Advances in Snow and High-Altitude Modelling

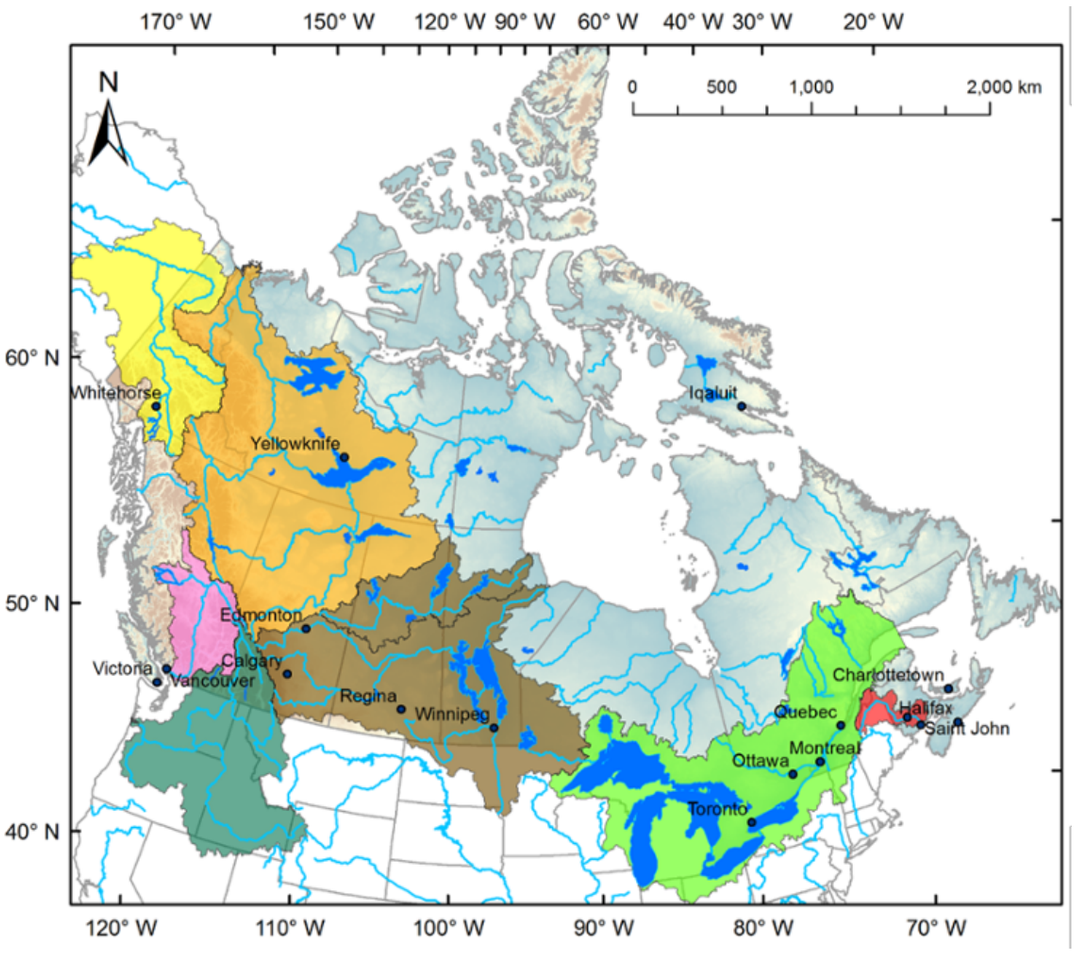
V. Vionnet[1], C. Marsh[1], B. Menounos[2], J. W. Pomeroy[1]

with the contribution of colleagues at University of Saskatchewan, University of Northern British Columbia and Environment and Climate Change Canada

