HyMELT-CC:

HYdro power: iMpact on the ELecTricity sector in Austria due to Climate Change in glaciated high alpine areas

Project duration:
December 2022 – May 2025

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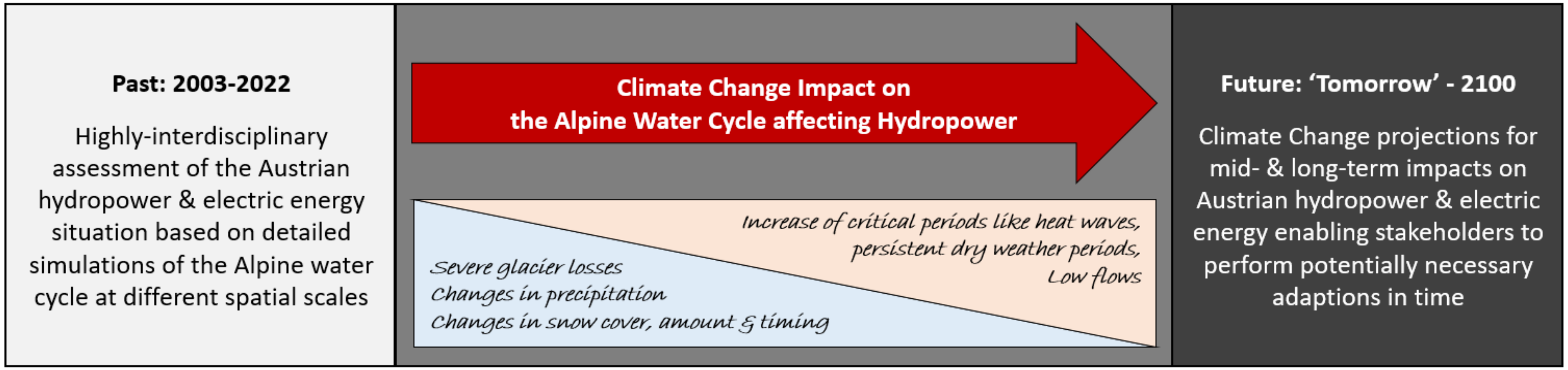
Project Overview

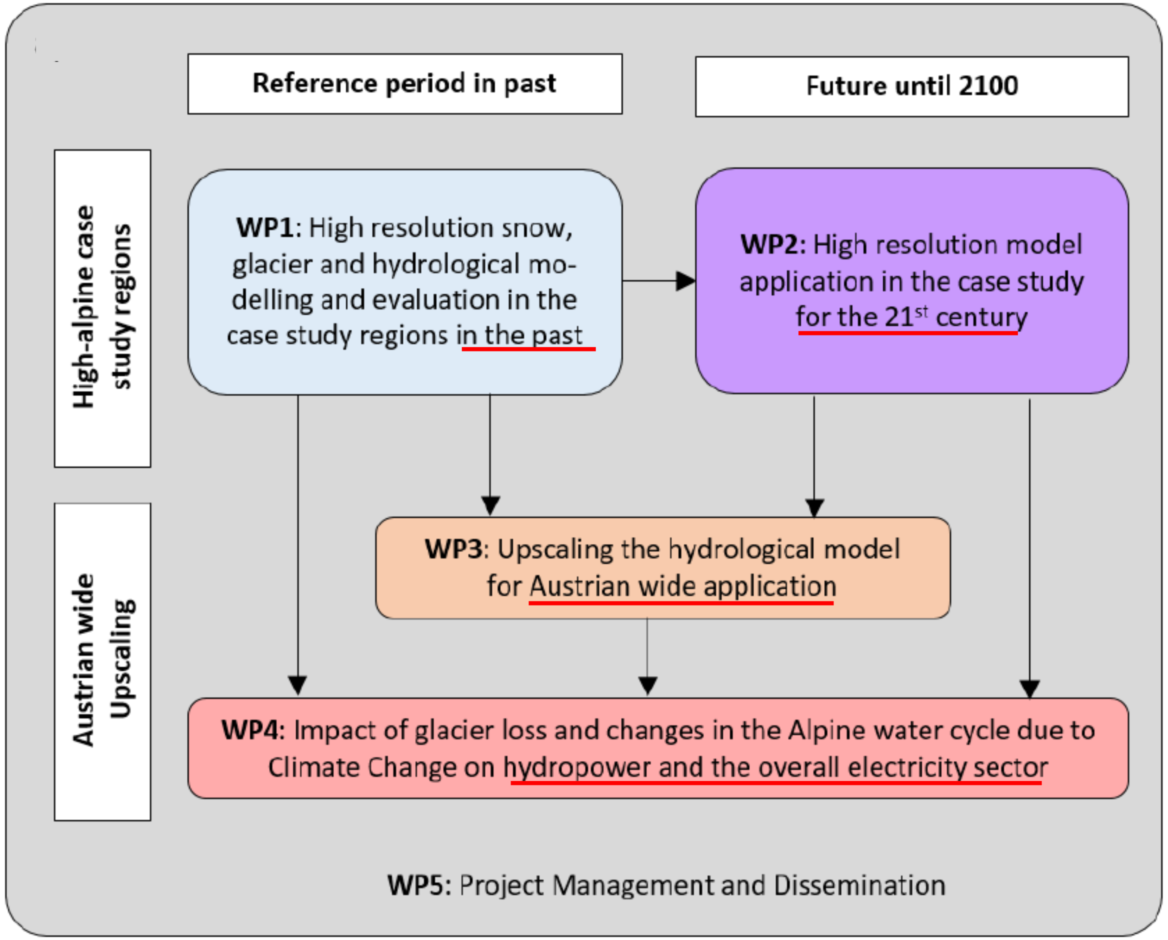
<u>Overall aim</u>: Performance of a <u>highly-interdisciplinary and detailed assessment</u> of the impact of a changing meteorology and hydrology, including <u>future glacier evolution</u>, <u>changes of the seasonal snow cover</u> on <u>hydropower supply</u> and the <u>overall electricity sector in Austria</u>, with a special focus on <u>critical periods</u> like heat waves or dry periods in summer as well as dark doldrums during winter.

