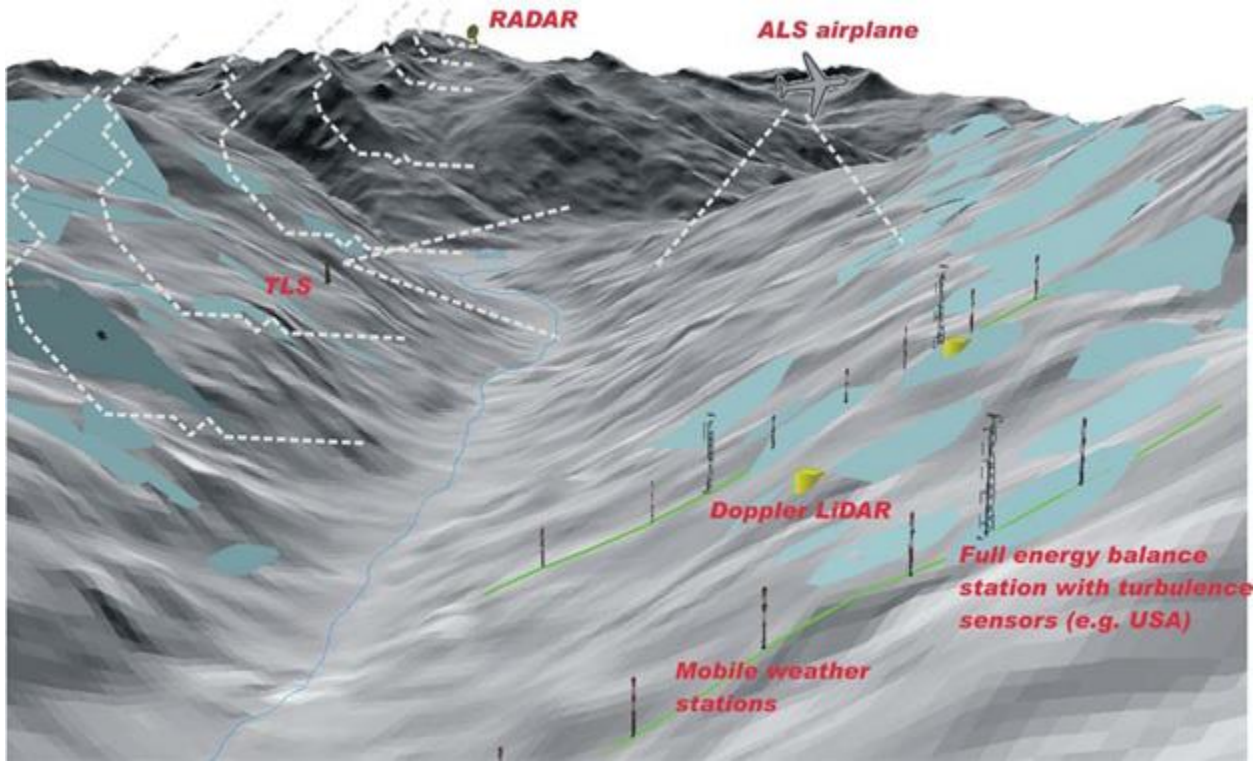
Advancing high-resolution snow simulations for the Dischma catchment



Jan Magnusson[1], Rebecca Mott[1], Bertrand Cluzet[1], Louis Queno[1], Nora Helbig[1], Guilia Mazotti[2], Adam Winstral[1], Tobias Jonas[1]

1) WSL Institute for Snow and Avalanche Research SLF, 2) Centre d'Etudes de la Neige, MétéoFrance

Background: The Snow Hydrology group at SLF

Our group performs applied research for improving snow simulations for flood and avalanche forecasting, along with fundamental research related to snow hydrological topics

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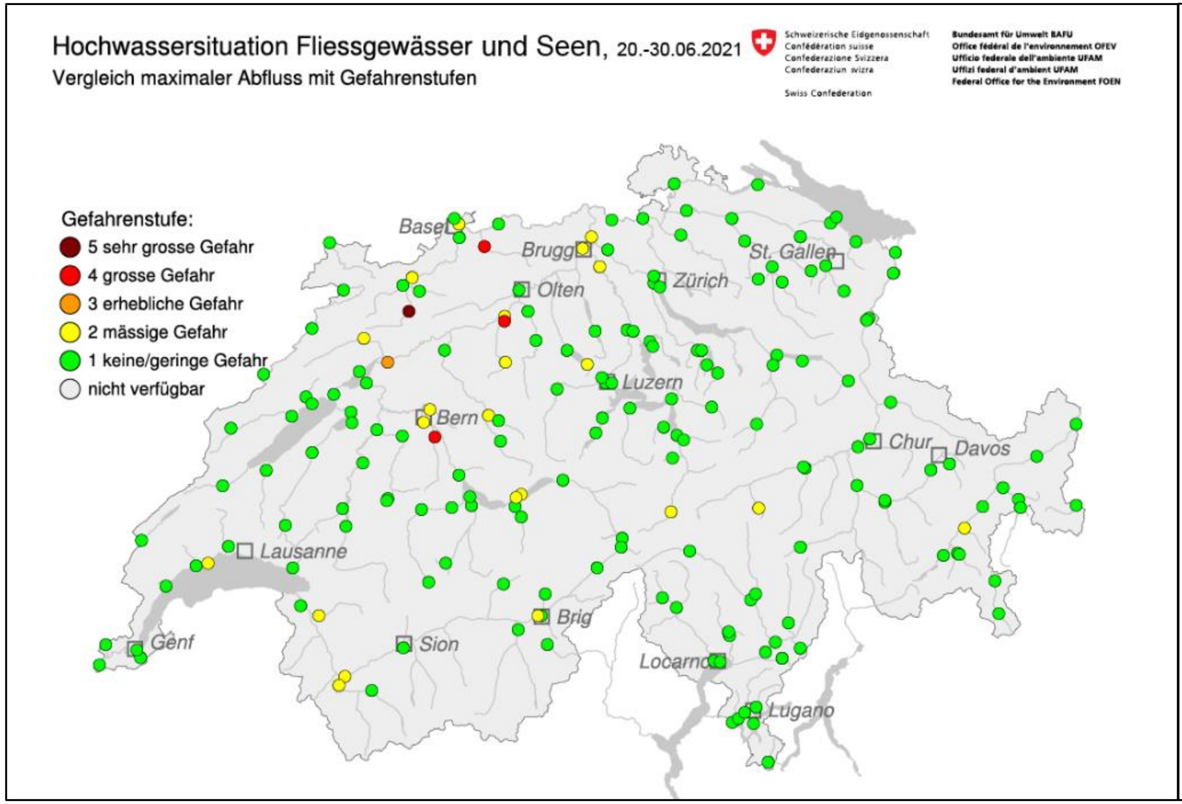
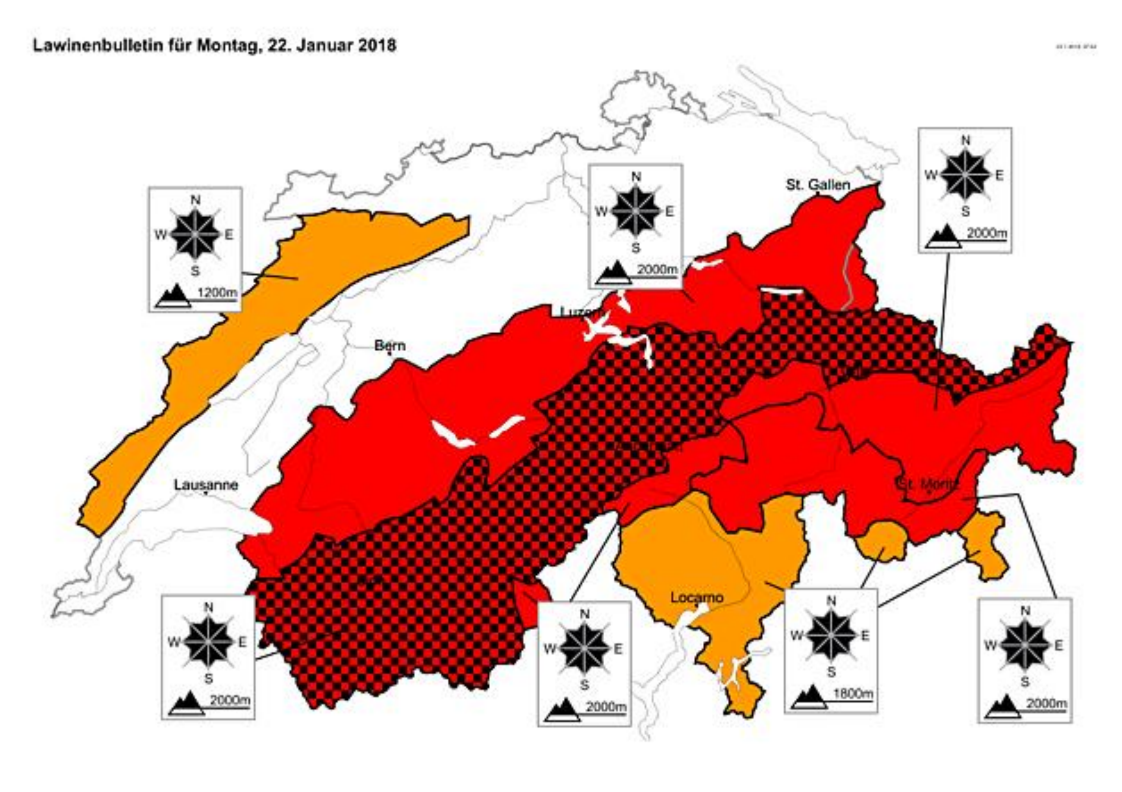
Background: Support for Swiss flood and avalanche forecasting

We also operate an operational service for providing flood and avalanche forecasters with snow information





Mott et al. (2023), Operational snow-hydrological modeling for Switzerland. Front. Earth Sci. 11:1228158. doi: 10.3389/feart.2023.1228158

