Hydro-CH2018 – Coordination Meeting

Evolution of stream and lake water temperatures under climate change

Research Project (Focus Area 2)

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

eawag aquatic research

Situation

- Temperatures in Swiss surface waters have increased by 1-2°C in the past 30 years
- Based on 5th IPCC AR & CH2011 scenarios it is expected that air/water temperatures will further rise
- Water temperature is a key abiotic variable in riverine and lentic ecosystems
- Future warming in streams and lakes is likely to exceed current limits prescribed in legislation
- Stream and lake temperatures are not independent from each other (coupled)
- → Project in Focus area 2 (3)

Objectives and research goals

- Coupling of lake and river thermodynamics
- Simulation and prediction of lake and river temperature
- Continued development of stream temperature model/s
- Impact studies of climate change (scenarios) on stream and lake thermodynamics
- Scenarios and prediction of coupled stream and lake temperature evolution
- Impact of changes in water temperature on aquatic ecology, biodiversity and ecosystem services
- Develop and suggest adaptation strategies to mitigate CC impact on surface waters in CH
- Evaluate possibilities and recommendations for operational surface water monitoring

Previous work (1)

Hydrol. Earth Syst. Sci., 19, 3727–3753, 2015
www.hydrol-earth-syst-sci.net/19/3727/2015/
doi:10.5194/hess-19-3727-2015

Hydrology and Earth System Sciences
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Stream temperature prediction in ungauged basins: review of recent approaches and description of a new physics-derived statistical model

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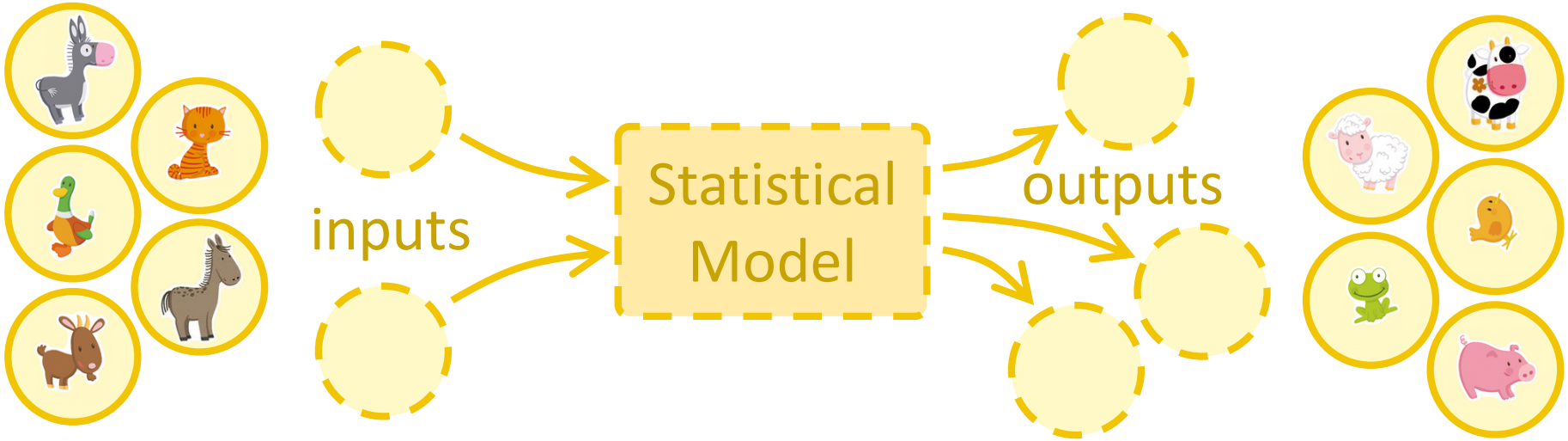
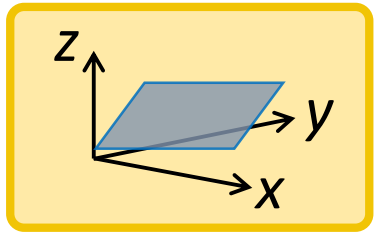
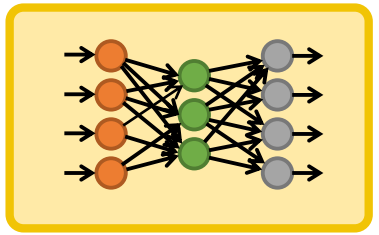
Standard modeling approach

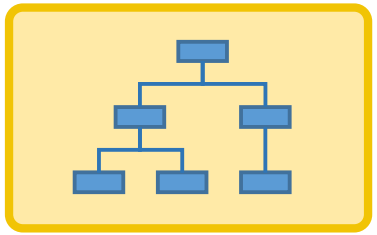




Multilinear Regression



Neural Networks



Classification Trees

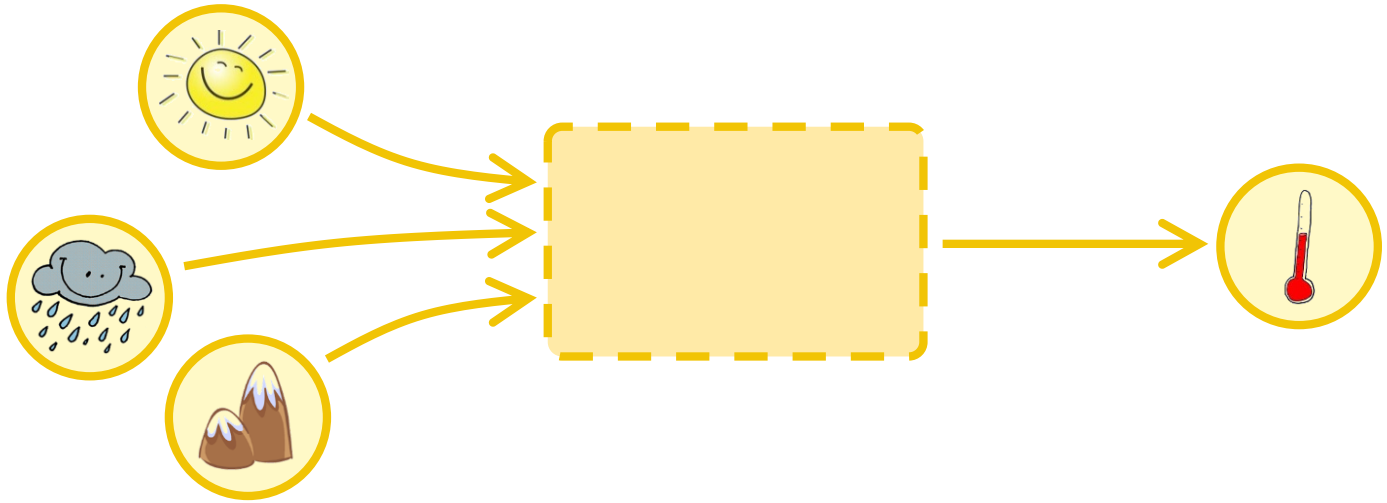
A new modeling approach

- Stream temperature obeys the energy-balance equation
- Analytical solution = relationship between in- and output

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_\ell, \tag{1}$$

$$\frac{\partial (A\,T)}{\partial t} + \frac{\partial (Q\,T)}{\partial x} = \frac{w\,\phi_\mathrm{a} + p\,\phi_\mathrm{b}}{\rho c_\mathrm{p}} + q_\ell\,T_\ell - Q\frac{g}{c_\mathrm{p}}\frac{\partial z}{\partial x}, \tag{2}$$

where w (m), p (m), A (m^2), Q ($\mathrm{m}^3\,\mathrm{s}^{-1}$) and T (°C) denote the width, wetted perimeter, cross-sectional area, discharge and temperature of the stream, respectively;



$$T_\mathrm{out} = (1-\eta)\delta_\mathrm{s}\left(a_w\overline{T_\mathrm{a}} + b_w\right) + \eta\delta_\ell\left(a_w\langle T_\mathrm{a}\rangle_\mathcal{L} + b_w\right) + (1-\delta_\mathrm{s}-\eta\delta_\mathrm{s}-\eta\delta_\ell)\langle T_\mathrm{eq}\rangle_\mathcal{L},$$

where

$$T_\mathrm{eq} = a_{\phi,\mathrm{isw}}\langle\phi_\mathrm{isw}\rangle_\mathcal{L} + a_{\phi,\mathrm{s}}\langle f_\mathrm{s}\rangle_\mathcal{L} + a_{\phi,\theta}\langle\theta\rangle_\mathcal{L} + a_{\phi,\mathrm{f}}\langle f_\mathrm{f}\rangle_\mathcal{L} + \langle T_\mathrm{a}\rangle_\mathcal{L} - L_\mathrm{c}\frac{g}{c_\mathrm{p}}\left\langle\frac{\mathrm{d}z}{\mathrm{d}x}\right\rangle_\mathcal{L} + b_\phi.$$

Physics-derived statistical/analytical model (1)