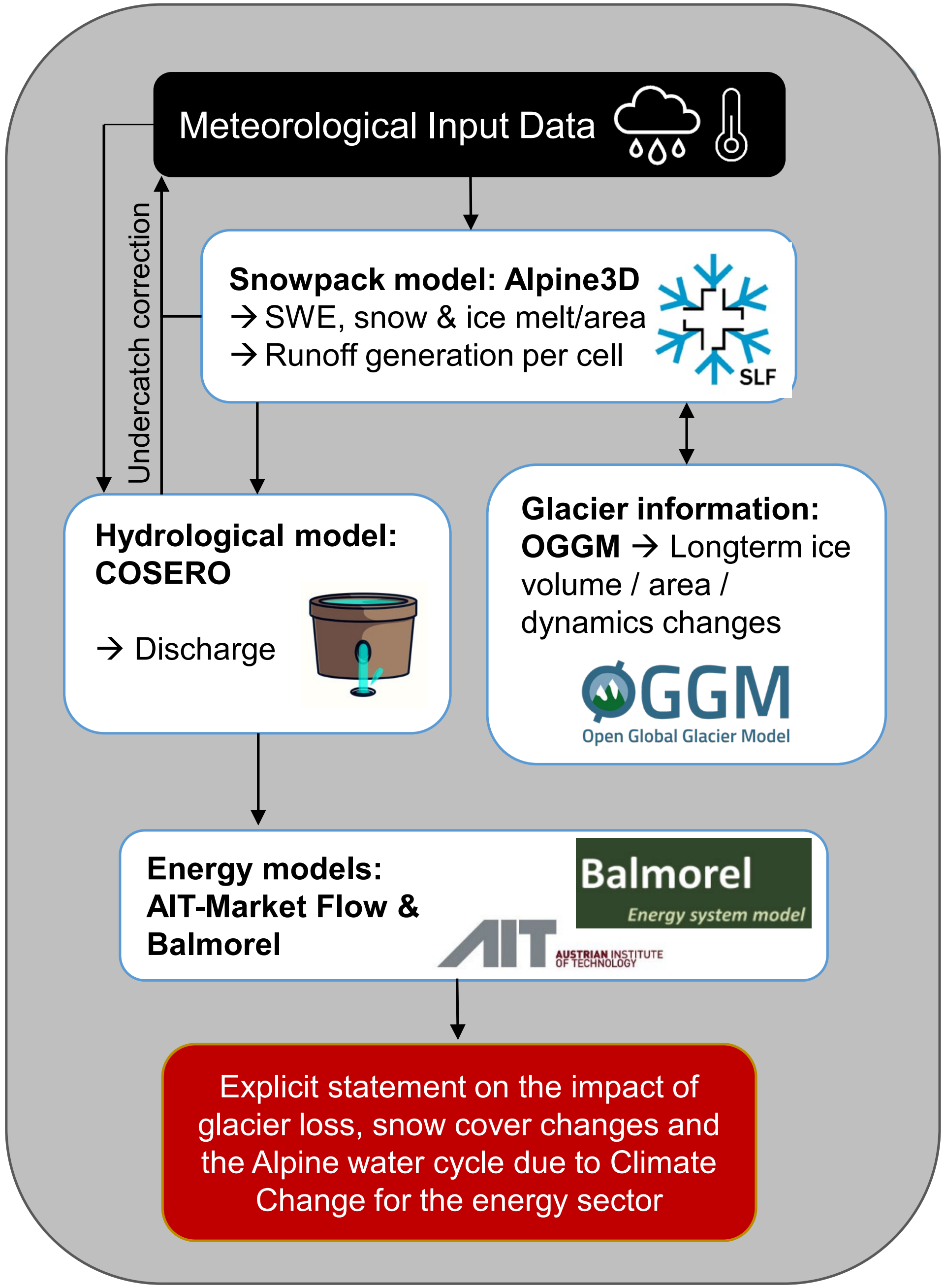


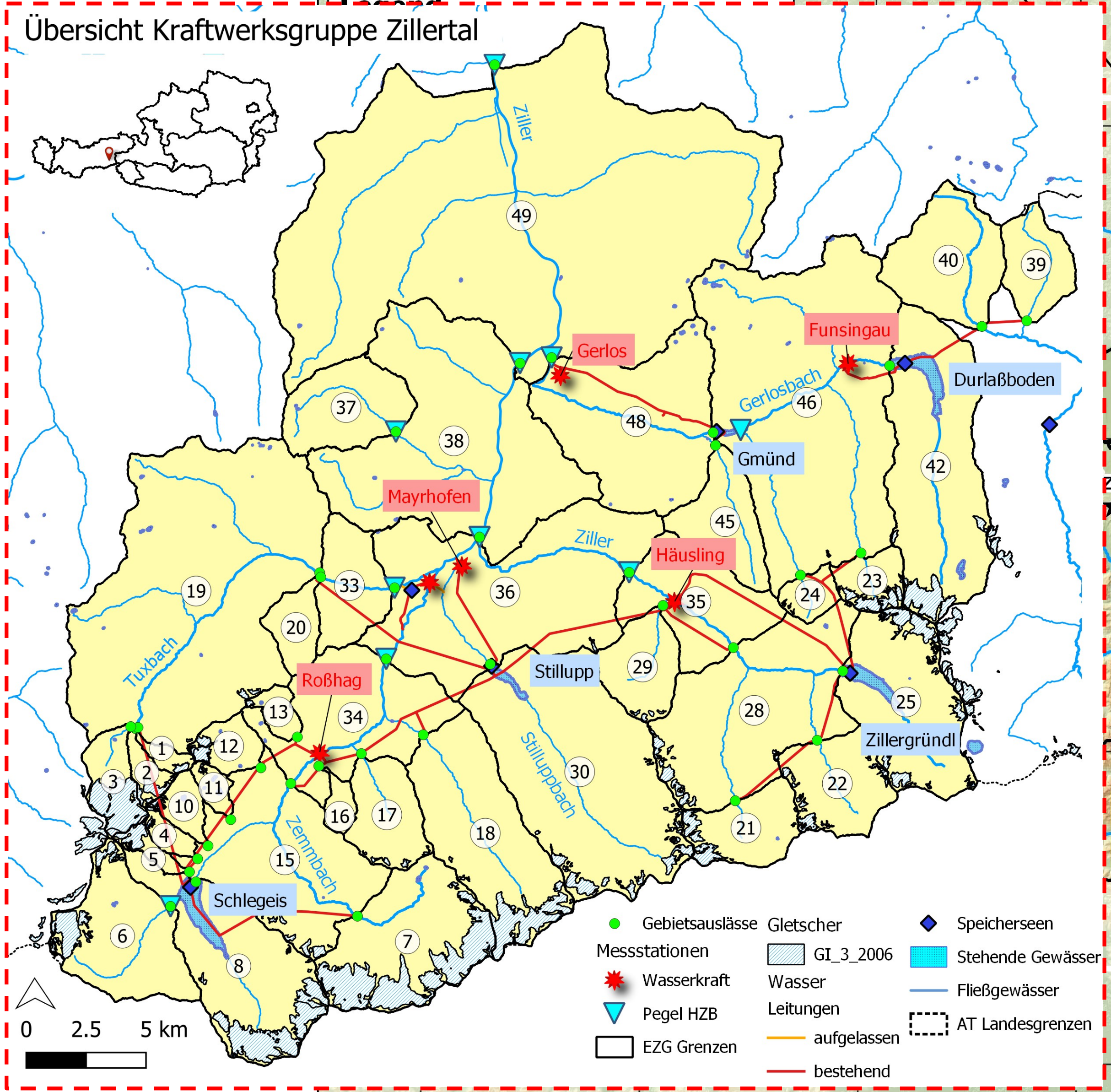
<u>Importance</u>:

1. the <u>very high importance of hydropower production in Austria</u> for the domestic electricity sector,
2. <u>changing hydrological systems</u> and the disruption of snow and glacier contribution to hydropower production
3. <u>ambitious Austrian energy and climate targets</u> that call for a rapid transformation of the entire energy system towards carbon neutrality.