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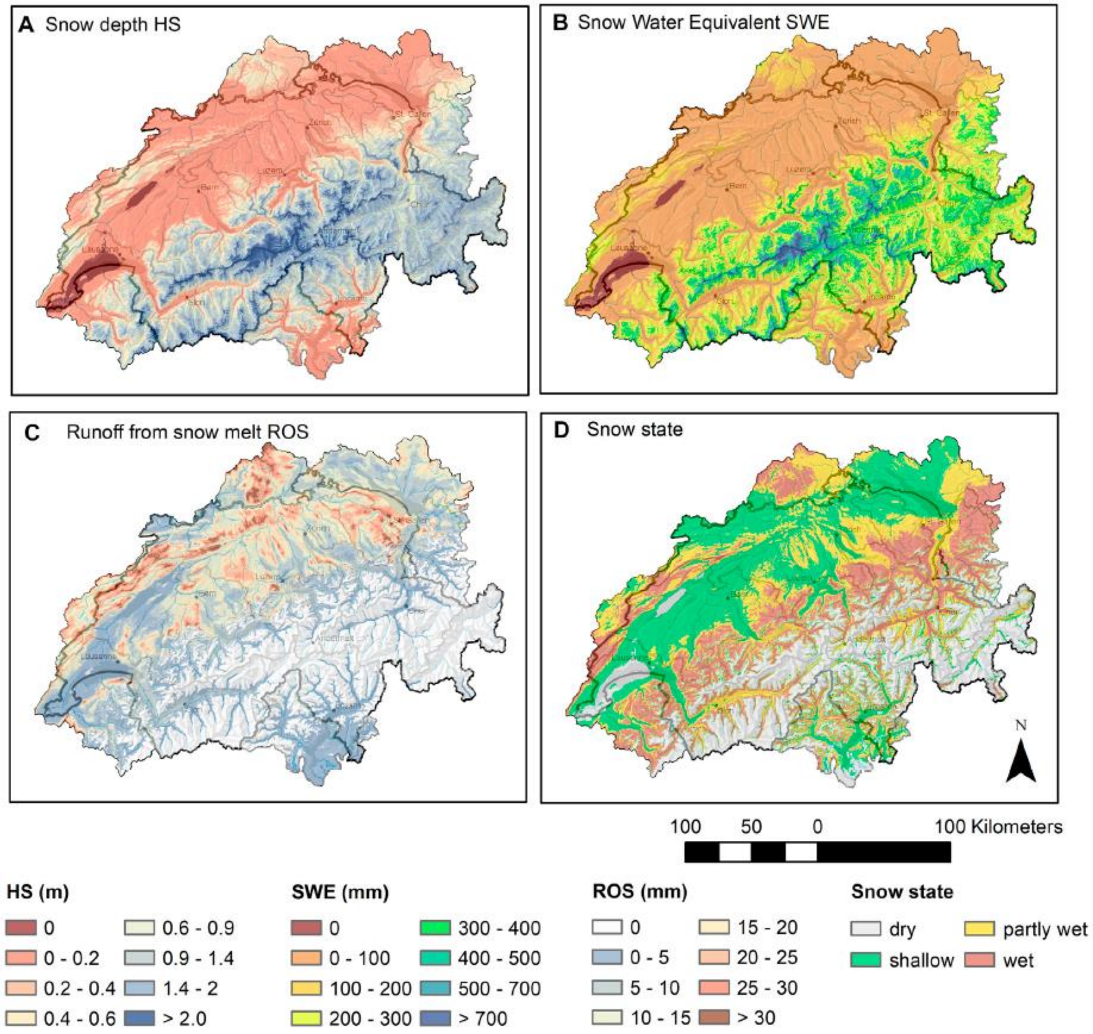
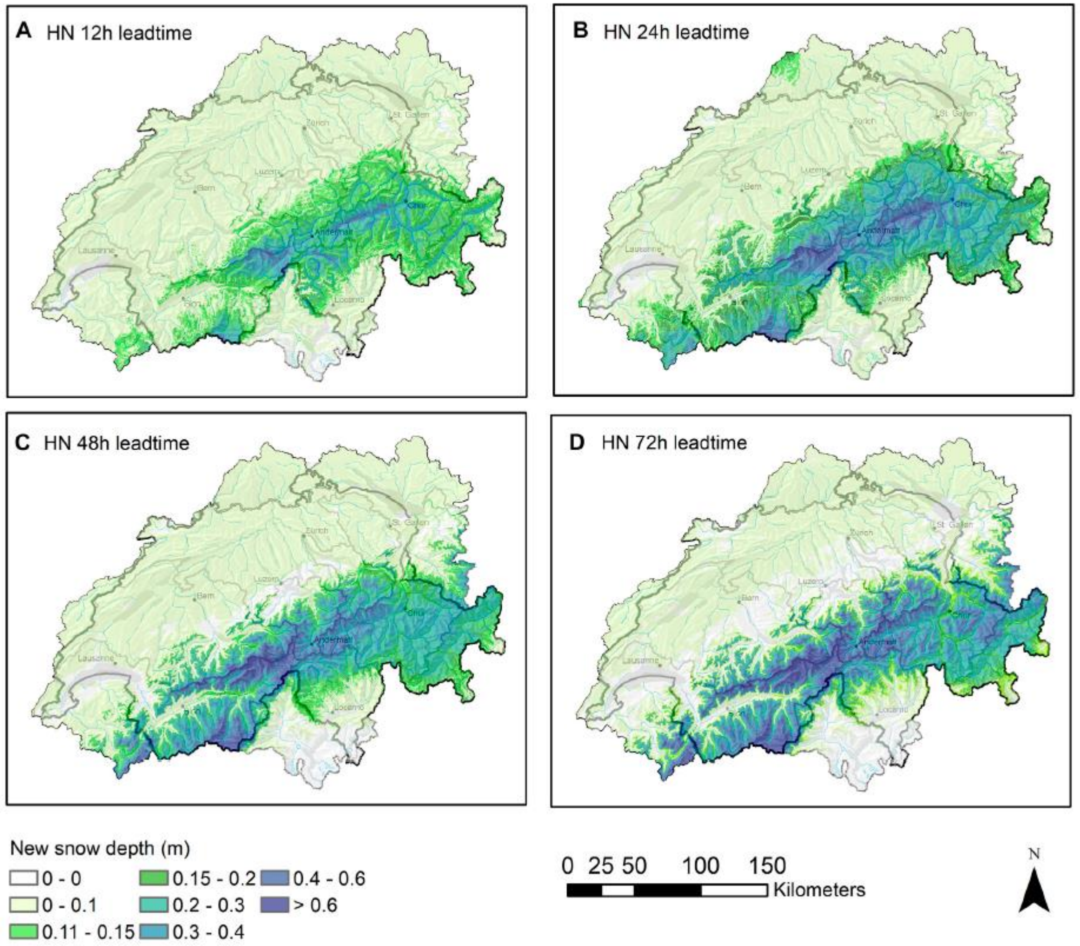
Background: Nation-wide snow simulations using physics-based modelling

Information for flood forecasting

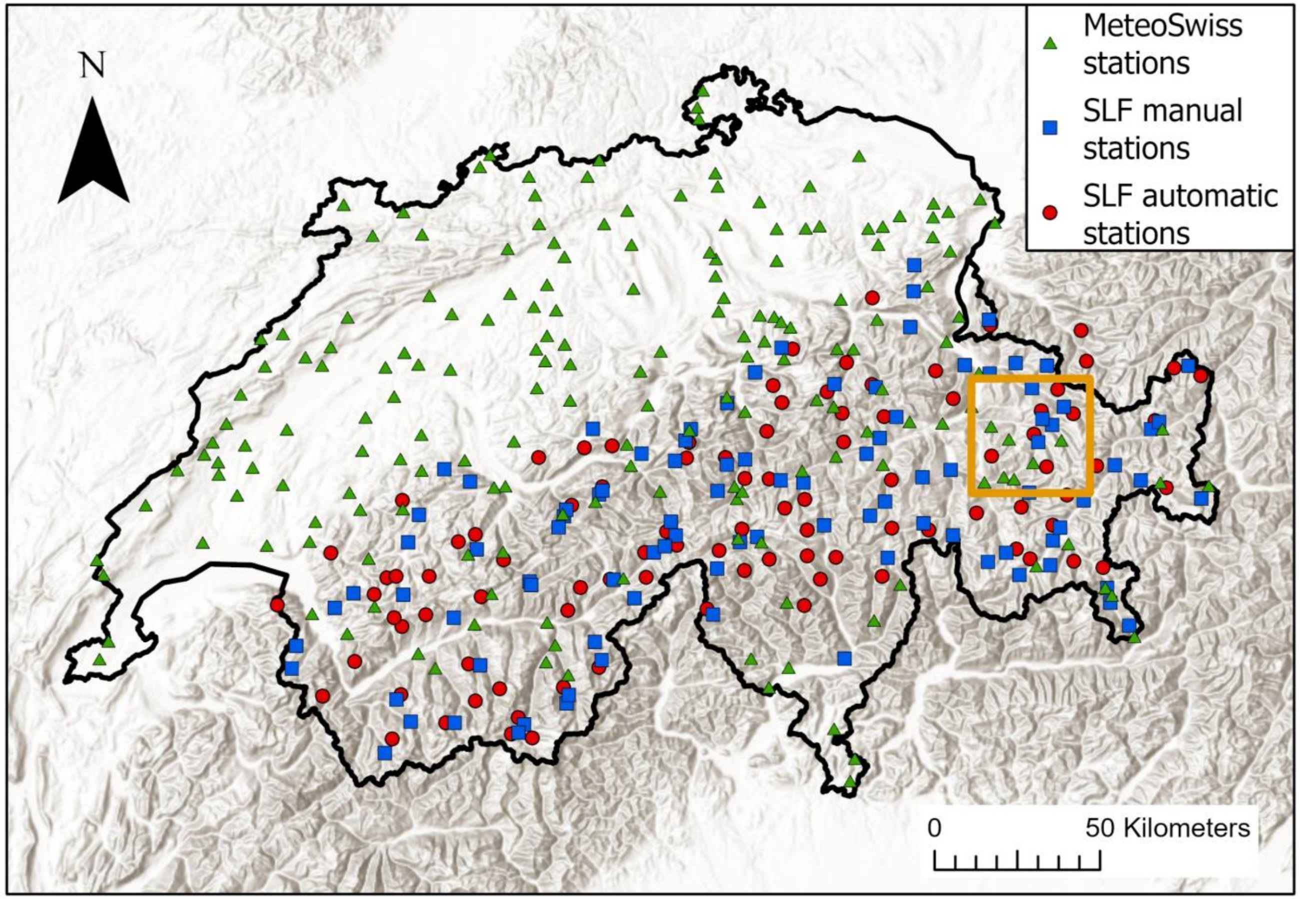


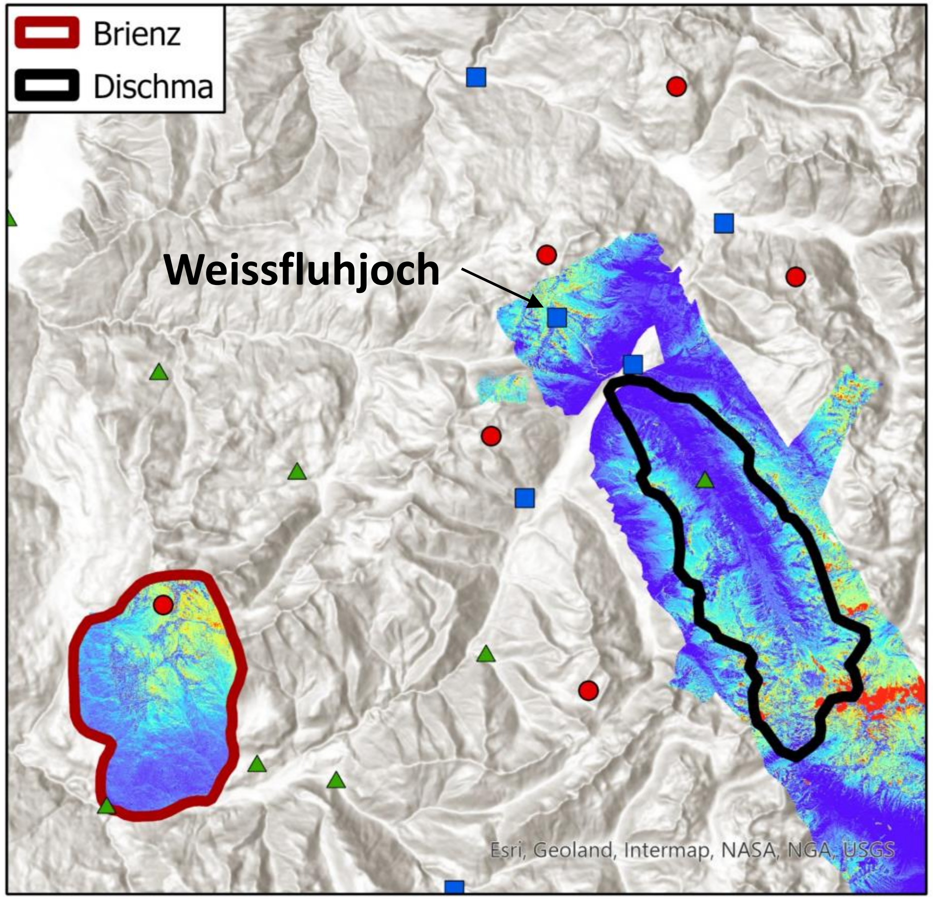
Information for avalanche forecasting



Mott et al. (2023), Operational snow-hydrological modeling for Switzerland. Front. Earth Sci. 11:1228158. doi: 10.3389/feart.2023.1228158

How can we improve our simulations – test case **Dischma** and **Brienz**





Queno et al. (In Discussion), Snow redistribution in an intermediate-complexity snow hydrological modelling framework, The Cryosphere. doi.org/10.5194/egusphere-2023-2071