[1] Centre for Hydrology, University of Saskatchewan, Saskatoon, Canada

[2] University of Northern British Columbia, Prince George, Canada

Mountain snow in Canada



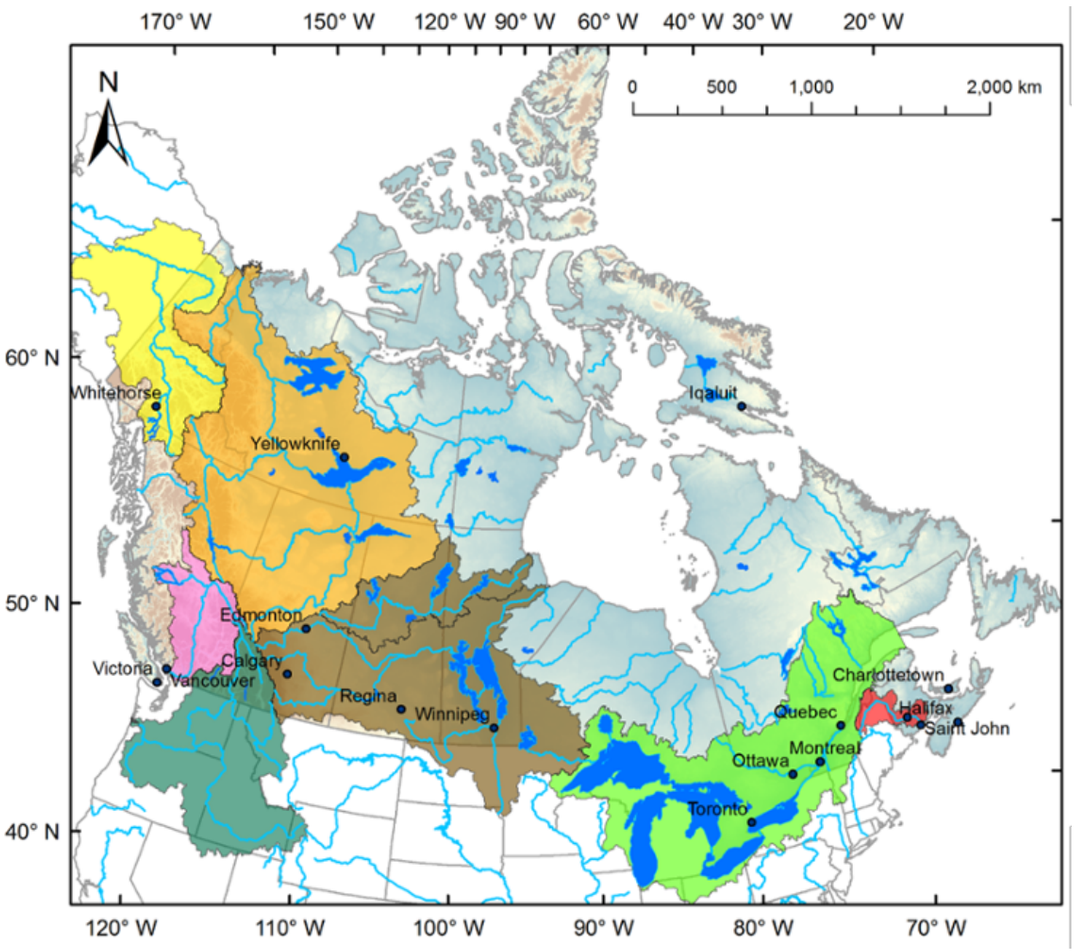
- Water stored as **snow in the mountains** represents a **key component** of the **hydrological cycle** of many **river basins** in **Canada**

- An accurate estimation of snow resources is crucial for **flood forecasting**, **water management**, **irrigation planning**, …





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Key questions in mountain snow hydrology:

- **How much is there?**
- **How fast does it melt?**

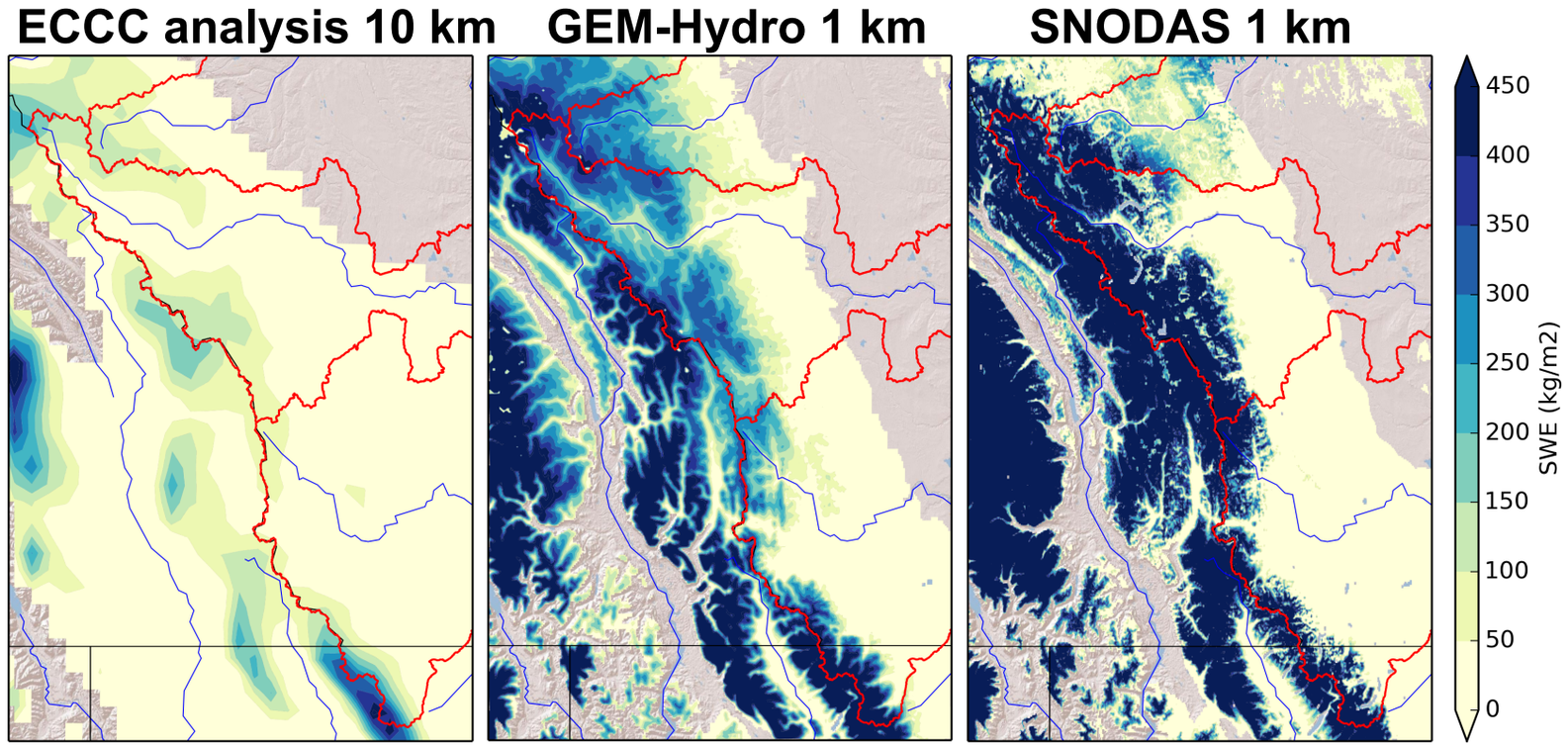
Available gridded snow products

- Several gridded snow products are available across the mountains of Canada:
  - **ECCC snow analysis** at 10 and 2.5 km
  - **US** snow analysis **SNODAS** at 1 km (up to 54 N)
  - Output of **hydrological models** such as **GEM-Hydro, VIC, …**
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- Example: **snow conditions** during **winter 2012/2013** before the Alberta flood in June 2013
- Large differences between the datasets close to peak SWE
- Impact on SWE estimation at the time of the flood



SWE on 1st May 2013 over the upper Bow and Elbow river catchments

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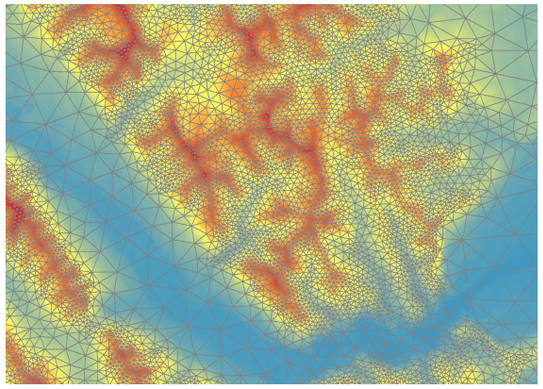
No reference snow products for the Canadian mountains