Project Structure and Model Setup



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Funsingau
Durlaßboden
Gerlosbach
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Gmünd
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Mayrhofen
Ziller
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Messstationen
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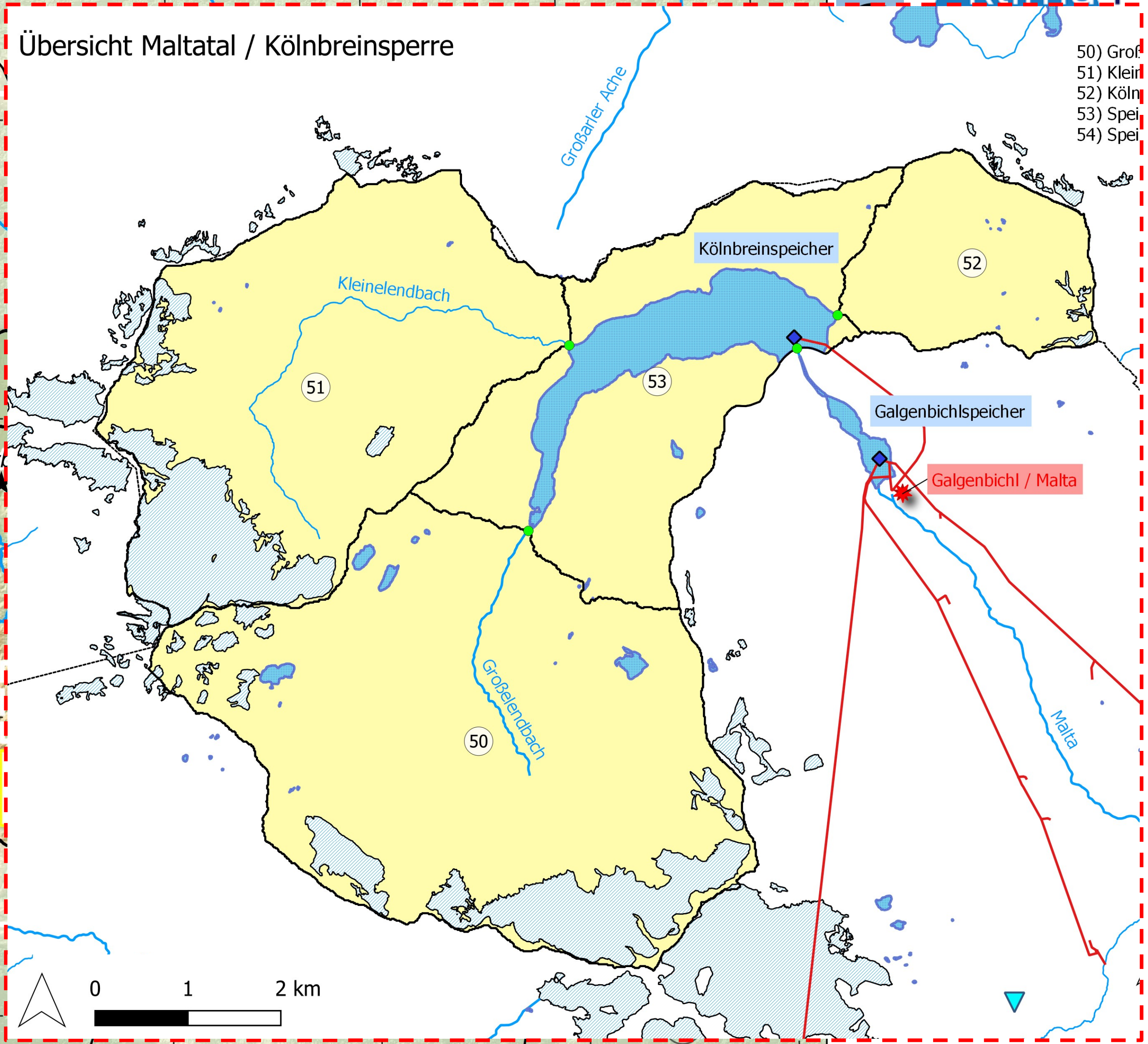
AT Landesgrenzen


Übersicht Maltatal / Kölnbreinsperre
Großarler Ache
Kölnbreinspeicher
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Kleinelendbach
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Galgenbichlspeicher
Galgenbichl / Malta
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50
Malta
0 1 2 km

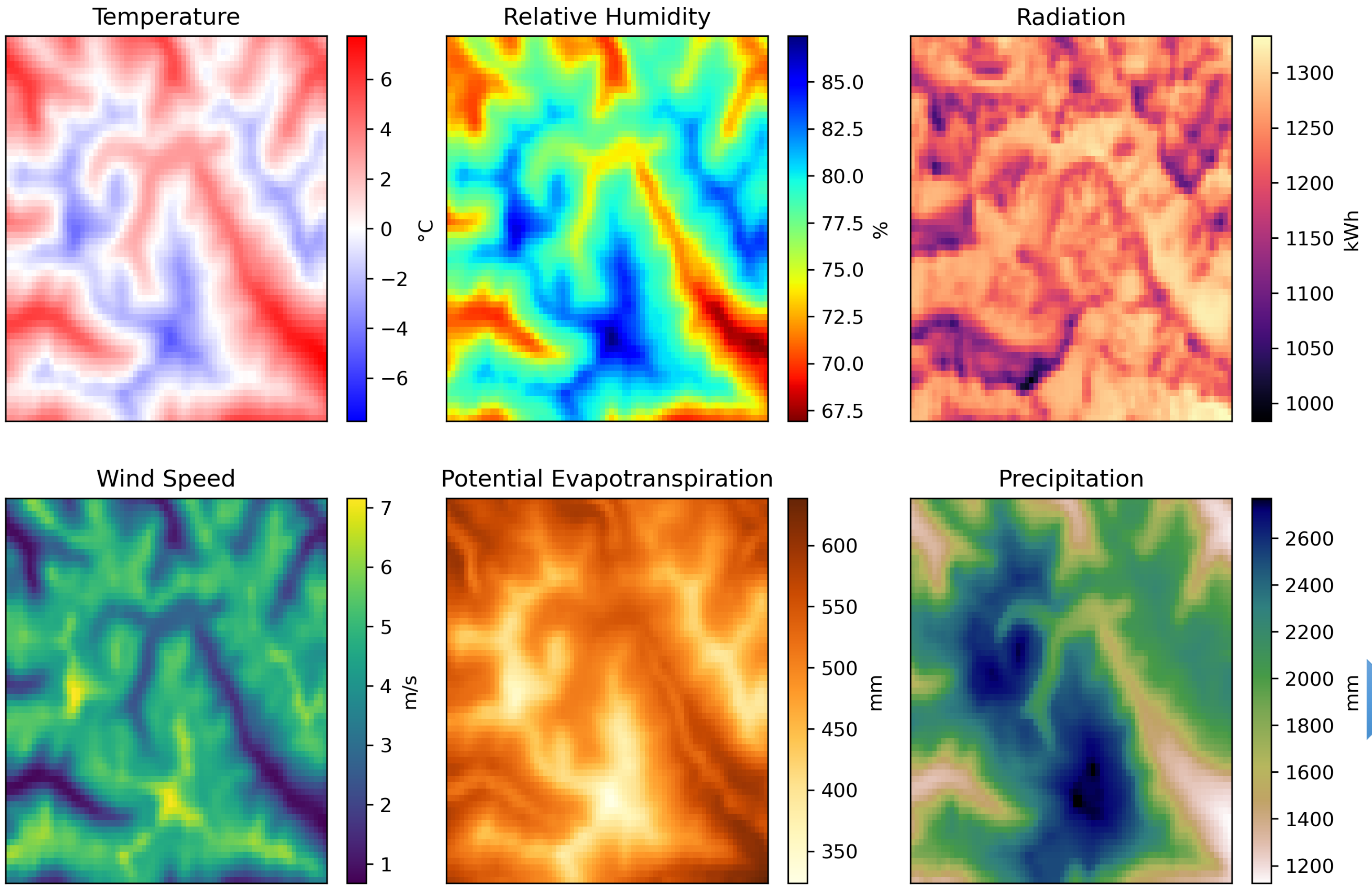
Meteorological Input

- Hourly data (several variables) for high-alpine case study regions domains Zillertal & Maltatal, resolution 4 km (underlying 250 m grid)
  - Regridding, temporal disaggregation daily → hourly data for all variables
  - Special emphasis on precipitation correction, as simulated discharge was too less compared to observed reservoir inflow, indicating too little precipitation in glaciated areas
- Historical data (1990-2022) + selection of representative climate projections covering 21st century

