Temperature transport model

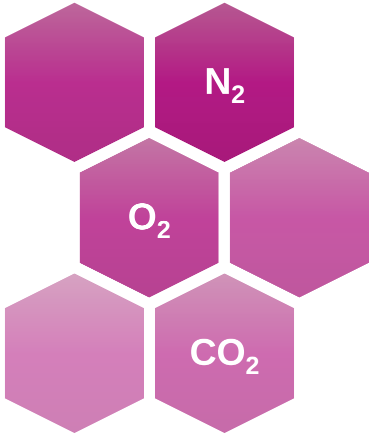
Dr. Davide Vanzo
Computational Fluid and Morpho-Dynamics group (CFMD)
Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich

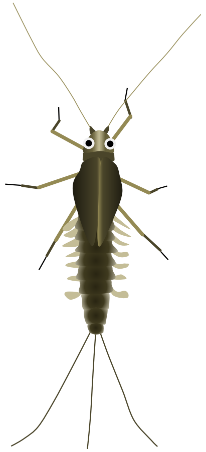
Outline

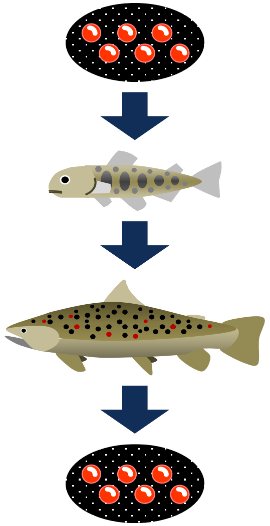
- Motivation for a temperature module
- Example: hydro-thermopeaking dynamics
- Under the hood: governing equations
- Setup example

Motivation

River water temperature is a fundamental physical property

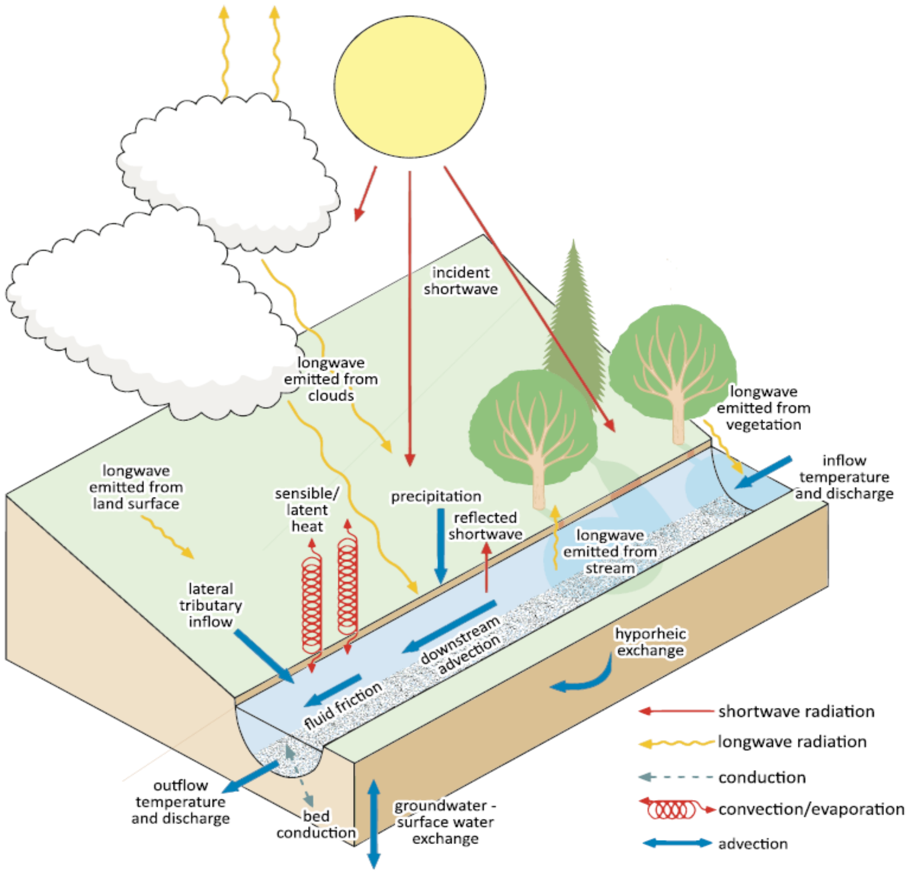






Motivation

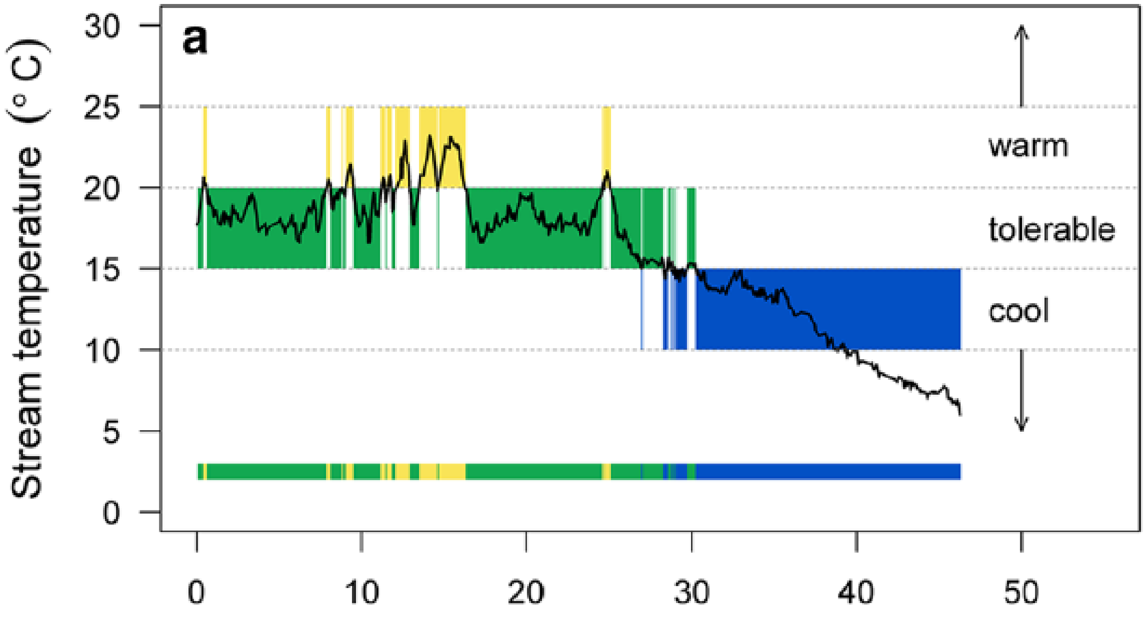
River water temperature results from multiple heat exchanges