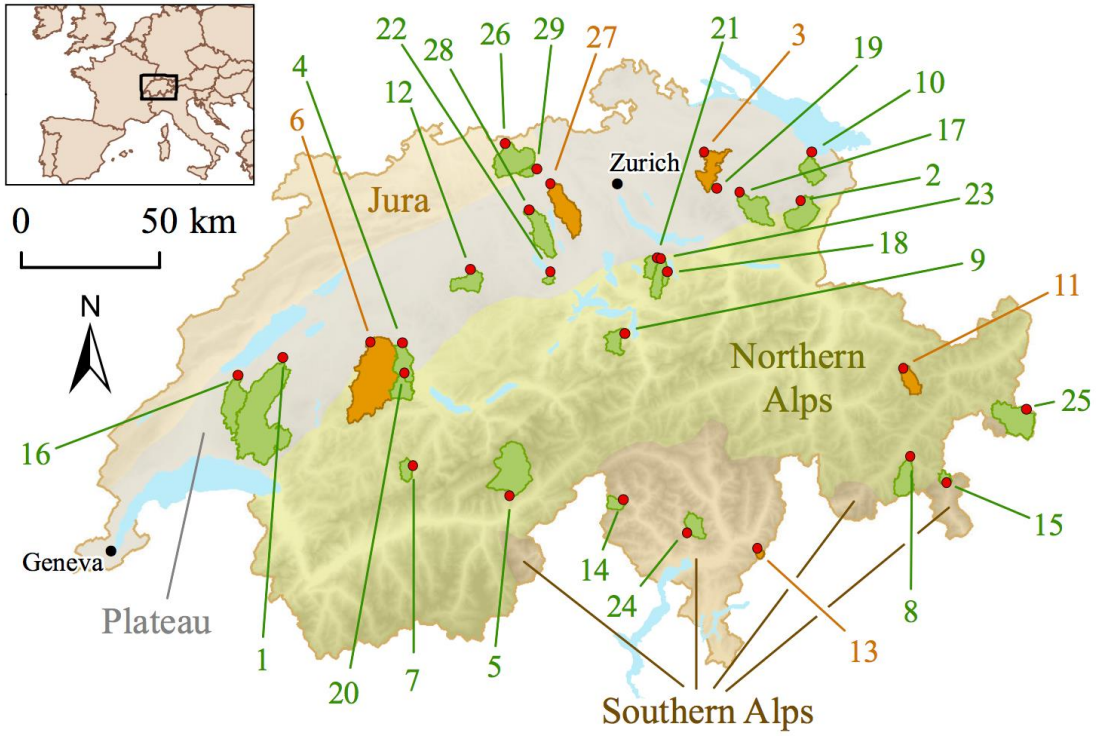
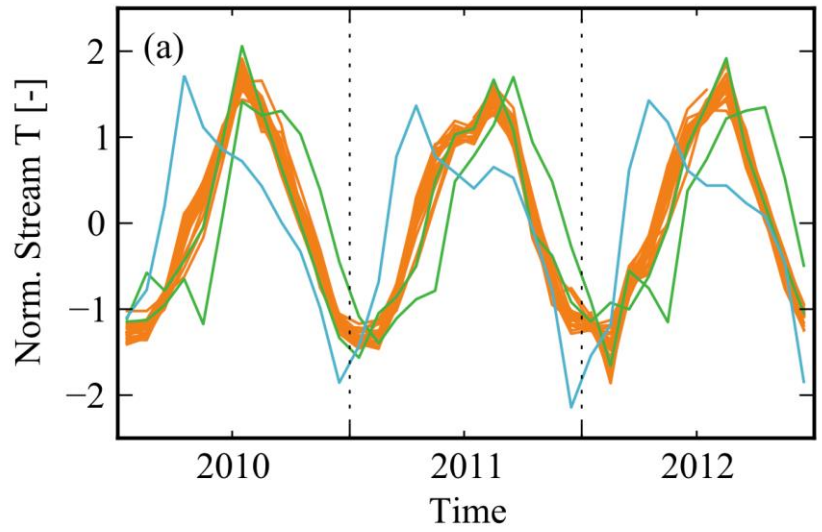
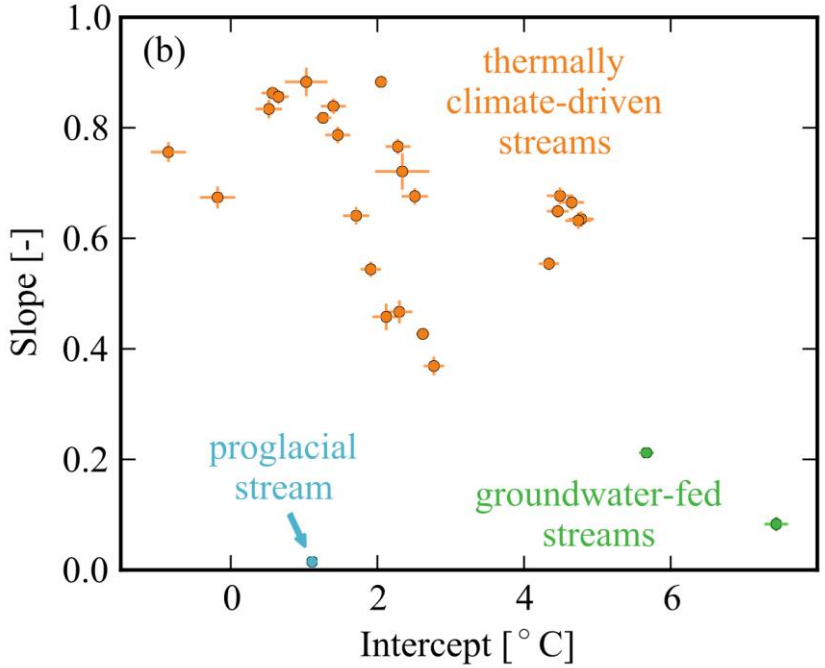


Figure 1. Locations of the gauging stations selected for the evaluation of the physics-inspired and standard statistical models. The stations are displayed as red points and their associated catchments as green or orange areas, depending on whether they are used to calibrate or validate the model. The four main climatic regions of Switzerland – the Jura mountains, Plateau, Northern Alps and Southern Alps – are displayed in different colours. The numbering





Physics-derived statistical/analytical model (2)

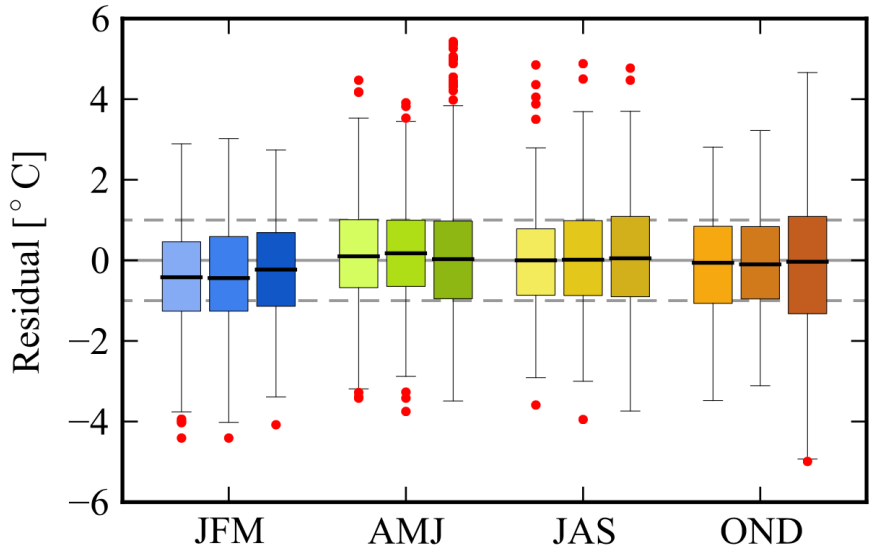


Figure 3. Prediction error of the physics-inspired statistical model for different resolutions of the stream network. The boxes extend from the first to the third quartile of the error distribution. Outliers are displayed as red dots. In each season, the network resolution decreases from left to right: the left box corresponds to the network with all stream reaches, whereas the central and right boxes contain only the stream segments whose Strahler order is greater than or equal to 2 and 3, respectively. The error values 0, −1 and +1 °C are displayed as a solid grey line and two dashed grey lines.

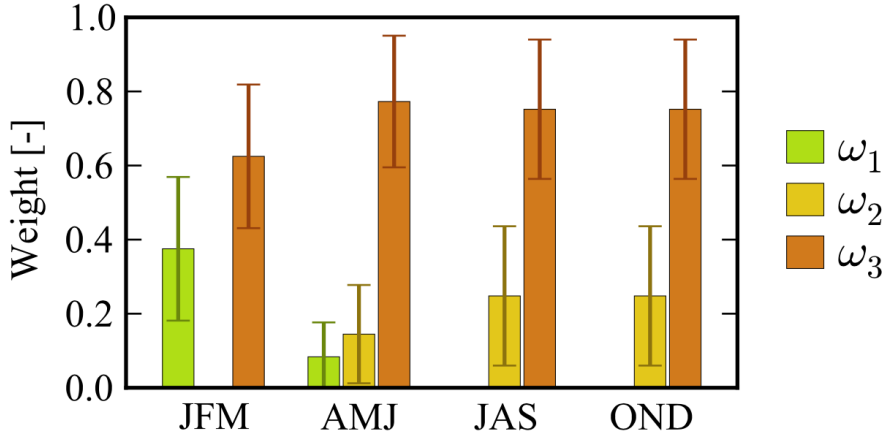


Figure 6. Seasonal values of the factors ω_1, ω_2 and ω_3 weighting the different terms in Eq. (8). The values of these weights are evaluated over the entire data set, i.e. both the calibration set and validation set 3. The error bars indicate the confidence interval centered around the mean and extending over 1 standard deviation on each side.