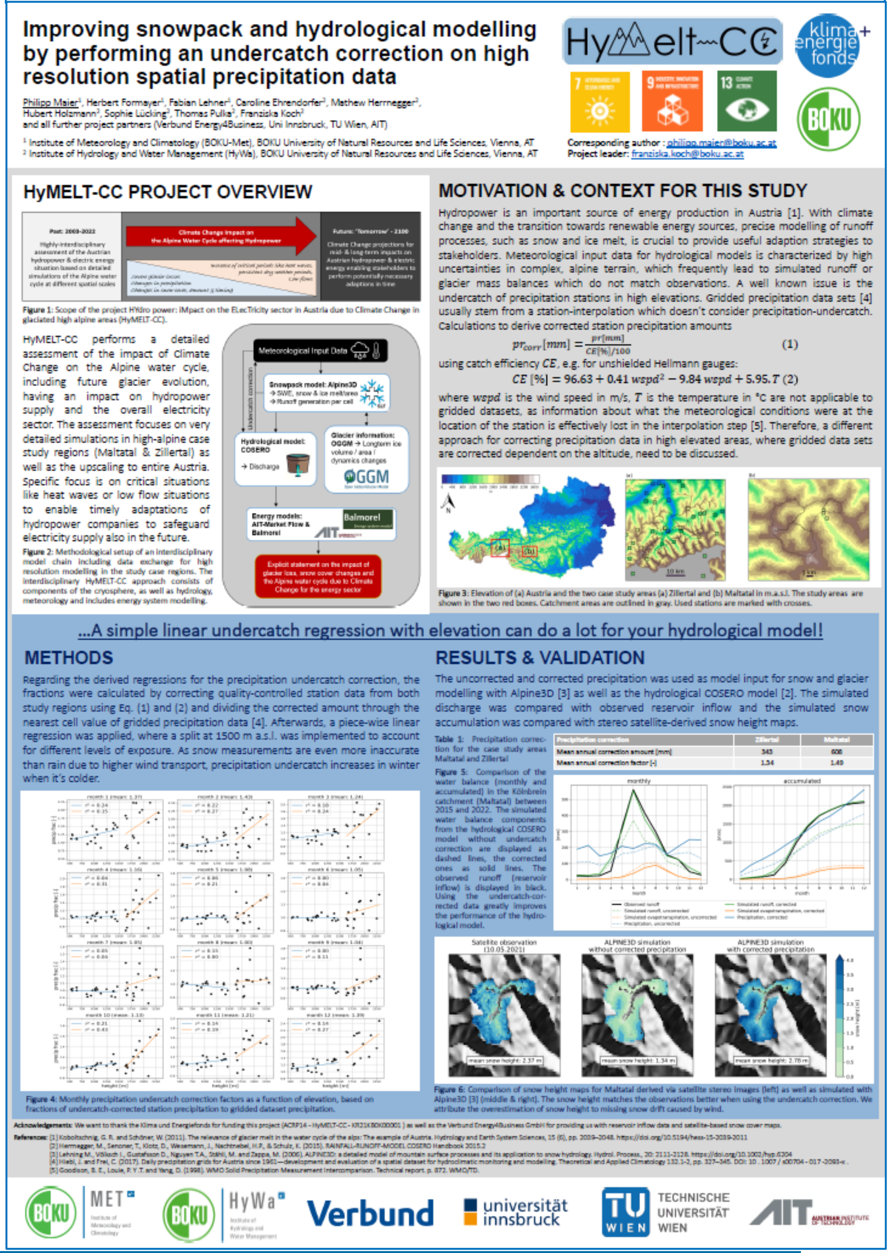
EURO-CORDEX Model [1]	*Closest Socioeconomic Shared Pathway (SSP) median*	*Precip. behavior*
MPI-M-MPI-ESM-LR_rcp45_r1i1p1_CLMcom-CCLM4-8-17	*1-2.6 (Paris agreeing)*	*Dry*
ICHEC-EC-EARTH_rcp85_r1i1p1_KNMI-RACMO22E	*3-7.0*	*Mixed*
MPI-M-MPI-ESM-LR_rcp85_r1i1p1_CLMcom-CCLM4-8-17	*2-4.5 / 3-7.0*	*Dry*
ICHEC-EC-EARTH_rcp85_r12i1p1_SMHI-RCA4	*3-7.0 / 5-8.5 (Business as usual)*	*Wet*

- Daily data (temperature, precipitation) for discharge modelling for whole Austria → ÖKS 15 [2] selection

Meteorological Variables: Annual Means (Maltatal)



Poster: Undercatch corrected precipitation



Improving snowpack and hydrological modelling by performing an undercatch correction on high resolution spatial precipitation data

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and all further project partners (Verbund Energy4Business, Uni Innsbruck, TU Wien, AIT)

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HyMELT-CC PROJECT OVERVIEW

Figure 1: Scope of the project HYdro power: iMpact on the ELecTricity sector in Austria due to Climate Change in glaciated high alpine areas (HyMELT-CC).

HyMELT-CC performs a detailed assessment of the impact of Climate Change on the Alpine water cycle, including future glacier evolution, having an impact on hydropower supply and the overall electricity sector. The assessment focuses on very detailed simulations in high-alpine case study regions (Maltatal & Zillertal) as well as the upscaling to entire Austria. Specific focus is on critical situations like heat waves or low flow situations to enable timely adaptations of hydropower companies to safeguard electricity supply also in the future.

Figure 2: Methodological setup of an interdisciplinary model chain including data exchange for high resolution modelling in the study case regions. The interdisciplinary HyMELT-CC approach consists of components of the cryosphere, as well as hydrology, meteorology and includes energy system modelling.

MOTIVATION & CONTEXT FOR THIS STUDY

Hydropower is an important source of energy production in Austria [1]. With climate change and the transition towards renewable energy sources, precise modelling of runoff processes, such as snow and ice melt, is crucial to provide useful adaption strategies to stakeholders. Meteorological input data for hydrological models is characterized by high uncertainties in complex, alpine terrain, which frequently lead to simulated runoff or glacier mass balances which do not match observations. A well known issue is the undercatch of precipitation stations in high elevations. Gridded precipitation data sets [4] usually stem from a station-interpolation which doesn't consider precipitation-undercatch. Calculations to derive corrected station precipitation amounts

$$pr_{corr}[mm] = \frac{pr[mm]}{CE[\%]/100} \quad (1)$$

using catch efficiency CE, e.g. for unshielded Hellmann gauges:

$$CE\,[\%] = 96.63 + 0.41\,wspd^2 - 9.84\,wspd + 5.95\,T \quad (2)$$

where $wspd$ is the wind speed in m/s, T is the temperature in °C are not applicable to gridded datasets, as information about what the meteorological conditions were at the location of the station is effectively lost in the interpolation step [5]. Therefore, a different approach for correcting precipitation data in high elevated areas, where gridded data sets are corrected dependent on the altitude, need to be discussed.

Figure 3: Elevation of (a) Austria and the two case study areas (a) Zillertal and (b) Maltatal in m.a.s.l. The study areas are shown in the two red boxes. Catchment areas are outlined in gray. Used stations are marked with crosses.

...A simple linear undercatch regression with elevation can do a lot for your hydrological model!

METHODS

Regarding the derived regressions for the precipitation undercatch correction, the fractions were calculated by correcting quality-controlled station data from both study regions using Eq. (1) and (2) and dividing the corrected amount through the nearest cell value of gridded precipitation data [4]. Afterwards, a piece-wise linear regression was applied, where a split at 1500 m a.s.l. was implemented to account for different levels of exposure. As snow measurements are even more inaccurate than rain due to higher wind transport, precipitation undercatch increases in winter when it's colder.

Figure 4: Monthly precipitation undercatch correction factors as a function of elevation, based on fractions of undercatch-corrected station precipitation to gridded dataset precipitation.

