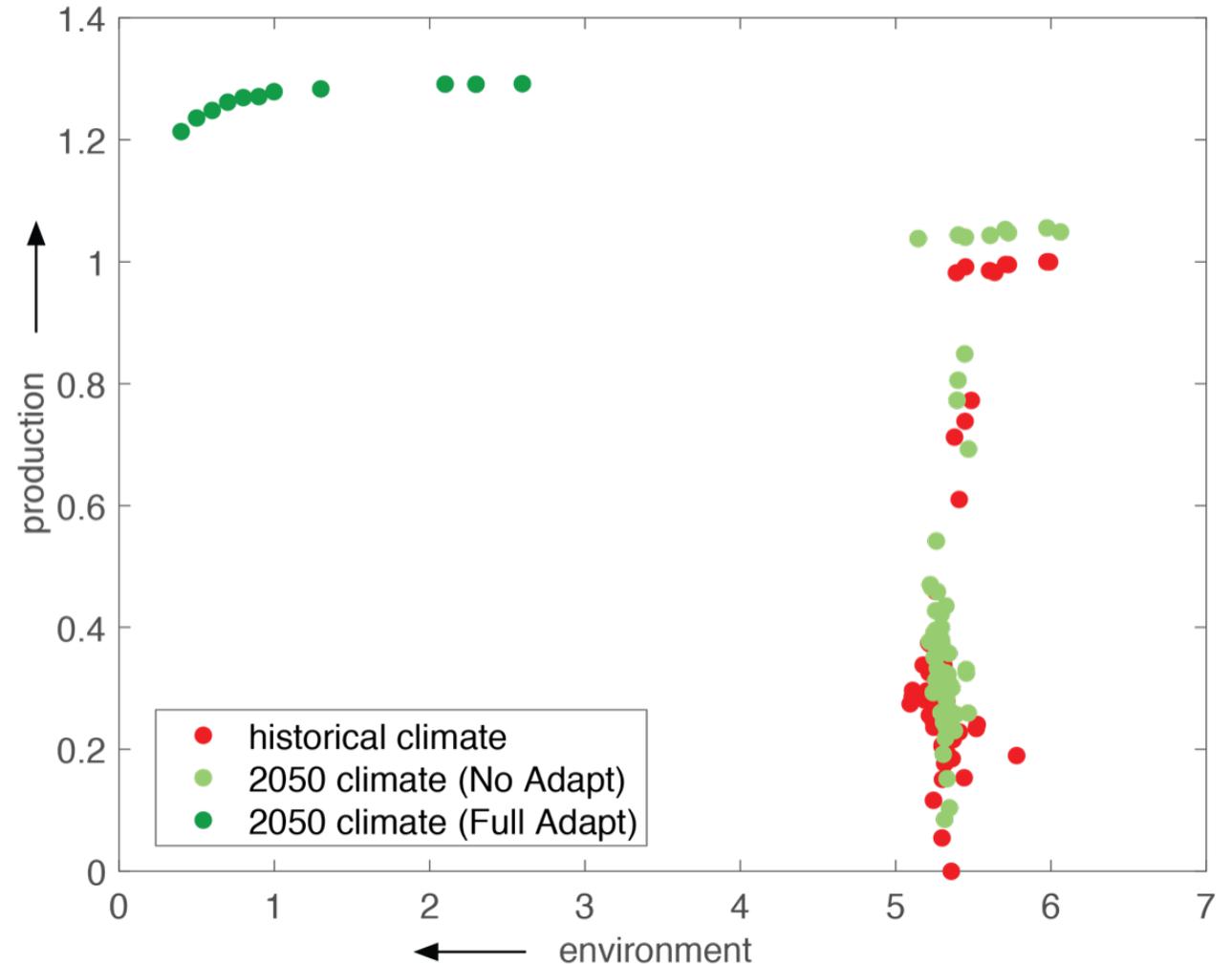
- Finalizing the setup of the model – adding the missing contributions (e.g. Gries reservoir and Altstafel tunnel and Sfundau reservoir).
- Switching from daily simulations to hourly, in order to simulate sub-daily hydrological processes (e.g. radiation variability) and flow dynamics including sediment production and transport.
- Increasing the spatial resolution to 100 m to match the resolution of the climate.
- Update the model parameterization to improve the model performance and to account for future hydropower operation policies (see next slides presented by Castelletti).

