Modelling future glacier evolution: Which feedbacks are relevant?

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Study site: Vadret da Morteratsch

Well studied valley glacier in the South-Eastern Swiss Alps (15 km^2)
(e.g., Oerlemans et al., 2009, 2017; Zekollari et al., 2013, 2014; Machguth et al., 2008; Huss et al., 2010 etc.)

Particular public interest due to a project aiming at large-scale artificial snow production for saving the glacier («MortAlive») **(Oerlemans et al., 2017)**

The approach

Glacier Evolution Runoff Model
(GERM, Huss et al., 2008)

- Spatially distributed, process-based mass balance computation
- Mass-conserving parameterization for glacier retreat, validated against a high-order 3D ice-flow model
- Calibration on observed ice volume change
- Detailed validation with various data sets covering the last 150 years: *length change, volume change, point mass balance, discharge*

New approaches / processes implemented

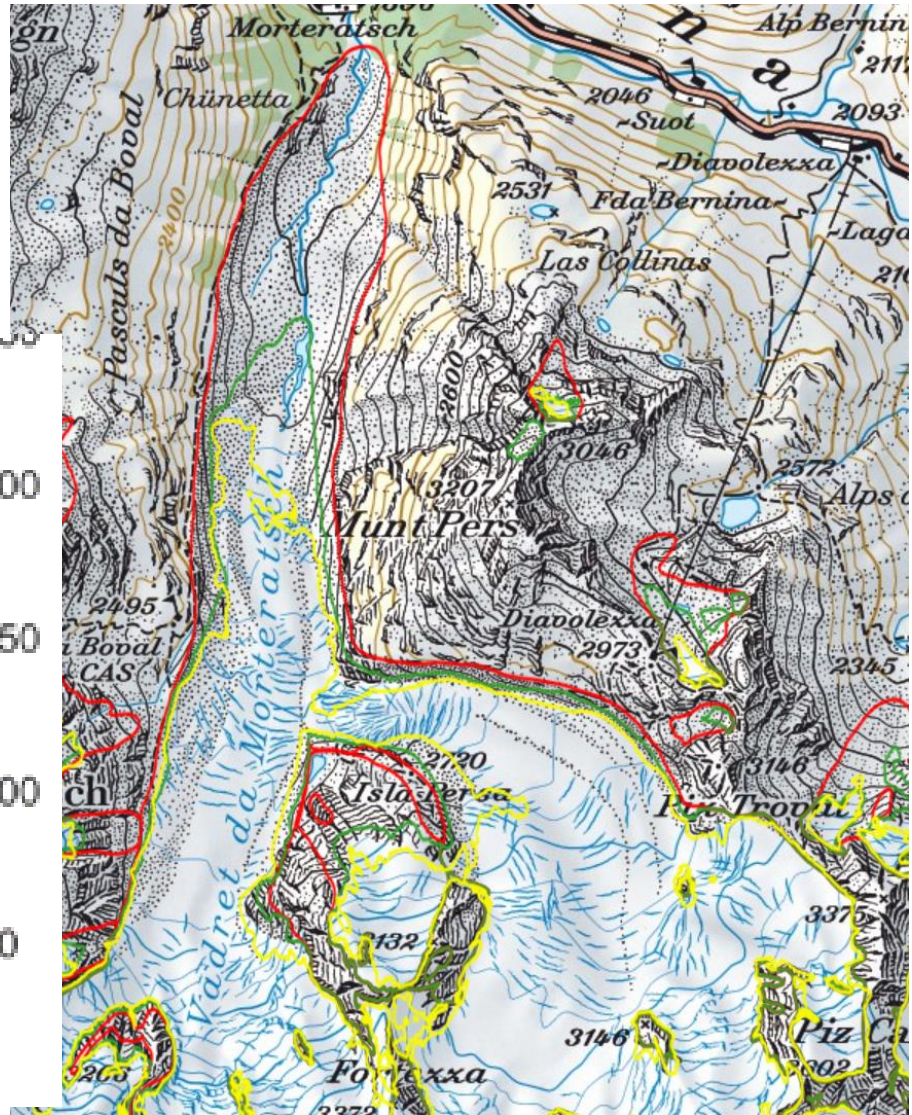
1. Different melt models, including a process-based full distributed energy-balance model
2. Effect of surface debris-coverage and spatio-temporal evolution
3. Potential impact of proglacial lakes
4. Effect of large-scale artificial snow production (MortAlive, Oerlemans et al., 2017)

Compare effect of submodels / parameterizations turned off/on against reference simulation

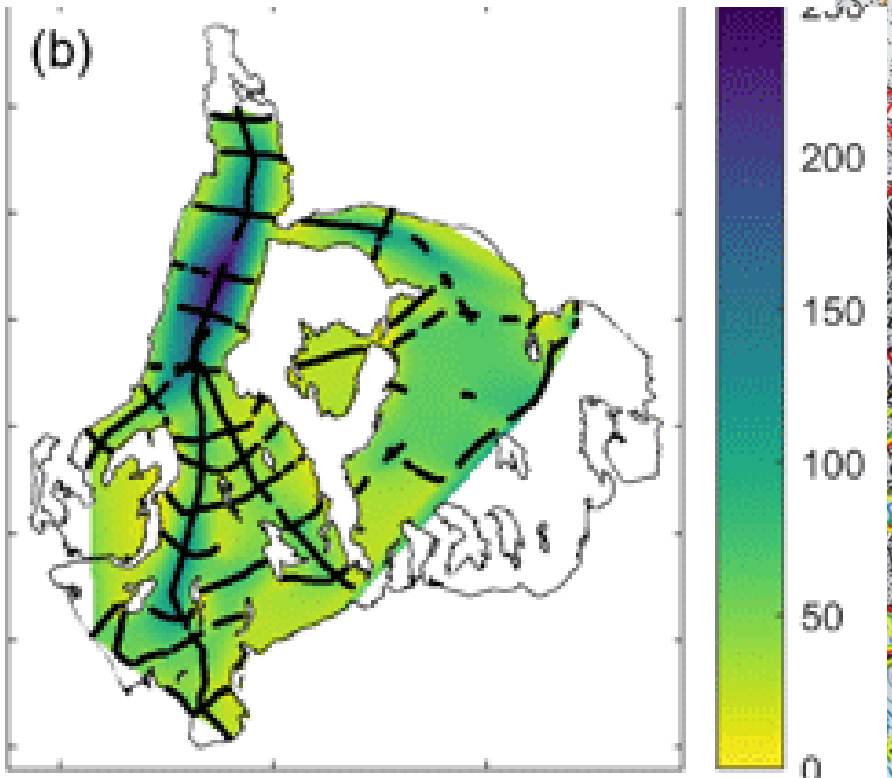
Input data

- **Nearby meteorological records (Corvatsch, Sils)** (MeteoSwiss)
- **Glacier inventories** (Fischer et al., 2014; GLAMOS)
- **Digital elevation models (incl. volume change) for 1875, 1935, 1955, 1985, 2008, 2015** (Bauder et al., 2007; Huss et al., 2010)
- **In-situ point mass balance data** (Zekollari & Huybrechts, 2018)
- **Glacier length change since 1850** (GLAMOS)
- **Catchment runoff** (BAFU)
- **Ice thickness distribution (measured, interpolated using different approaches)** (Langhammer et al., 2019; Huss&Farinotti, 2012)
- **Climate projections until 2100 based on regional climate models** (CH2018)