RESULTS & VALIDATION

The uncorrected and corrected precipitation was used as model input for snow and glacier modelling with Alpine3D [3] as well as the hydrological COSERO model [2]. The simulated discharge was compared with observed reservoir inflow and the simulated snow accumulation was compared with stereo satellite-derived snow height maps.

Table 1: Precipitation correction for the case study areas Maltatal and Zillertal

Precipitation correction	Zillertal	Maltatal
Mean annual correction amount [mm]	343	608
Mean annual correction factor [-]	1.34	1.49

Figure 5: Comparison of the water balance (monthly and accumulated) in the Kölnbrein catchment (Maltatal) between 2015 and 2022. The simulated water balance components from the hydrological COSERO model without undercatch correction are displayed as dashed lines, the corrected ones as solid lines. The observed runoff (reservoir inflow) is displayed in black. Using the undercatch-corrected data greatly improves the performance of the hydrological model.

Figure 6: Comparison of snow height maps for Maltatal derived via satellite stereo images (left) as well as simulated with Alpine3D [3] (middle & right). The snow height matches the observations better when using the undercatch correction. We attribute the overestimation of snow height to missing snow drift caused by wind.

Acknowledgements: We want to thank the Klima und Energiefonds for funding this project (ACRP14 - HyMELT-CC - KR21KB0K00001) as well as the Verbund Energy4Business GmbH for providing us with reservoir inflow data and satellite-based snow cover maps.

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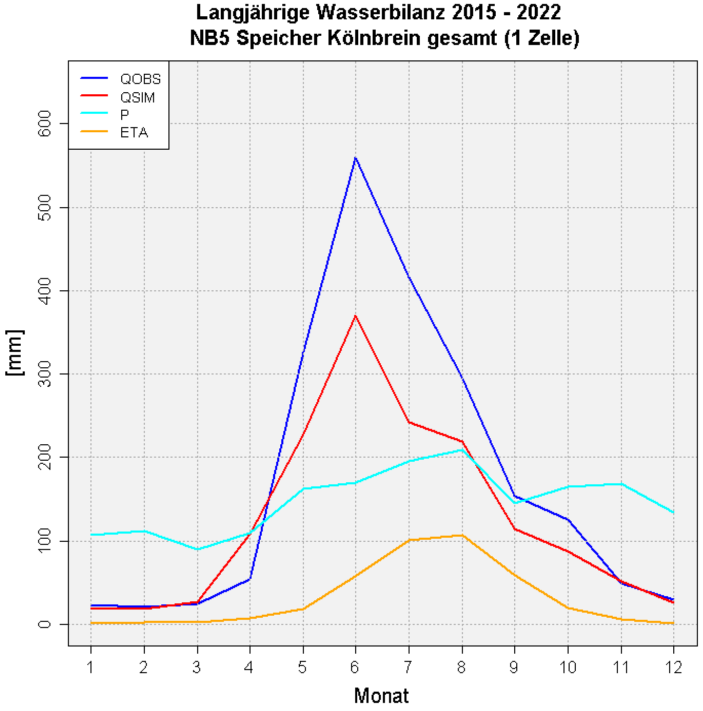
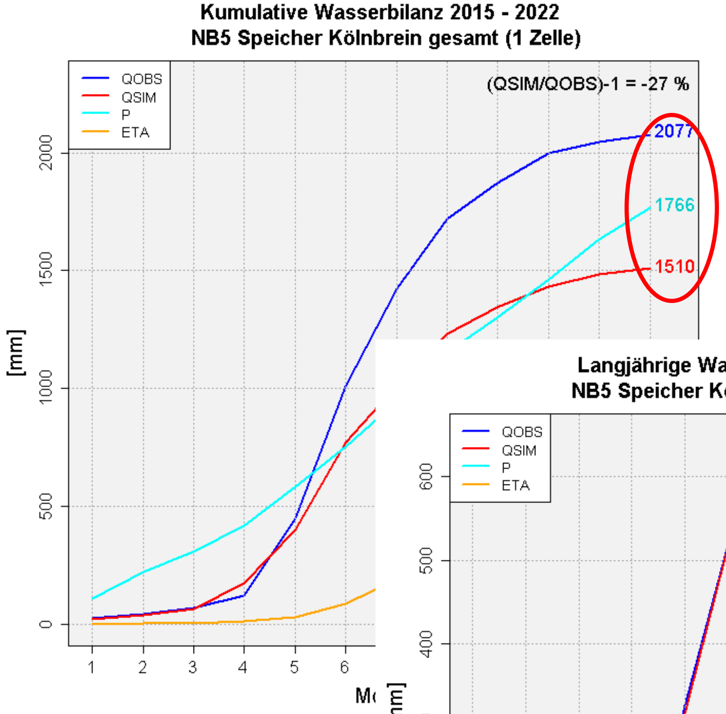
METEOROLOGICAL VARIABLES

Variable	Unit	Additional preparation methods	Used for	Used data sets
Temperature	°C		Input for Alpine3D, OGGM and COSERO	SPARTACUS [3,4]
Wind Speed	m/s	Ridge regression machine learning approach	Input for Alpine3D	GeoSphere station data [5]
Wind Direction	°N	Creation of one representative wind direction field per month for days with and without precipitation	Input for Alpine3D	INCA [6]
Radiation	kWh	Aspect-dependent radiation correction	Input for Alpine3D	APOLIS [7] INCA [6]
Precipitation	mm	Quality control of data set and local station data Undercatch correction using a elevation regression derived from undercatch-corrected local station data [10]	Input for Alpine3D, OGGM and COSERO	SPARTACUS [3,4] Stations from various sources ERA5-Land [8] CHELSA [9]
Potential Evapotranspiration	mm	Derived quantity using the FAO 56 Penman-Monteith equation [11]	Validation for COSERO	SPARTACUS [3,4] APOLIS [7] ERA5-Land [8]
Relative Humidity	%		Input for Alpine3D	SPARTACUS [3,4]