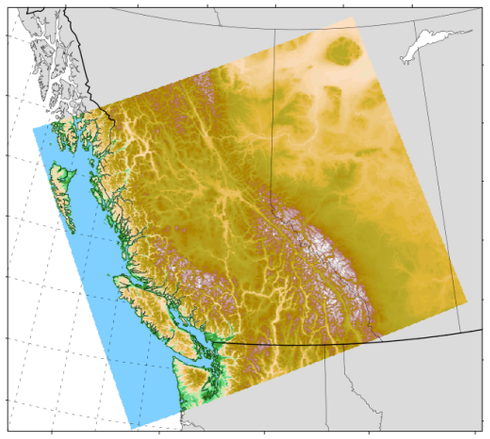
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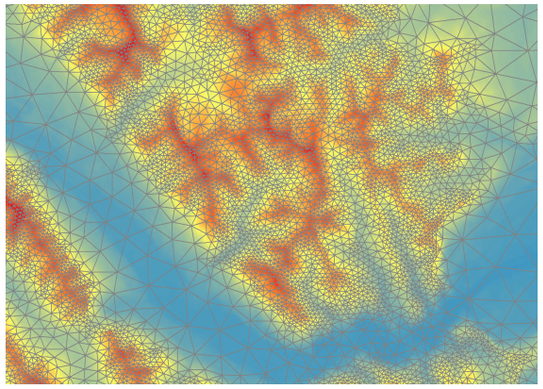


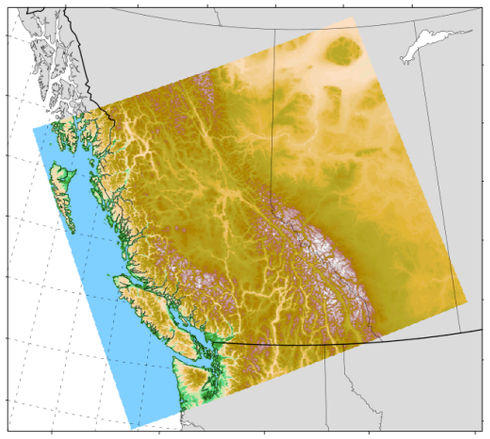




Towards a reference snow product

- Capturing the **spatial** and **temporal variability** of snow water resources in mountainous terrain