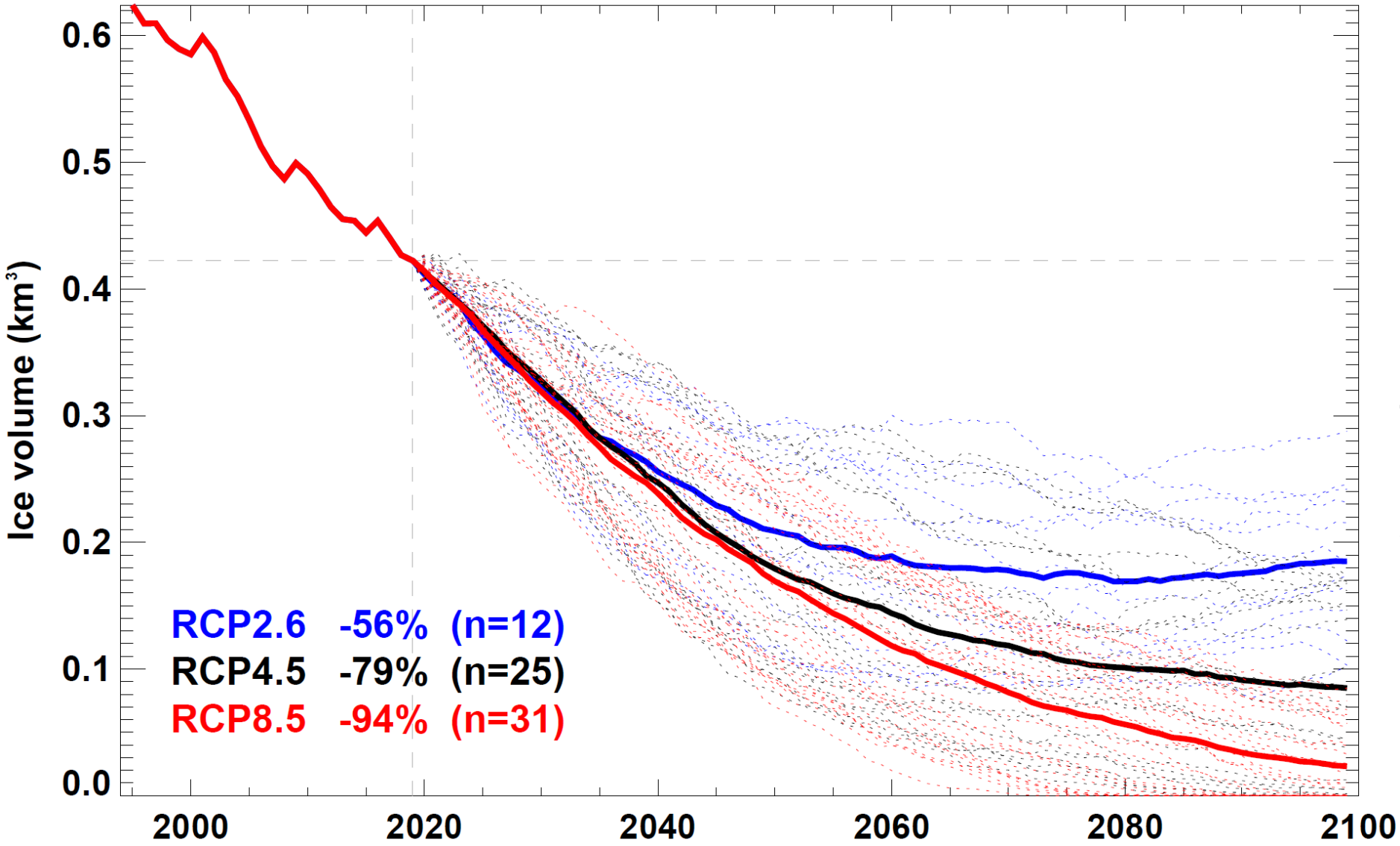
Glacier inventories



Ice thickness



Modelled evolution of future ice volume

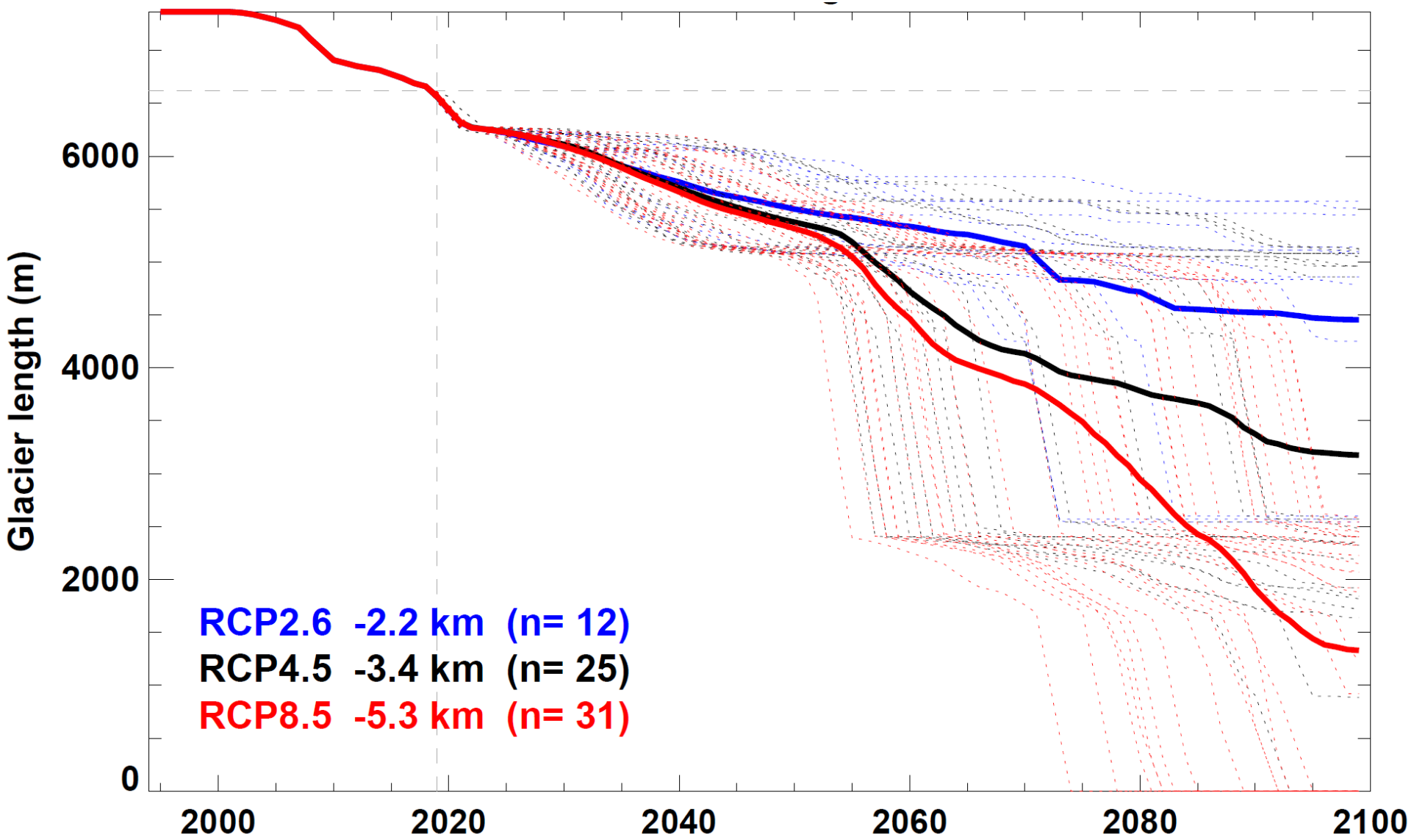


Three CO_2-emission pathways (RCPs)
➔ Loss of between >50% and almost everything

68 regional climate model runs (dashed lines)
Thick lines show mean for respective RCP

Just considering main branch (Morteratsch)

Modelled evolution of future glacier length



Morteratsch tongue remains in valley floor until 2100 in the very best case (RCP2.6)