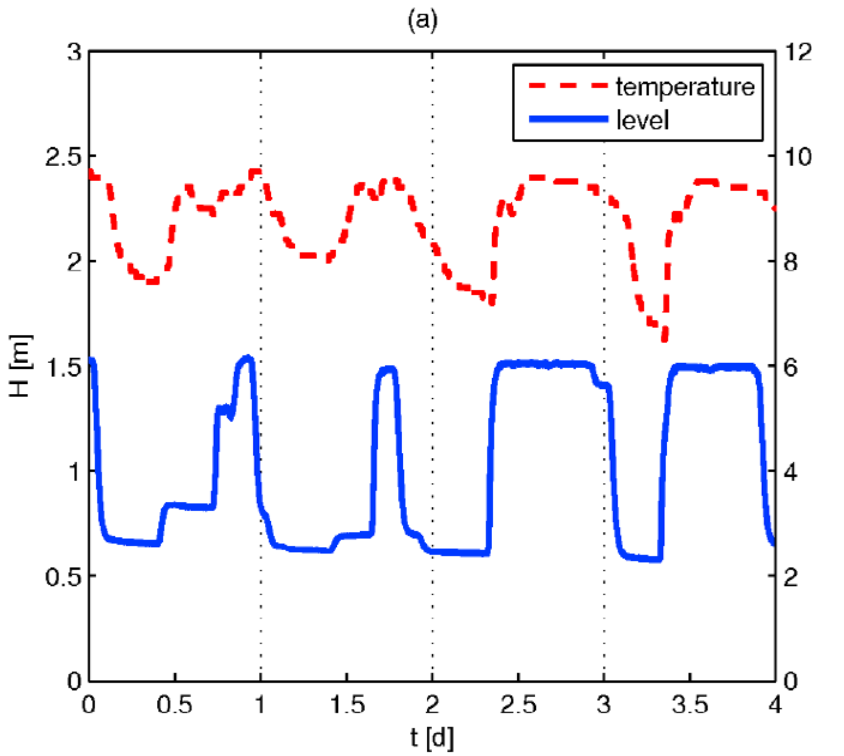
Dugdale *et al*. 2017

Motivation

Thermal dynamics occur at multiple temporal and spatial scales



Fullerton *et al*. 2018



Toffolon *et al*. 2010

Motivation

Global warming

Meteorological

Hydrological

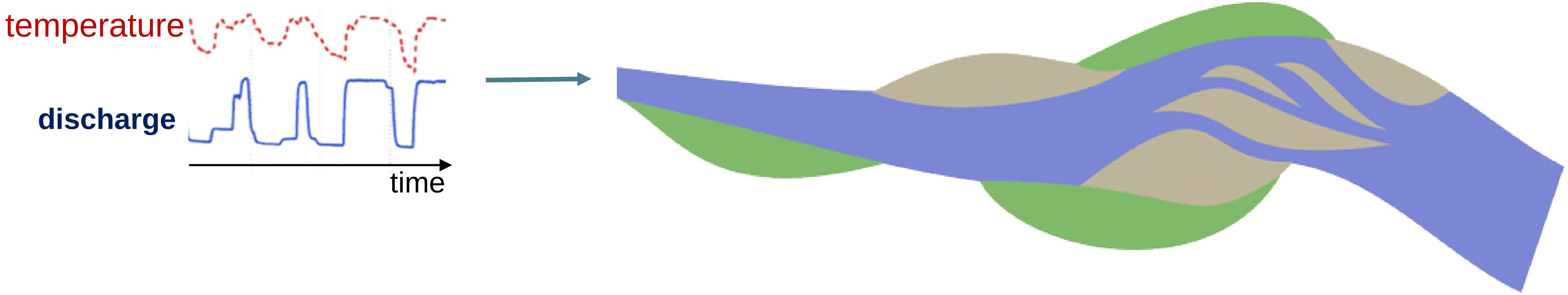
Hydropower

Complementary data

BASEMENT

- process understanding
- scenario-based simulations
- decision support
- template for eco/biological studies

