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From measurements in the field to physically based modelling: openAMUNDSEN

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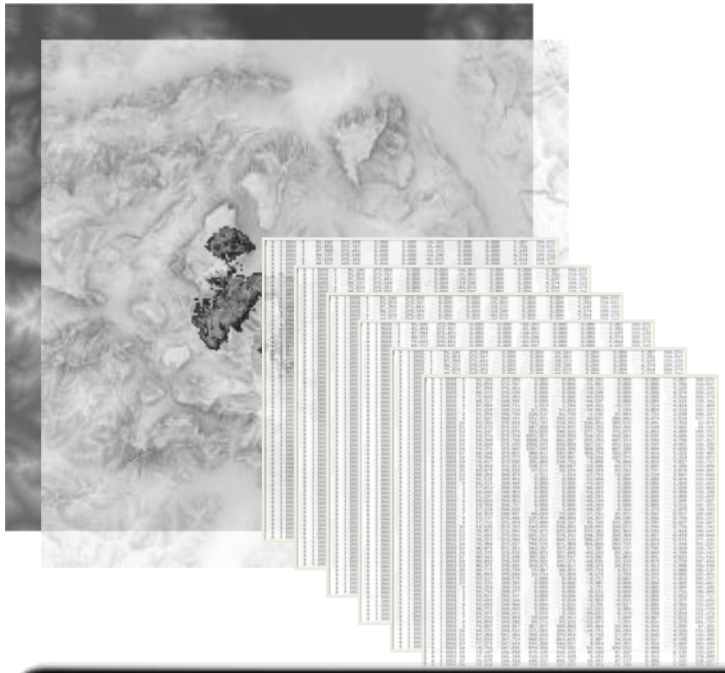
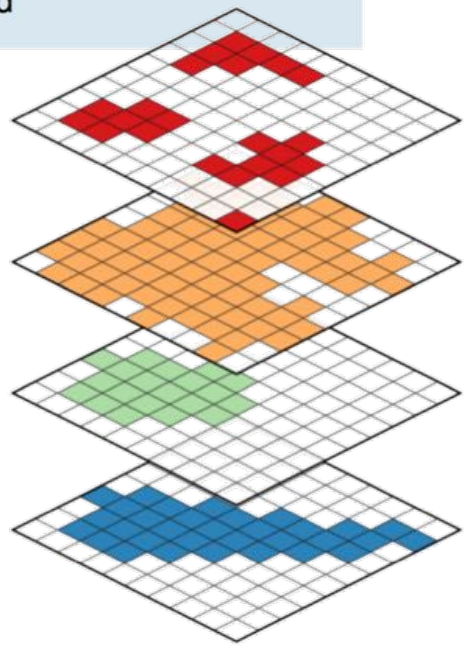


- Fully distributed physically based energy and mass balance model for complex topography
- Spatial resolution: ≈ 10 m–1 km (here: 50 m)
- Temporal resolution: 1–3 h (here: 3 h)
- Meteorological input: air temperature, precipitation, relative humidity, shortwave radiation, wind speed



openAMUNDSEN

- A distributed, physically based model for the simulation of the mountain snow cover (accumulation, re-distribution, ablation) and hydrology using forcing from meteorological observations and/or model output (P, T, H, R, W)
- Developed (in IDL) as AMUNDSEN since 2001, many projects and publications
- AMUNDSEN now goes openAMUNDSEN
- New open source version in a modular python structure:
- https://github.com/openamundsen/openamundsen

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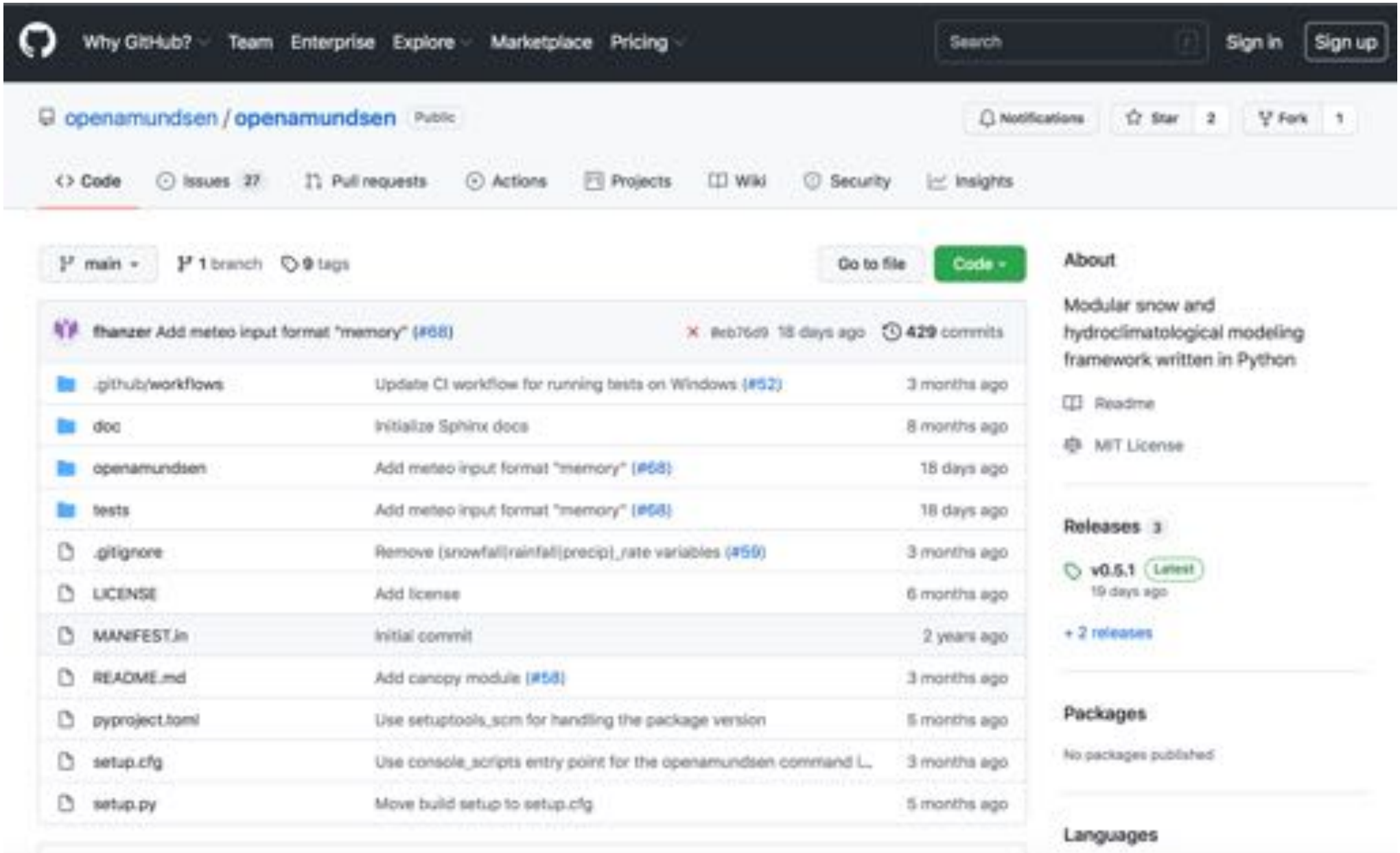
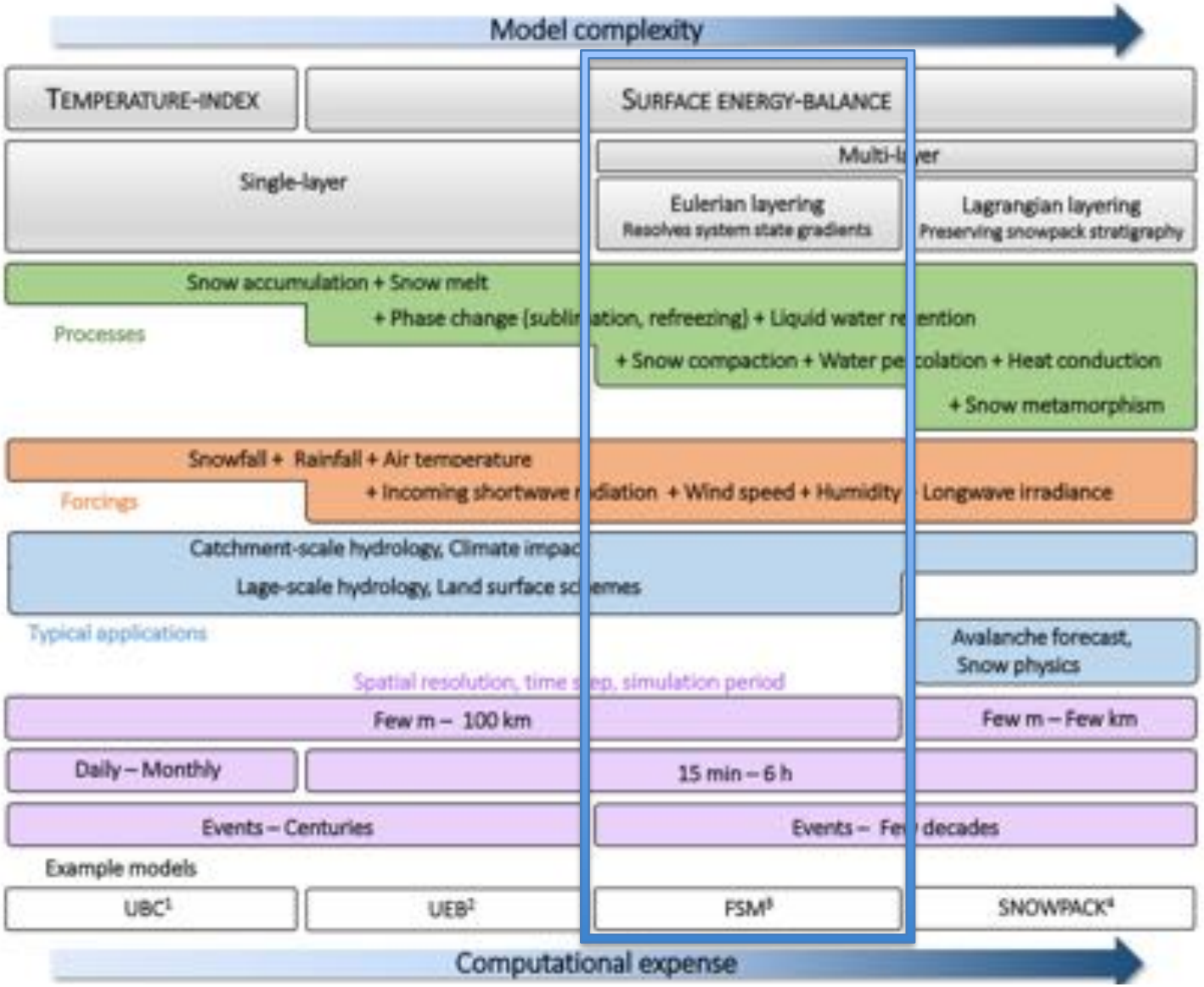
openAMUNDSEN@GitHub