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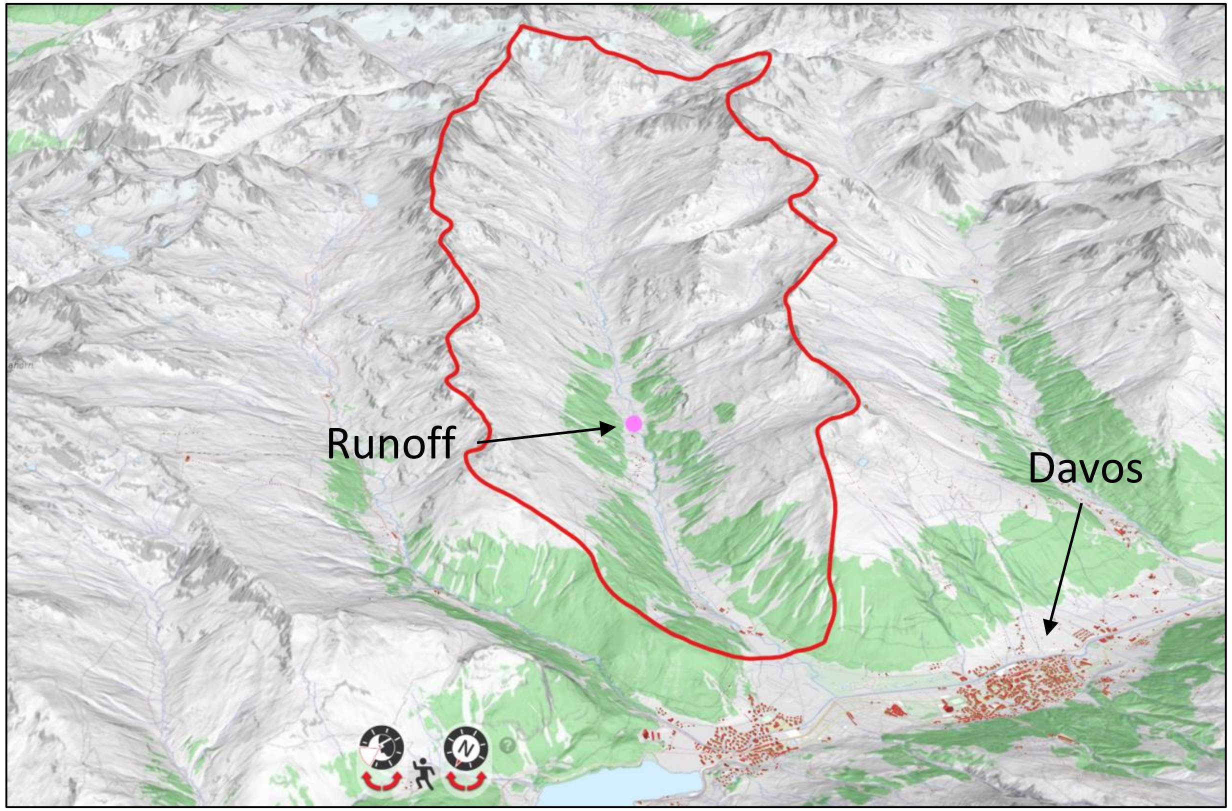
Meteorological input data for physics-based snow models



Inputs from 1 km regional NWP model COSMO downscaled to 25 m, 50 m and 100 m:

- Near-surface air temperature
- Relative humidity
- Air pressure
- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Figure shows another view of Dischma catchment with stream gauging station

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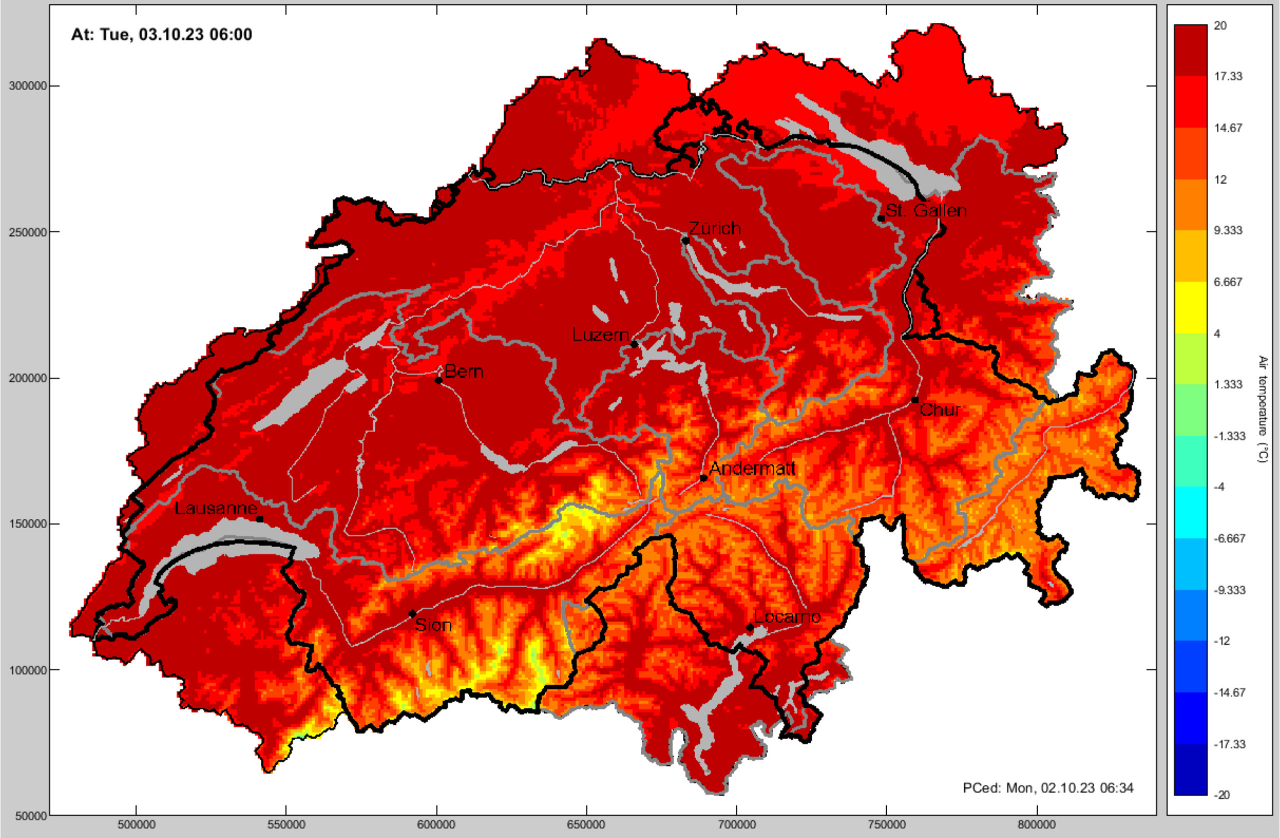
Meteorological input data for physics-based snow models



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- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Method: Linear interpolation with lapse rates

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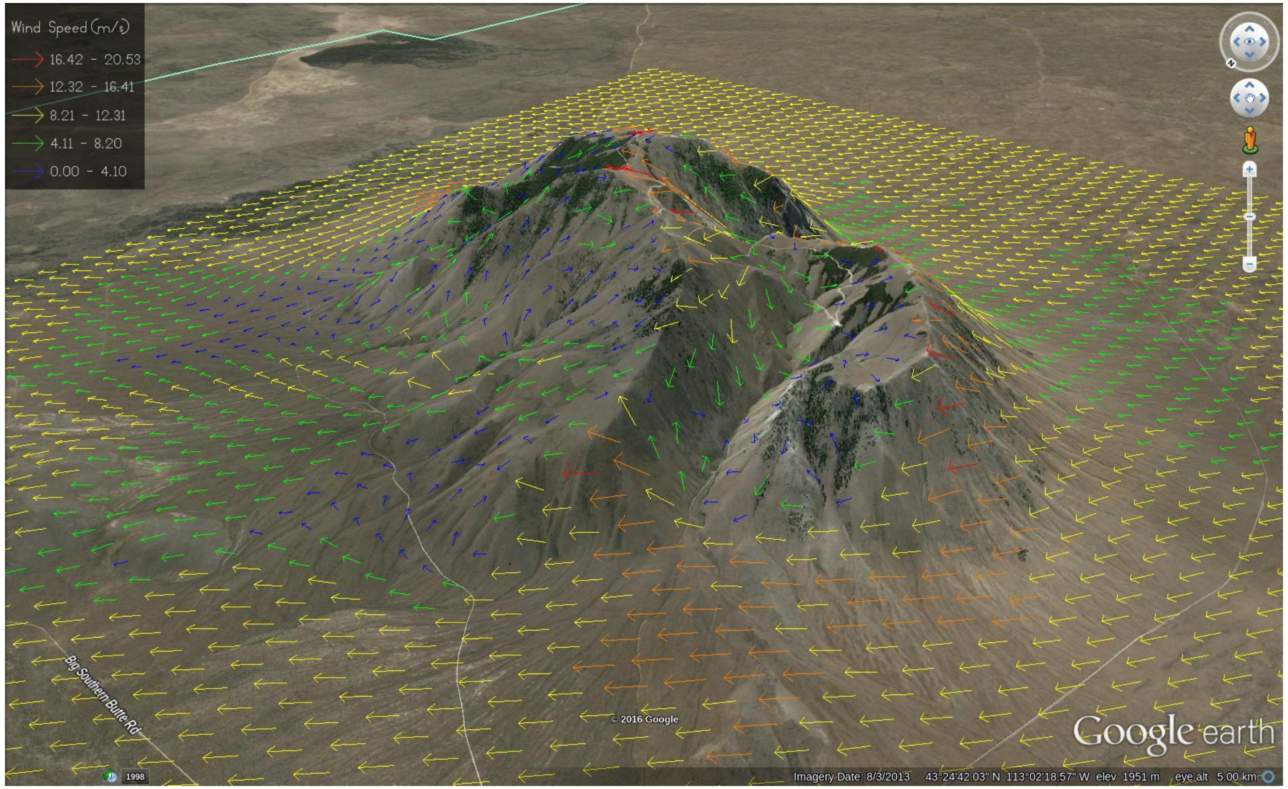
Meteorological input data for physics-based snow models



<u>Inputs from 1 km regional NWP model COSMO downscaled to 25 m, 50 m and 100 m:</u>

- Near-surface air temperature
- Relative humidity
- Air pressure
- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Method: Mass-conserving dynamical downscaling model WindNinja

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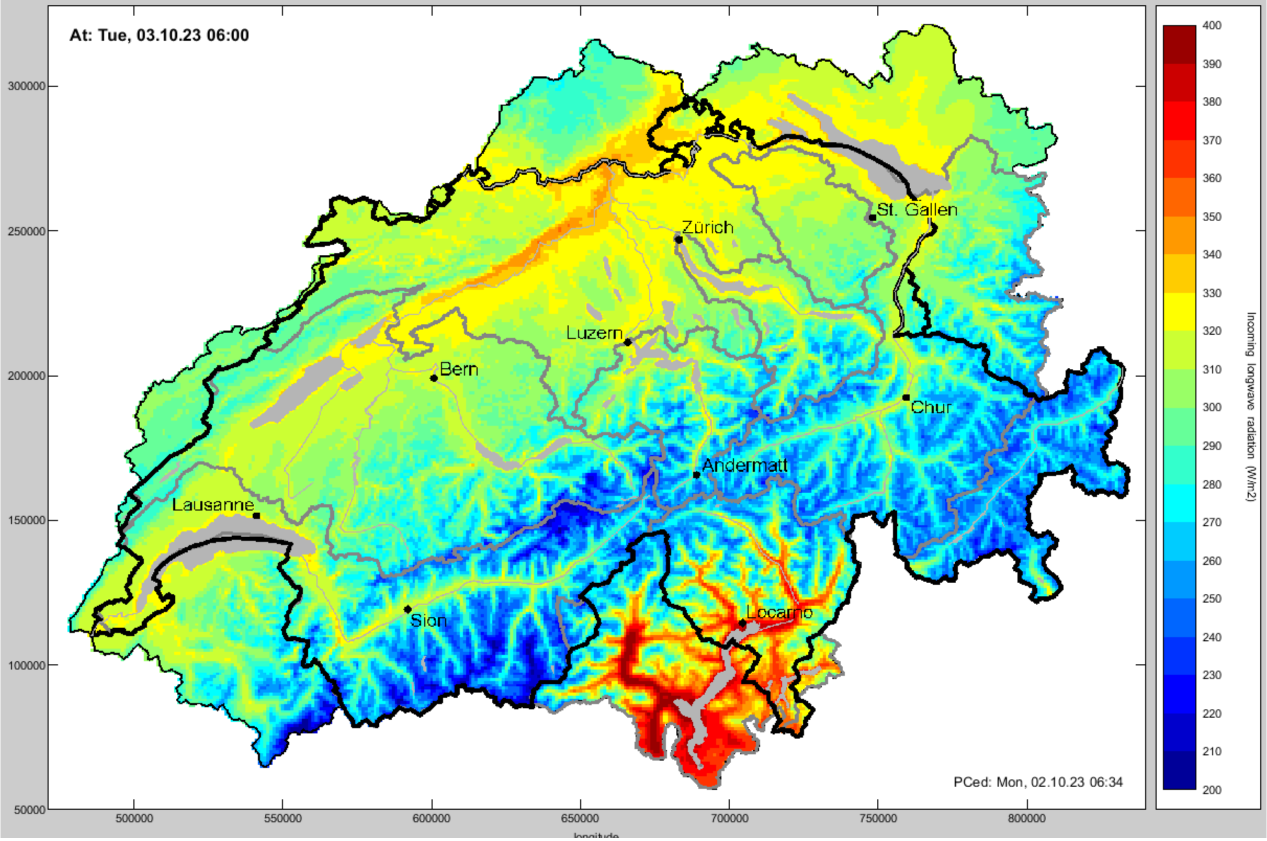
Meteorological input data for physics-based snow models