Check out:
https://youtu.be/vgwS-n49tss

Evolution of the Morteratsch glacier system

Matthias Huss & Enrico Mattea

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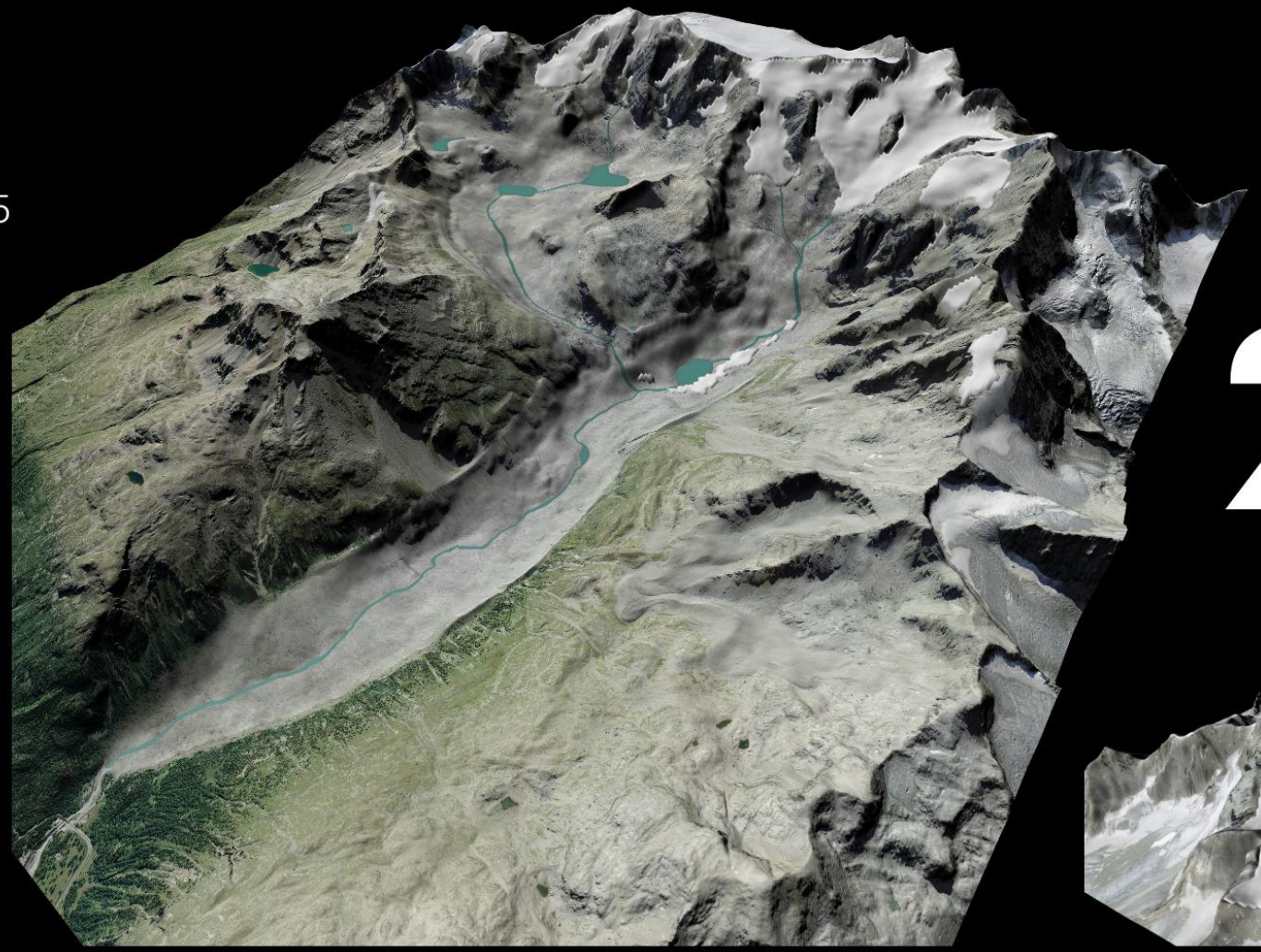
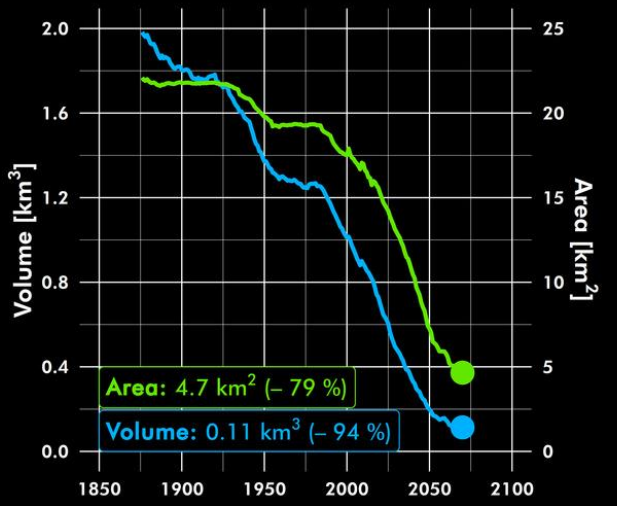
Model: temperature index

Climate scenario: RCP4.5





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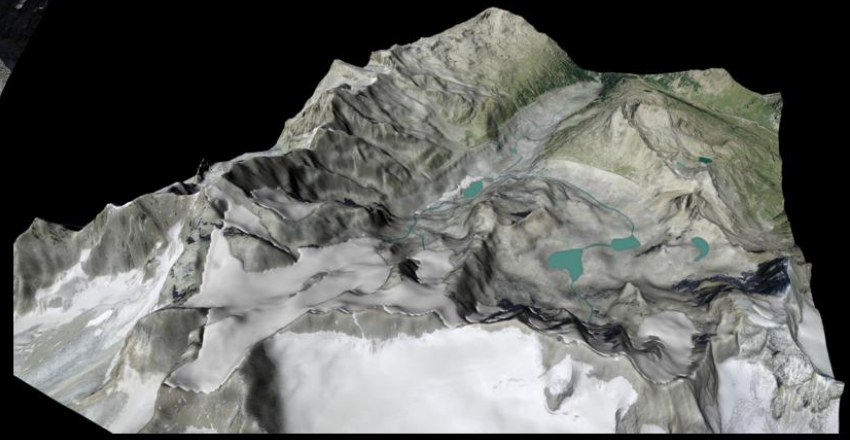

Sources: topography and past glacier surfaces by swisstopo --- meteorological data by MeteoSwiss --- climate scenarios by CH2018 --- glacier outlines by GLAMOS and GLIMS --- bedrock from ETH Zurich, interpolated by GlaTE and HF2012 --- glacier modelling by Matthias Huss --- data processing and visualization by Enrico Mattea.

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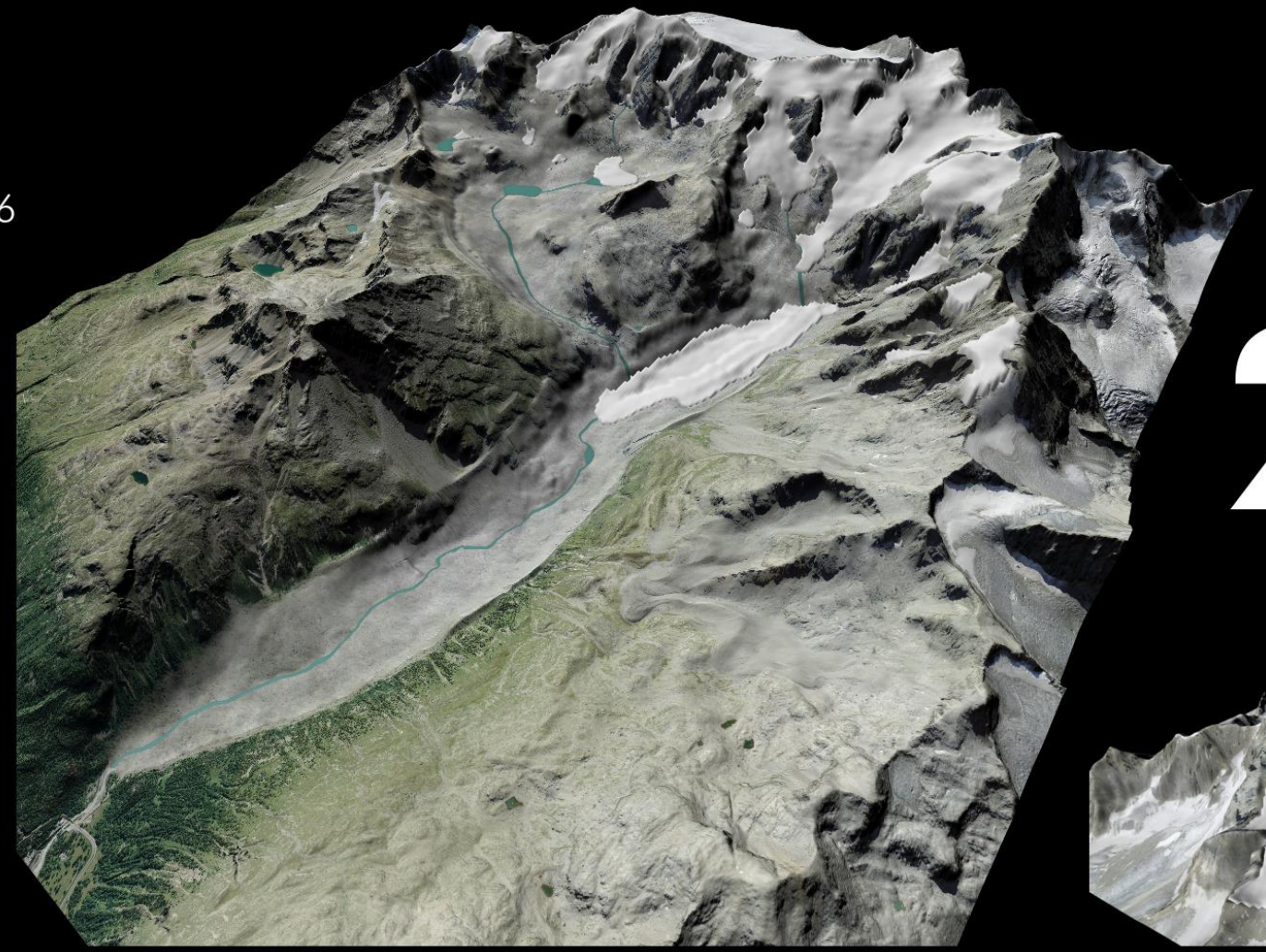