openAMUNDSEN@GitHub

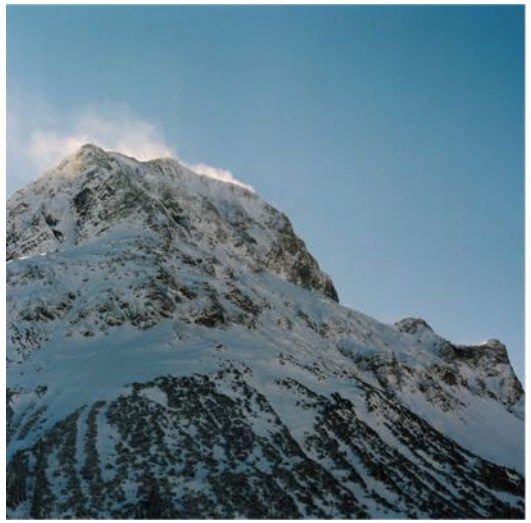
- Pure Python codebase (performance-optimized with Numba)
- 1 person-year development time
- 11,000 lines of code
- IP at UIBK, code licensed under MIT license
- flexible choice of timestep (e.g. 10 min vs 1 day) and process representation (e.g., type of layering)

openAMUNDSEN: complexity

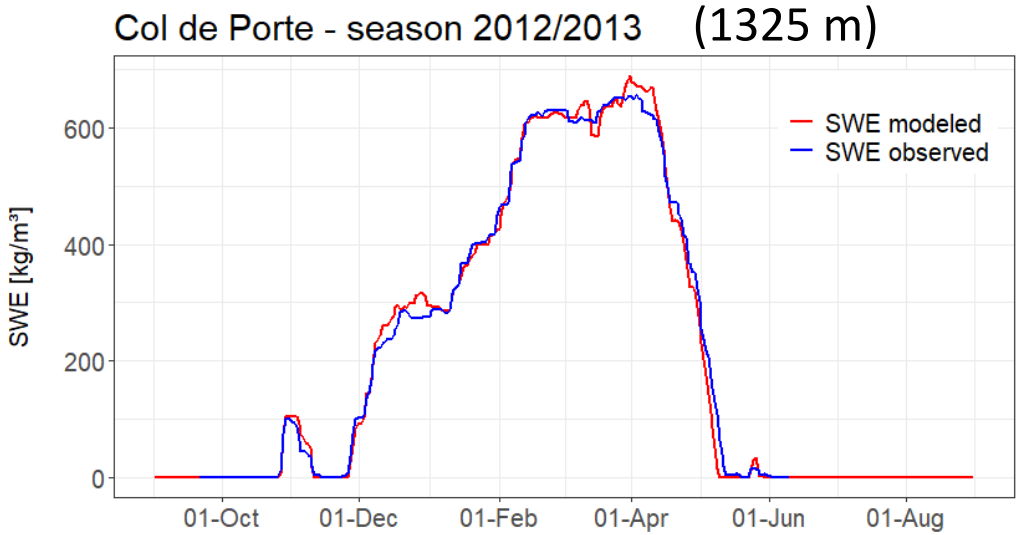


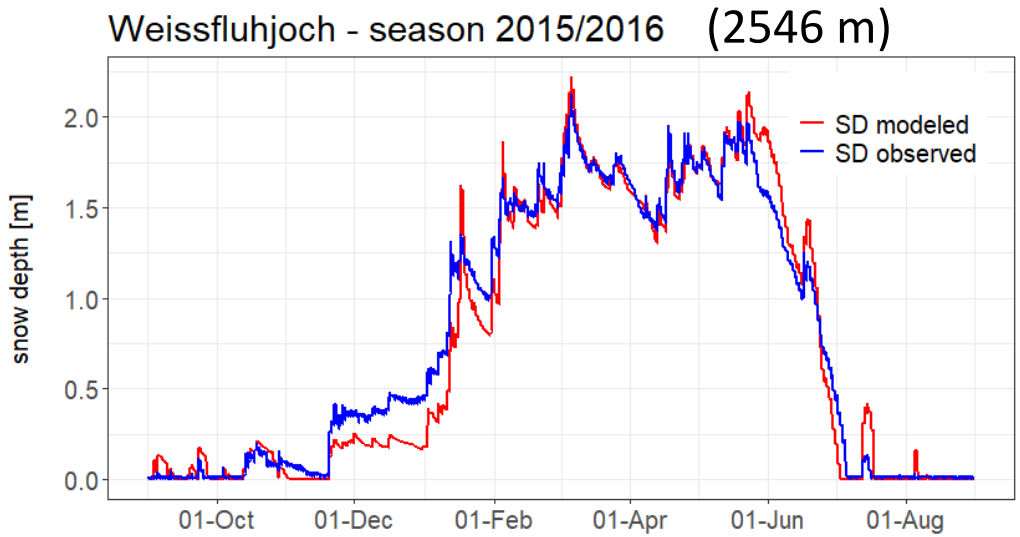
Example processes in openAMUNDSEN

- Coupled mass and energy balance (multilayer scheme)
- Precipitation distribution
- Transfer of heat from the atmosphere to the snow
- Solar radiation/shadows
- Albedo
- Heat conduction in snow
- Compaction of snow
- Retention and refreezing of melt water
- Snow in forests
- Evapotranspiration
- Glacier retreat and advance