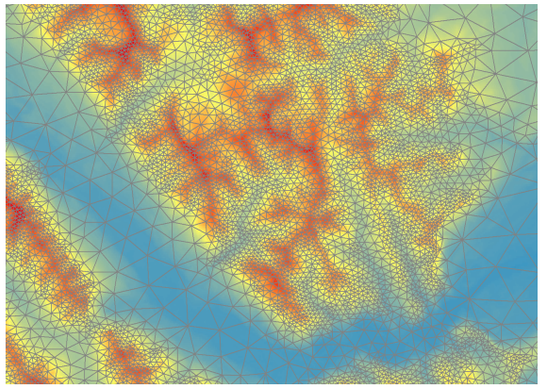


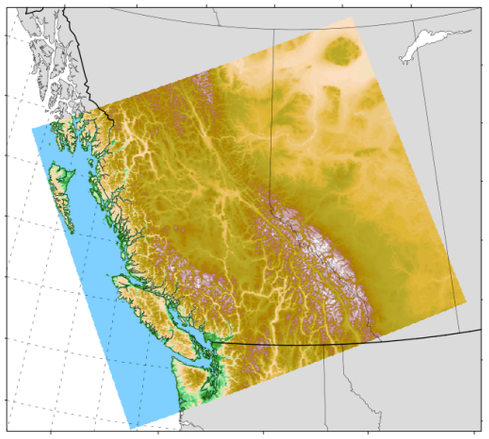




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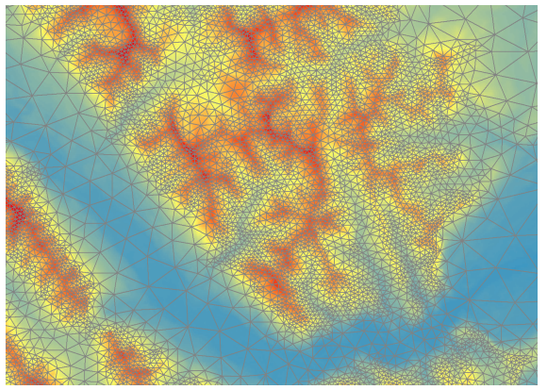
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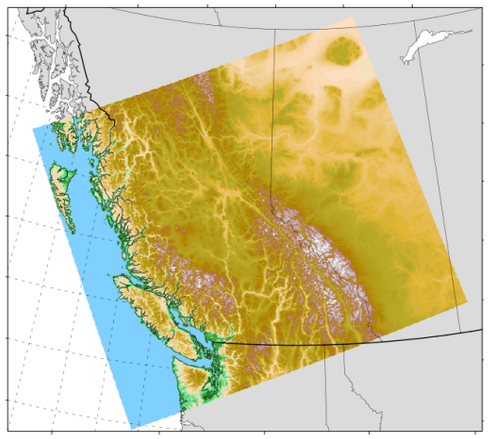




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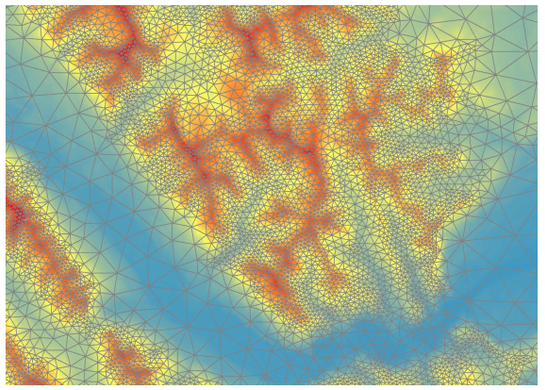


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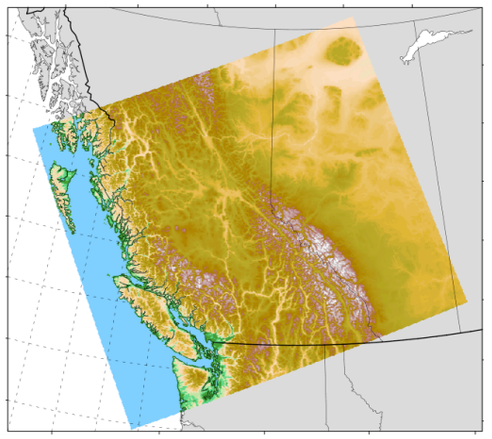




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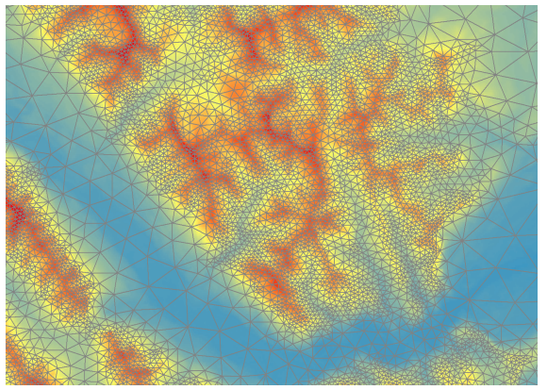


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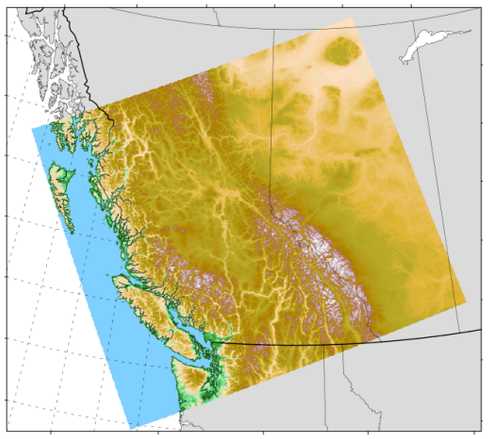