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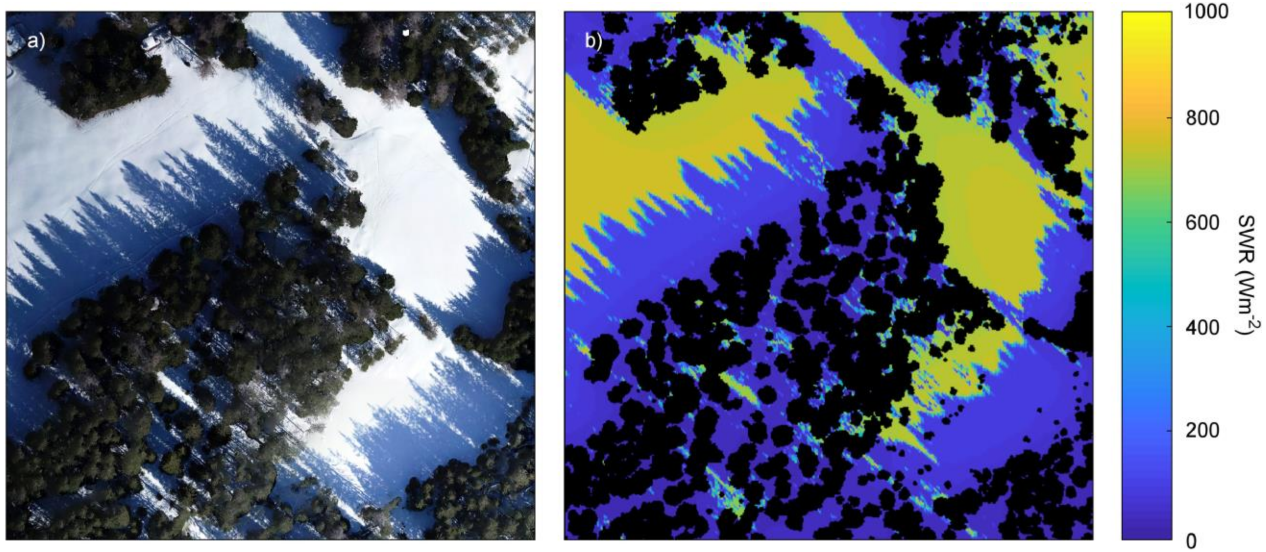
- Near-surface air temperature
- Relative humidity
- Air pressure
- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Method: Based on a method developed by Helbig et al. (2014) - Parameterization of the spatially averaged sky view factor in complex terrain – JGR Atmosphere

Meteorological input data for physics-based snow models



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- Near-surface air temperature
- Relative humidity
- Air pressure
- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Method: Based on the modelling tool developed by Jonas et al. (2020) – HPEval: A canopy shortwave radiation transmission model using high-resolution hemispherical images – Agriculture and Forest Meteorology

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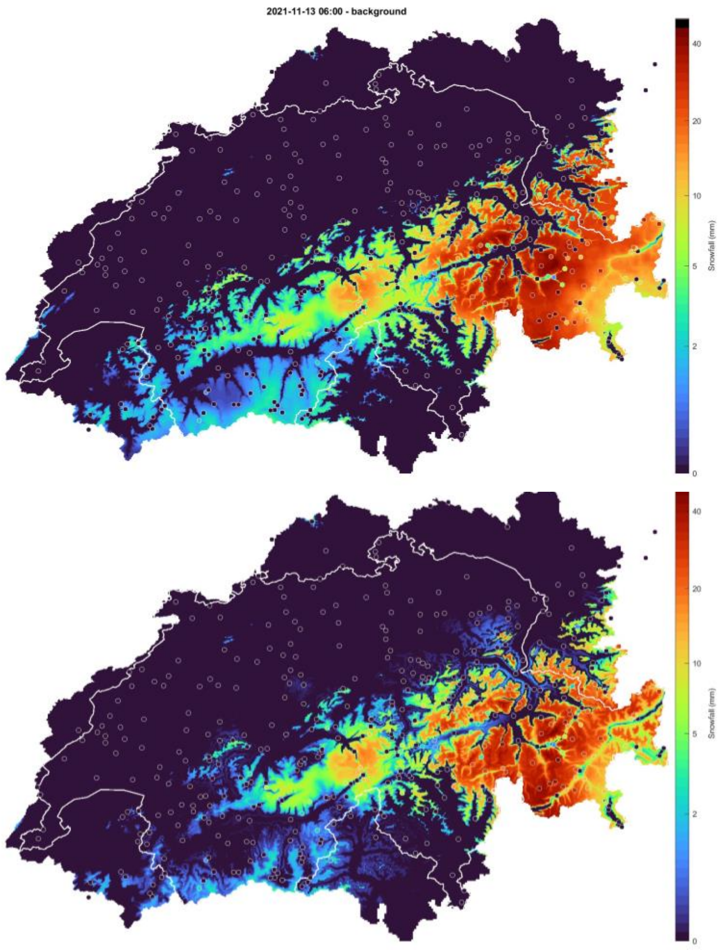
Meteorological input data for physics-based snow models

Background

Analysis



Inputs from 1 km regional NWP model COSMO downscaled to 25 m, 50 m and 100 m:

- Near-surface air temperature
- Relative humidity
- Air pressure
- Wind speed
- Wind direction
- Longwave radiation
- Direct and diffuse radiation
- Rainfall and snowfall

Method: Based on a data assimilation method by Magnusson et al. (2014) – Assimilation of point SWE data into a distributed model comparing two contrasting methods – Water Resources Research

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Choice of modelling method for high-resolution simulations

Computation time ↑

Wind fields

<u>Atmospheric model</u>
WRF
Meso-NH

<u>Dynamical downscaling</u>
MicroMet
➡ WindNinja

<u>Interpolation of station data</u>
Bilinear interpolation
…

Snowdrift module

<u>3D Turbulent diffusion equation</u>
Alpine 3D
Snowdrift3D
snow2blow

<u>Parameterization by vertical integration</u>
PBSM
➡ SnowTran-3D

Erodible snow

<u>Snow microstructure</u>
SNOWPACK
Crocus

➡ ?????????

<u>Models with “simple” layering</u>
SnowModel
Snobal
Distributed Snow Model

Queno et al. (In Discussion), Snow redistribution in an intermediate-complexity snow hydrological modelling framework, The Cryosphere. doi.org/10.5194/egusphere-2023-2071

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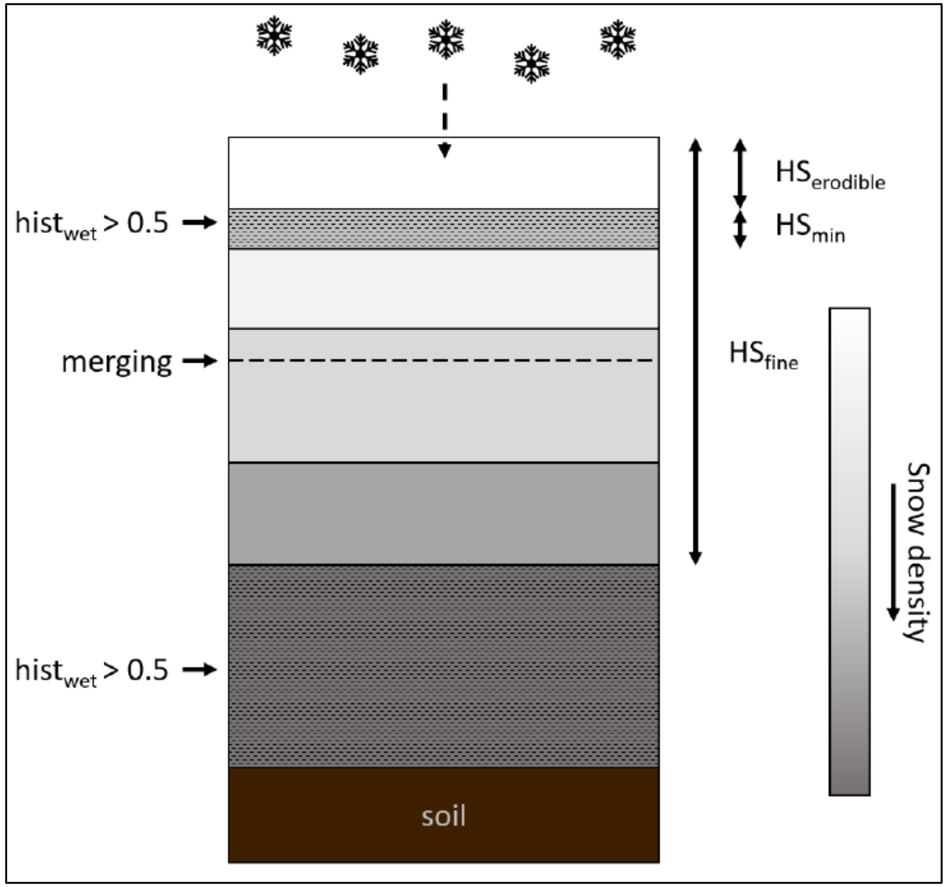
Improved snow layering in computational efficient modelling

Improved layering in intermediate-complex energy-balance model:

- New dynamical layering suitable for “simpler” models
- Density-dependent erodibility
- Density-dependent layering, finer layers at the top, one base layer

Some rules:

- New snow creates a new layer
- All snow below the fine layers moved to the base layer
- All layers thinner than a minimum are merged
- Layers are also merged if they become too many
- Layers are split if they become too few
- Wetted layers are identified and tracked => non-erodible



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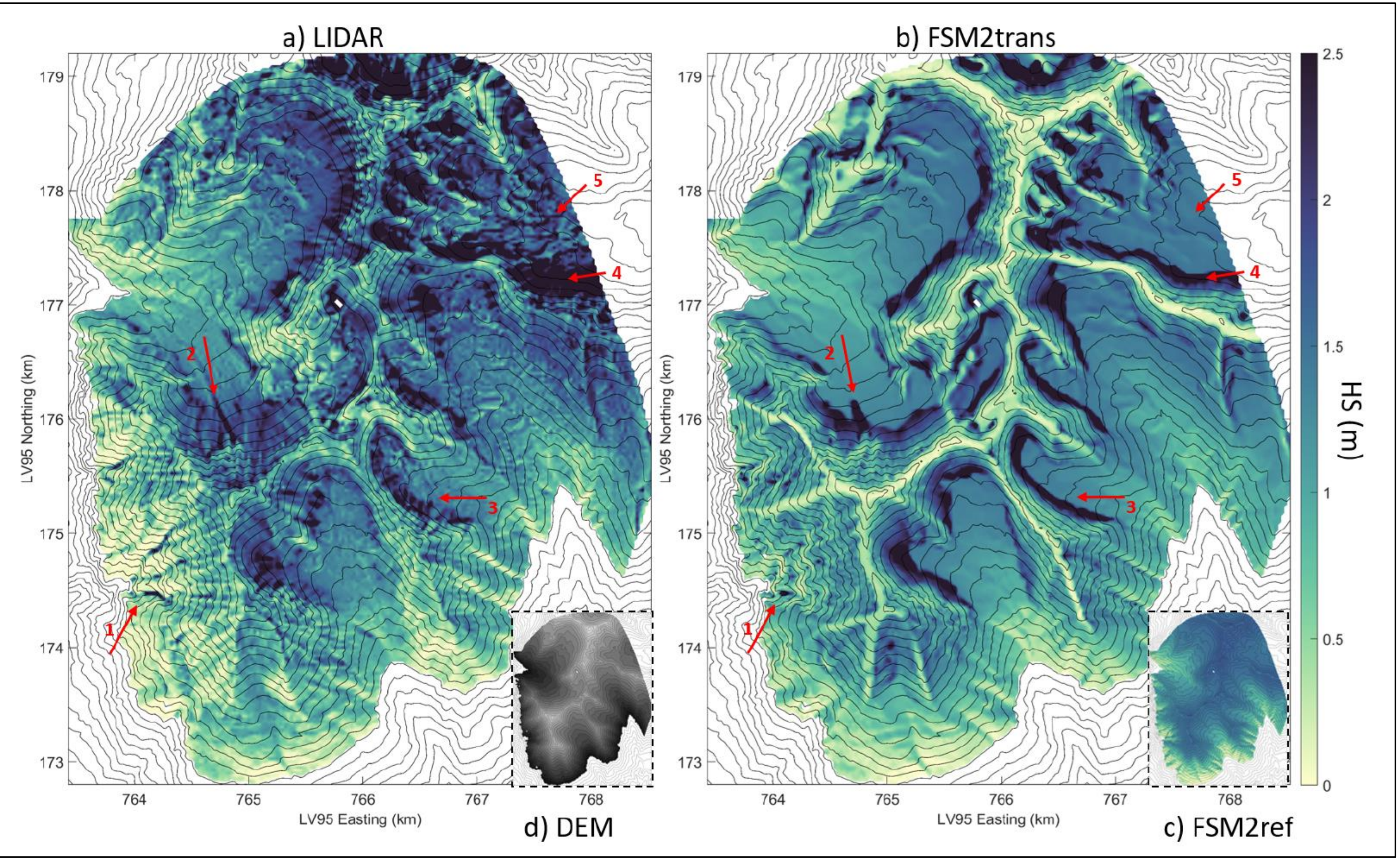
Results for the Brienz area (2020-03-17)



Model with snow transport due to wind and avalanches (FSM2trans) matches observations (LIDAR) much better than reference (FSM2ref).