Analytical solution

$$T = w_1 T_s + w_2 \langle T_l \rangle + w_3 \langle a s_a + T_a + L_c g / c_p S \rangle$$

distance-weighted average

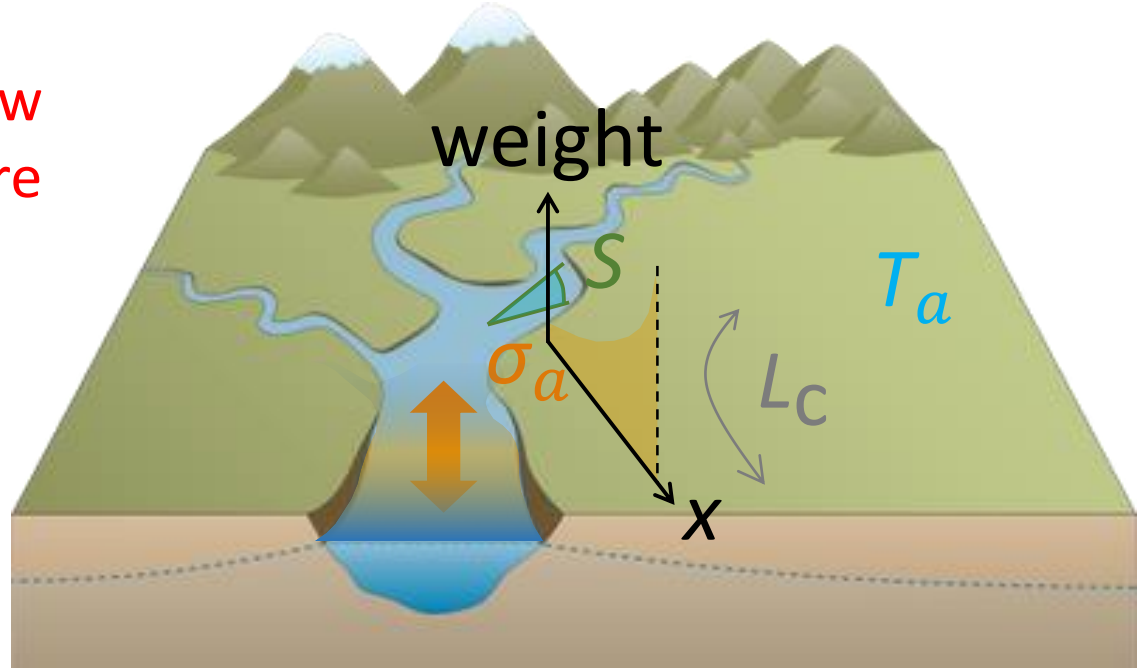
weights (sum up to 1)

friction

mean source temperature

lateral inflow temperature

heat exchange with the atmosphere



Previous work (2)

Geosci. Model Dev., 9, 4491–4519, 2016
www.geosci-model-dev.net/9/4491/2016/
doi:10.5194/gmd-9-4491-2016

Geoscientific Model Development
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EGU

StreamFlow 1.0: an extension to the spatially distributed snow model Alpine3D for hydrological modelling and deterministic stream temperature prediction

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[2]SLF, WSL Institute for Snow and Avalanche Research, 7260 Davos, Switzerland

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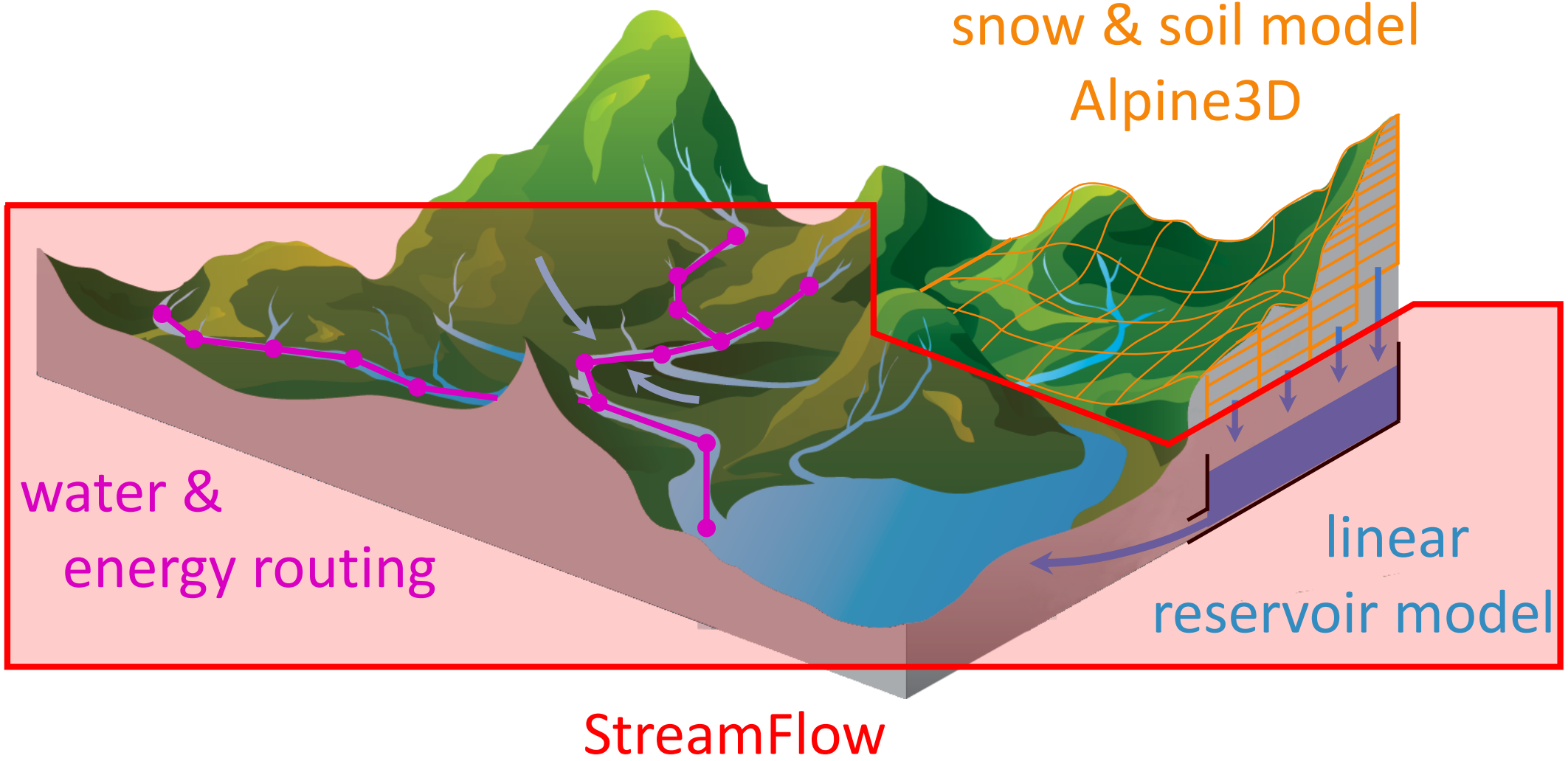
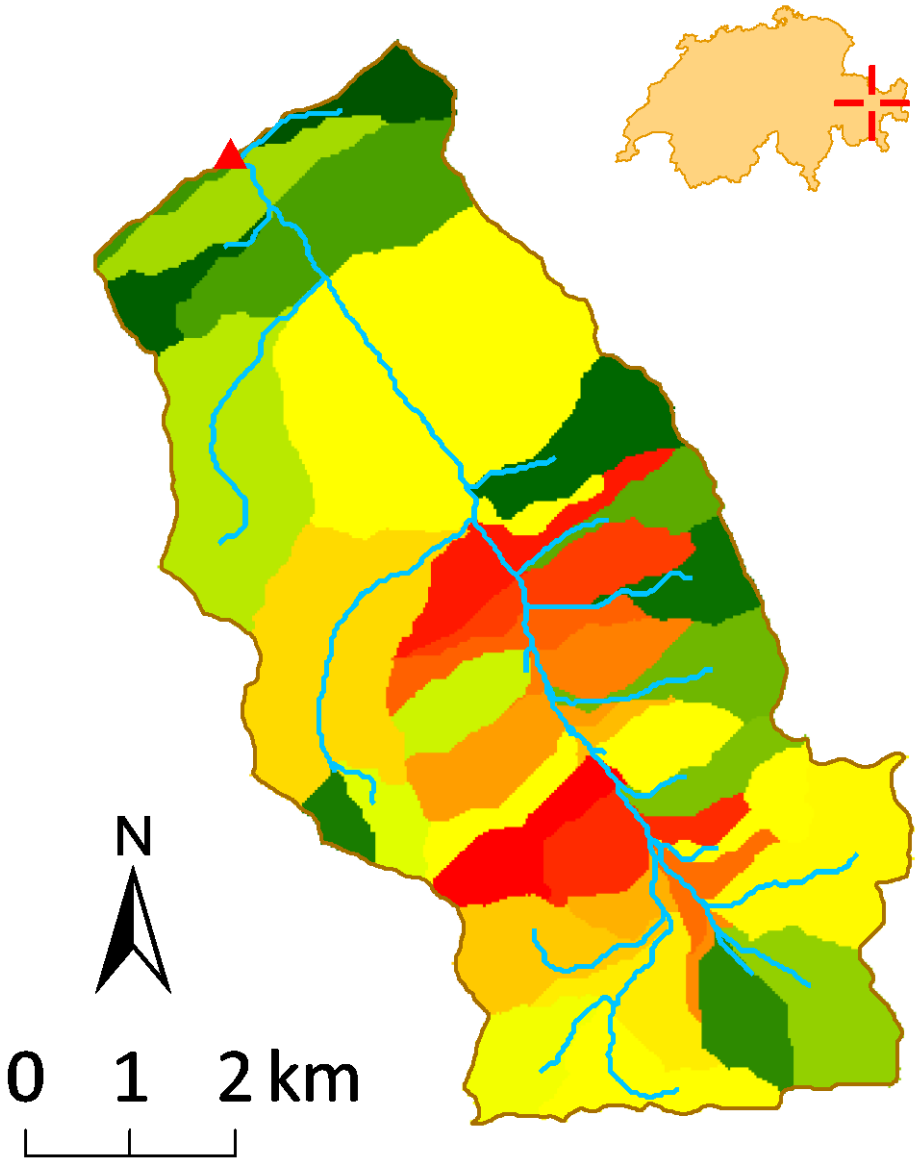
Modeling framework