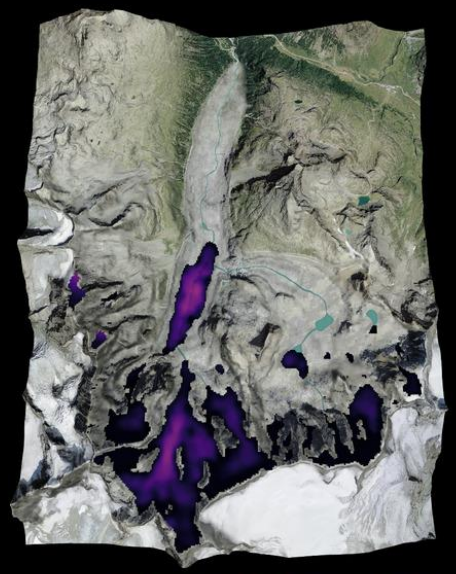

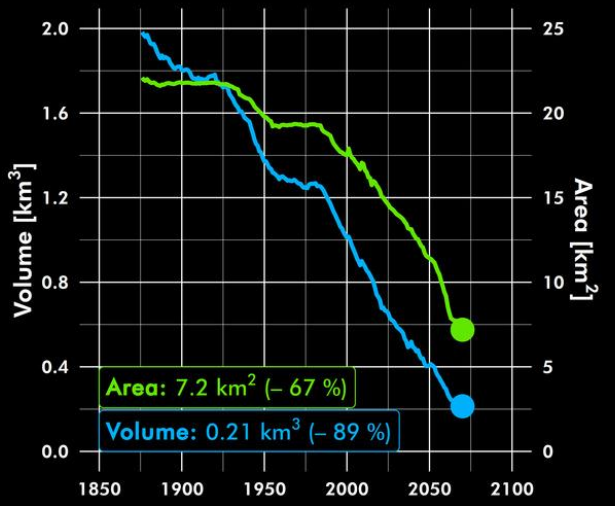

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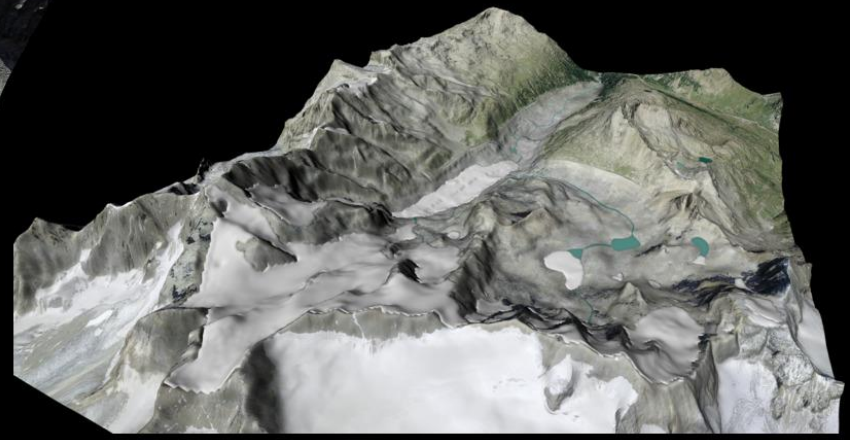

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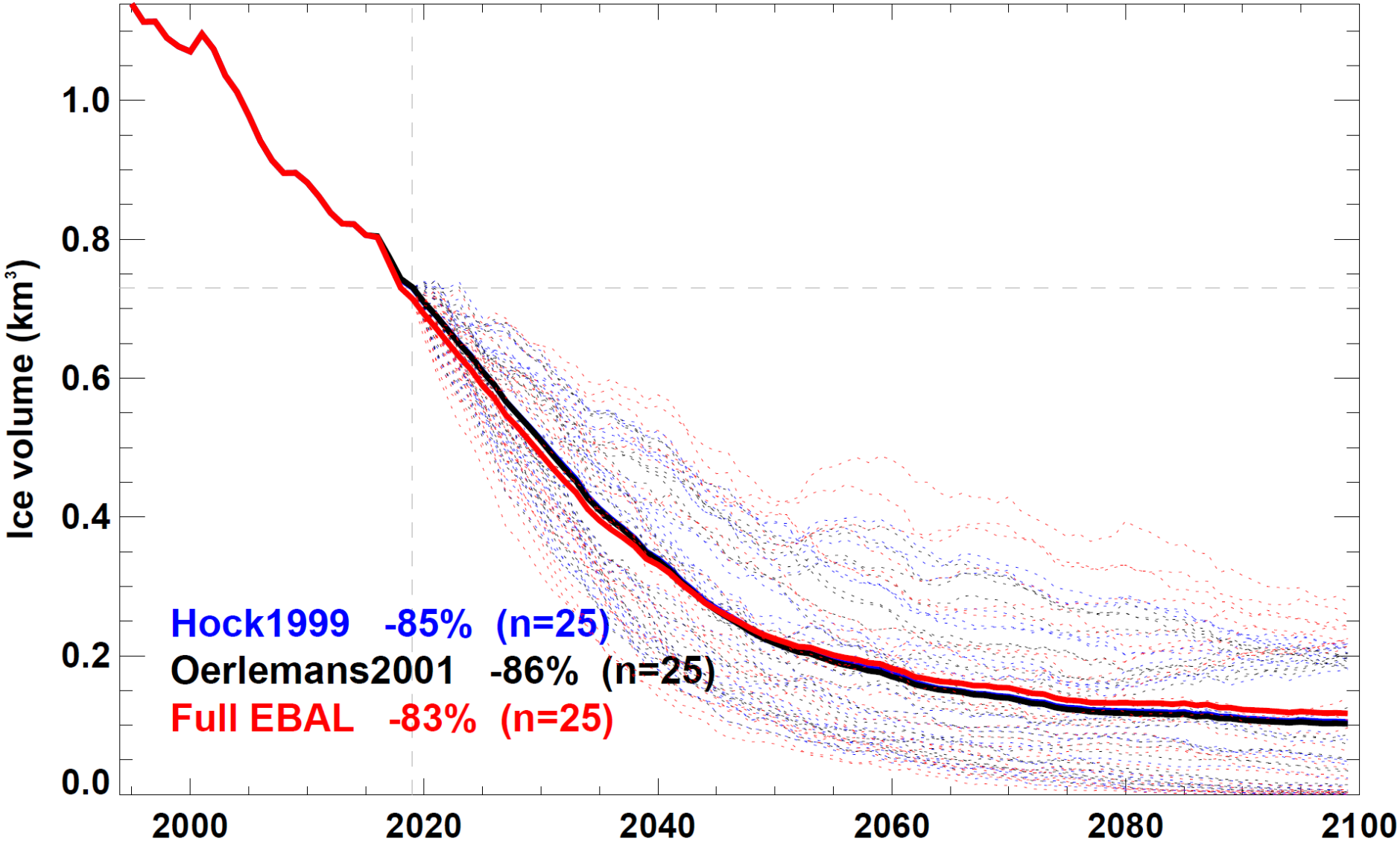
Evaluation of model uncertainties