Example: modelling thermal dynamics in hydropeaking river



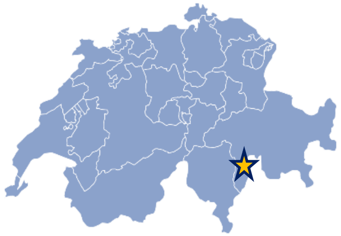
SPECIAL ISSUE PAPER

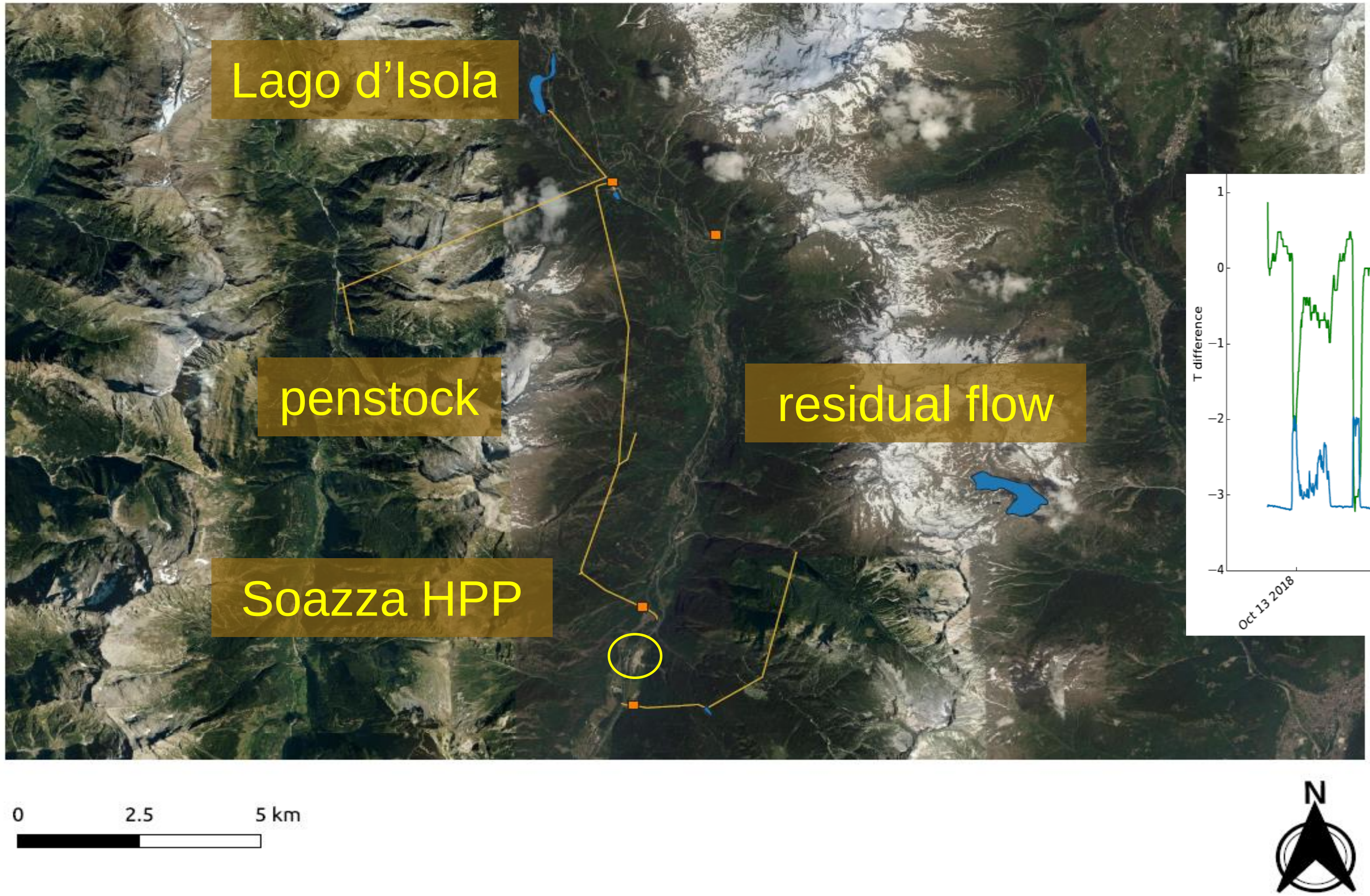
WILEY

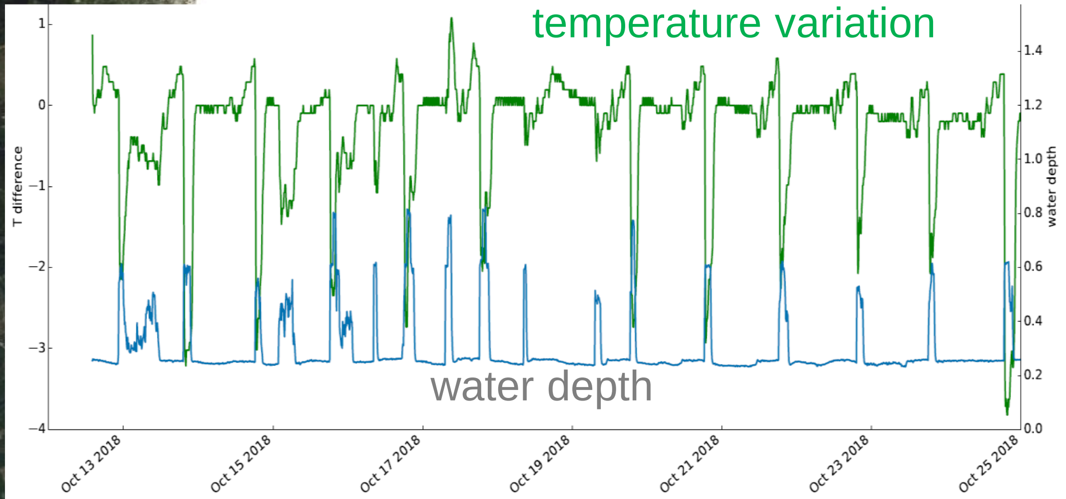
Integrating two-dimensional water temperature simulations into a fish habitat model to improve hydro- and thermopeaking impact assessment

Manuel Antonetti[1] | Luca Hoppler[1] | Diego Tonolla[1] | Davide Vanzo[2,3] | Martin Schmid[2] | Michael Doering[1]

Study case: Moesa River, Graubünden (CH)







Study case: Moesa River, Graubünden (CH)