Impact on the operations (preliminary)



Impact on the operations (preliminary)

- Increasing spring inflow will have no impact with NO ADAPTATION
- With ADAPTATION production will increase
- And the conflict between HP and environment will be reduced



Thank you for your attention!

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Climate change effects on reservoir inflows (Maggia valley, OFIMA)

Sebastian Moraga, Nadav Peleg, Daniela Arghirei, Simone Fatichi, Paolo Burlando

Motivation

Climate change is expected to affect the hydrological system (e.g. modifying river flow, snow accumulation and melt) with consequences for the inflows to hydropower reservoirs and therefore their operation policies.

In the context of Task 2.4, we studied the effects of climate change on the three largest reservoir systems of the OFIMA hydropower system in the Maggia valley, Robiaco, Caviglioglio, and Sambuco.

Objectives

- To estimate local climate change effects (precipitation and temperature) over the Maggia region for mid of the century and for a severe emission scenario (RCP8.5).
- To estimate the changes of the future inflows to the three reservoir systems.
- To provide inflows scenarios to Task 2.4 for the investigation of new hydropower operational policies, which account for uncertainties of changes in climate and hydrology.

Methods

- Changes in precipitation and temperature are estimated using 9 climate models that were post-processed in the official CH2018 climate change scenario initiative.
- The AWE-GEN-2d stochastic weather generator model is used to produce local climate variables needed for the hydrological projections (present and future) at high-resolution of 2km and 1-.
- The TopogeoETH distributed hydrological model is used to simulate the basin hydrology and estimate the inflows to the reservoirs.

Climate change

- Temperatures in the Maggia valley are projected to increase during all seasons. The changes in precipitation are less pronounced, with most months showing small changes that are within the range of the natural variability (Fig. 1).

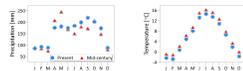


Fig. 1 Example of changes in precipitation (left) and temperature (right) averaged over the Maggia valley, downloaded from the ECEARTH_CCMO-CO-GCM4M model using AWE-GEN-2d for the period 2030-2059.

- While the increase in temperature is projected to be relatively homogeneous in space, precipitation is projected to change more in the central and southern areas than the northeast and southwest areas (Fig. 2).

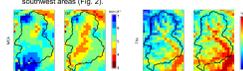


Fig. 2 Comparison between present and future mean daily rainfall (left) and total day of the year (right) over the Maggia valley. Changes indices were computed from downscaled simulations driven by the IPSL-SMIR-RCM model.

Present inflows to the reservoirs

- Inflow data for the three reservoirs were obtained from OFIMA for the period of 2008-2016.
- Outputs (100 simulations, daily runs) from a preliminary set-up of the TopogeoETH model accounting only for the main diversions and intakes were compared with the observed data (Fig. 3).
- The seasonality and flow dynamics are reasonably reproduced by the model, while the absolute inflow values are either underestimated for the peak season, Sambuco and Robiaco-Zuf, or overestimated (all seasons, Caviglioglio), due to the preliminary set-up.

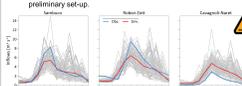


Fig. 3 Comparison between the observed (blue lines) and 100 simulations (gray lines) of inflows to the three reservoirs. Red lines represent the median of the stochastic simulations.

Future inflows to the reservoirs

- 200 simulations were conducted to analyze the impacts of climate change on the hydrology for the mid of the century.
- The hydrological system is sensitive to the changes in climate, particularly with respect to the contribution of snow water equivalent, which declines significantly in all reservoirs in the future simulation (Fig. 4).
- Results point at a reduction in the total inflows into the reservoirs, with a clear seasonal pattern (increase during April-May, and decrease between June and October, Fig. 5).



Fig. 4 Relative change in snow water equivalent contributing to the flow between future and present climate.