Arrows with small numbers ☺

1) Avalanches

2) Avalanche

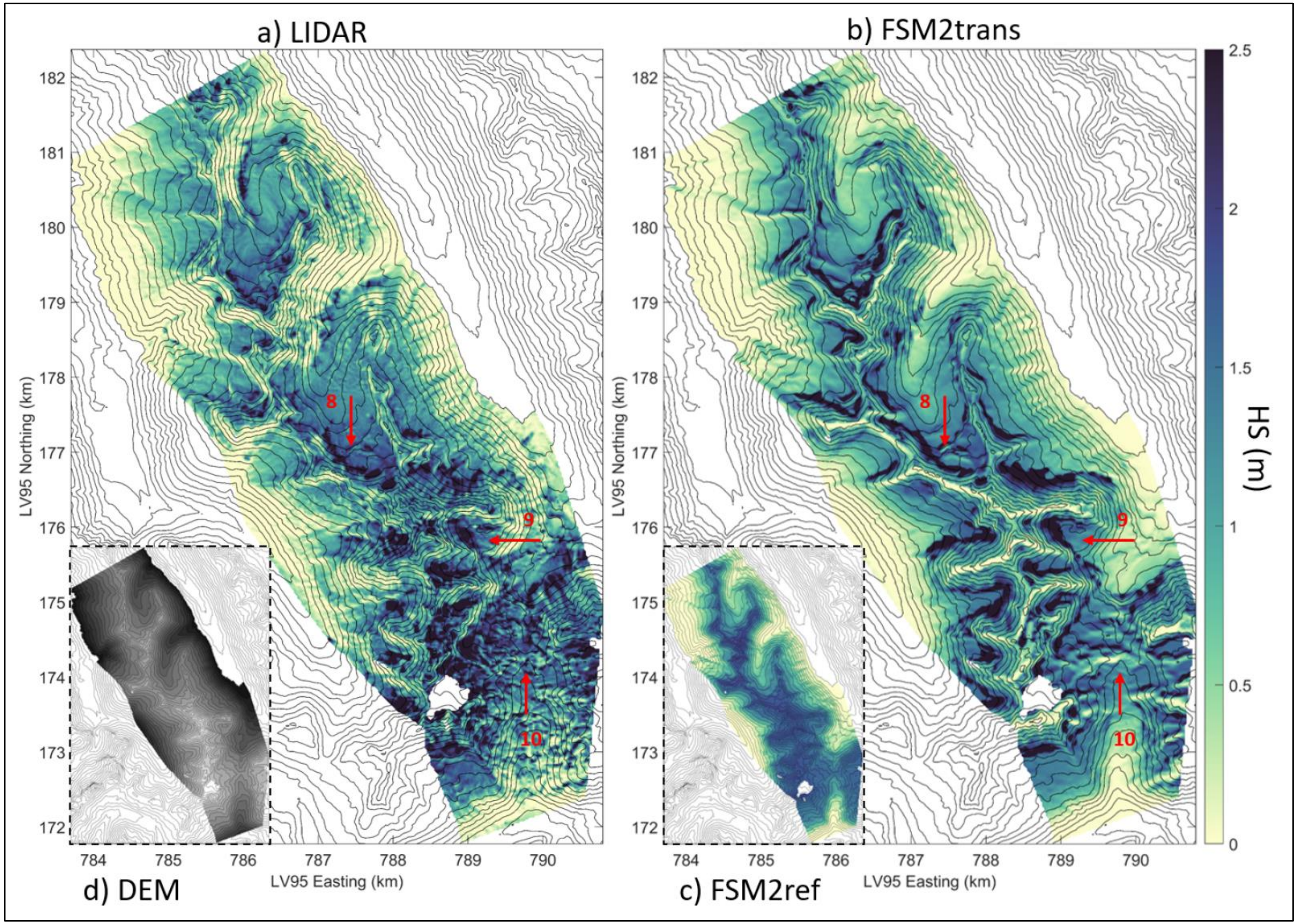
3) Snowdrift plus avalanches

4) Snowdrift plus avalanches

5) Underestimated variability in intermediate slopes

Too strong erosion on ridges!

Result for the Dischma area (2017-05-17)



Model with snow transport due to wind and avalanches (FSM2trans) matches observations (LIDAR) much better than reference (FSM2ref).

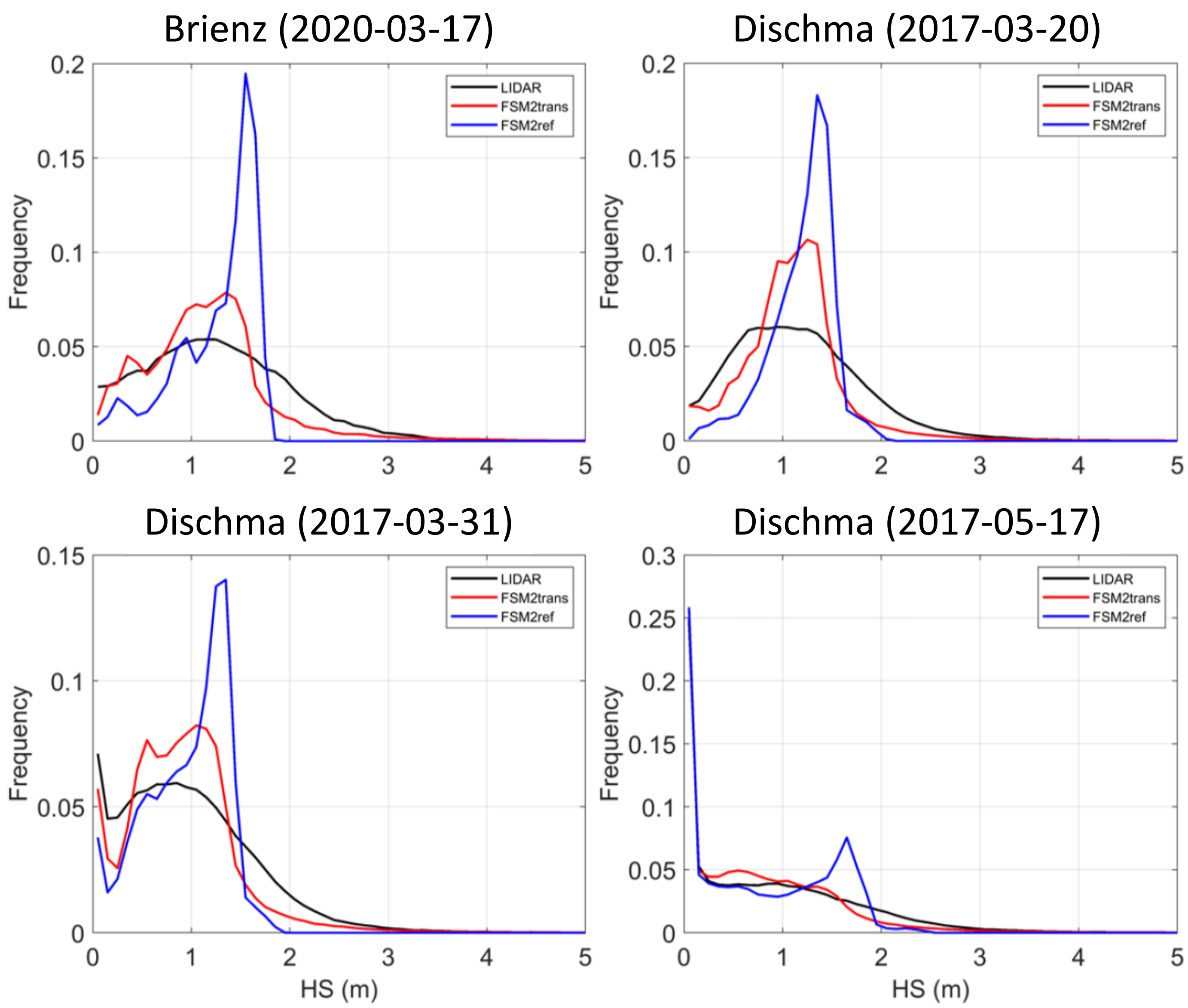
Arrows with small numbers ☺

8) Snowdrift plus avalanches

9) Snowdrift plus avalanches

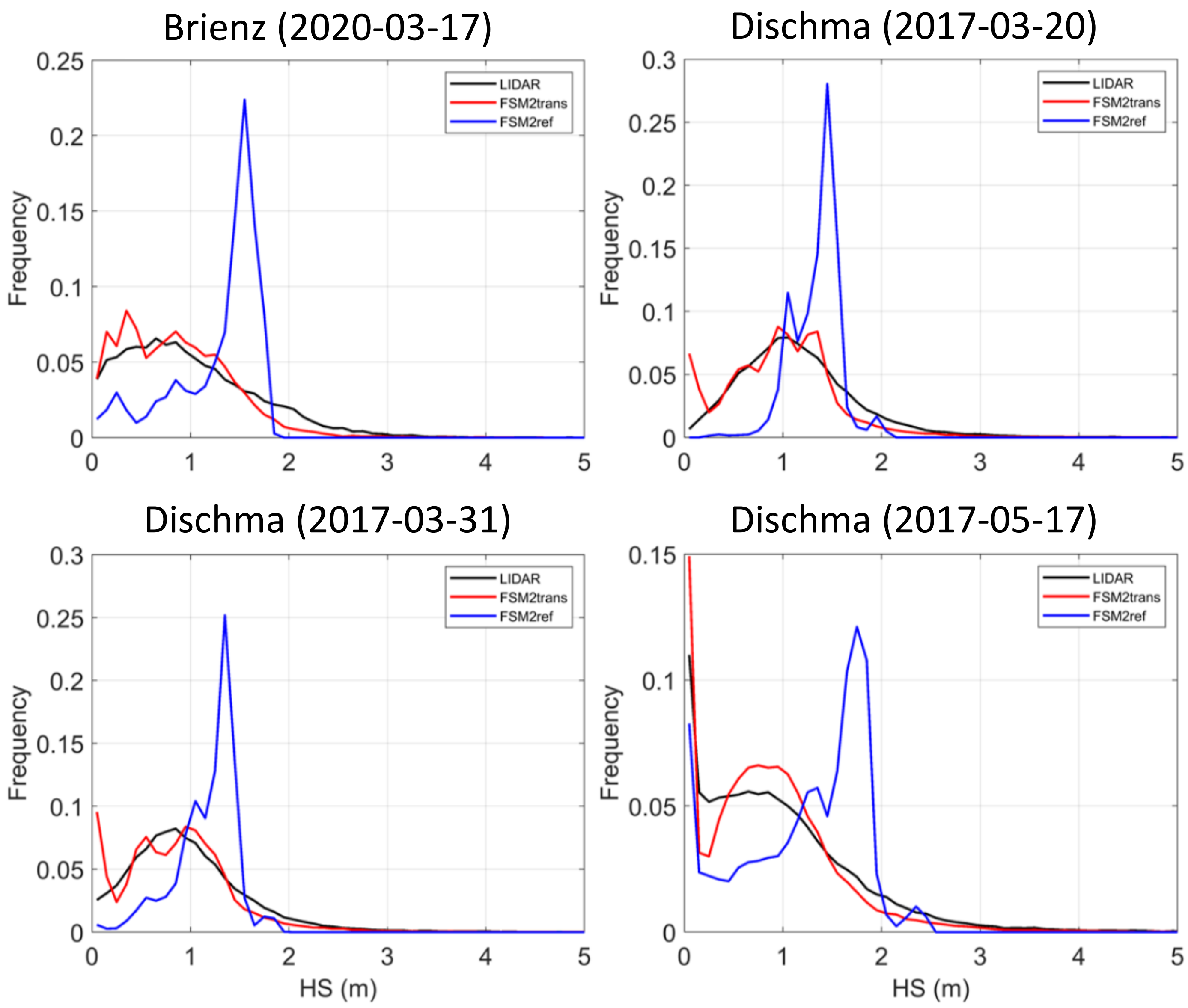
10) Variability in a pass exposed to strong wind

Frequency distributions for snow depth



Model with snow transport due to wind and avalanches (FSM2trans) matches observations (LIDAR) <u>better</u> than reference (FSM2ref) for the <u>complete areas</u>.