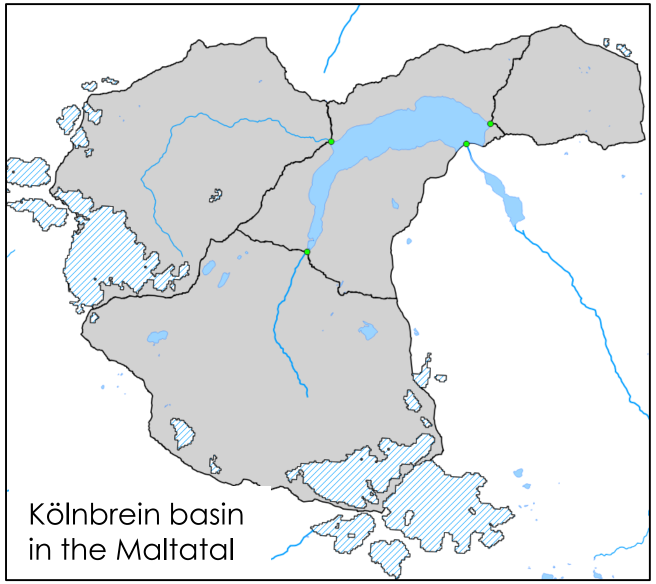
RESULTS - WATER BALANCE: CORRECTED PRECIPITATION

Uncorrected precipitation

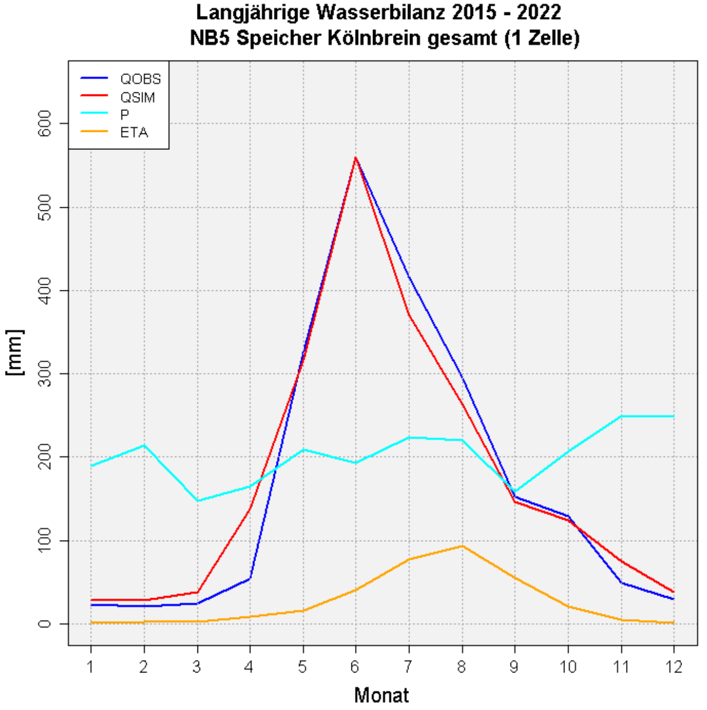


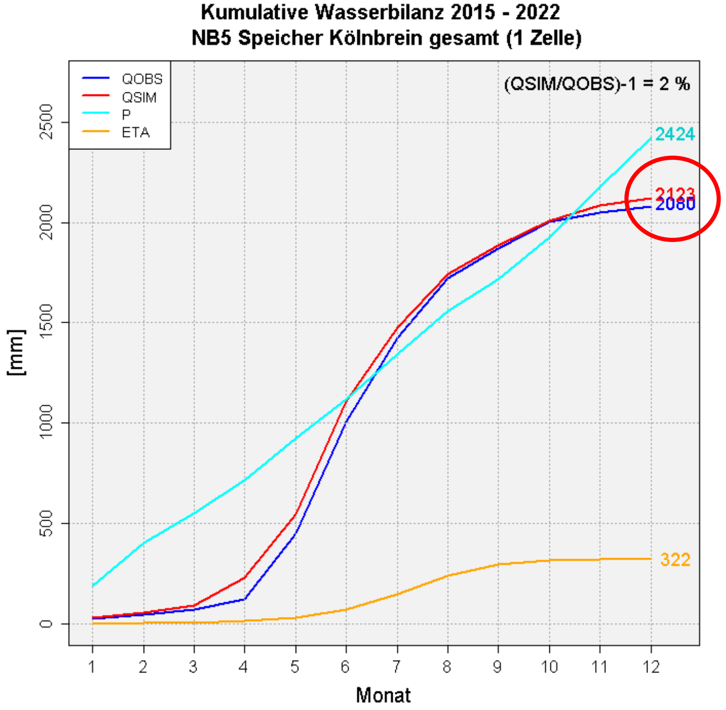


Observed runoff
Simulated runoff
Precipitation
Actual Evapotranspiration



Corrected precipitation



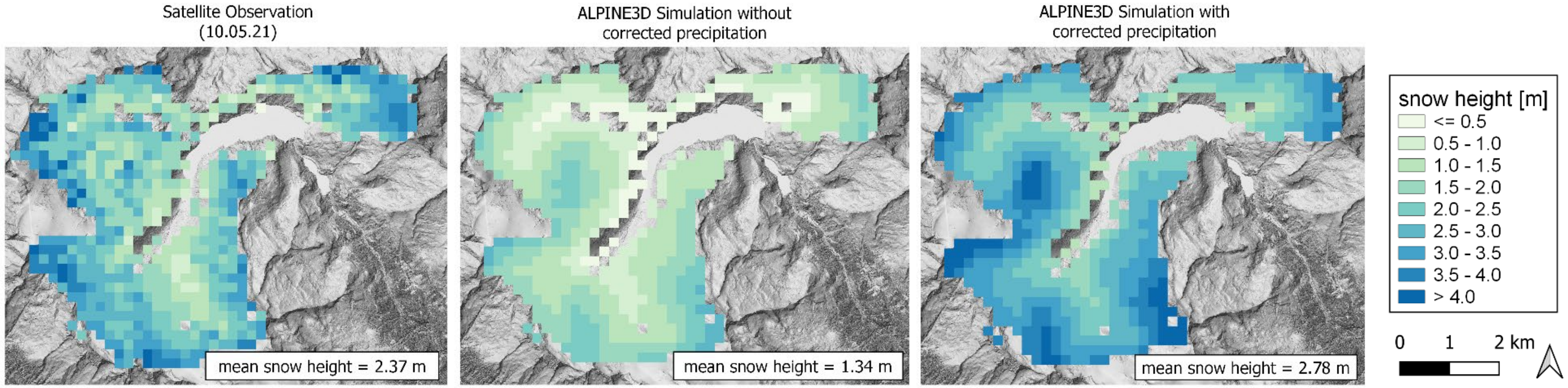


Mean monthly and cumulative water balance using the first meteo product (M1) in the Kölnbrein catchment as input for the COSERO [12] model.

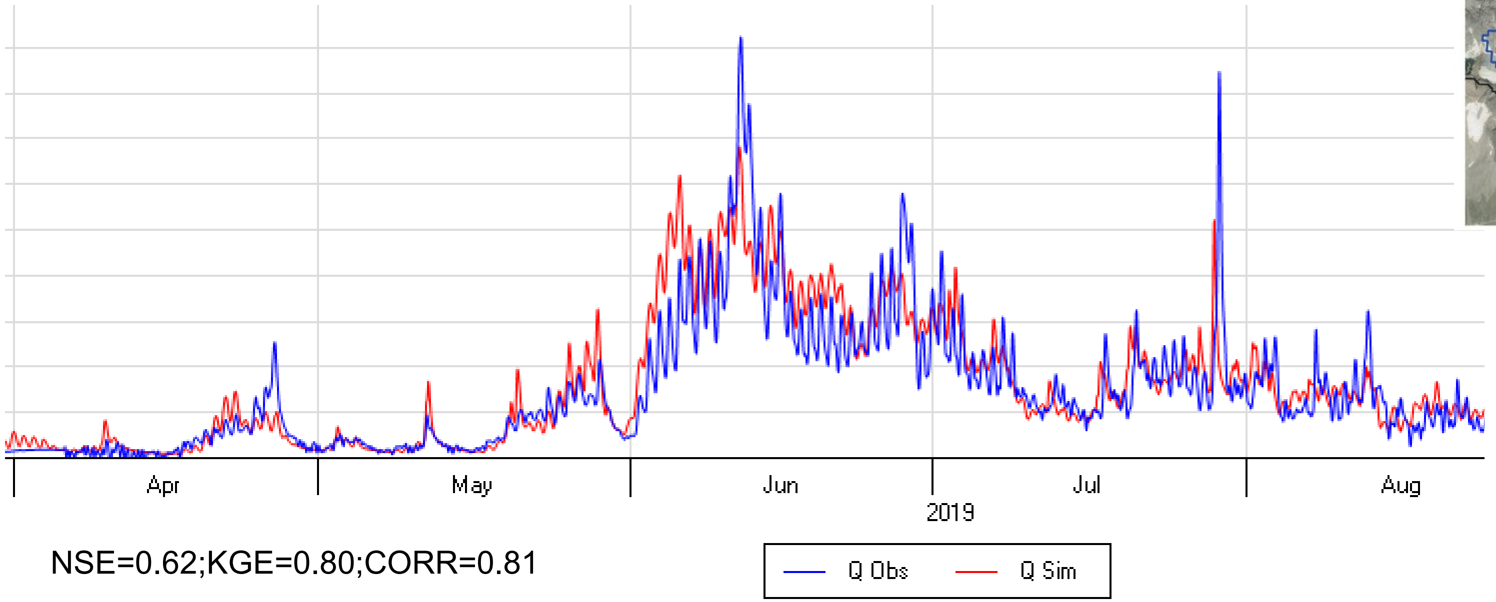
Mean monthly and cumulative water balance using the second meteo product (M2) in the Kölnbrein catchment as input for the COSERO model.