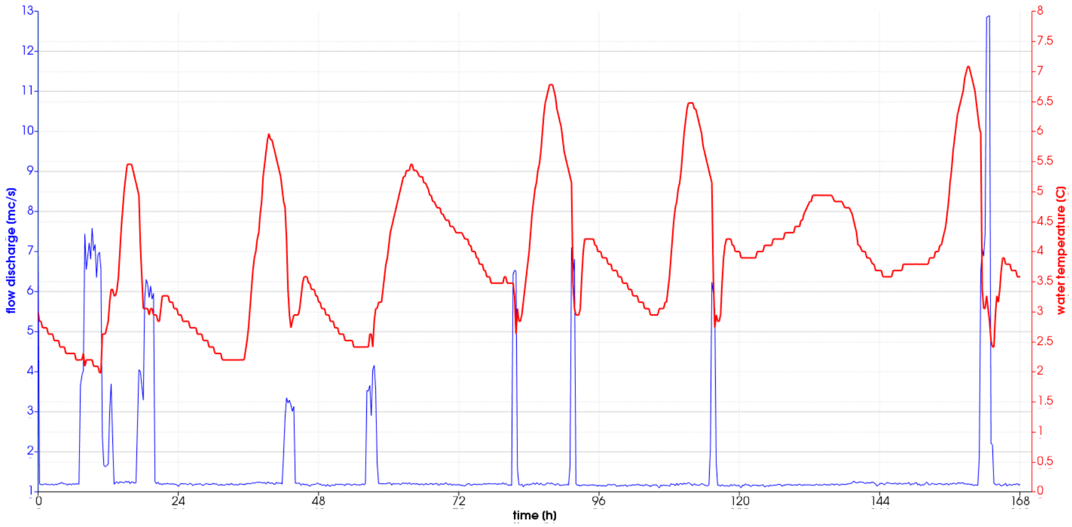
flow direction

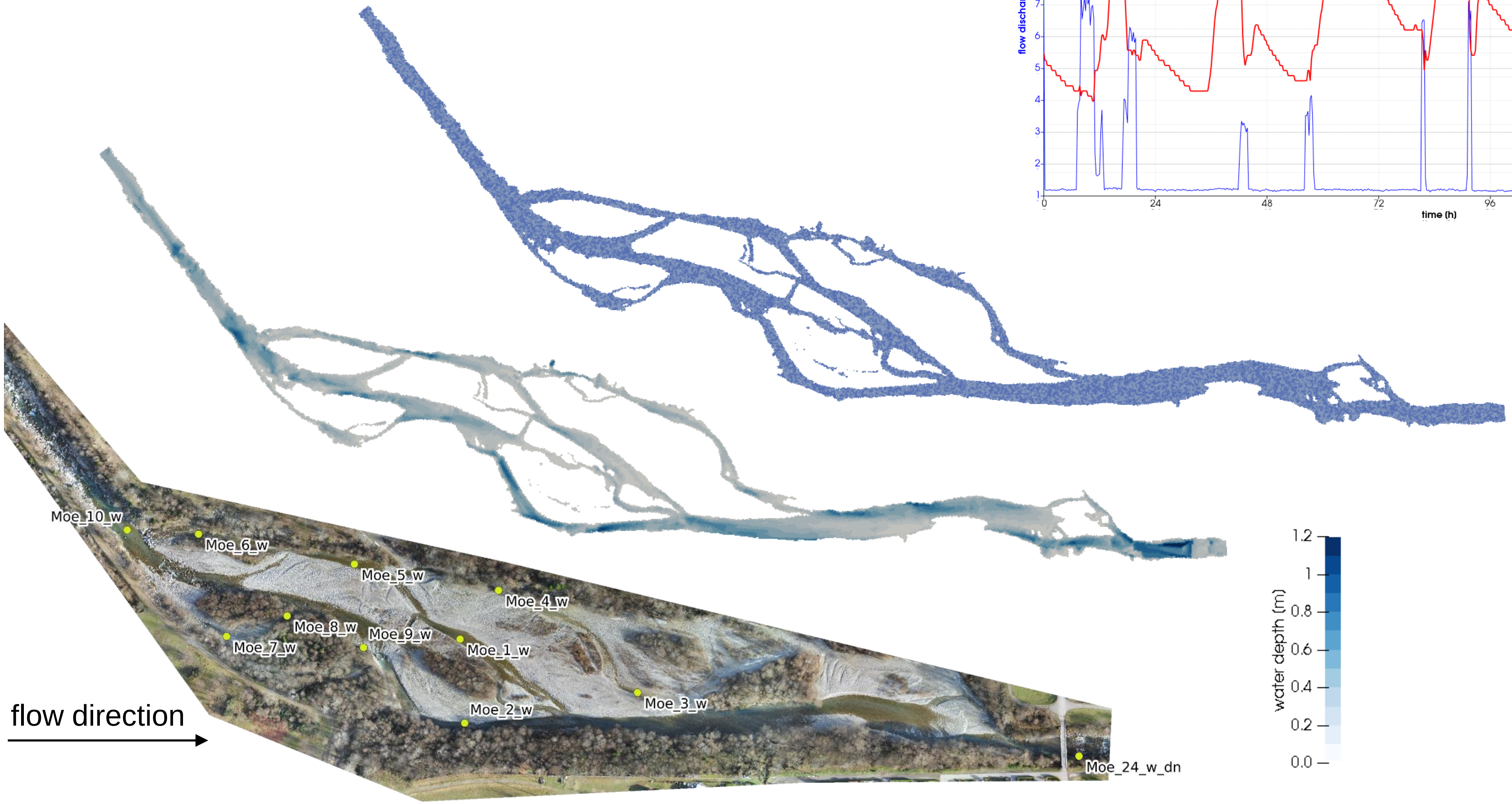
Simulation results

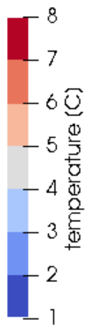
❄ Winter week: 5-12 Feb 2019

discharge [m³/s]