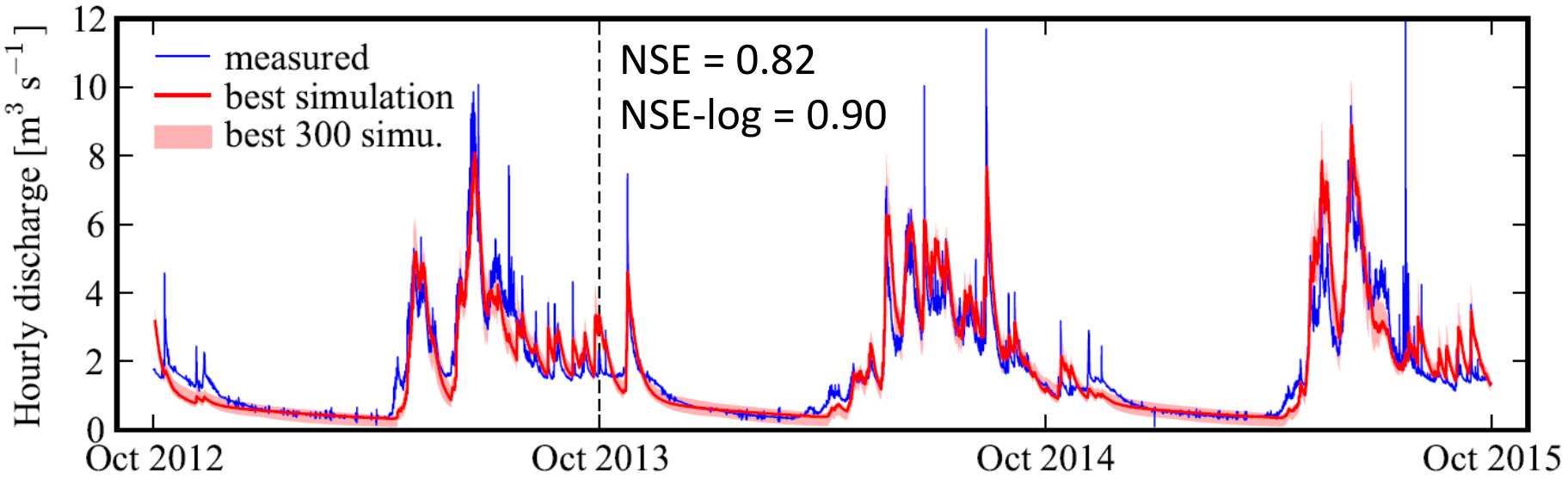


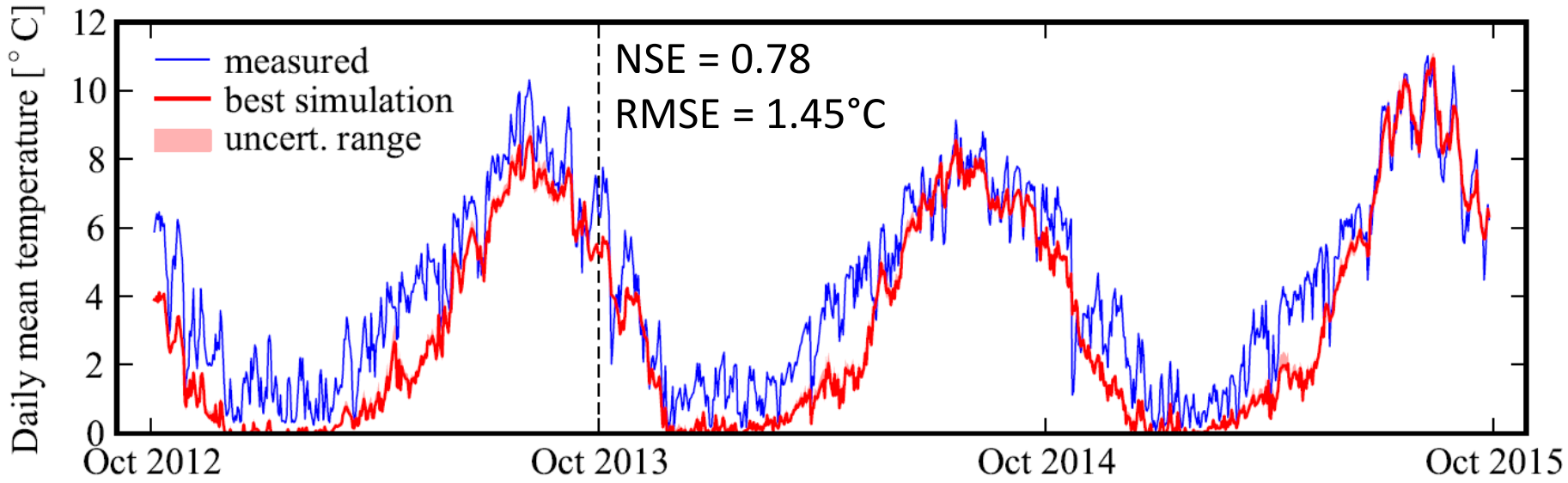
Case study: Dischma catchment, Davos



- Area: 43 km^2
- Elevation: 1700m to 3100m a.s.l.
- Snow-dominated (+ small glacier)
- Split into 39 sub-watersheds