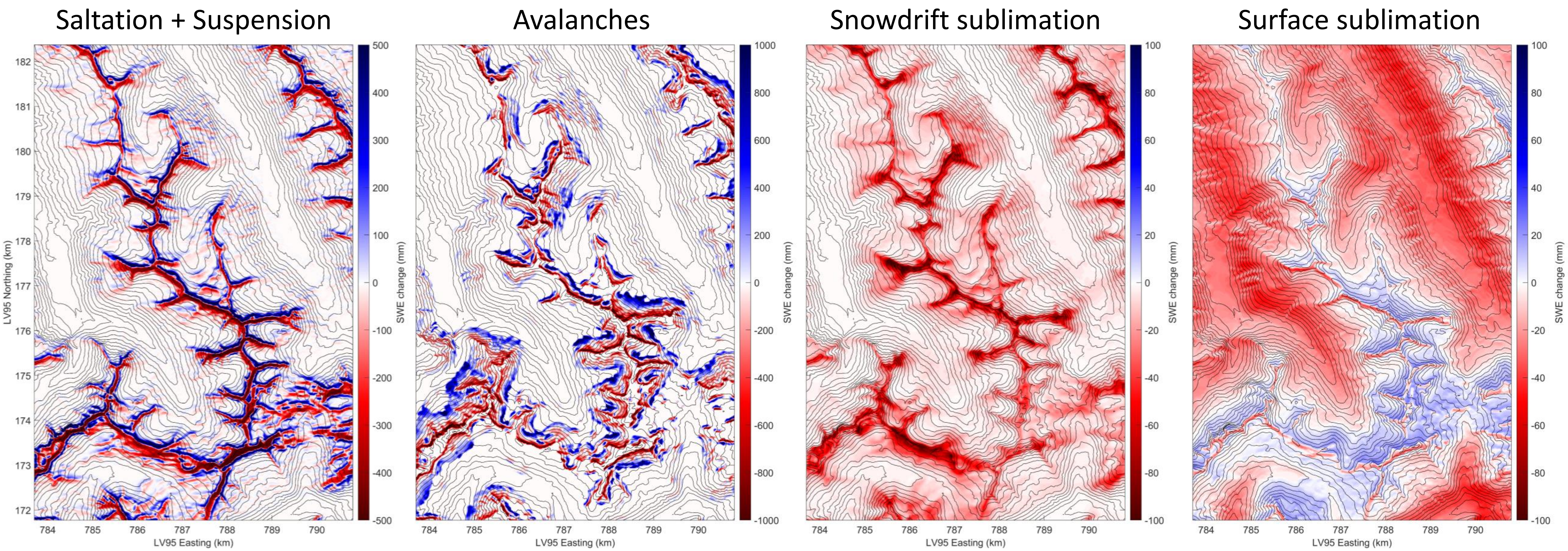
Frequency distributions for snow depth



Model with snow transport due to wind and avalanches (FSM2trans) matches observations (LIDAR) <u>much better</u> than reference (FSM2ref) for the <u>exposed areas (ridges and surroundings)</u>.

=> We need more variability in the snow cover simulations at lower elevations

Contribution of different processes to mass balance



Total sublimation loss between 2016-09-01 to 2017-06-30:

Snowdrift = 1.0 %

Surface = 4.3 %

Work-in-progress for improving high-resolution simulations

Computation time ↑

Wind fields
Atmospheric model WRF Meso-NH
Efficient atmospheric model **HICAR**
Dynamical downscaling MicroMet WindNinja
Interpolation of station data Bilinear interpolation …

Snowdrift module
3D Turbulent diffusion equation Alpine 3D Snowdrift3D snow2blow
Parameterization by vertical integration PBSM SnowTran-3D

Erodible snow
Snow microstructure SNOWPACK Crocus
Simple models with improved layering **FSM2trans**
Models with “simple” layering SnowModel Snobal Distributed Snow Model

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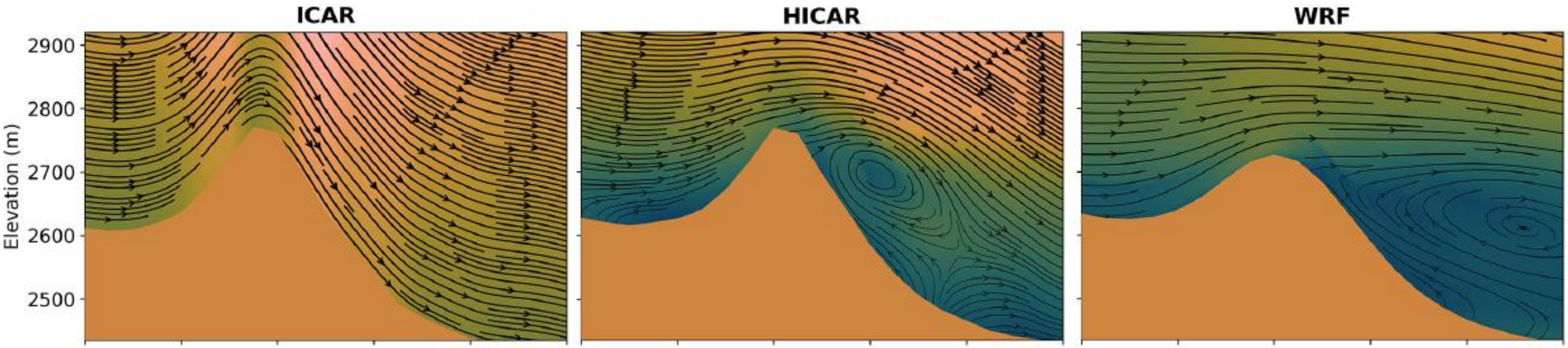
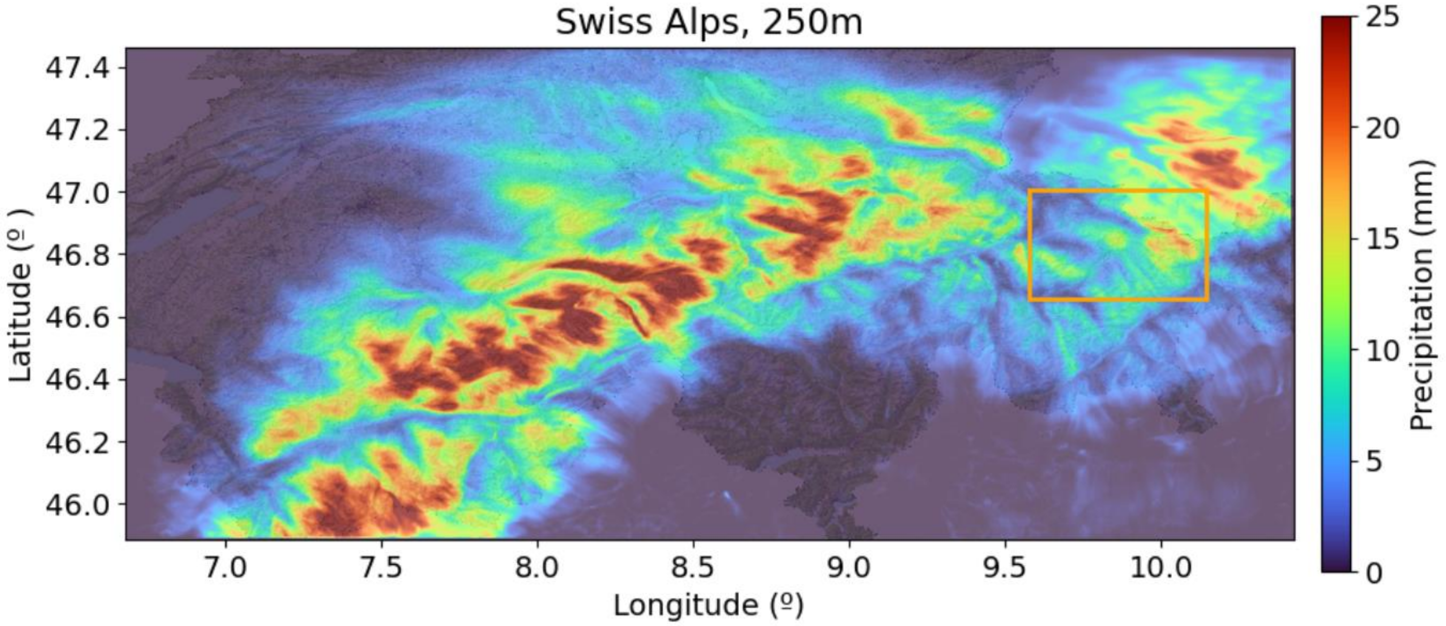
Work-in-progress for improving high-resolution simulations



Reynolds et al. (2023), The High-resolution Intermediate Complexity Atmospheric Research (HICAR v1.1) model enables fast dynamic downscaling to the hectometer scale, GMD, doi.org/10.5194/gmd-16-5049-2023



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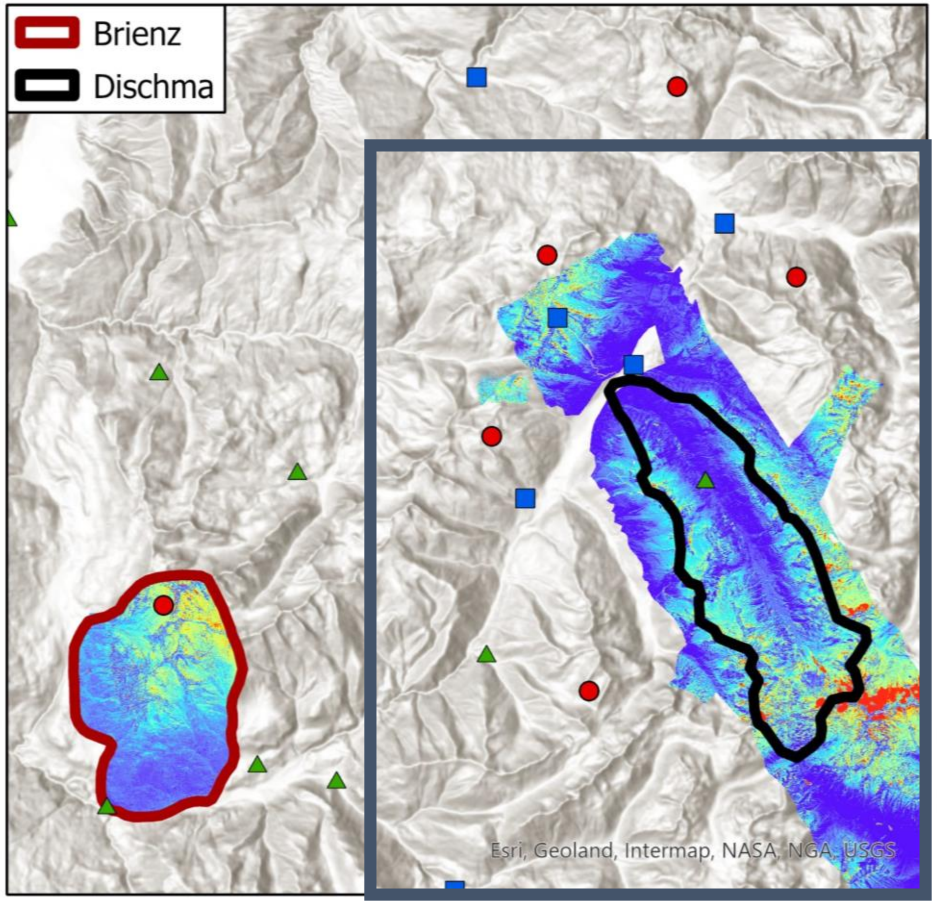
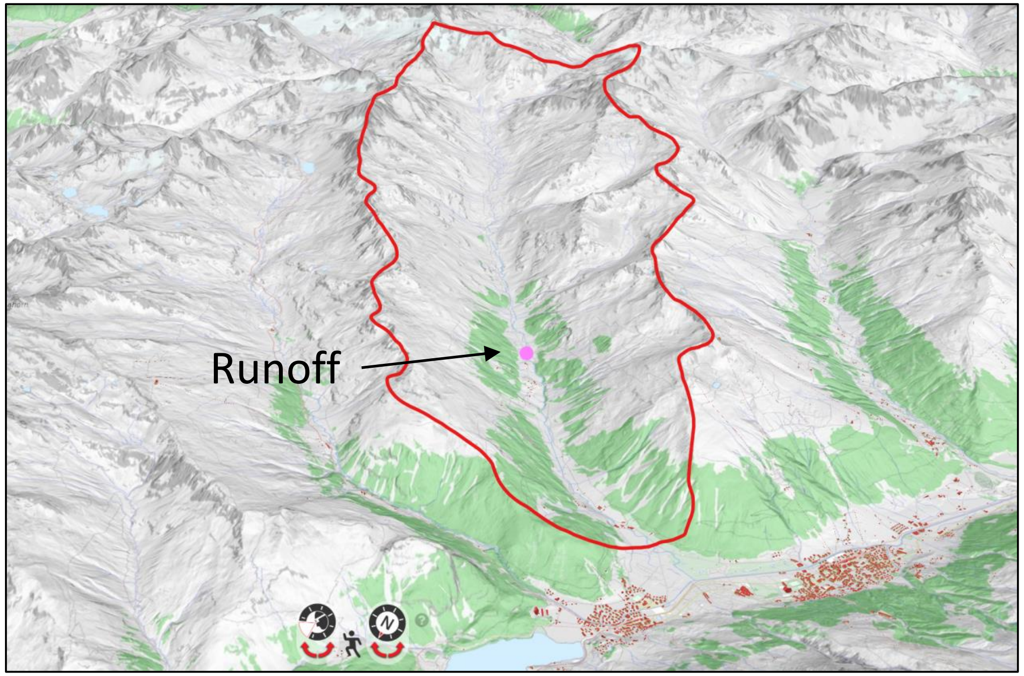
Data collaboration – Dischma catchment