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- Able to **assimilate** the latest products available in **snow remote sensing** (**Lidar**-derived maps of **snow depth**, high-resolution maps of **snow cover** from visible **satellite imagery**, …)



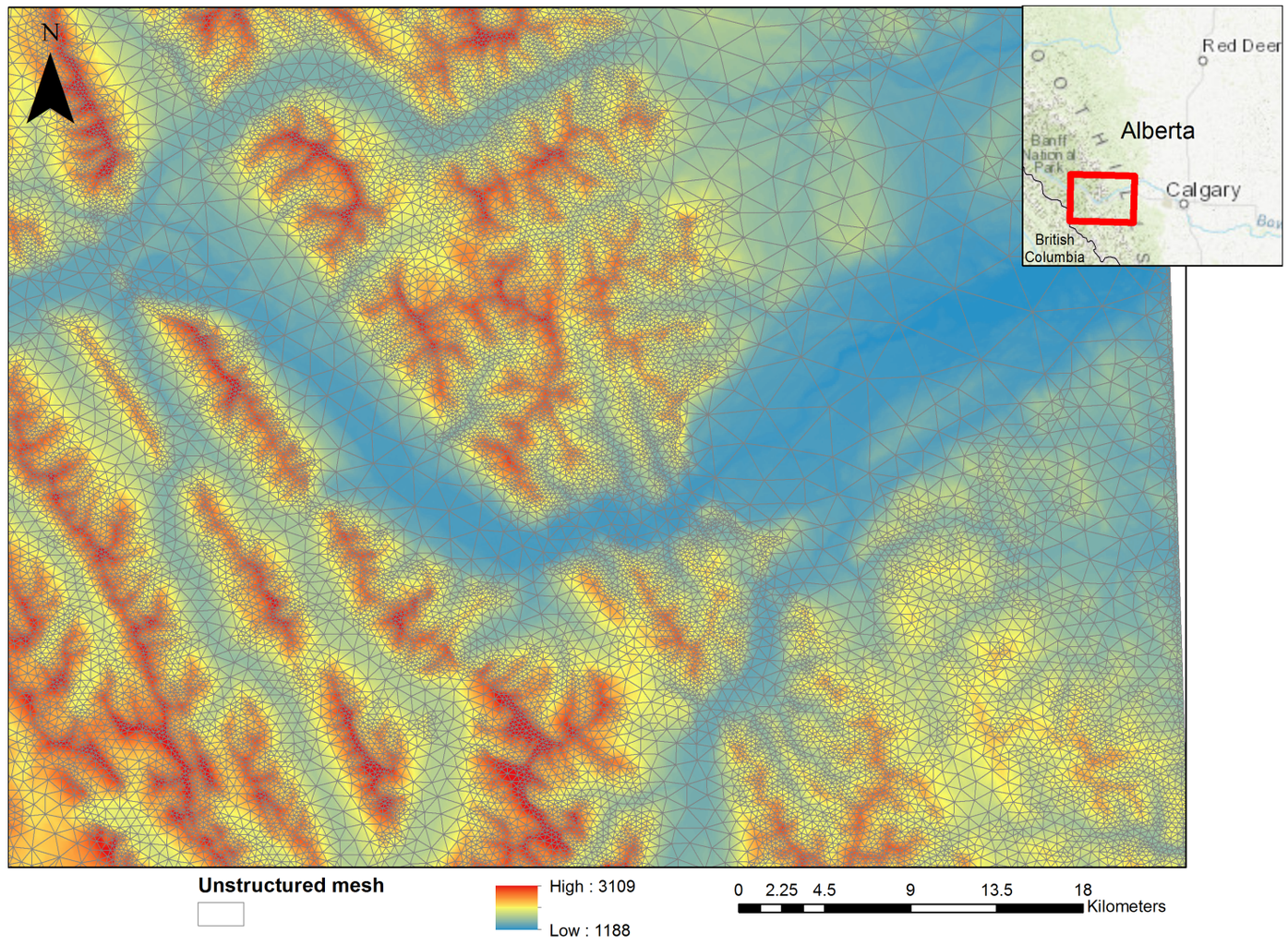


5-m 3D map of snow depth derived from airborne Lidar over the Kananaskis region (Alberta) on 27 April 2018