Simulations & Validation

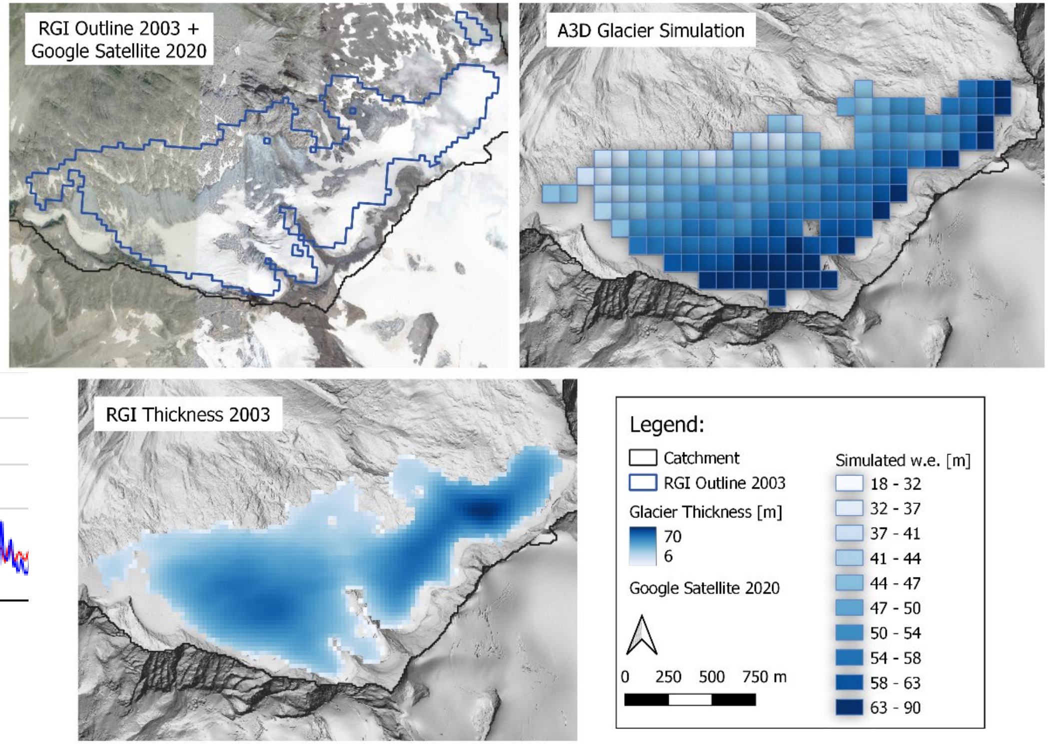
- Satellite-based snow depth and cover information
- Glacier outline, mass balance and thickness information
- Runoff and reservoir inflow data



Hydrological simulation with the hydrological model COSERO [12] compared to inflow observations into the Kölnbrein reservoir