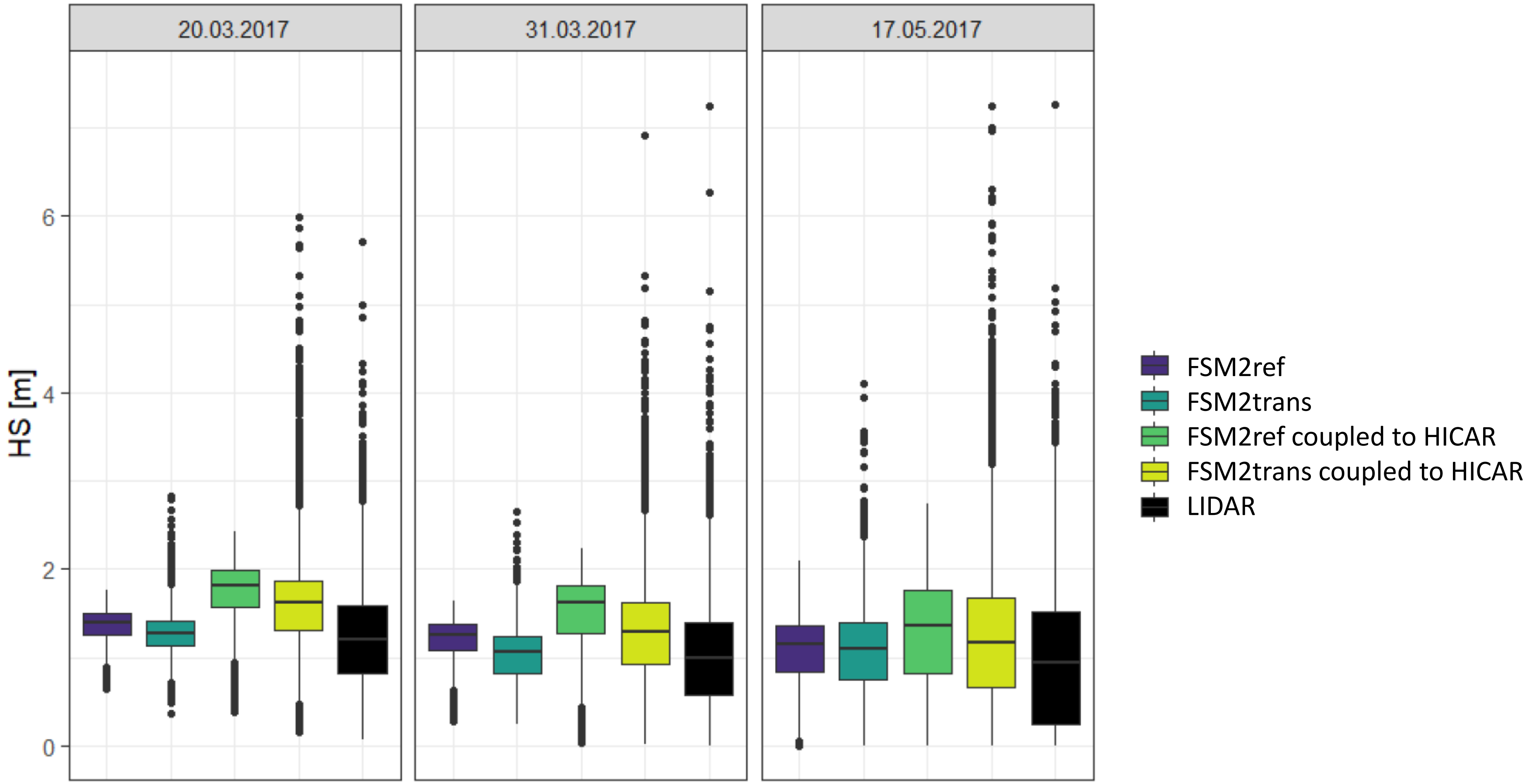


Data for model collaboration:

- Meteorological input data on a grid with 50 m (?) resolution
- Discharge measurements
- Snow measurements – automatic and manual
- Snow covered area
- …

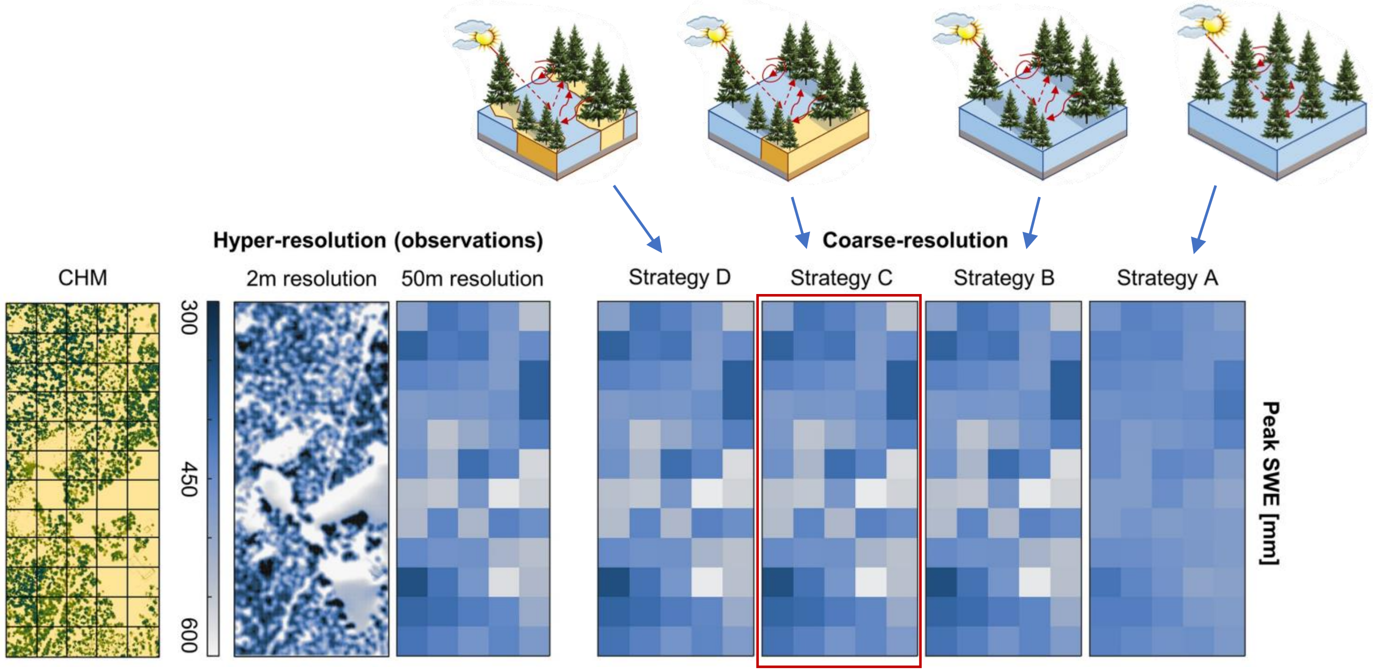
Data paper with raw data from automatic stations (Mathias Bavay)

FSM2trans coupled to HICAR shows a better variability than other methods



OSHD framework – forest representation

Lidar derived canopy information

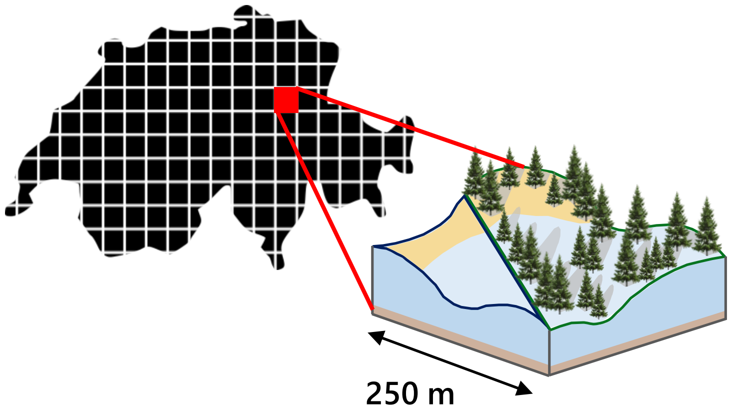


Implicit heterogenous canopy and fractional snow cover

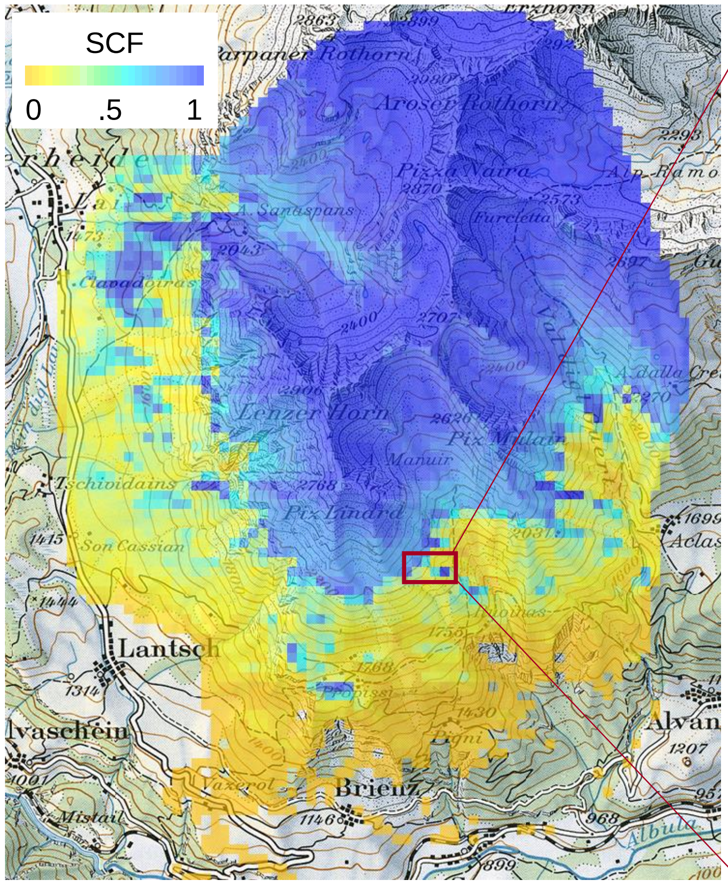
Mazzotti, G., Webster, C., Essery, R., Jonas, T. (2021). Increasing the physical representation of forest-snow processes in coarse-resolution models: Lessons learned from upscaling hyper-resolution simulations. Water Resources Research.