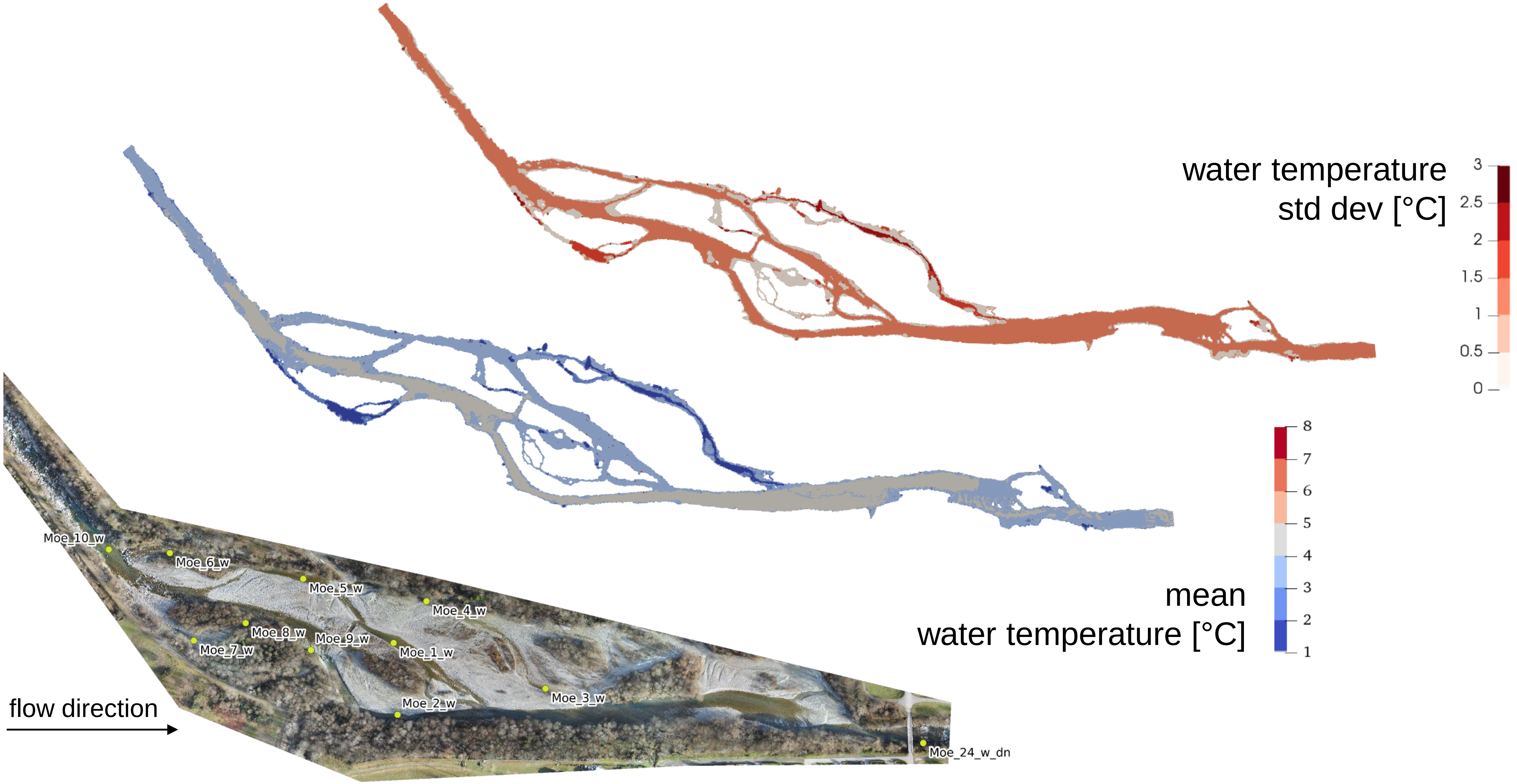
temp [°C]







Simulation results



Under the hood: governing equations

$$\partial_t q_T + \partial_x \left[\frac{q_x q_T}{h} - h \left(K_{xx} \partial_x T + K_{xy} \partial_y T \right) \right] + \partial_y \left[\frac{q_y q_T}{h} - h \left(K_{yx} \partial_x T + K_{yy} \partial_y T \right) \right] = \frac{H_{atm}}{c_w \rho_w} + \frac{H_b}{c_w \rho_w}$$

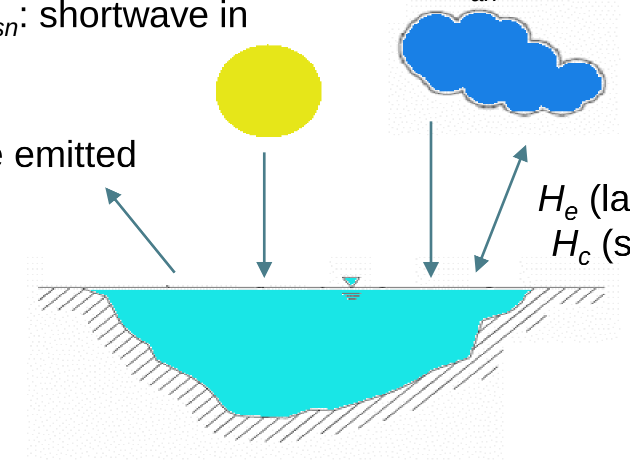
DIFFUSION

SOURCE

- Water temperature as passive tracer
- Advection-diffusion-reaction equation
- Evaluated variable is $q_T = hT$
- Possibility to switch on/off DIFFUSION and SOURCE terms
- Available for BASEHPC domain (GPU-ready)

Under the hood: governing equations

Exchanges with atmosphere



$$H_{atm} = H_{sn} + H_{an} + H_{br} + H_e + H_c$$

$$H_{sn} = 0.97 H_{si} (1.0 - SF)$$

$$H_{an} = \sigma (T_a + 273.15)^4 (Ca + 0.084900481 \sqrt{e_a})(1 - R_l)$$

$$H_{br} = -\sigma\epsilon (T + 273.15)^4$$

$$H_e = -\left(9.2 + 0.46 v_w^2\right) \cdot (e_v - e_a)$$

$$H_c = -0.47 \left(9.2 + 0.46 v_w^2\right) \cdot (T - T_a)$$

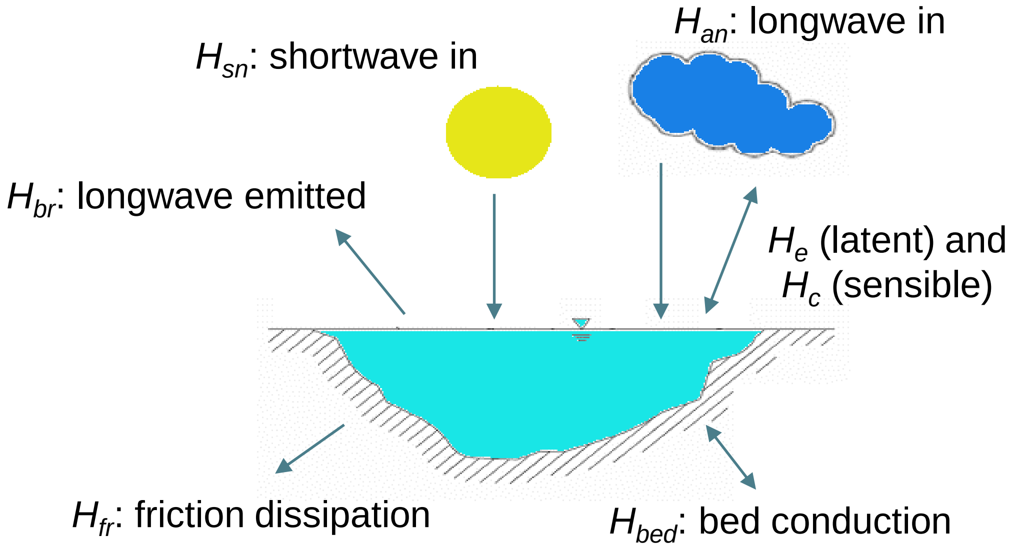
Under the hood: governing equations

Exchanges with river bottom

$$H_b = H_{bed} + H_{fr}$$

$$H_{bed} = -k_b \frac{\partial T}{\partial z} \approx -k_b \frac{T - T_b}{L_b}$$

$$H_{fr} = -f_{fr} \rho_w \frac{u^3}{c_f^2}$$



DISCLAIMER: use with caution

- H_{bed} is a crude simplification, use with caution
- H_{fr} proposed for modelling ice formation in rivers