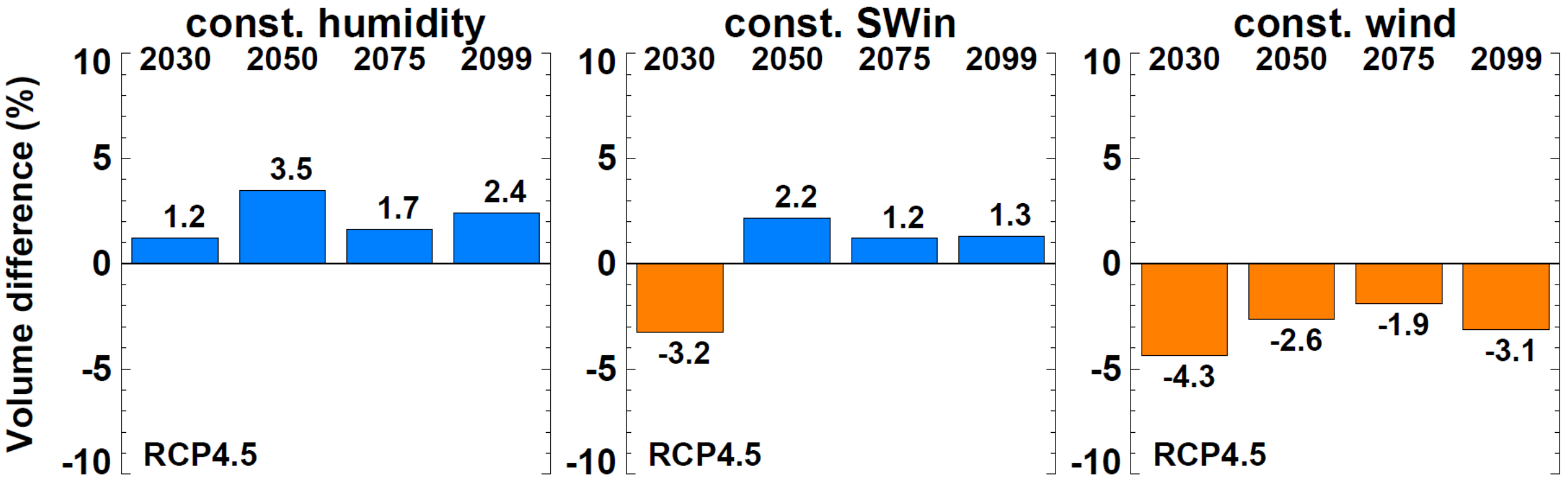


Different types of glacier melt models implemented agree well with each other
➔ Robust result!

Full energy balance model versus temperature-index model:
Although melt models strongly differ in their complexity, the average future glacier evolution is the same

Results for entire glacier system (RCP4.5)

Assessing the impact of sub-models – energy-balance components



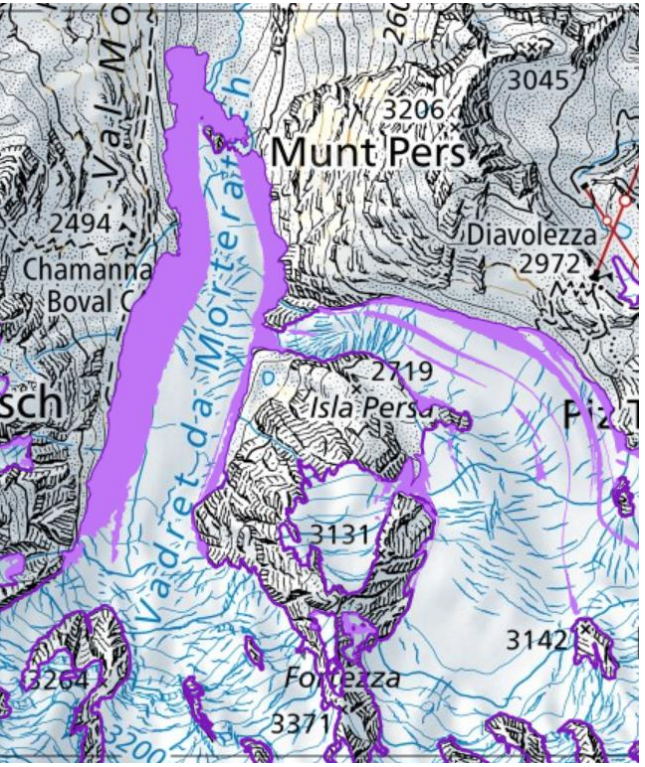
somewhat less mass loss without taking into account scenarios for humidity of the air mass

somewhat less mass loss by 2100 without taking into account changes in short-wave radiation

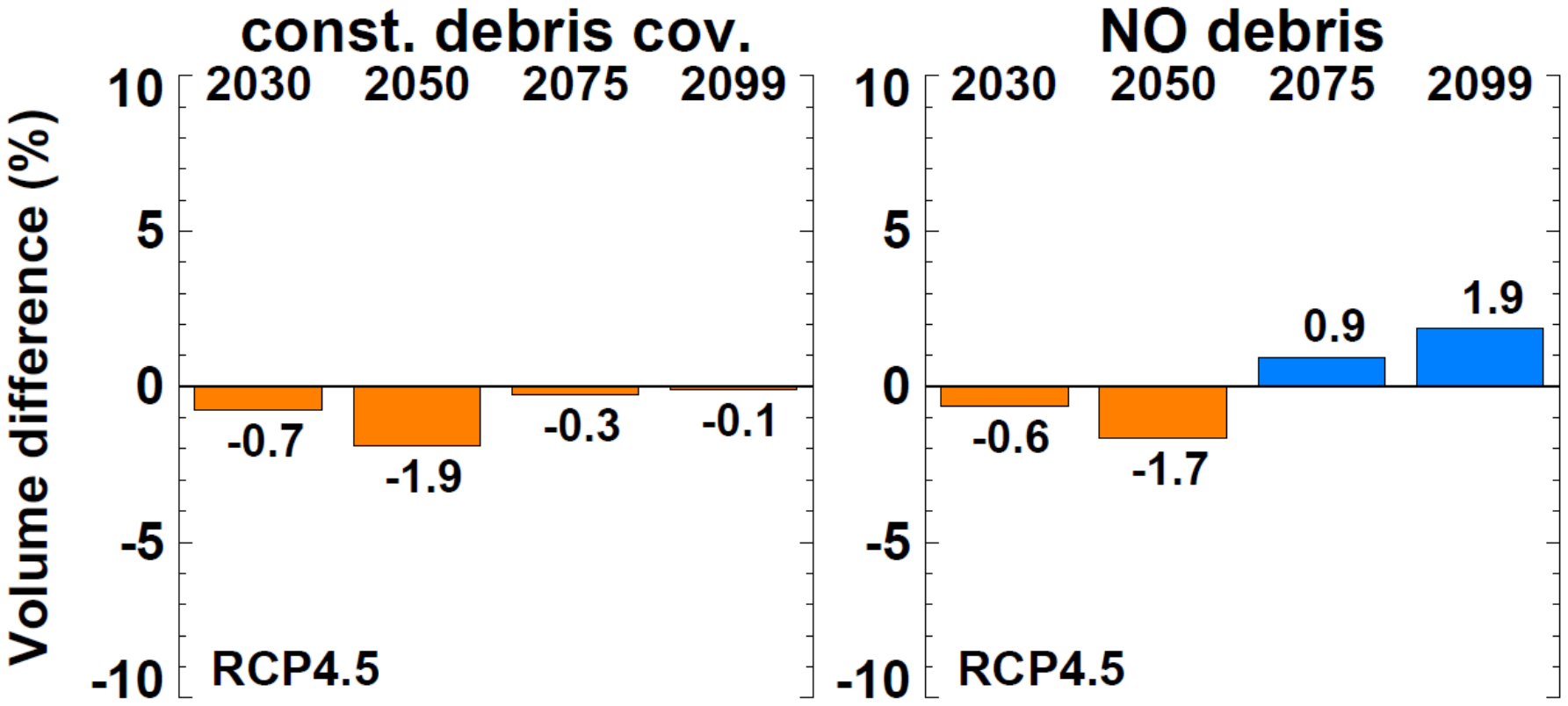
somewhat more mass loss without changes in wind speed