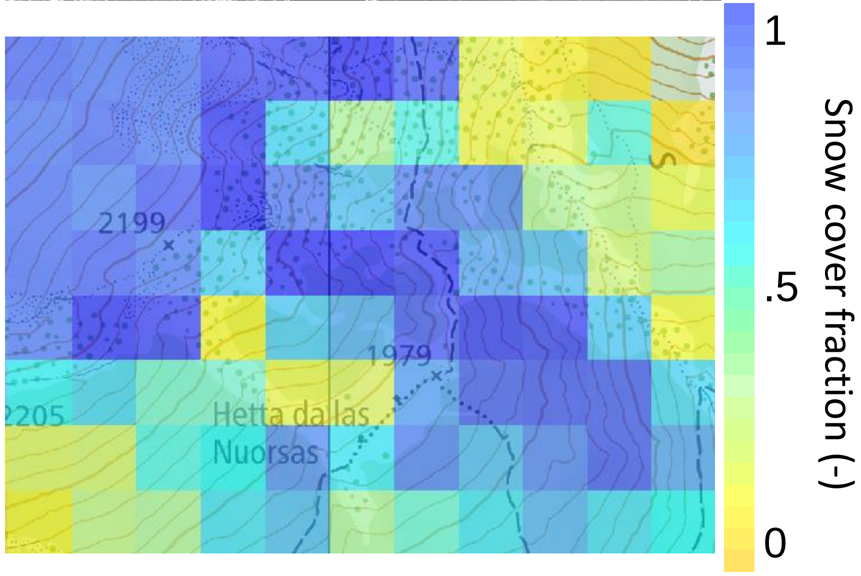
OSHD framework – forest representation

Tiled model simulations



24 March 2020





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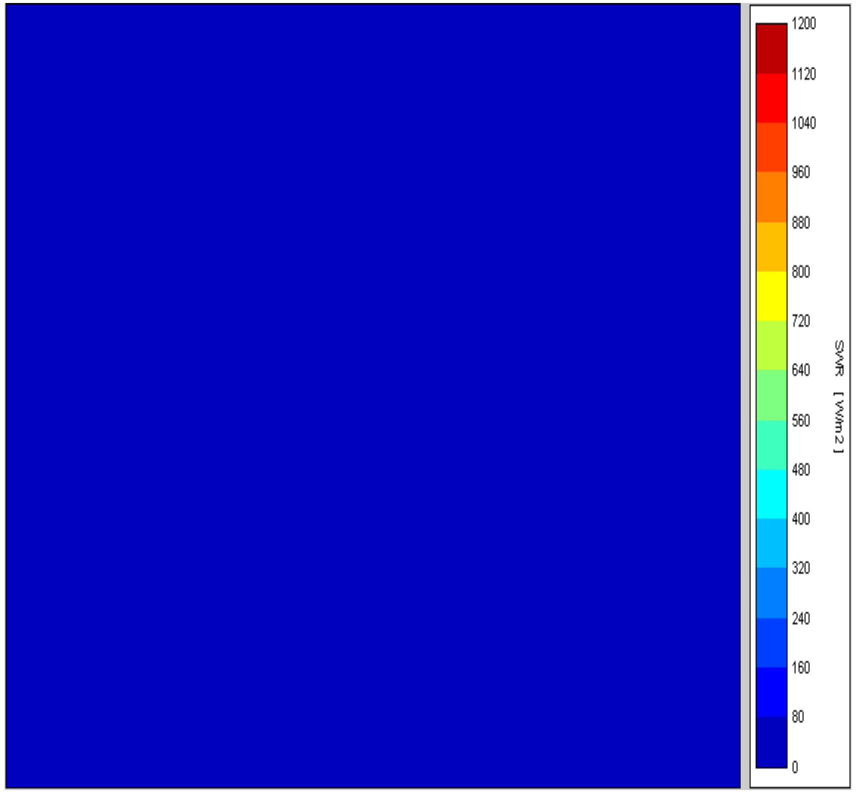
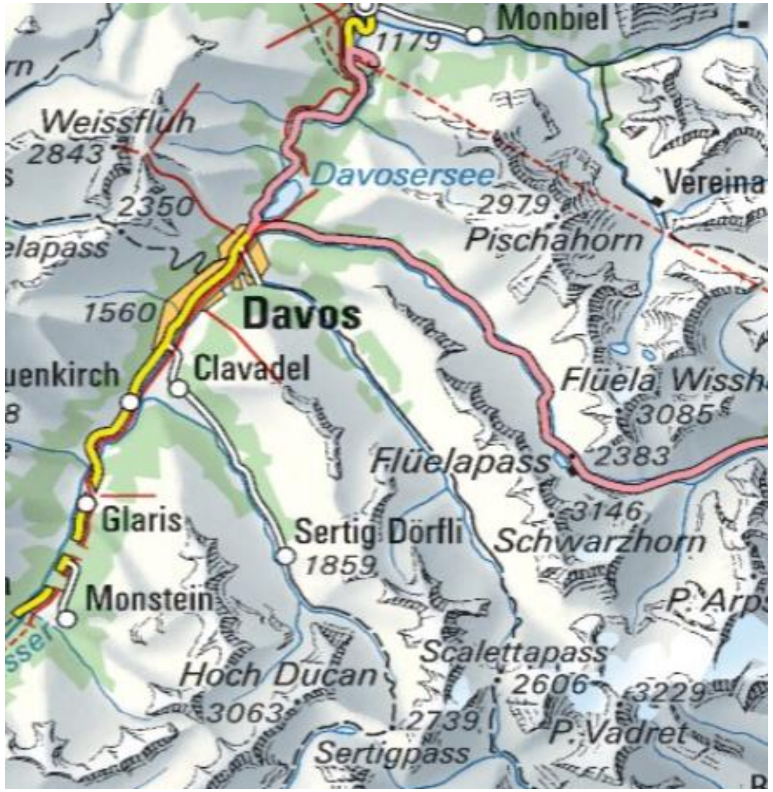
OSHD framework – shortwave radiation data

Dynamical downscaling of shortwave radiation to include high-resolution terrain shading and forest effects





Jonas, T., Webster, C., Mazzotti, G., Malle, J., (2020), HPEval: a canopy shortwave radiation transmission model using high-resolution hemispherical images. Agricultural and Forest Meteorology.

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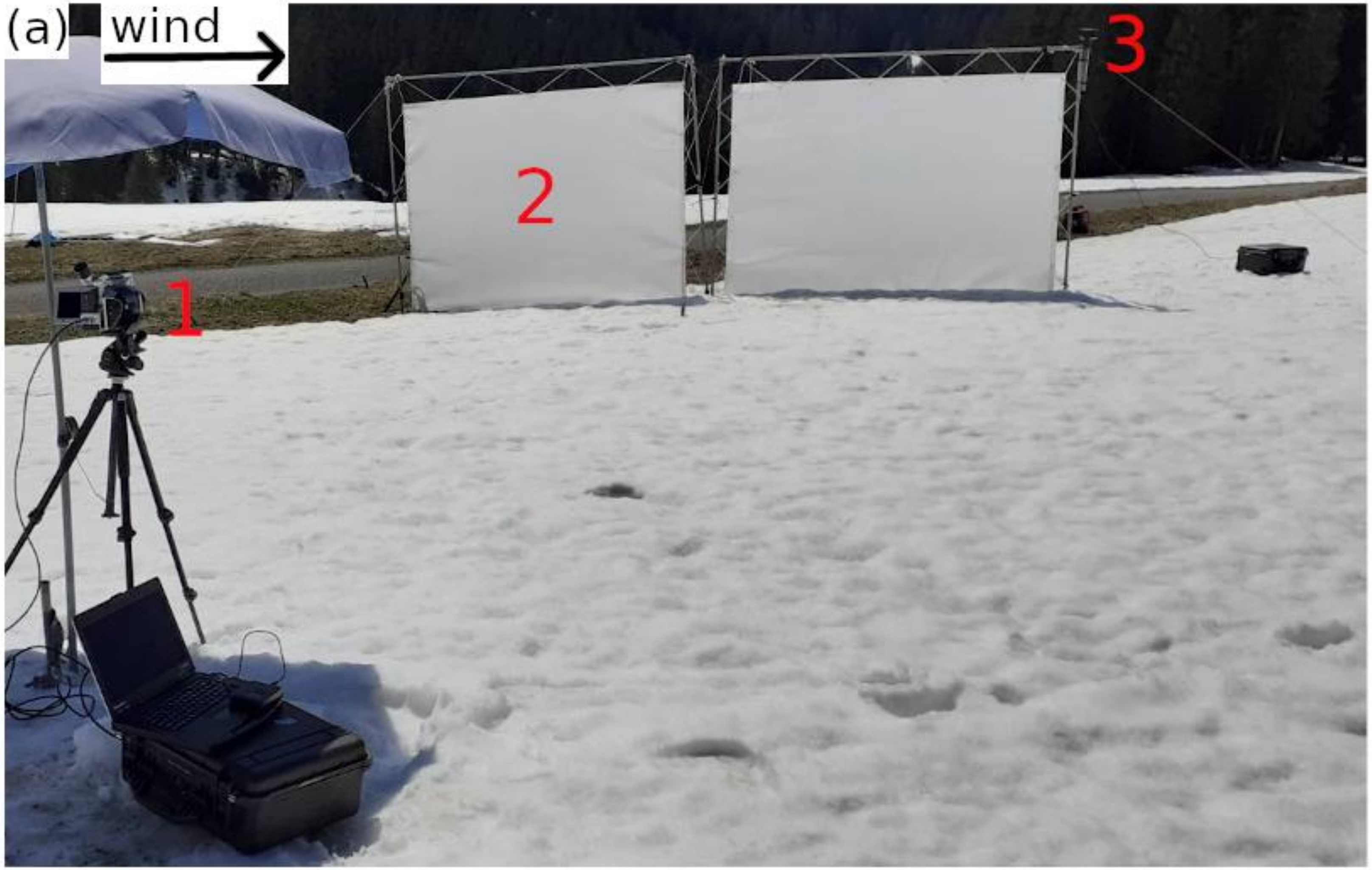
OSHD research – improving snow melt simulations



1) Sun-shielded thermal infrared camera

2) Streched thin synthetic screens

3) Two-dimensional ultrasonic anemometer

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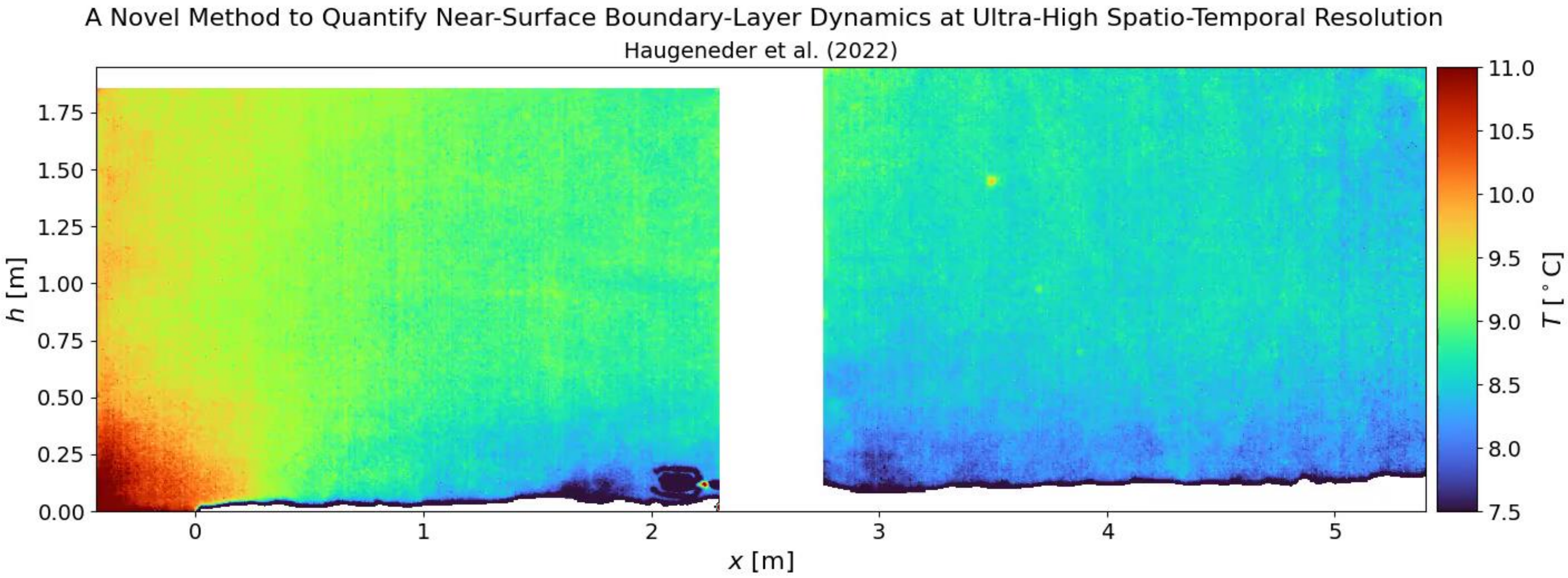
OSHD research – improving snow melt simulations



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