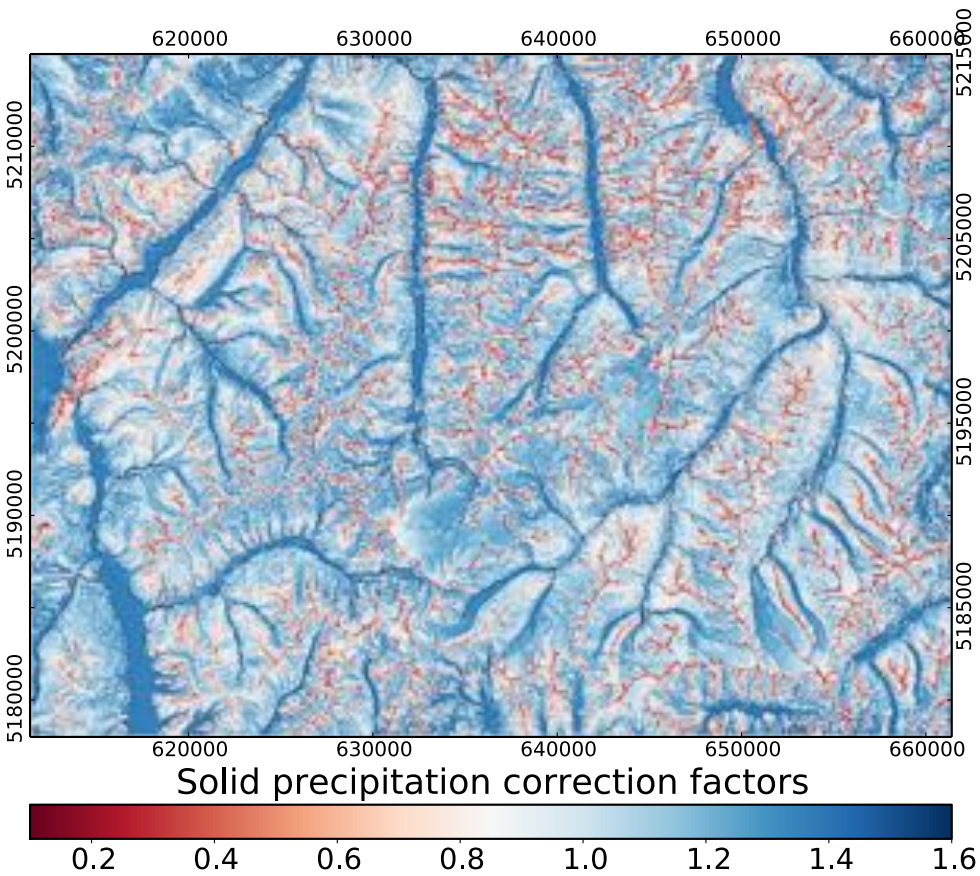


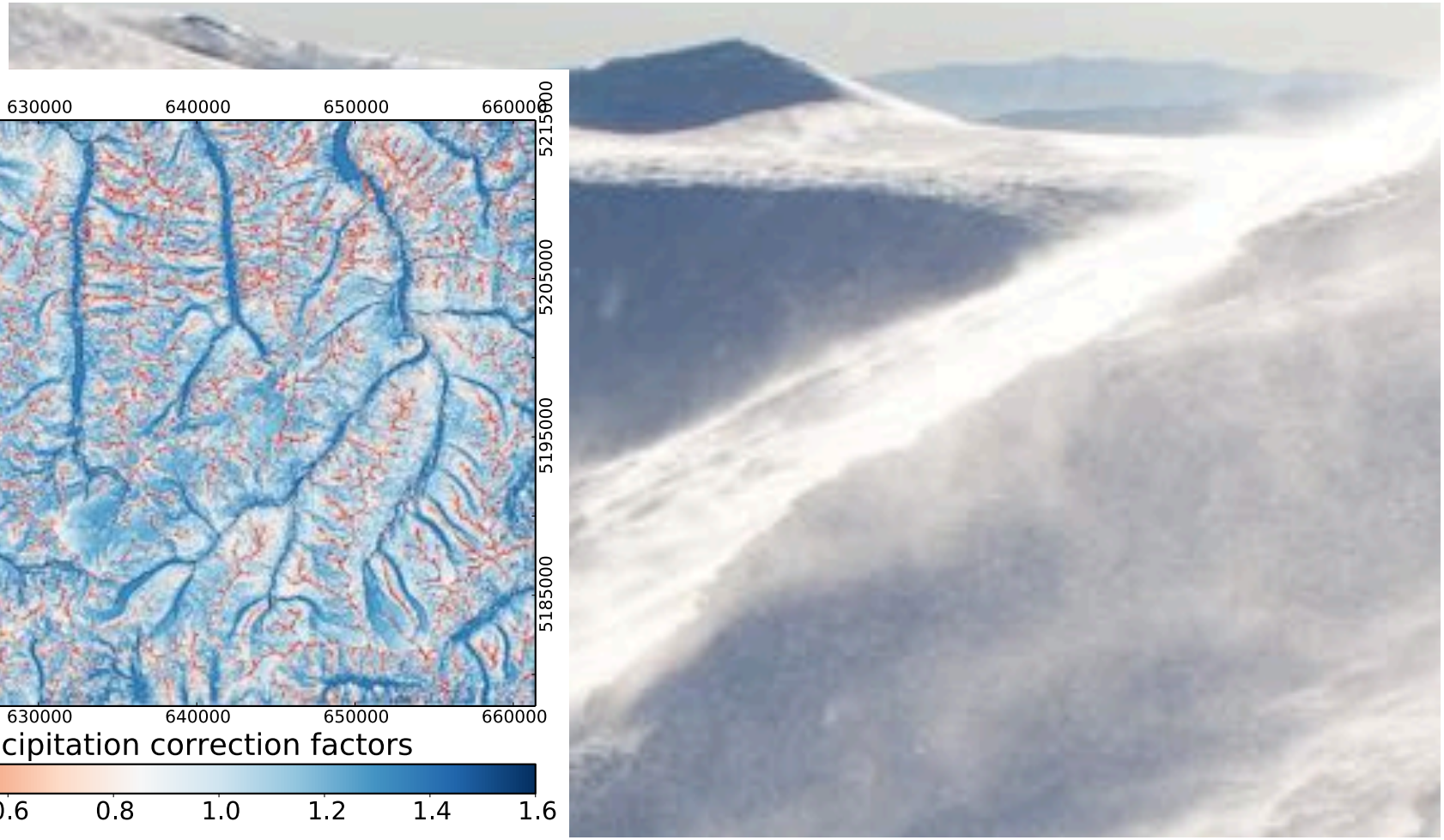
openAMUNDSEN: validation with ESM-SnowMIP data





Lateral snow redistribution





Steps of snow adjustments :