Discharge and temperature simulation at the outlet

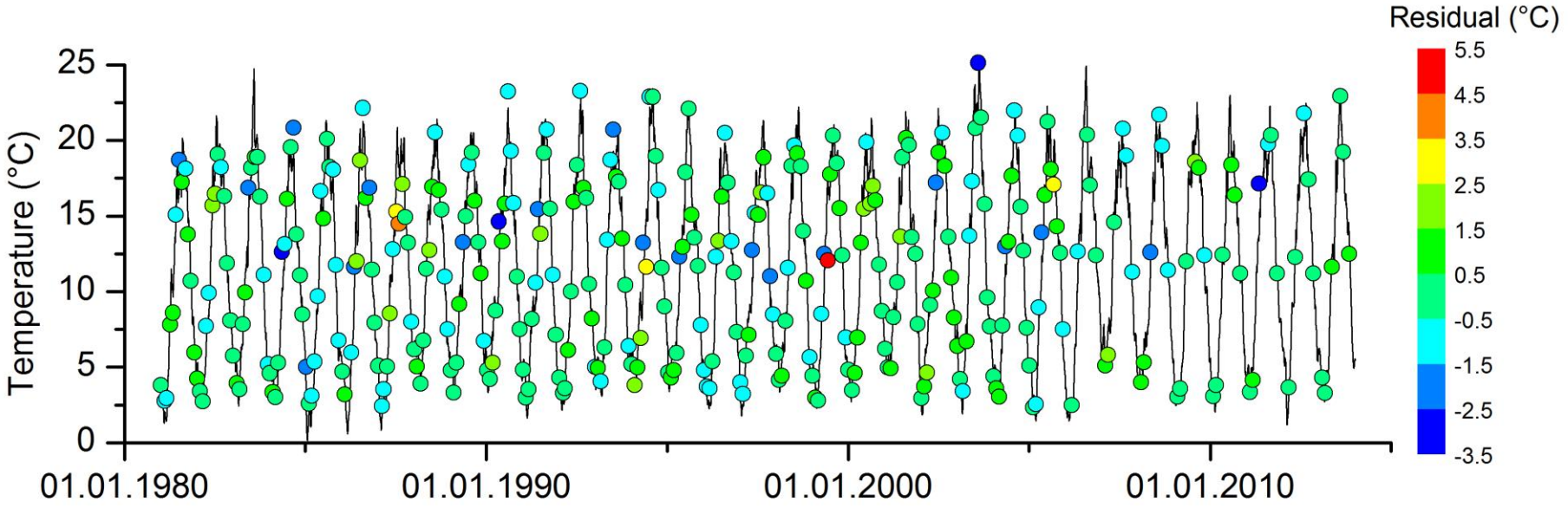


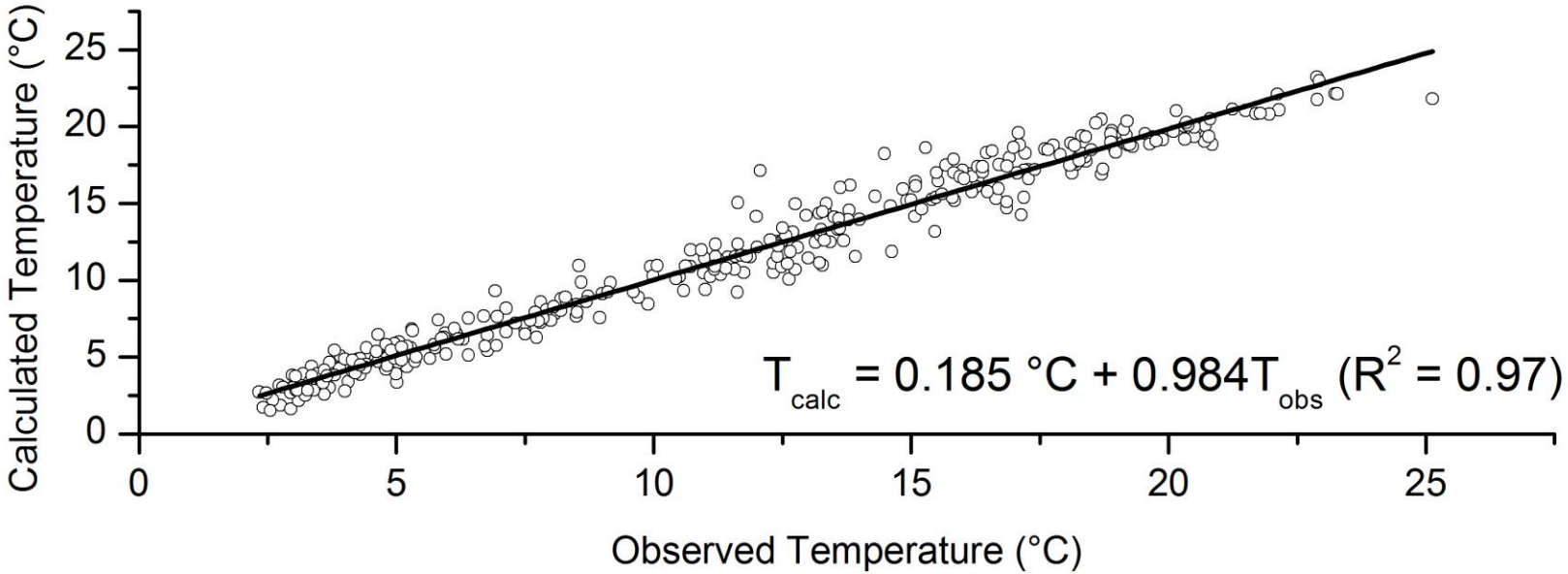


Summary stream temperature models

- Statistical model:
  - New approach based on physical principles
  - RMSE = 1.3°C at monthly time scale
  - Can be used to investigate tempemperature dynamics
- Deterministic model:
  - Particularly suited for high-altitude areas
  - RMSE = 1.45°C at hourly time scale
  - Can be used to investigate CC scenarios

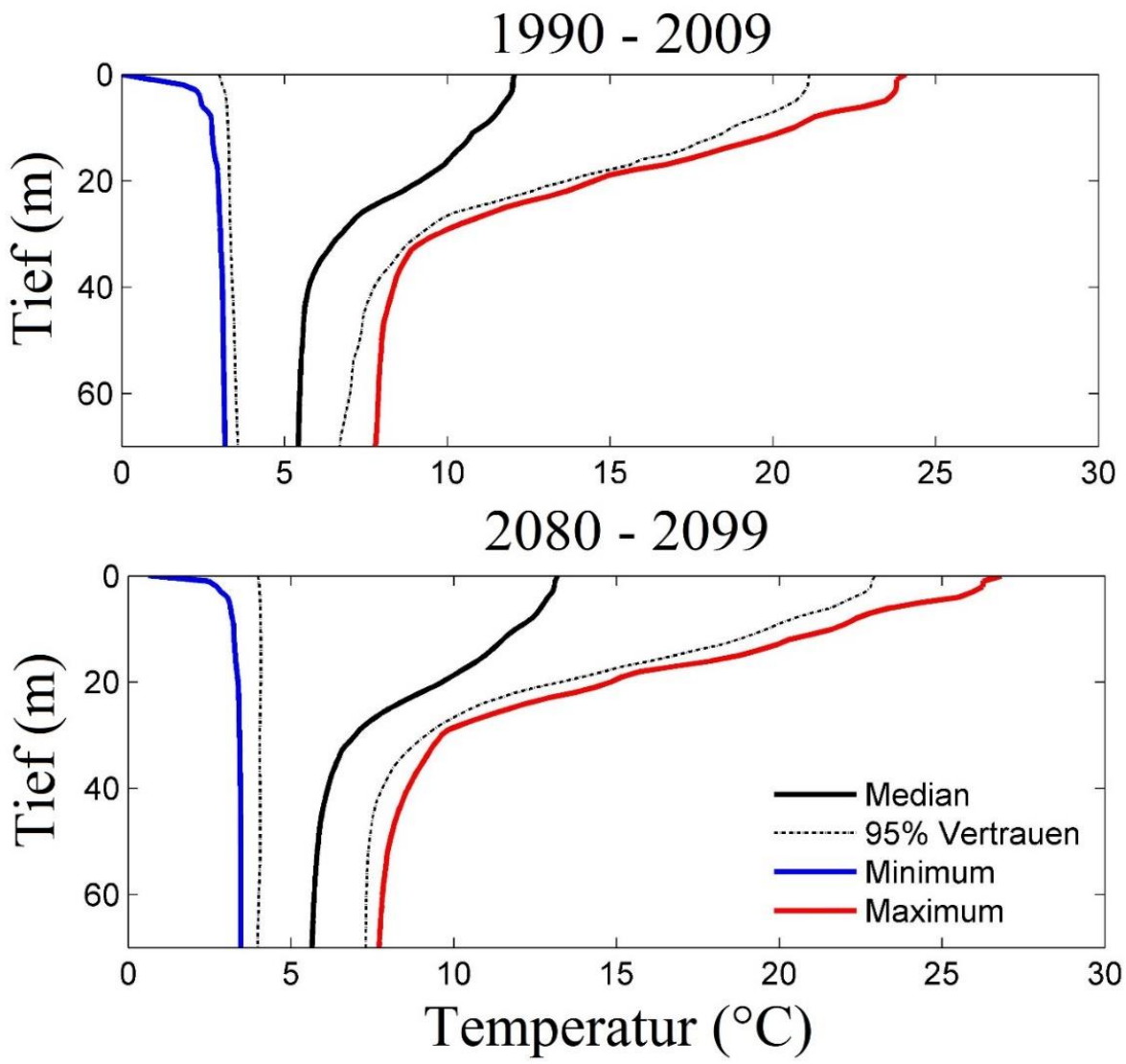
Modeling – Long term evolution of lake surface temperatures