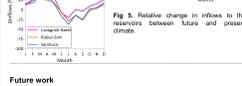


Fig. 5 Relative change in inflows to the reservoirs between future and present climate.

Future work

This poster presents preliminary results from the project. For the next year, the following steps are planned:

- Finalizing the setup of the flow model - adding the missing contributions (e.g. Gires reservoir and Albaluco tunnel and Striburca reservoir).
- Switching from daily simulations to hourly, in order to simulate sub-daily hydrological processes (e.g. rotation variability, fast flow dynamics).
- Update the model parameterization to account for the new HF scheme and to improve the model performance.
- Providing the final set of inflow scenarios to be used for the investigation of future hydropower operation policies in Task 2.4.

Climate change effects on reservoir inflows (Maggia valley, OFIMA) (Moraga et al.)

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Rebalancing hydropower and ecosystem services in the Swiss Alps

Andrea Castelletti, Matteo Giuliani, Enrico Weber, Nadav Peleg, Paolo Burlando

Motivation and Objectives

Increasing hydrologic uncertainty and changes in societal perceptions of natural resources represent emerging challenges for the operation of multi-reservoir systems.

In this context, we tested advanced Reinforcement Learning approaches to re-design the coordinated operation of the OFIMA hydropower system in the Maggia valley and to explore tradeoffs and synergies between hydropower benefits and ecosystem preservation. We also explored the impacts of alternative Environmental Flow Regulations, including the regulation recently approved by the Cantonal authorities, which constrains hydropower operators to release a time-varying environmental flow.

Methods

Pareto optimal operating policies are designed via Evolutionary Multi-Objective Direct Policy Search (Giuliani et al. 2018) to explore tradeoffs between hydropower production and revenue with ecosystem preservation.

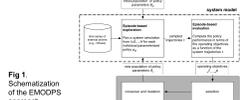


Fig. 1 Schematization of the ENCOEPS approach.

The operating policies are parameterized as Gaussian radial basis functions with 5 inputs: day of the year, day of the week, 3 reservoir storages. The optimization relies on the self-adaptive Borg Multi-Objective Evolutionary Algorithm. Each optimization was run for 1 million function evaluations and repeated for 20 random optimization trials, requiring approximately 5,600 computing hours.

Tradeoff Analysis

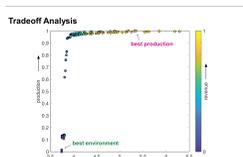


Fig. 2 Performance of the Pareto optimal solutions over the 2007-2015 time period under past Environmental Flow regulation. Hydropower production and environmental distance from natural conditions are plotted on the primary axis, while the circles colour represents hydropower revenue.

Analysis of the operating policies

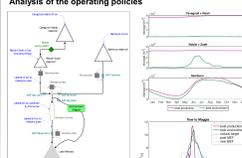


Fig. 3 Comparison of the simulated system dynamics under alternative operating policies.

Analysis of alternative Environmental Flow Regulations

The new regulation does not produce significant environmental benefits with respect to past constraints but penalizes hydropower operators, including ecosystem preservation as objective rather than constraint allows discovering win-win solutions.

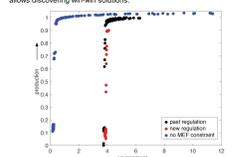


Fig. 4 Performance of the Pareto optimal solutions over the 2007-2015 time period under different Environmental Flow Regulations.

Future Works

This poster presents preliminary results from the project. For the next year, the following experiments are planned:

- Testing more restrictive environmental targets.
- Improving the formulation of the environmental objective (e.g. using indices of hydrologic alterations).
- Quantifying the value of hydrologic forecasts for informing the system operation.
- Assessing the impacts of climate change and the adaptive capacity of the system with past and current EFRs, as well as stipulated environmental objectives.

Giuliani, M., Castelletti, A., Peleg, N., Weber, E., and Burlando, P. (2019). Rebalancing hydropower and ecosystem services in the Swiss Alps. In Proceedings of the 12th International Conference on Environmental Modelling and Software Engineering (EMSE), 1-10. Cham, Switzerland: Springer.

Rebalancing hydropower and ecosystem services in the Swiss Alps (Castelletti et al.)