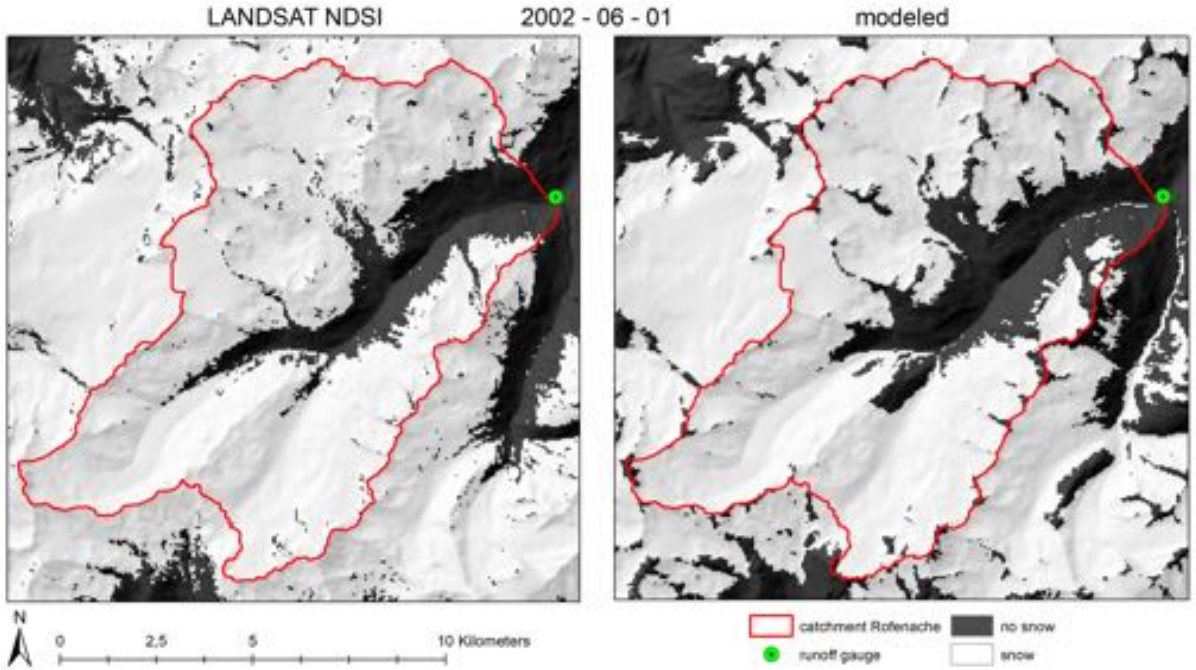
(i) the wind speed and temperature-dependent correction of measured precipitation at the meteorological stations

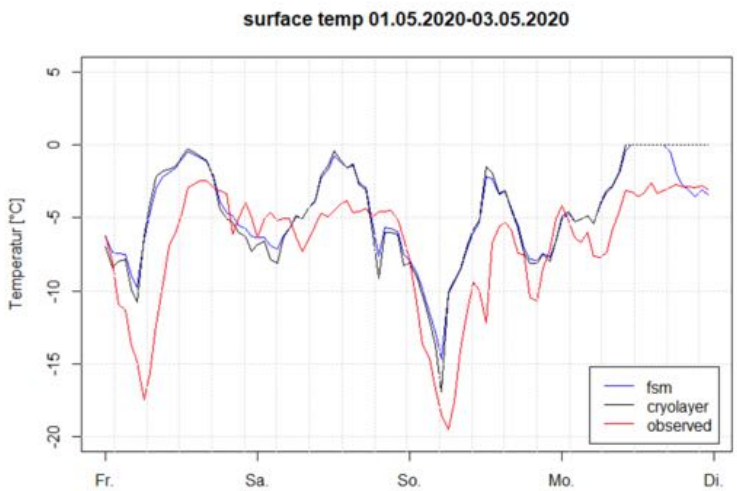
(ii) (ii) the additional post-interpolation snowfall adjustment using a fixed snow correction factor, and

(iii) (iii) the adjustment using the snow redistribution factors (derived from topographic openness/closedness at several scales).

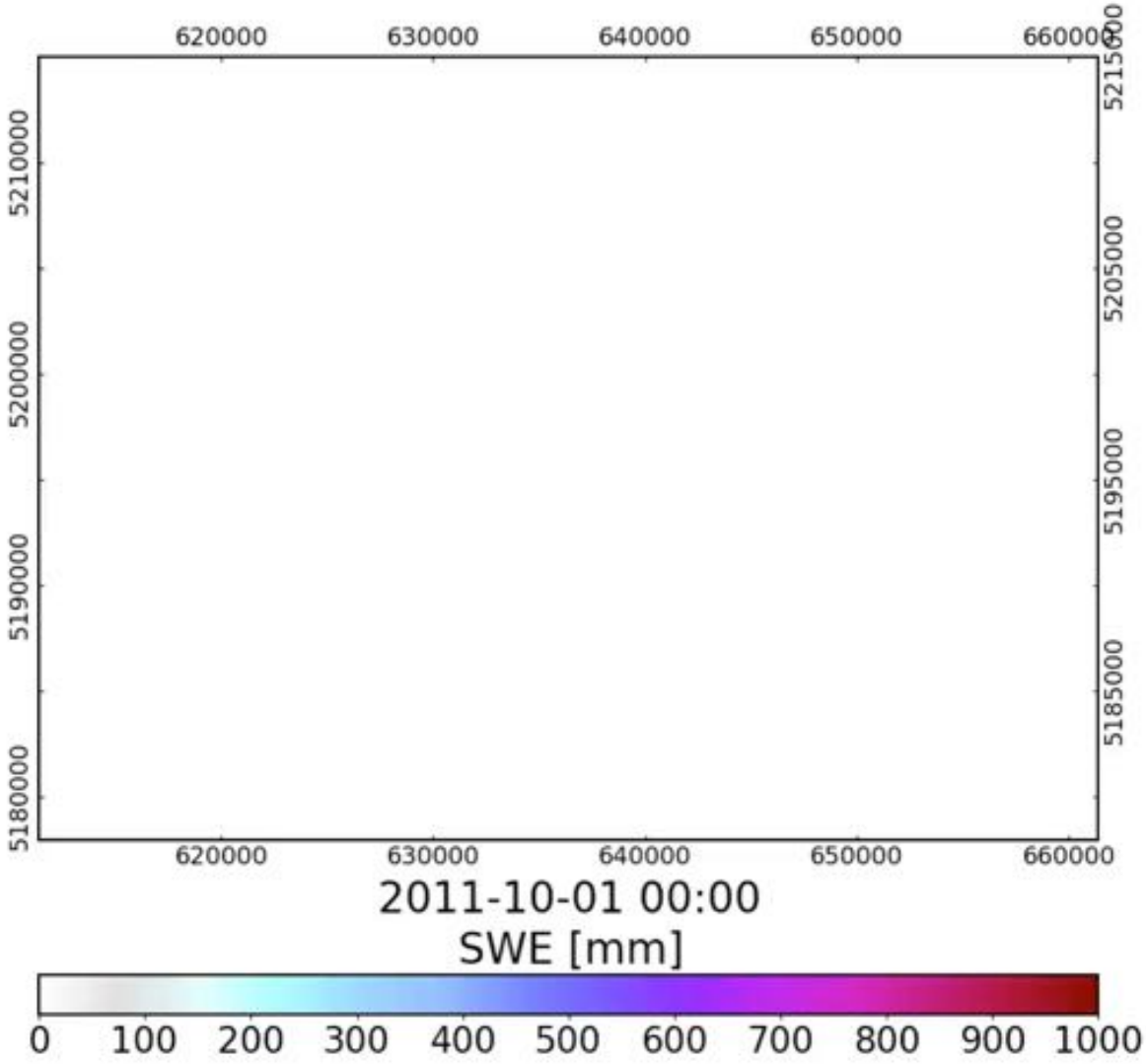
Whereas the first two steps are required to correct precipitation input towards a realistic precipitation volume, the latter does not change the total volume but rather redistributes the solid precipitation with respect to the terrain.