Setup example

☀ Summer week

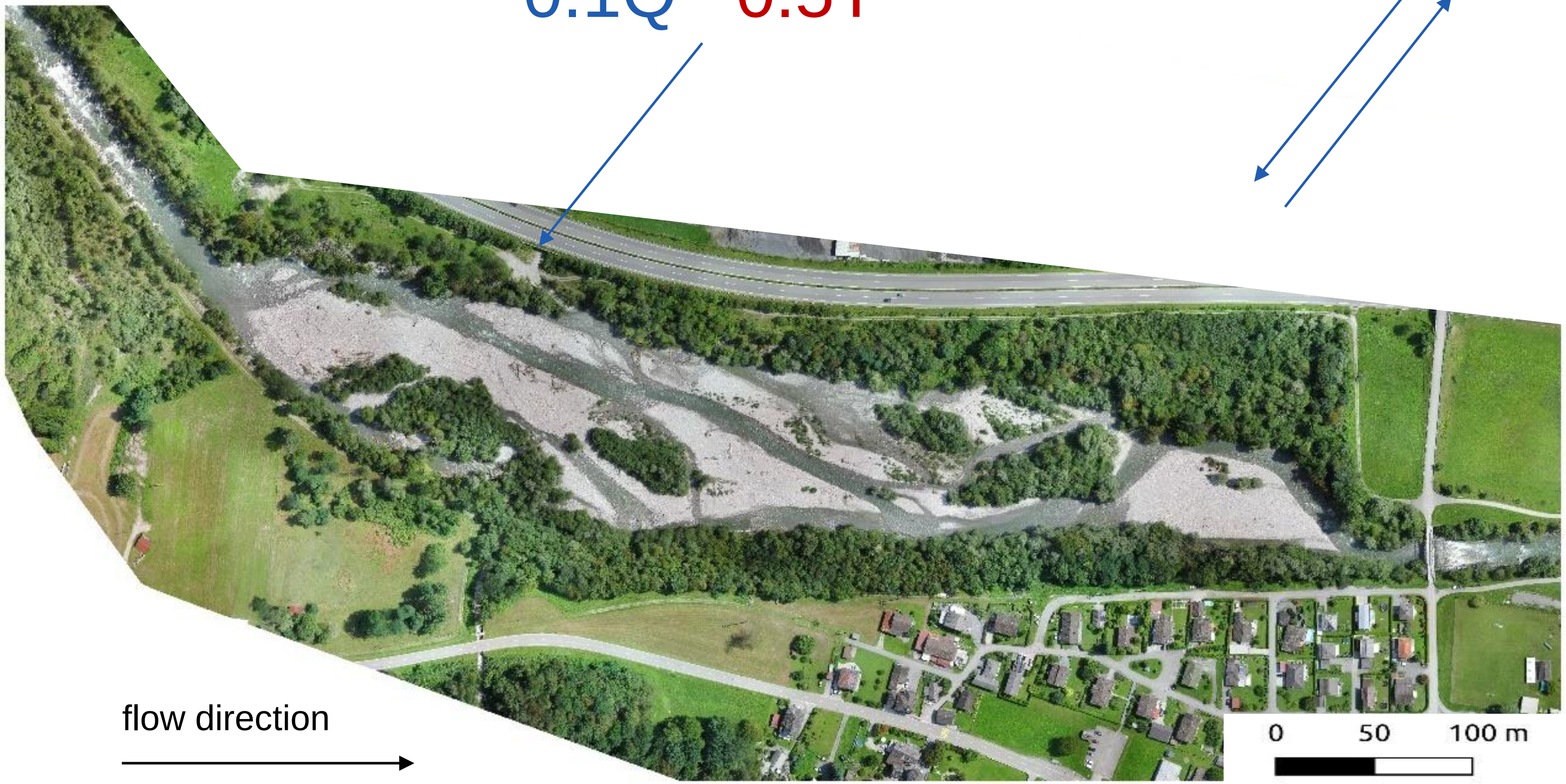
residual flow →

Q T

small lateral tributary

0.1Q 0.5T

Exchanges with atmosphere



outflow →

flow direction →

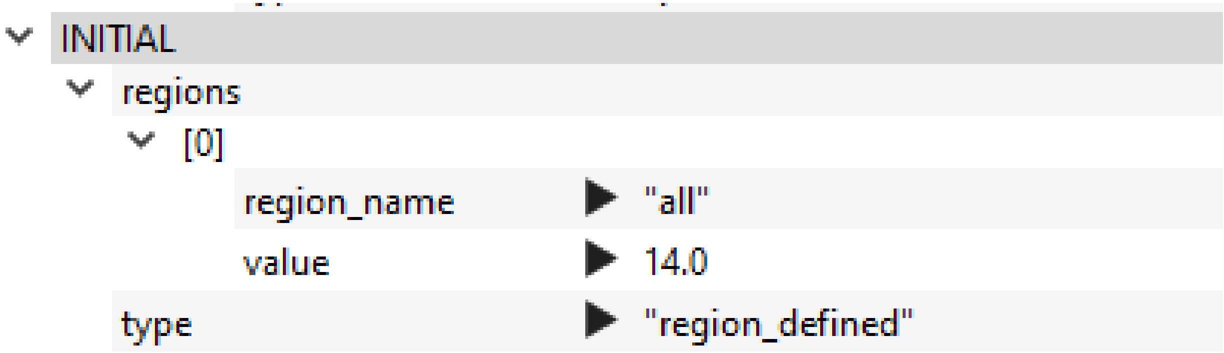
Setup example: REGION definition

- Region definition for diffuse meteorological forcing terms
- WARNING: the same MatID can define 2 different regions ONLY if regions are not used in the same MODULE