➔ Small impact overall, but maybe worth to be considered

Assessing the impact of sub-models – debris cover



Debris coverage is moderate at present (purple, ca. 10%)



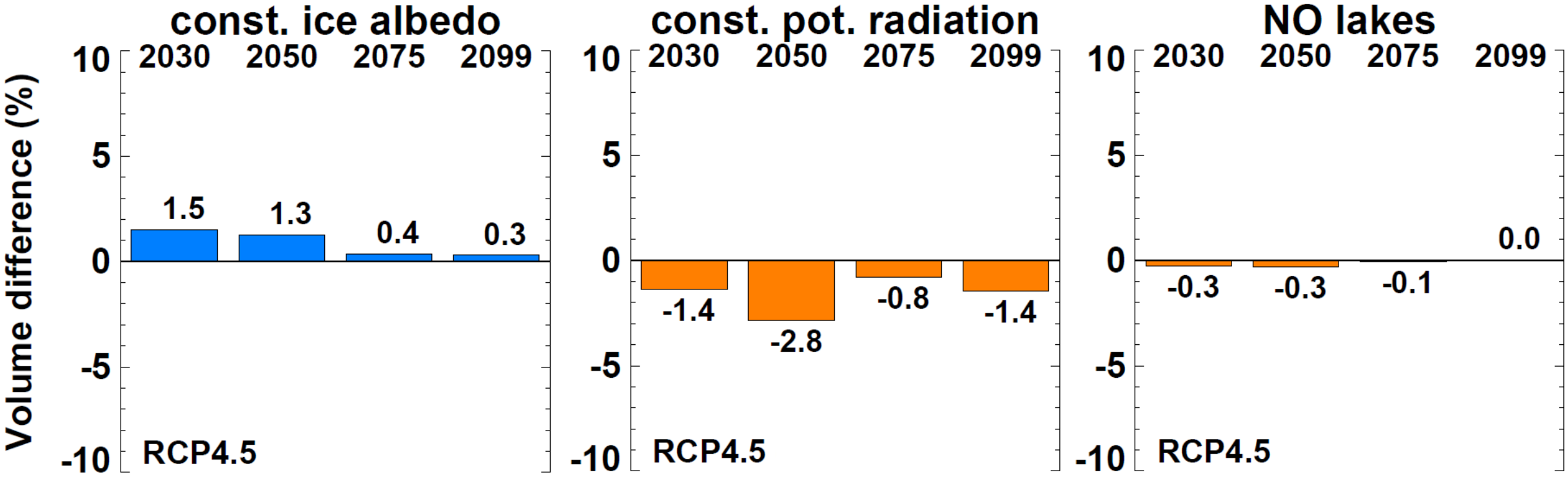
Only minor impact of thickening and expanding debris coverage!

NOT accounting for debris at all leads to larger glacier volume by 2100! (Explained by mass balance sensitivity, calibrated with observations)

➔ **Feedbacks of debris cover are relatively small**

Assessing the impact of sub-models

– ice albedo decrease, shading at valley floor, potential lakes



somewhat less mass loss when NOT accounting for future ice ice albedo decrease

more mass loss when NOT accounting for lowering of glaciers into the shaded valley

very small impact when NOT accounting for impact of proglacial lakes (compensating effects of glacier area!)

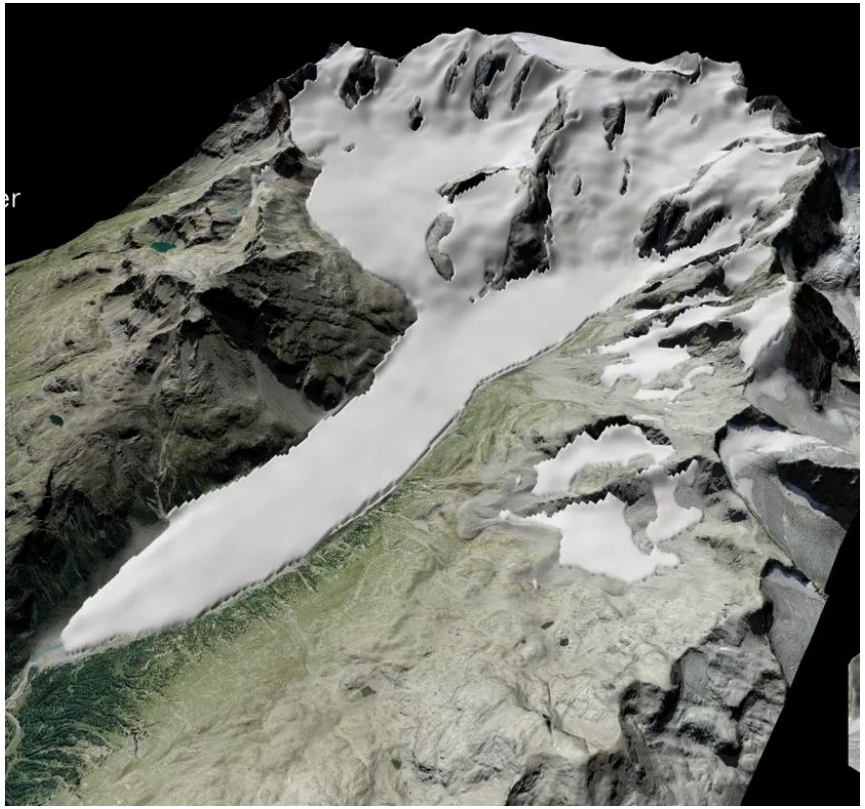
➔ Rather small impacts of feedbacks

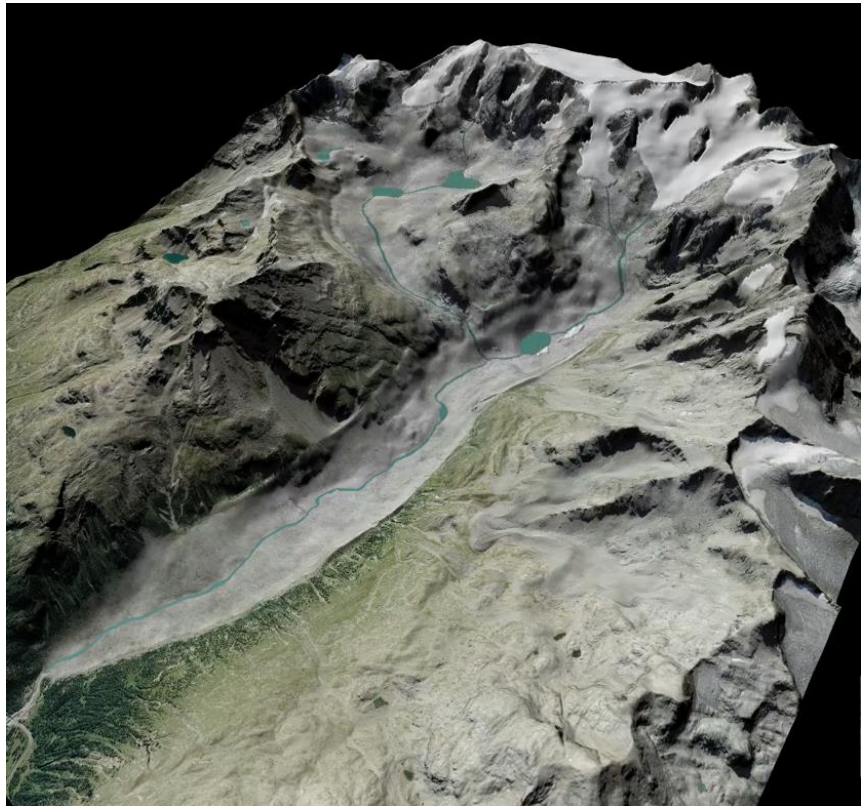
Modelling future glacier change:

(1) Most important uncertainty: Future climate evolution

(2) Data basis for model initialisation (ice thickness) and calibration (seasonal mass balance, volume change etc.) is crucial!