openAMUNDSEN: validation with Rofental data

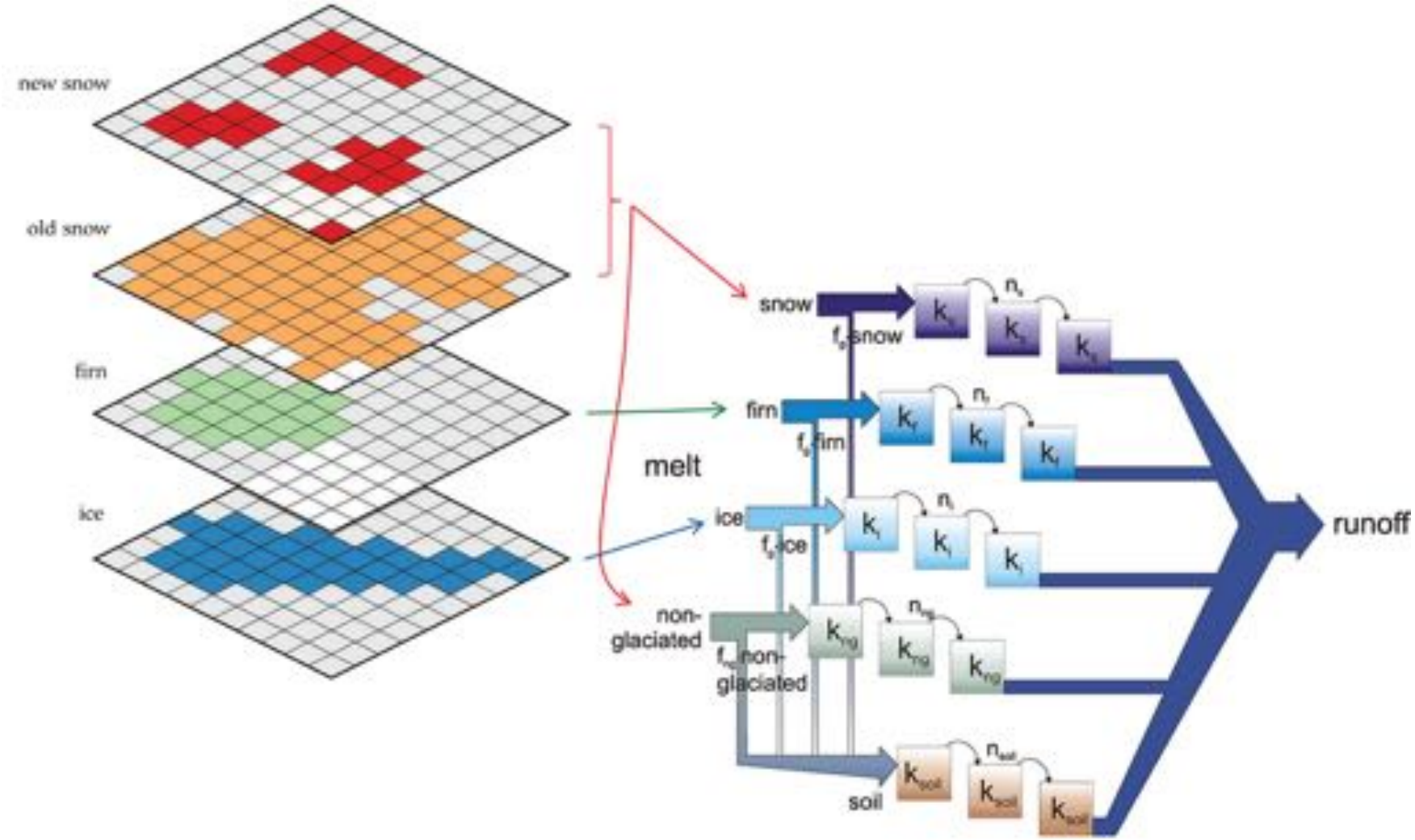




Seasonal snow cover evolution at the regional scale



Runoff concentration



openAMUNDSEN: streamflow

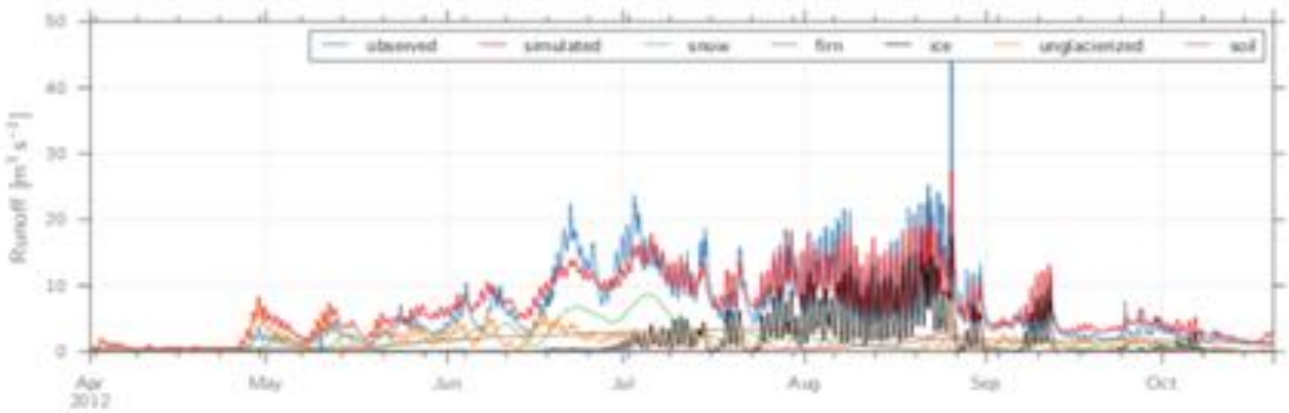
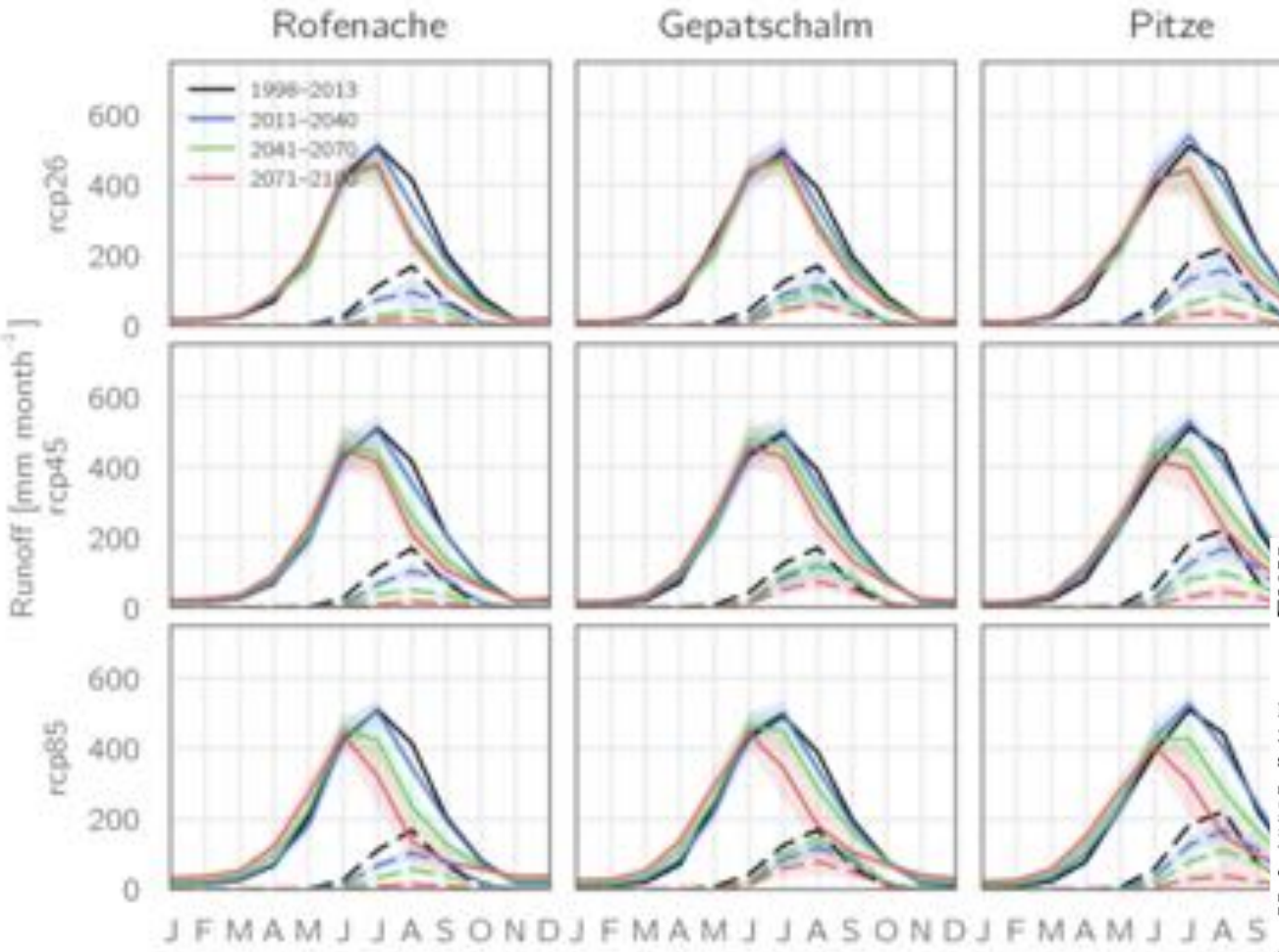


Figure 15. Observed vs. simulated runoff (including individual runoff components) for gauge Gepatschalm (1893–3526 m a.s.l.) in the period April–October 2012.