Parameter	Value	Validation
GEOMETRY		
INTERPOLATION		
method	"weighted"	
REGIONDEF		
[0]		
[1]		
[2]		
[3]		
index		
[0]	4	
name	"Blocksatz"	
[4]		
index		
[0]	5	
name	"Blockwurf"	
[5]		
index		
[0]	1	
[1]	2	
[2]	3	
[3]	4	
[4]	5	
name	"all"	

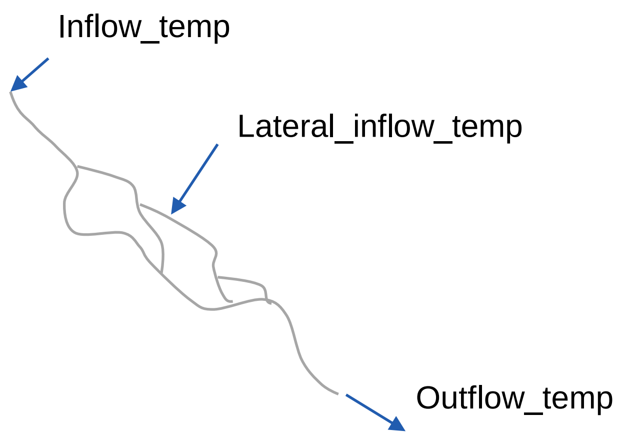
Setup example: INITIAL CONDITIONS

- Options
  - “zero”
  - “region_defined”
  - “continue”
  - “assigned_from_file*



*for developers: temperature read from text file with correct cell order

Setup example: BOUNDARY CONDITIONS



- currently only STANDARD type
- “passive_in” for inflows
- “passive_out” for outflows
- single value (“value”) or timeseries (“value_file)
- “factor” multiplies the timeseries from “value_file” (default value 1)

- BOUNDARY
  - STANDARD
    - [0]

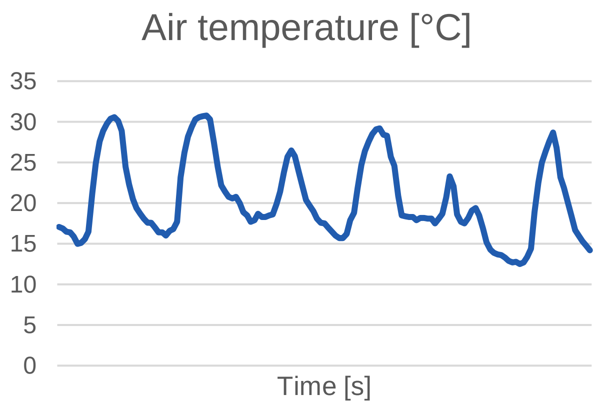
name	"inflow_temp"
string_name	"inflow"
type	"passive_in"
value_file	"input_data/waterT_rf.txt"

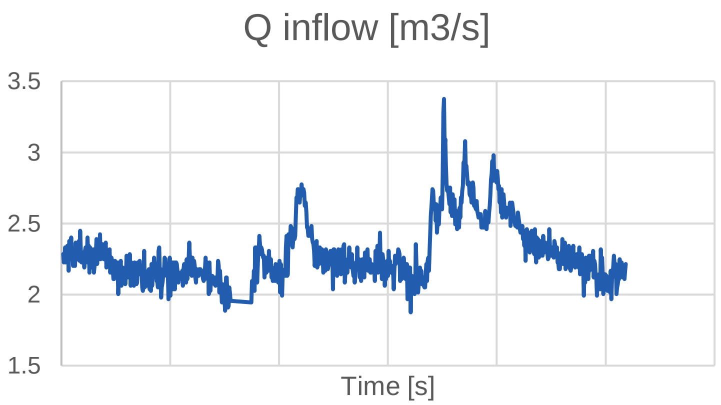
    - [1]

name	"lateral_inflow_temp"
string_name	"lateral"
type	"passive_in"
factor	0.5
value_file	"input_data/waterT_rf.txt"

    - [2]

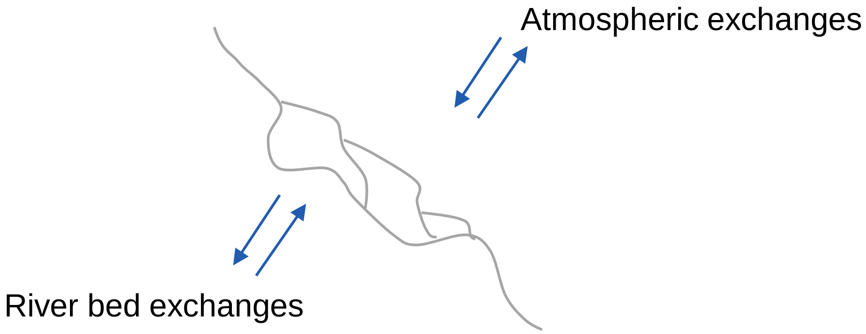
name	"outflow_temp"
string_name	"outflow"
type	"passive_out"





Setup example: SOURCE TERMS

- currently only “meteo” type: meteorological forcing terms
- all forcing terms as single value (“air_temp”) OR timeseries (“air_temp_file”)



SOURCE

[0]

type	"meteo"
region_name	"all"
name	"meteo_forcing"
air_temp_file	"input_data/air_temp_GRONO.txt"
relative_humidity_file	"input_data/rel_hum_GRONO.txt"
total_incoming_rad_file	"input_data/glob_rad_GRONO.txt"
wind_speed_file	"input_data/wind_speed_GRONO.txt"
shade_factor	0.4
bed_temp	13.0

Setup example: PARAMETER

- They all have default values
- “temperature_start”: possibility to delay the beginning of temperature calculation
- “source_update_time”
  - 0 = at every computational timestep
  - >0 [sec] update at given interval (faster, but convergence to be tested)
- “friction_heating_factor”: to calibrate the heat dissipation by friction (0 by default, i.e. deactivated)
- “bed_thermal_thickness”: vertical thickness to reach constant soil temperature
- “bed_thermal_conductivity”: depends on soil type
  - TIP: set to 0.0 to exclude from simulation