(3) Impact of model choice and various feedback effects relatively limited compared to (1) and (2)





Artificially saving Morteratsch?

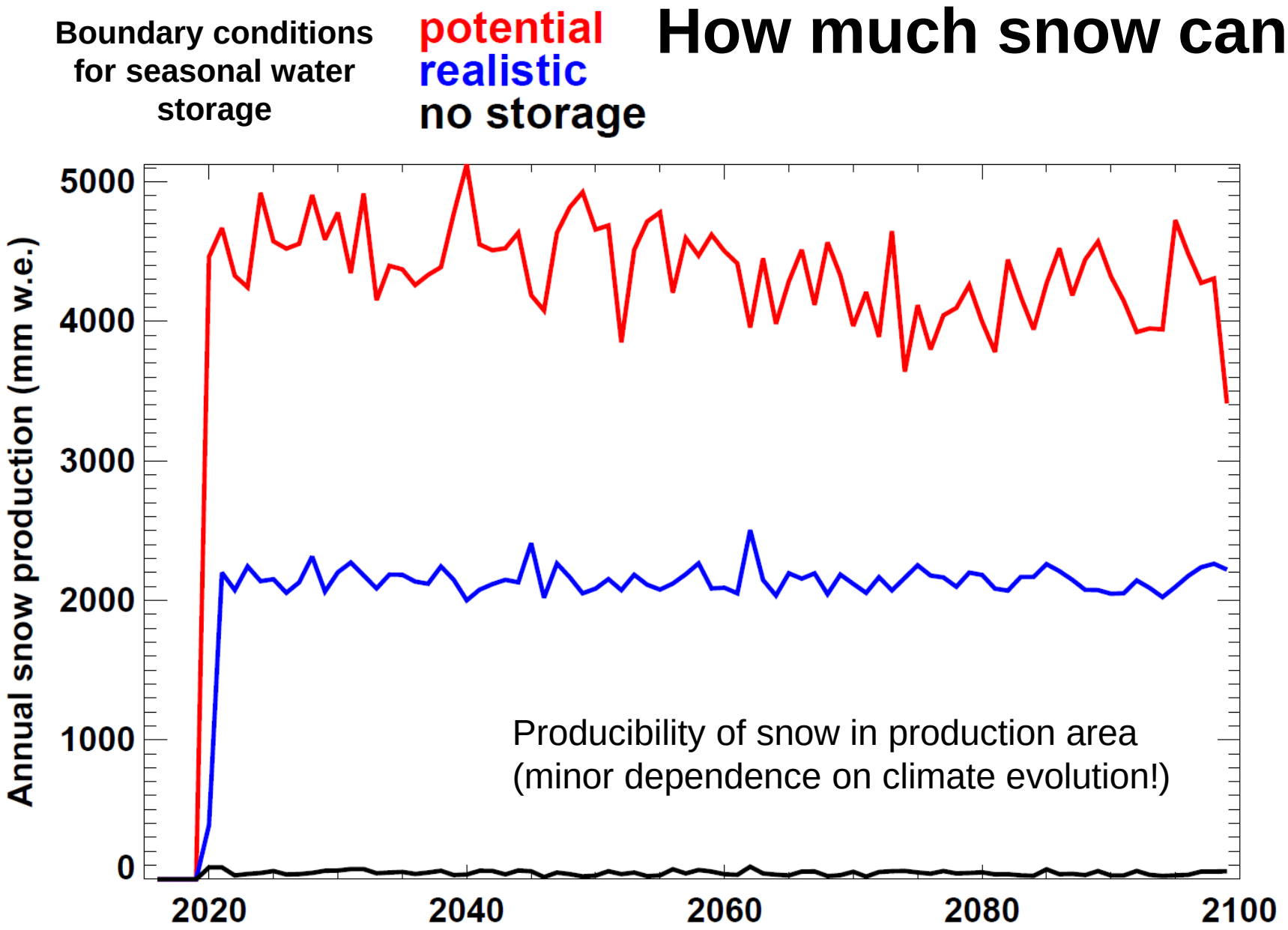
(see Oerlemans et al., 2009, for details)

Area with artificial snow production

Artificial water storage lake
(max. 2 mio. m³ feasible)

Catchment of storage lake

How much snow can be produced?



A full glacio-hydrological model for water availability and producibility of snow under local meteorological conditions

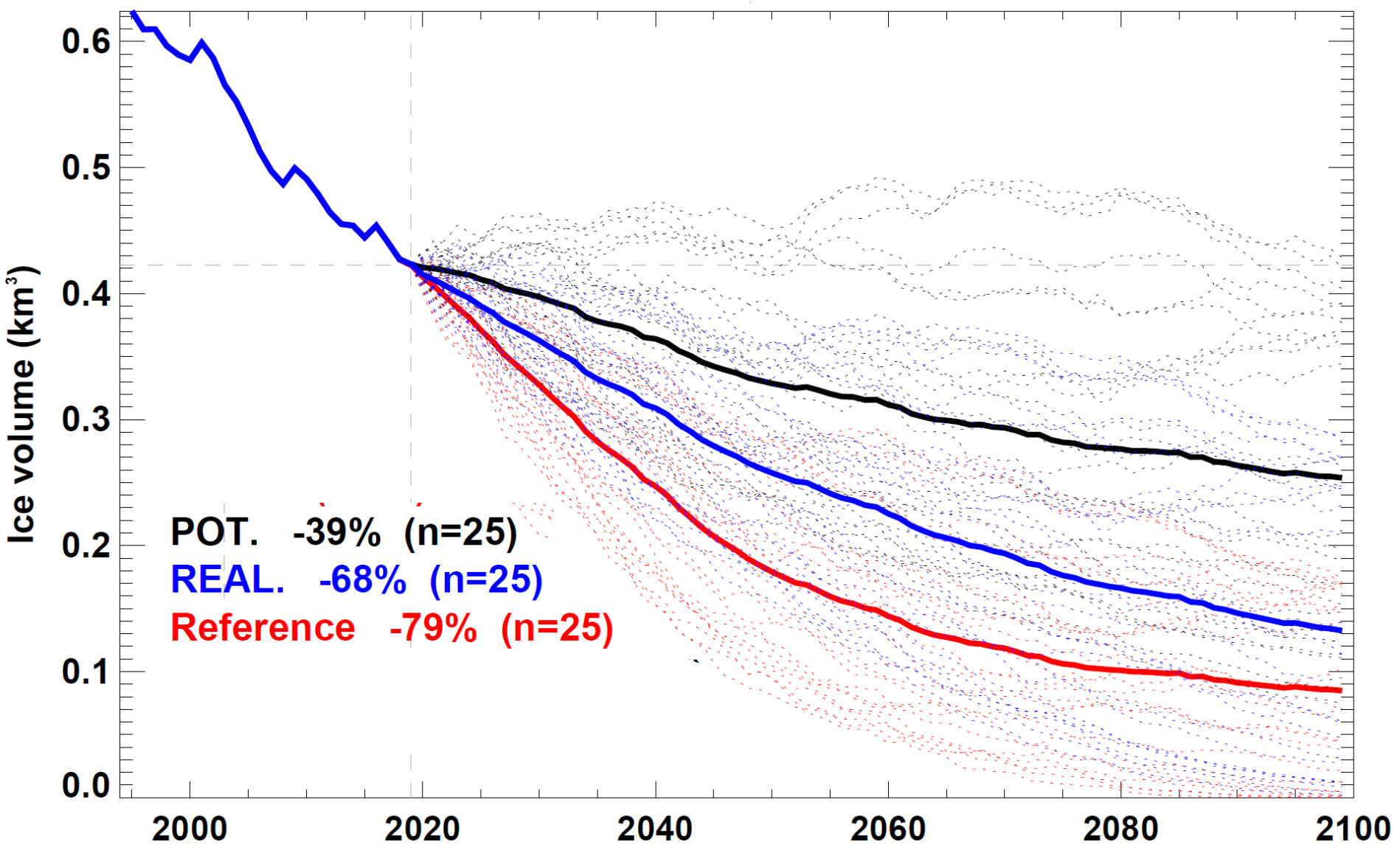
Bottleneck:
Water availability!