Scenario modelling: runoff regime changes



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https://doi.org/10.5194/hess-22-1593-2018

Hydrology and Earth System Sciences
EGU

Projected cryospheric and hydrological impacts of 21st century climate change in the Ötztal Alps (Austria) simulated using a physically based approach

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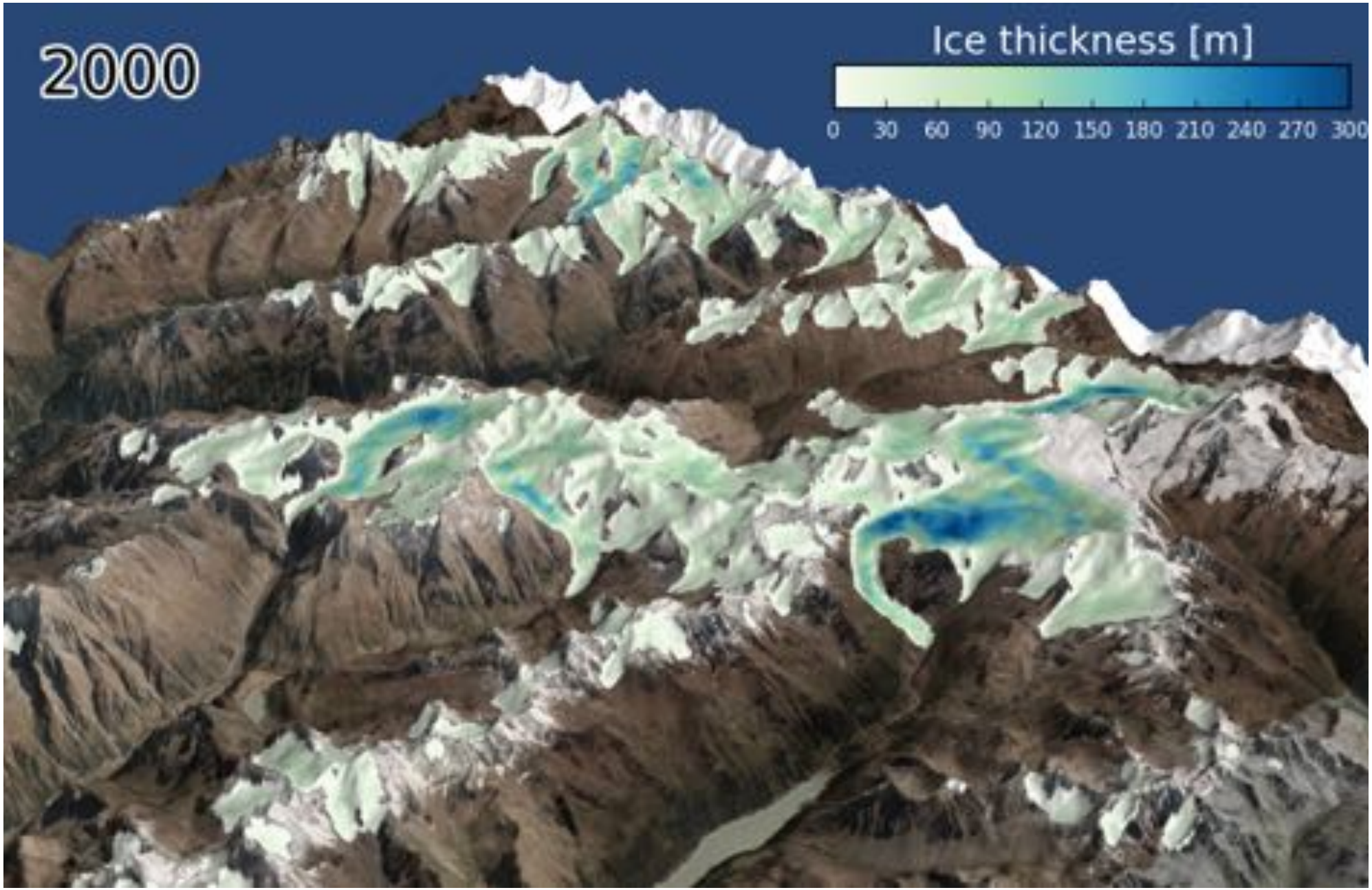
Abstract. A physically based hydroclimatological model (AMUNDSEN) is used to assess future climate change impacts on the cryosphere and hydrology of the Ötztal Alps (Austria) until 2100. The model is run in 100 m

ment and scenario, whereas runoff volumes decrease by up to 39 % (total) and 47 % (summer) towards the end of the century (2071–2100), accompanied by a shift in peak flows from July towards June.

Average monthly runoff (multi-model mean ±1 SD indicated as shaded bands) as simulated for the early, middle, and late 21st century for four catchments/gauges and the three emission scenarios. Dashed lines indicate bare ice melt runoff. From Hanzer et al. (2018).