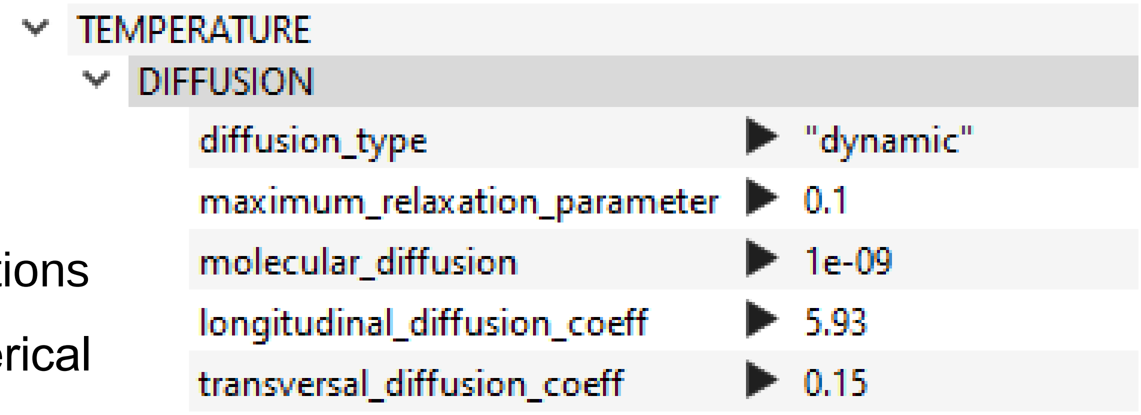
PARAMETER	
fluid_specific_heat	4186
temperature_start	0.0
source_update_time	0.0
friction_heating_factor	0.0
bed_thermal_thickness	1.0
bed_thermal_conductivity	1.5

$$H_{fr} = -f_{fr}\rho_w \frac{u^3}{c_f^2}$$

$$H_{bed} = -k_b \frac{\partial T}{\partial z} \approx -k_b \frac{T - T_b}{L_b}$$

Setup example: DIFFUSION parameters

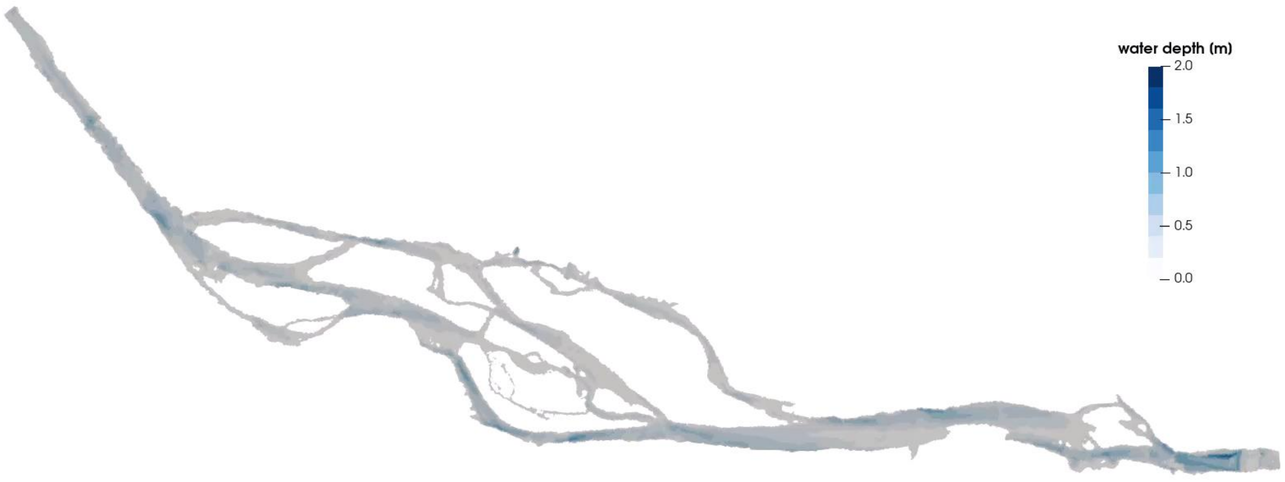
- “diffusion_type”
  - none (equivalent to removing the block)
  - constant: fixed diffusion coefficients
  - dynamic: diffusion coefficients depend on flow conditions
- “maximum_relaxation_parameter”: deals with the numerical solver* (default value is ok)
- “molecular diffusion” [m2/s] with default value
- “longitudinal_diffusion_coeff” (default=0)
  - constant value in [m2/s] if type=constant
  - non-dimensional factor* if type=dynamic
- “transversal_diffusion_coeff” (default=0)
  - constant value in [m2/s] if type=constant
  - non-dimensional factor* if type=dynamic

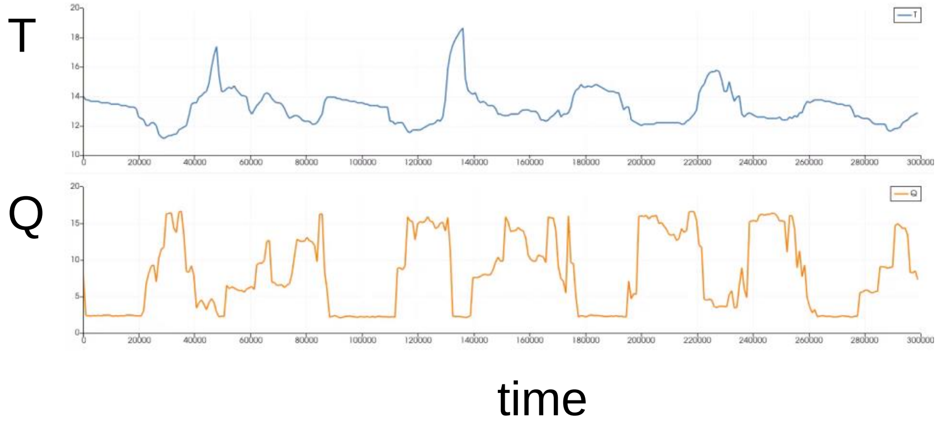


*See manual and

Vanzo, D et al. (2016). Pollutant transport by shallow water equations on unstructured meshes: Hyperbolization of the model and numerical solution via a novel flux splitting scheme. JCP.

Simulation results





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Davide Vanzo
vanzo@vaw.baug.ethz.ch