Three scenarios:
potential: infinite amount of water available for snow production

realistic: Reservoir lake with 2 mio. m^3, actually available amount of water

No water storage installed

Effect of artificial snow production (RCP4.5)



POT. (potential): infinite amount of water available

REAL. (realistic): Reservoir lake with 2 mio m³, actually available amount of water

Reference: no artificial interaction

Just main branch (Morteratsch)

➔ Artificial snow production cannot save the glacier but reduce losses!

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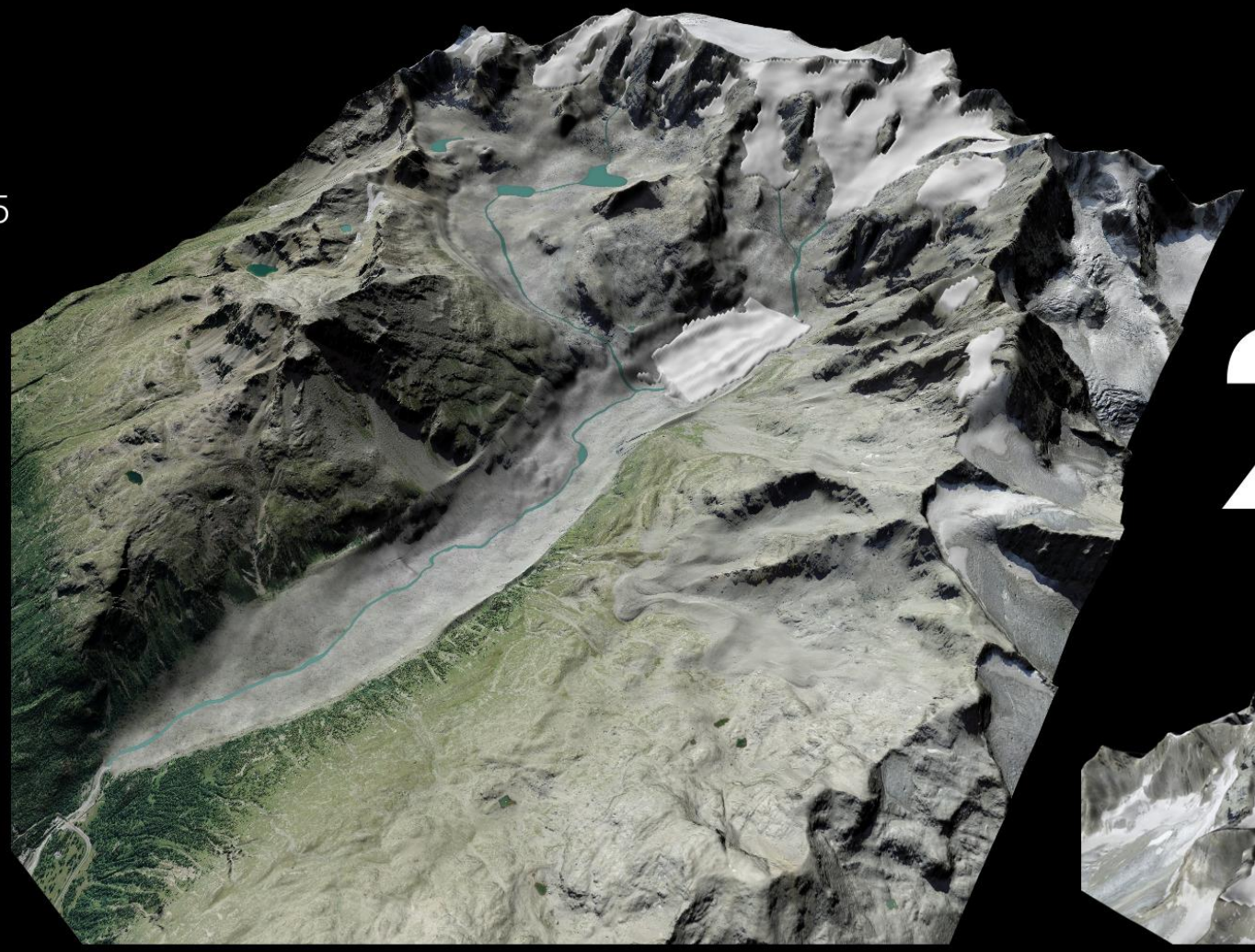
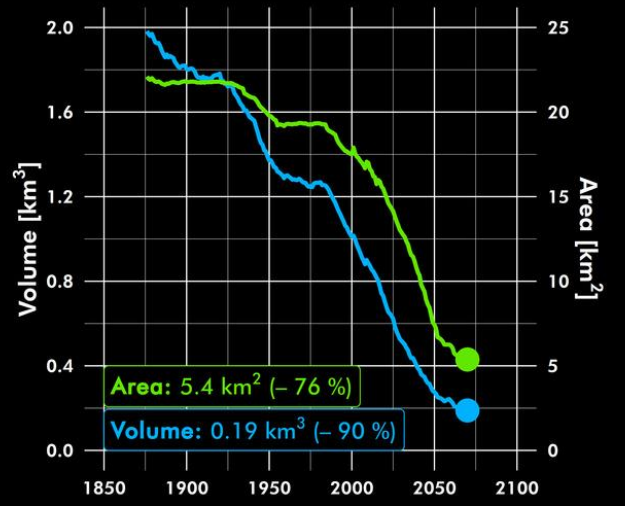
Model: temperature index
Climate scenario: RCP4.5
realistic snow





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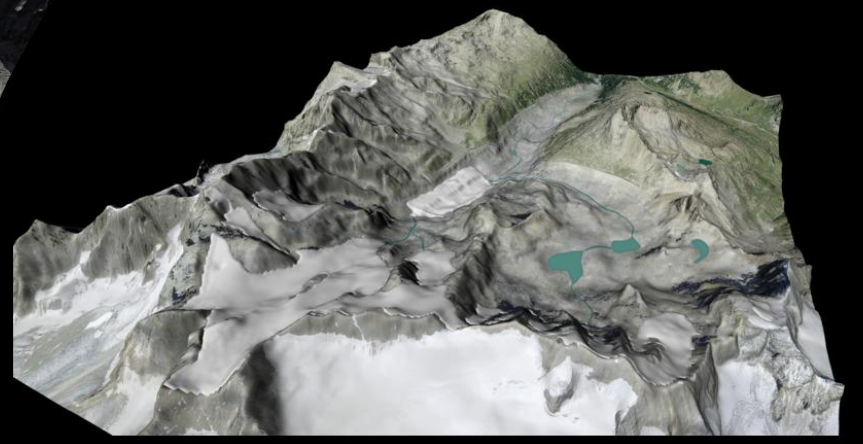

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Animations

Median of CO_2-emission scenarios:

https://youtu.be/vgwS-n49tss **RCP4.5**

https://youtu.be/KW1uKvO56iA **RCP8.5**

https://youtu.be/kK54zeb3tAs **RCP2.6**

With artificial interaction (snow production):

https://youtu.be/6mfwZEgfe24 **RCP4.5, unlimited water availability**

https://youtu.be/9qZk8QusJcY **RCP4.5, realistic water availability (feasible storage lake)**

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