2000
Ice thickness [m]
0 30 60 90 120 150 180 210 240 270 300

Example application: „committed loss“

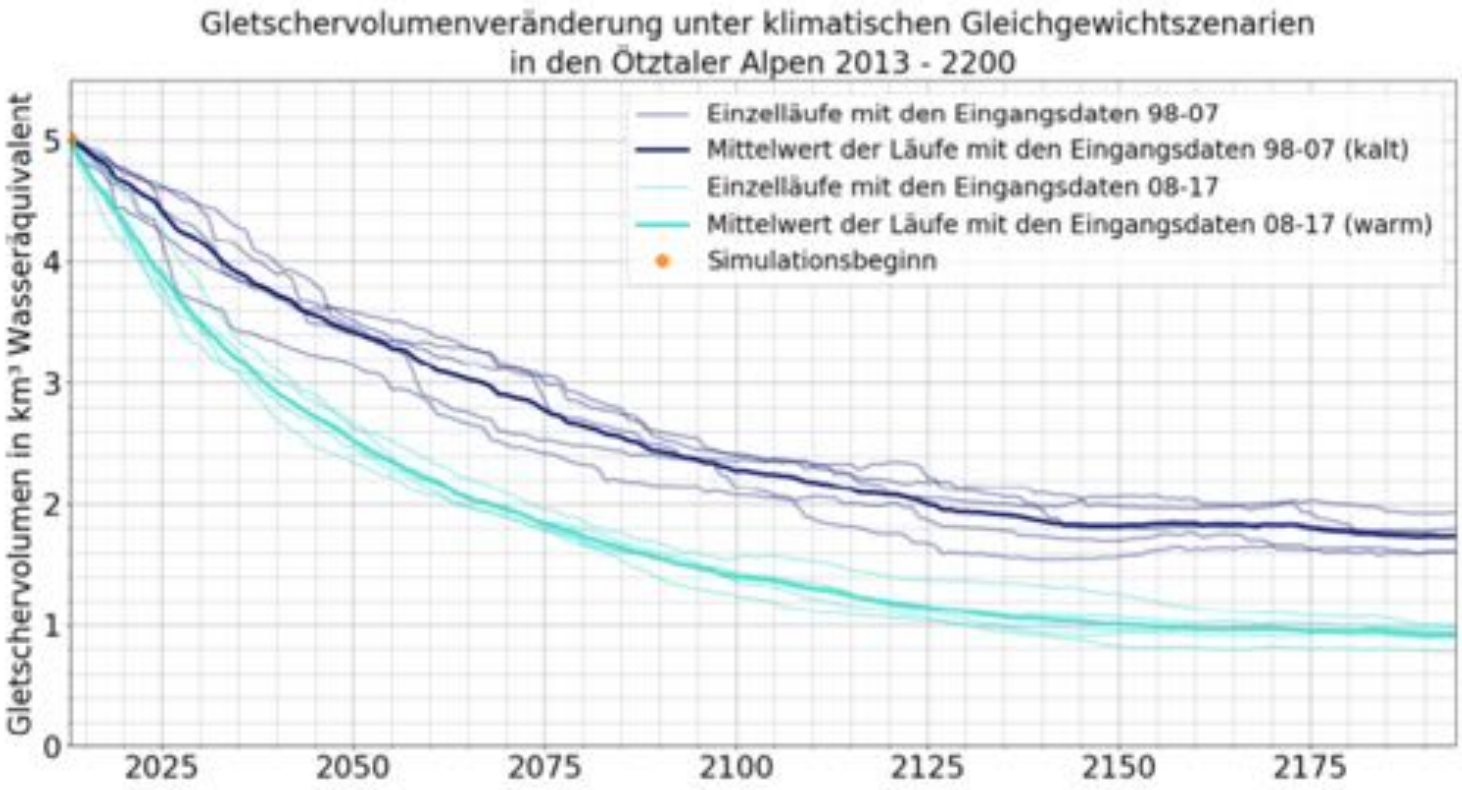
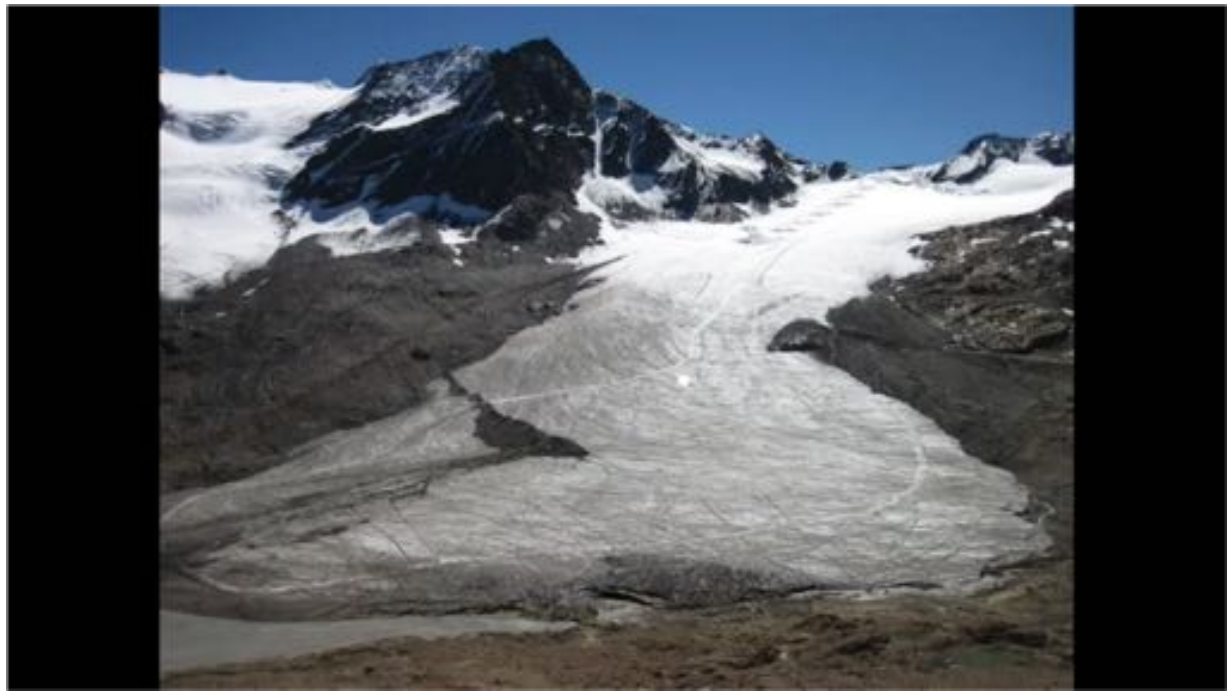


Abbildung 27: Gletschervolumenveränderung unter verschiedenen Gleichgewichtsklimaszenarien in den Ötztaler Alpen.

openAMUNDSEN – what comes next?

- Many mountain valleys undergo a *transition to getting glacier-free*. We should not miss this last chance to learn... What changes in the processes, and what in the balances?



openAMUNDSEN – what comes next?

Processes ...

- What about the (still empirically modelled) *subsurface water fluxes*, (how) can we model them (physically based)? What are the storage volumes (much larger?) and transit times (much slower)?
- Can we couple our hydrological mountain models with *forest canopy evolution* models for scenario simulations? Species composition is expected to mostly change, and so will the hydrological properties ...

  (☞ project to come in the Berchtesgaden National Park forest together with TUM and others)

openAMUNDSEN – what comes next?

- Could an *idealized mountain* – set up in several catchments across the globe – tell us more about the pattern regional hydrological sensitivity to climate (change)?
  - Jungfraujoch / Interlaken (3580 m / 577 m)
  - Mt. Fuji / Honshu (3775 m / 11 m)
  - Mt. Washington / Pinkham Notch (1905 m / 613 m)
  - Sonnblick / Kolm Saigurn (3114 m / 1622 m)
  - Zugspitze / Garmisch-Partenkirchen (2964 m / 719 m)
- Forced by station data and model output, e.g. CORDEX

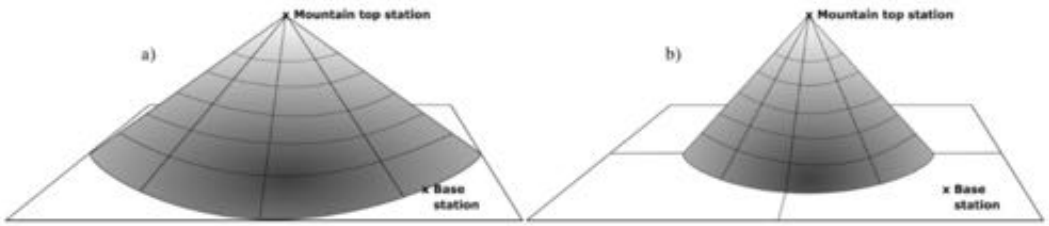


Figure 1: Example of the idealized mountain in the two described setup variations and the meteorological stations to be used in the simulation experiments: a) with even slopes at an angle resulting from the real horizontal and vertical distances between the base and mountain top stations; b) even, fixed slope angle (30 degree) resulting in a certain distance between base station and foot of the mountain.

openAMUNDSEN – what comes next?
Application ...

- Many stakeholders want *operational applications* – the way to go, but how? What changes technically in the model application, what is important? How to design the interfaces? What about availability, redundance, tolerance, etc. ... ?

Prominent example applications from Austria:

- flood warning
- hydropower plant operation
- skiing tourism
- avalanche warning

openAMUNDSEN – what comes next?

Modelling techniques ...

- We often keep constant the *spatial resolution* and *time step* within our model runs; however, do we know what the “best” resolution/time step for every single process is? How can we find it, and identify respective bottlenecks in our model setup?
- How can we *better assimilate* what is already there (station recordings, field observations, satellite data, UAV data, webcams, laser scans, climate/weather model output, stakeholder knowledge, ...)?

openAMUNDSEN – what comes next?

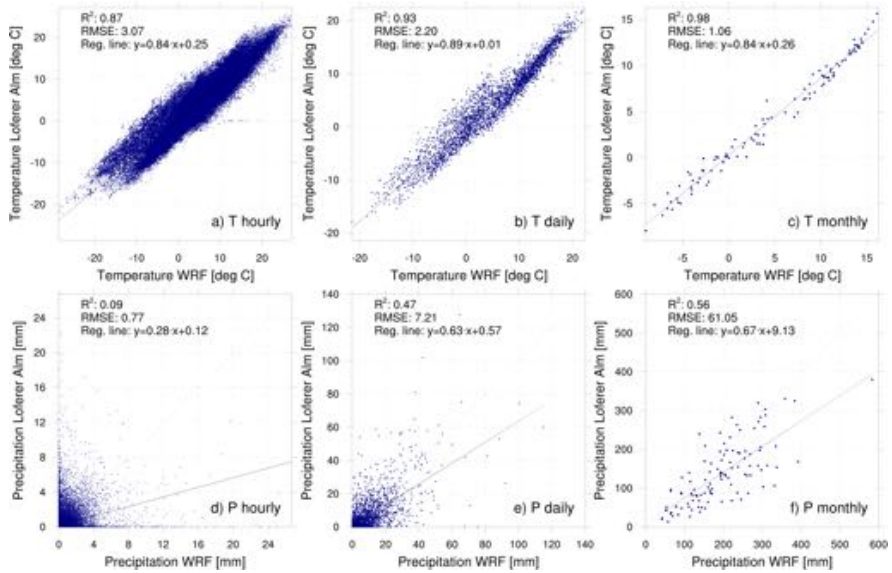
Maybe most important: forcing?