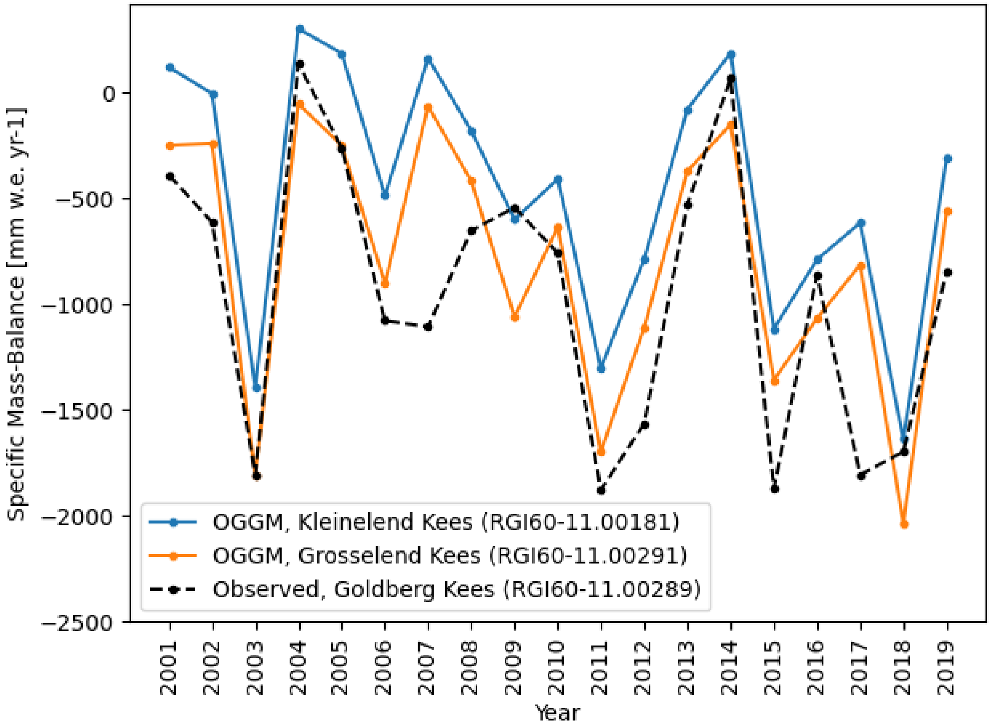
NSE=0.62;KGE=0.80;CORR=0.81

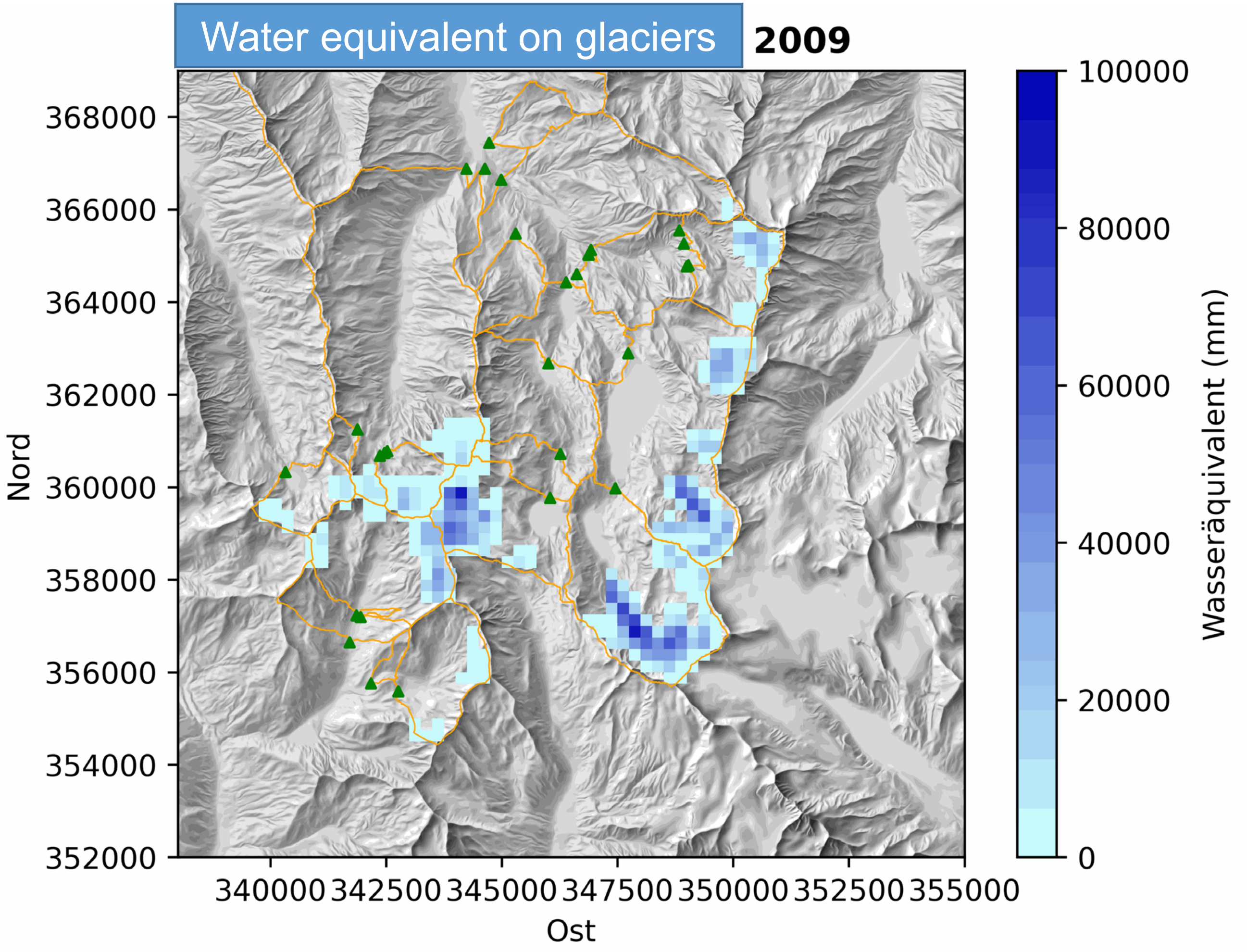


SIMULATION OF GLACIER MASS BALANCE

Glacier mass balance simulation with glacier model OGGM [13] for Groß- and Kleinelendkees in Maltatal and reference glacier

Basis for coupling with Alpine3D [14] & Cosero [12] in a next step





Progress & Synergies

03.04.2024

Work packages HyMELT-CC	Project Year 1												Project Year 2												Project Year 3					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
WP1	High resolution snow, glacier and hydrological modelling and evaluation in the case study regions in the past																													
WP2										High resolution model application in the case study regions for 21st century																				
WP3															Upscaling the hydrological model for Austrian wide application															
WP4																			Impact due to CC on hydropower and the overall electricity sector											
WP5	Project management																													

<u>Next steps</u>:

- Future simulation of alpine case study areas
- Hydrological simulation of entire Austria
- Coupling with energy modelling
- Explicit statement on the impact of glacier loss, snow cover changes and the Alpine water cycle for the energy sector

<u>Synergies</u>:

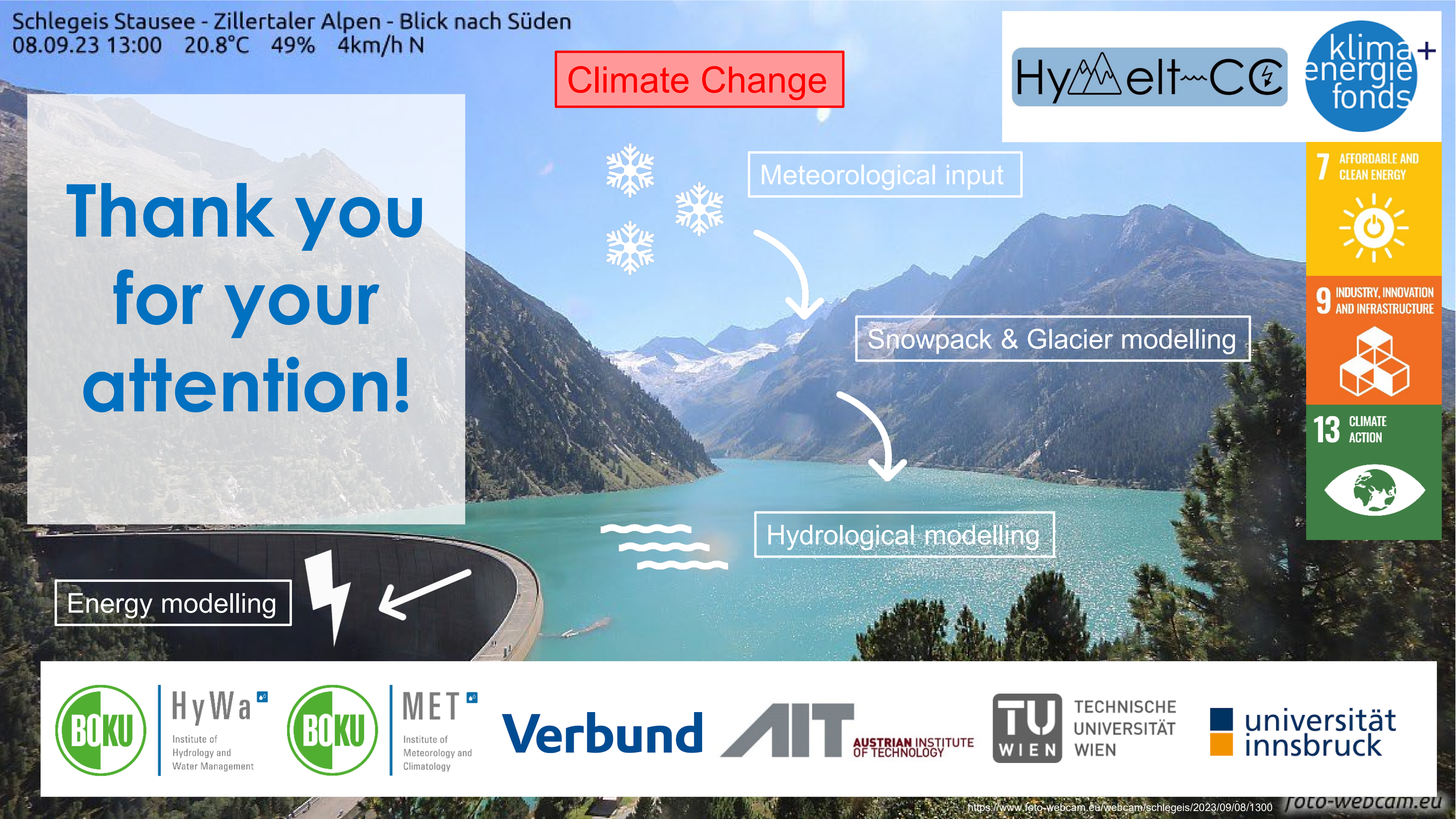
- SNOWPOWER (VERBUND)
- SnowModVis (HyWa)
- Groundwater Recharge Study (HyWa)
- G-MONARCH (HyWa) etc.

<u>Changes</u>: in some WP-tasks due to several meteo-hydro-iterations in high-alpine catchments

<u>Dissemination</u>:

- Journal publication in preparation
- HydroCarpath 2024:
  - *Ehrendorfer et al.* (2023) [15]
  - *Lücking et al.* (2023) [16]
  - *Pulka et al.* (2023) [17]
- EGU 2024:
  - *Ehrendorfer et al.* (2024) [18]
  - *Maier et al.* (2024) [19]

Thank you for your attention!



HyMelt-CC
klima+ energie fonds

7 AFFORDABLE AND CLEAN ENERGY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
13 CLIMATE ACTION

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BOKU | MET Institute of Meteorology and Climatology
Verbund
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY
TU WIEN TECHNISCHE UNIVERSITÄT WIEN
universität innsbruck

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