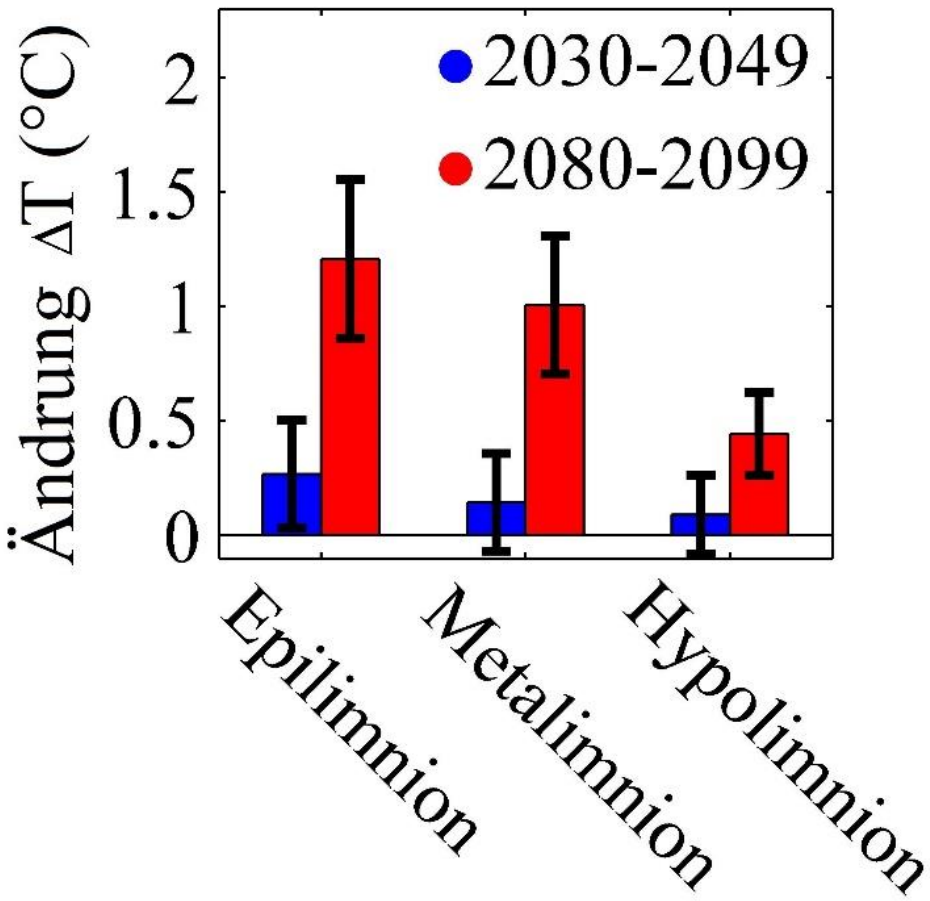




Lake Zürich

Modeling – vertical temperature structure in lakes – example "Lake Biel"



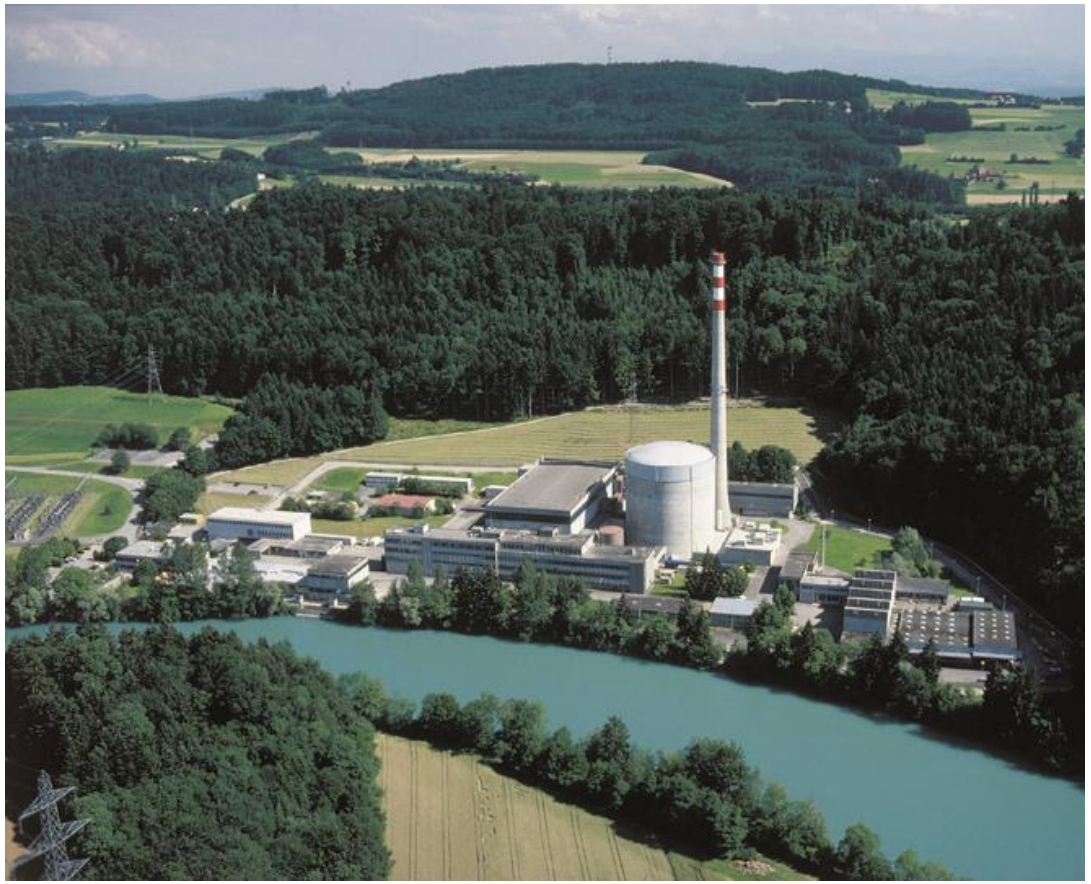


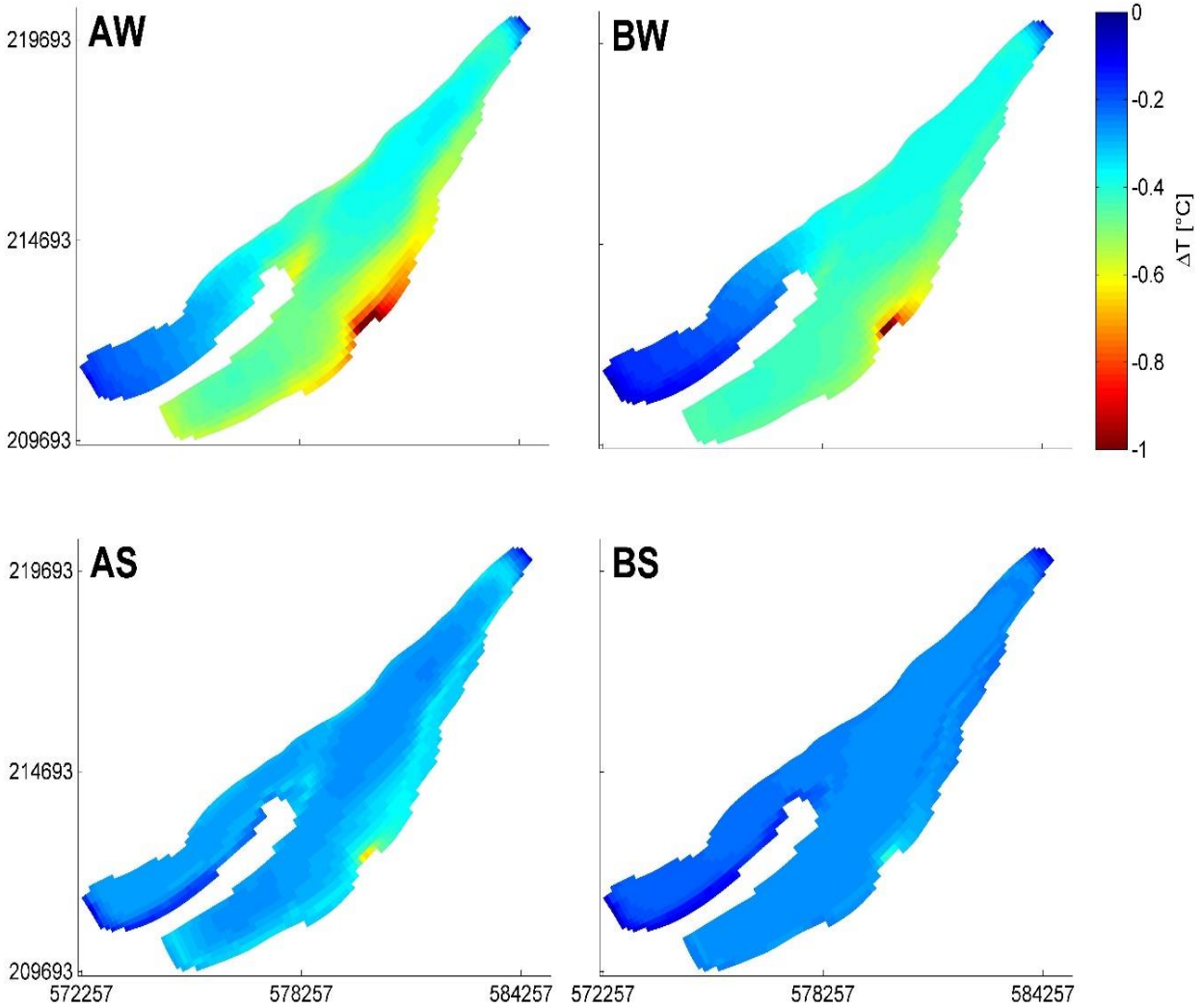
Effects in Lake Biel: *Temperature*

Modeling of lakes – Calibration of 3-dimensional models

Lake Biel, example Mühleberg:

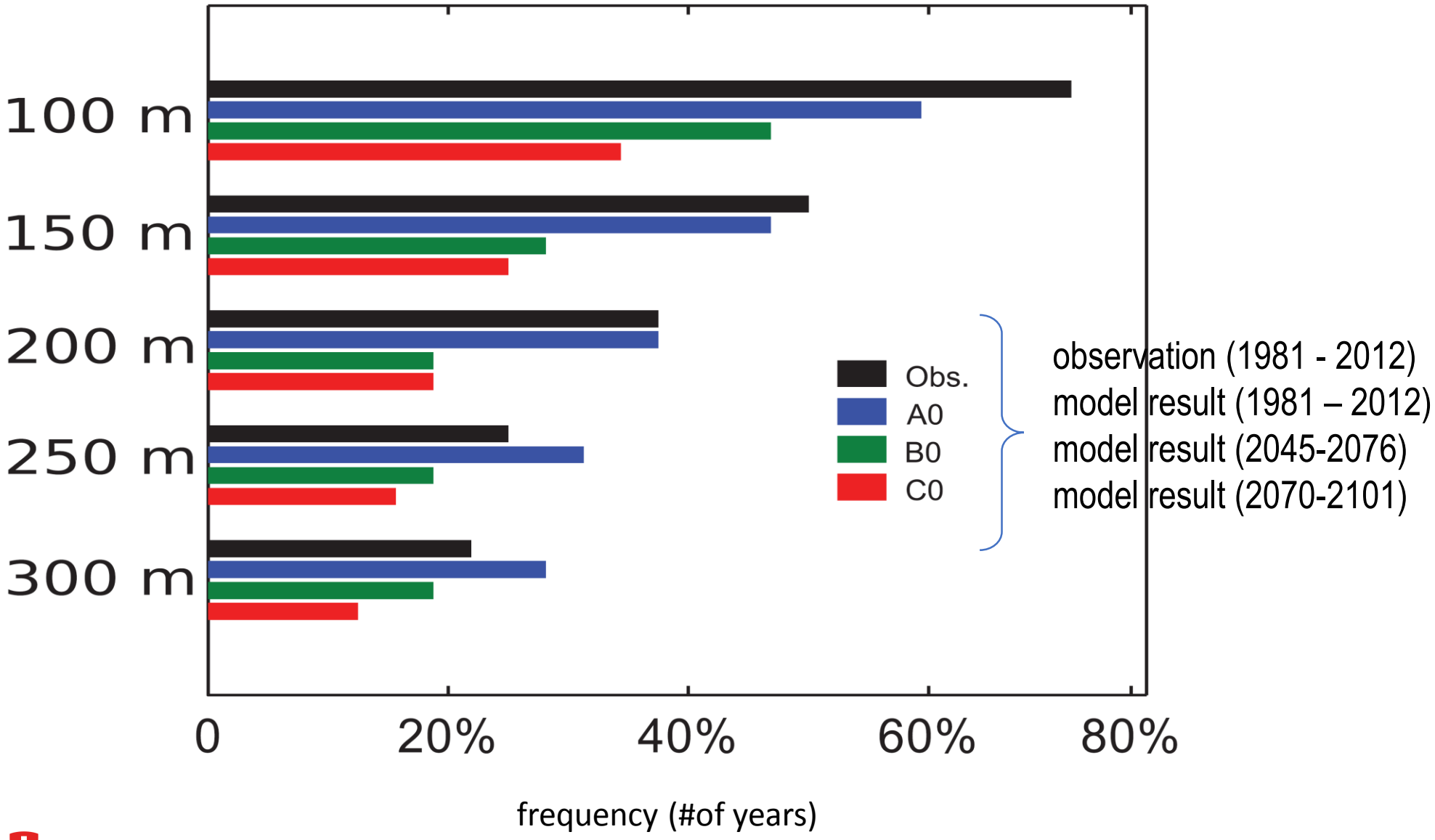
700 MW → 18 W m^{-2}



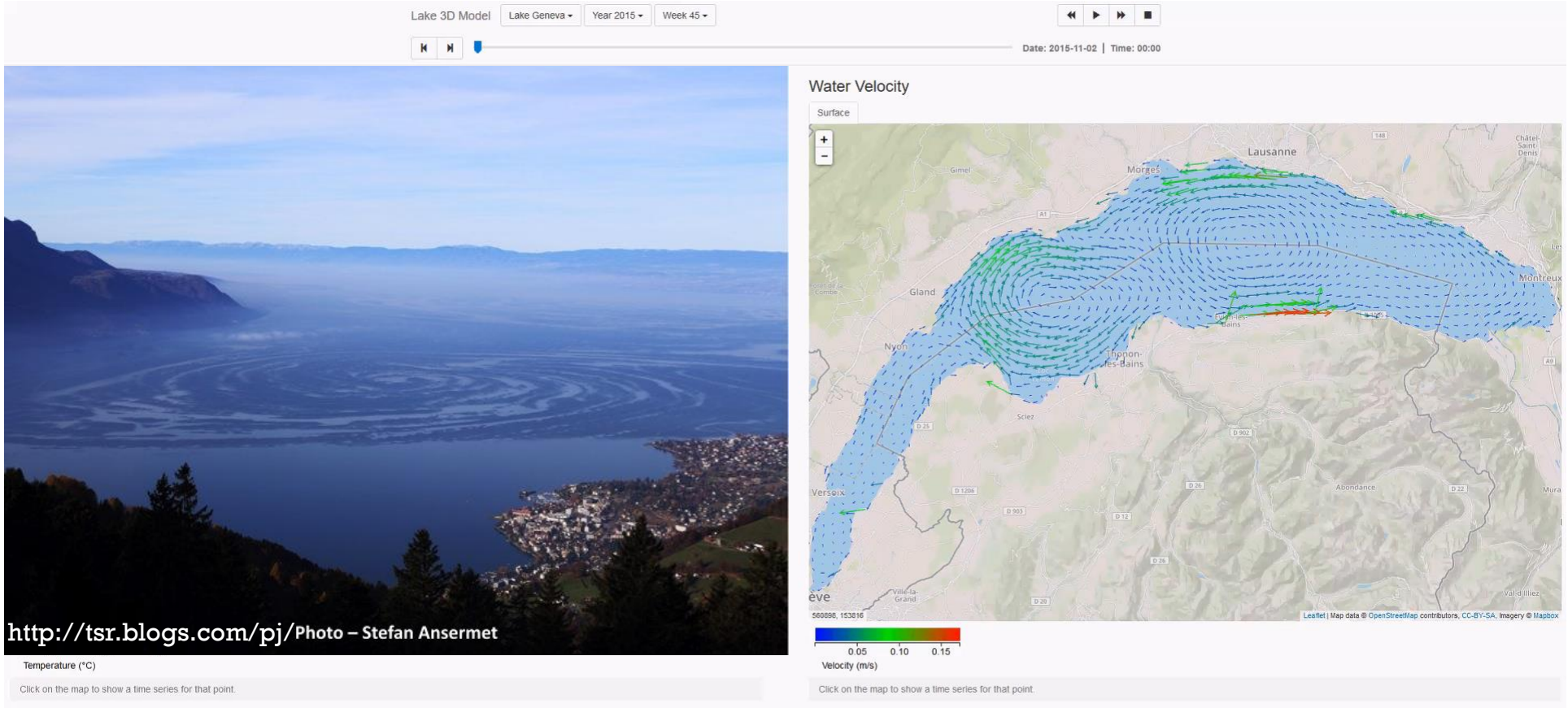


Raman 2017

Development of deep convective mixing due to climate change – Lake Geneva



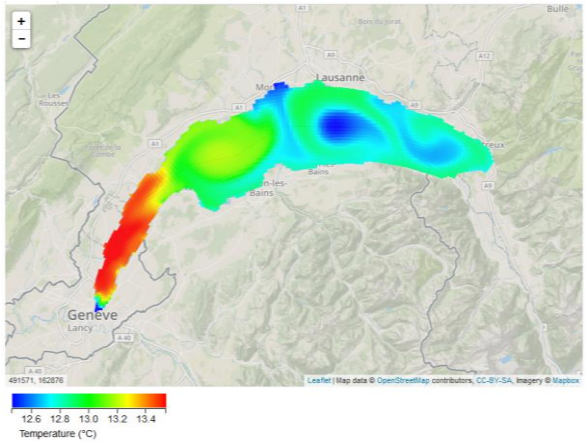
3D Modeling – Spatial heterogeneity

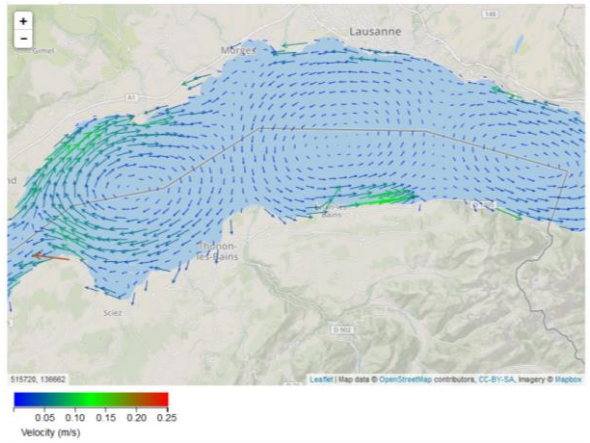


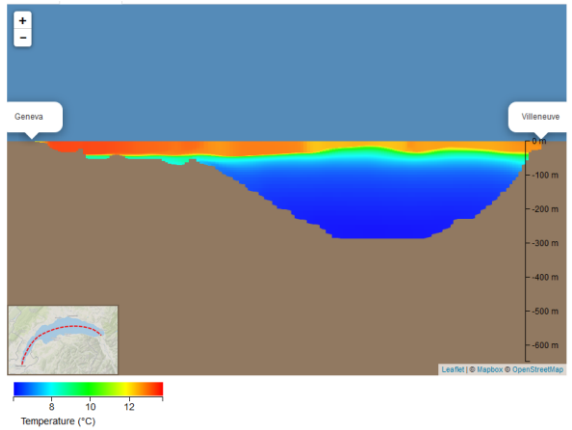
www.meteolakes.epfl.ch

Online real-time platform

www.meteolakes.epfl.ch







System operation:

- Daily computations (hydrodynamics + water quality)
- 5d forecasts
- Real-time data assimilation

Applications:

- *Scientists*: in-situ measurements planning, understanding 3D physical phenomenon (e.g. upwelling)
- *Gov. agencies*: monitoring lakes at every location in space and time, trackthe stratification and mixing
- *Public awareness:* 120 daily users on avg., up to 1600

Project outline and Tasks

- Task 1: Stream temperature evolution under climate change
  - (a) Continued model development and extensions (StreamFlow1.0, Gallice et al., 2016)
  - (b) Specific applications and coupling to natural lakes
  - (c) Simulation of climate change scenarios and mitigation strategies.

- Task 2: Effects of climate change on lake temperature
  - (a) 1D and 3D lake models for selected lakes to understand the physical processes affecting lake temperatures.
  - (b) Evaluate lake internal processes (stratification, mixing, water-air heat fluxes and how they are affected CC.
  - (c) Use 3D-simulations to identify optimal locations for the monitoring of climate change in lakes.
  - (d) provide guidelines for future monitoring and research on such high altitude natural lakes

- Task 3: Impact of atmospheric warming on the ecosystem services of rivers and lakes
  - (a) Statistics on water temperature thresholds
  - (b) Usage of lakes and rivers as heat sinks for buildings and infrastructure
  - (c) Sensitivity analyses

- Task 4: Synthesis report on water temperature in lakes and rivers

List of tentatively selected lakes

Lake (natural)	Task 2a		Task 2b	Task 2c
	1D	3D	1D	3D
Biel	X	X	X	X
Zurich	X	X	X	X
Geneva	X	X	X	X
Constance	X		X	
Zug	X		X	
Joux	X		X	
Silvaplana	X		X	
Sils	X		X	
St Moritz	X		X	
Greifensee	X		X	X

Synthesis report chapter

Table of content

- *Introduction*:
  - Introduction to the subject; review of past work (literature) and assessment of current situation.

- *Observed water temperature changes*
  - *Lakes:* Changes in lake surface temperatures, changes in deep-water temperatures, summary of observations in Switzerland, comparison to global observations.
  - *Rivers:* Spatially and temporally resolved changes in observed river temperatures, discussion of available data and identification of potential for network optimization

- *Causes of observed water temperature changes*
  - *Lakes*: Air temperature, solar radiation (atmospheric brightening), inflow temperatures, other meteorological variables, water clarity
  - *Rivers:* Air temperature, solar radiation (atmospheric brightening), changes in discharge, snow and glacier melt, land-use and vegetation, and hydropower management

- *Impacts of changing temperatures*
  - *Lakes:* Physical effects (stratification, ice cover), microbial effects (process rates, etc.), ecological effects, effects on ecosystem services (e.g., heat usage)
  - *Rivers:* Ecological effects, shifts in aquatic habitats, effects on lake temperatures, effects on ecosystem services, limitation of thermal potential (e.g. for cooling)

- *Future development of water temperatures*
  - Summary of predicted extent of future warming of lakes and rivers, based on the analysis of the causes and the future projections of the driving forces.

- *Open research questions*: Summary of knowledge gaps and research needs.

Hydro-CH2018:

Discharge and water temperature

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Objective: regime analysis

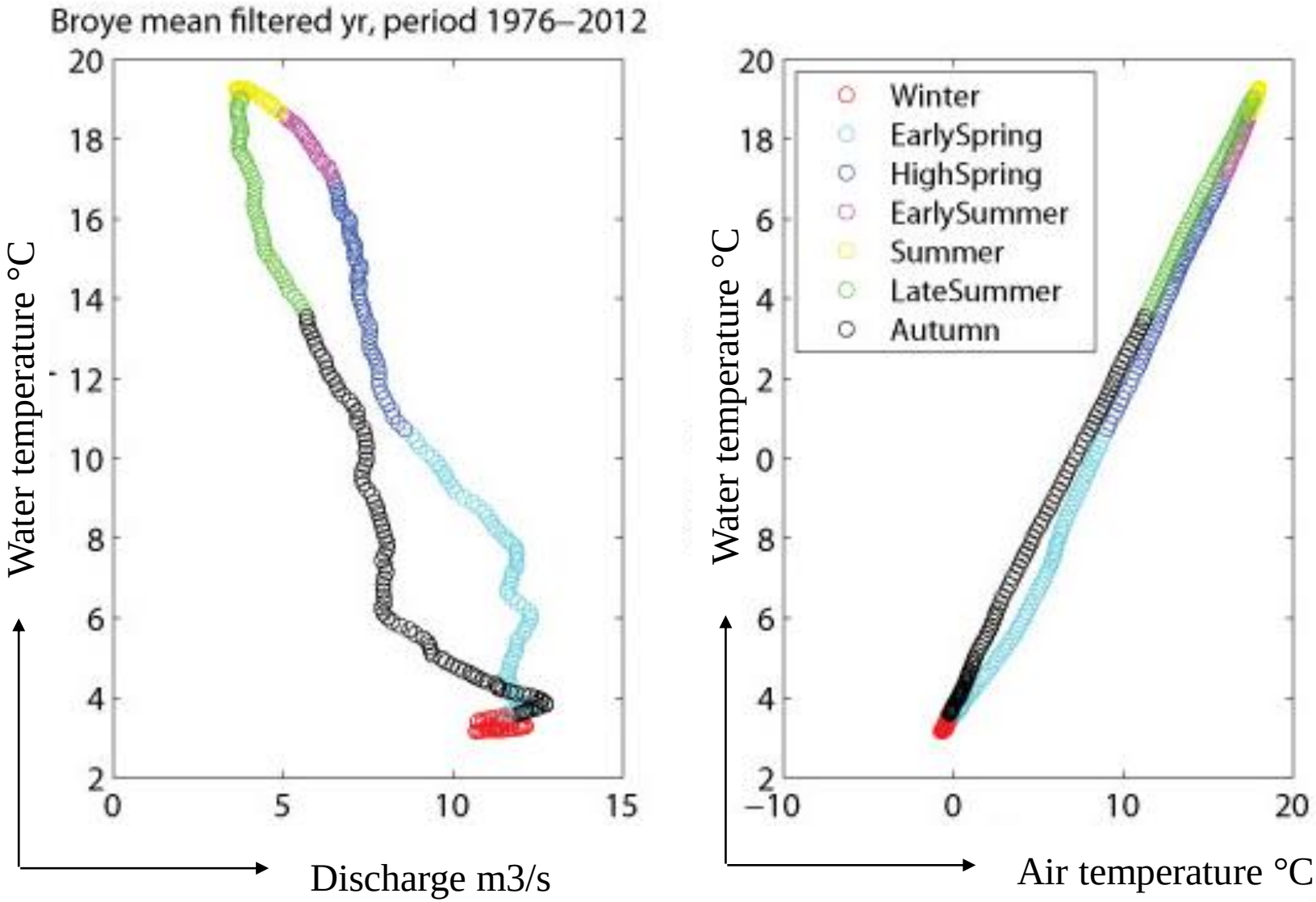
Quantifying interplay between discharge & water temperature:

Covers statistical aspects of stream temperature evolution geographically characterizing and identifying Swiss watersheds and their behavior under climate change.

Steps:

- ***Classification of bi-variate water temperature-discharge regimes***
- ***Assessment of existing water temp. models: how do they capture bi-variate regimes?***
  - A) Analytic model proposed by Toffolon and Piccolroaz (2015)
  - B) Physical model of EPFL project
- ***Analysis of projections***
  - Quantify the significance of simulated water temperature and discharge changes with respect to water temperature regime shifts.

Bi-variate regimes- example



Outcome & Synthesis report

- New method to classify bi-variate water temperature- discharge regimes & to assess potential changes
- An assessment of the ability of reference models to reproduce observed water temperature-discharge regimes
- A collection of potential bi-variate regime scenarios for Switzerland based on the scenarios run by our project partners (Huwald et al., EPFL).
- The above points I to III will feed directly into the planned synthesis report.

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The end

- Thanks for the attention
- Questions and comments welcome !