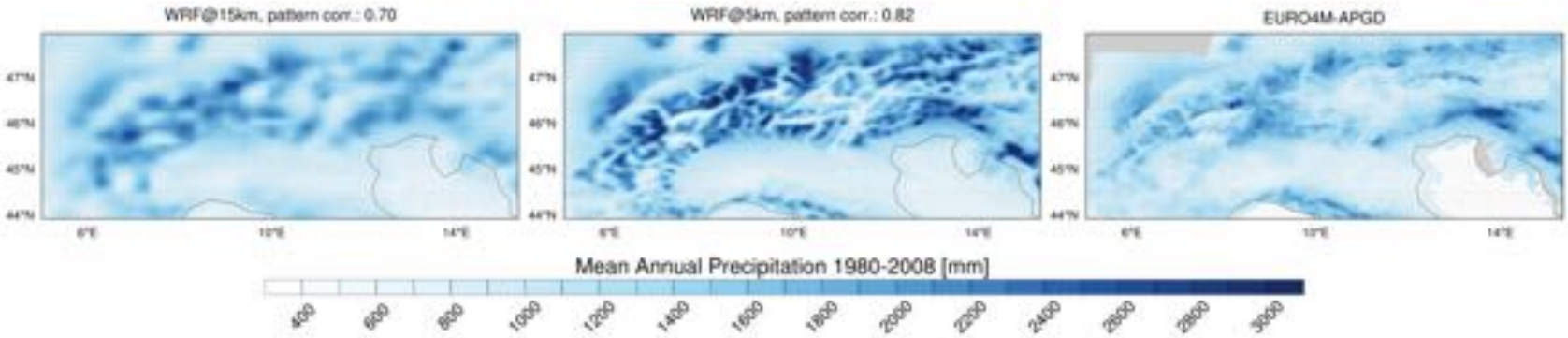
- Soon – or now? – ultra-high resolution weather and climate models (i.e., convection-permitting) can replace meteorological fields derived from interpolation of local station data
- Re-analysis data sets compiled by integration of model output and station recordings enable seamless simulation of *past-present-prediction-scenario*, including operational data assimilation, using e.g.
  - COSMO (2.8 km for DACH)
  - DWD ICON (4 km for Europe, 9 km global)
  - ECMWF (7 km)
  - WRF-LES (< 1 km for FPS)

UIBK research activity: high resolution RCM data

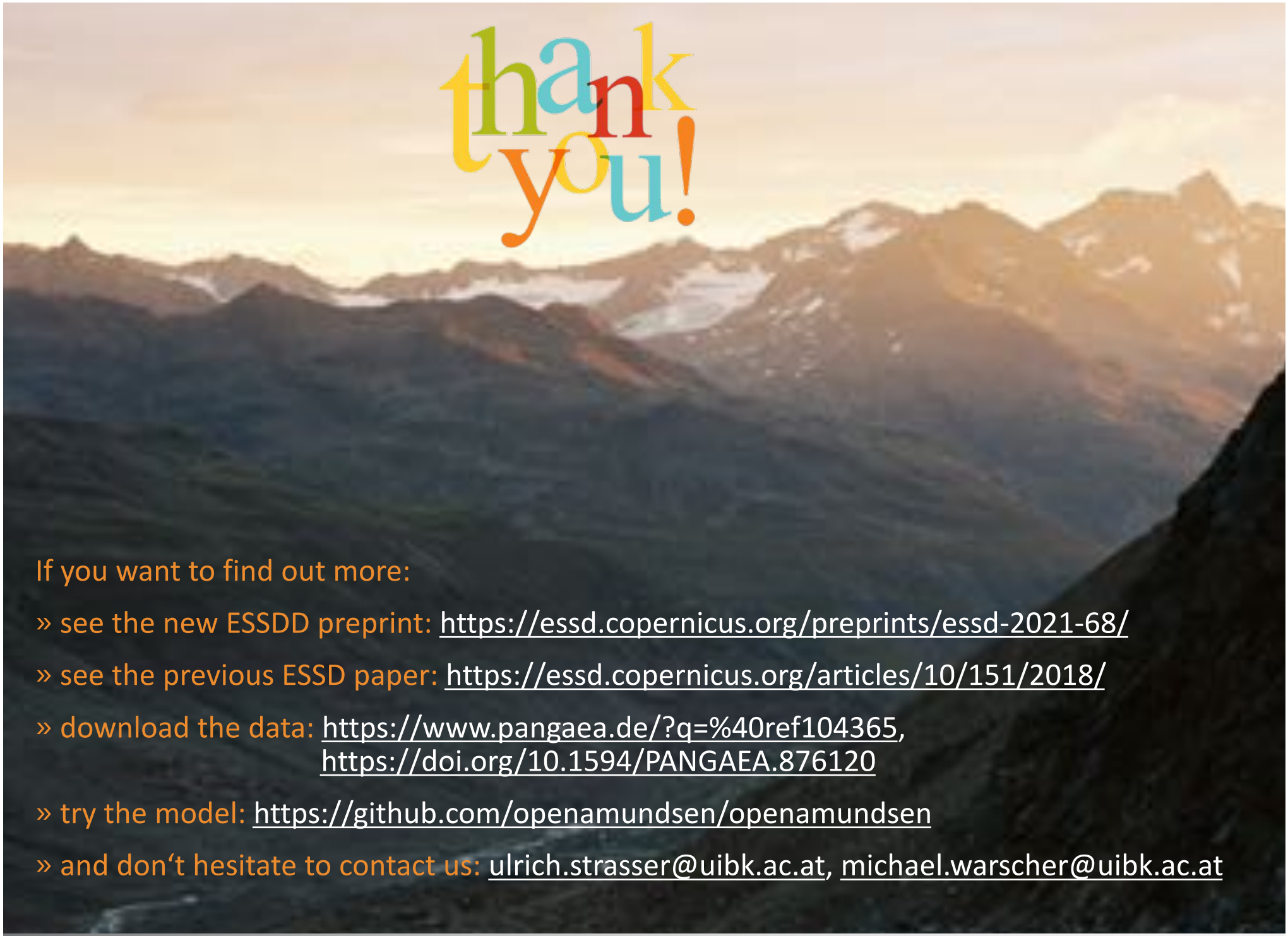
- Long-term measurements *and* modelling
- Resolution of (long-term) RCM simulations come close to the resolution of our LSMs

- Proposal with Ban/Nicholson (ACINN)
- Rofental as reference catchment





Warscher, M., Wagner, S., Marke, T., Laux, P., Strasser, U. and Kunstmann, H. (2019): A 5 km Resolution Regional Climate Simulation for Central Europe: Performance in High Mountain Areas and Seasonal, Regional and Elevation-dependent Variations. Atmosphere, https://doi.org/10.3390/atmos10110682.



thank you!

If you want to find out more:

» see the new ESSDD preprint: https://essd.copernicus.org/preprints/essd-2021-68/

» see the previous ESSD paper: https://essd.copernicus.org/articles/10/151/2018/

» download the data: https://www.pangaea.de/?q=%40ref104365,
https://doi.org/10.1594/PANGAEA.876120

» try the model: https://github.com/openamundsen/openamundsen

» and don‘t hesitate to contact us: ulrich.strasser@uibk.ac.at, michael.warscher@uibk.ac.at