Multi-scale variability of mountain snowpacks

Canadian Hydrological Model (CHM)

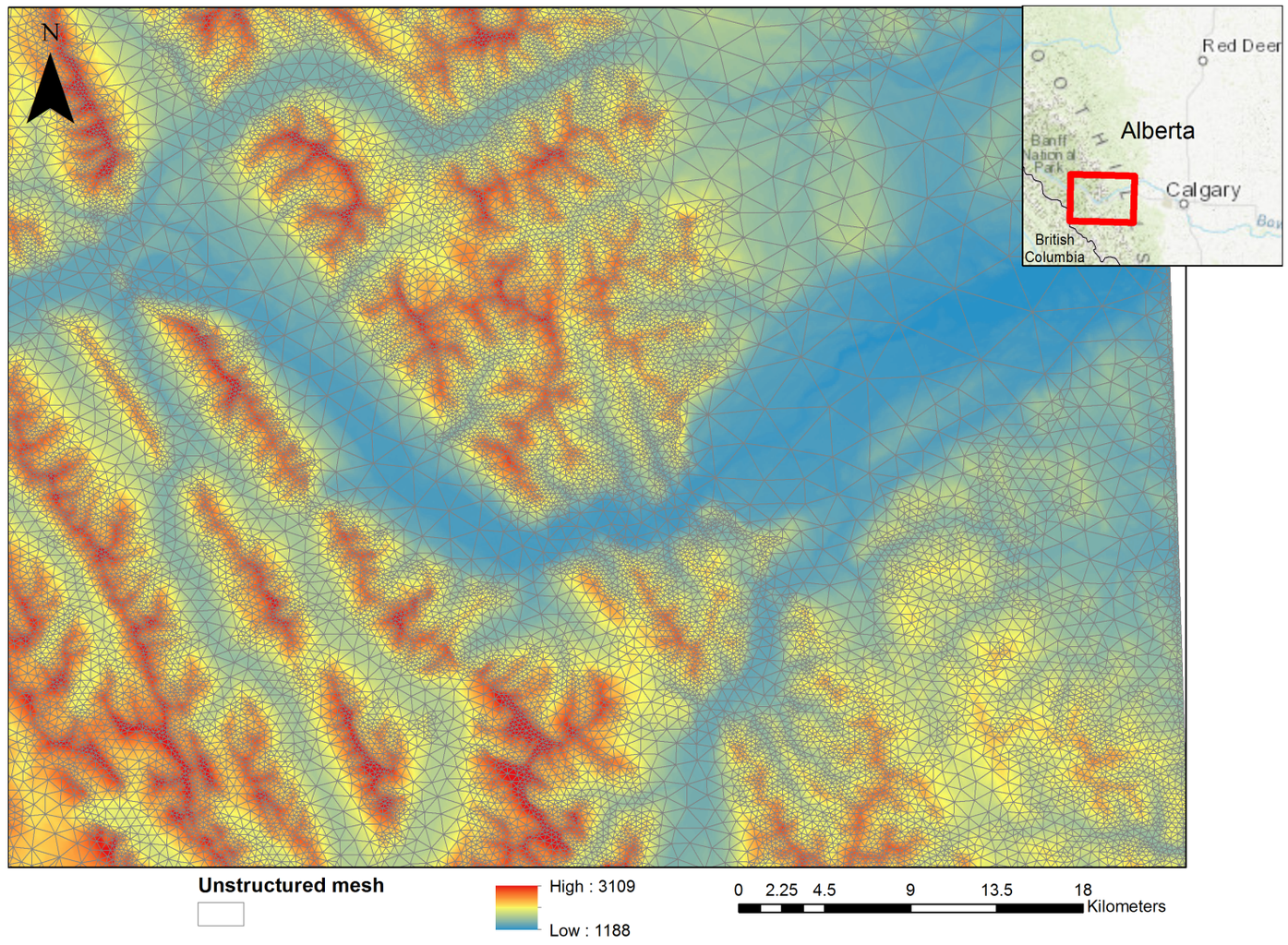
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Marsh et al. (2018)

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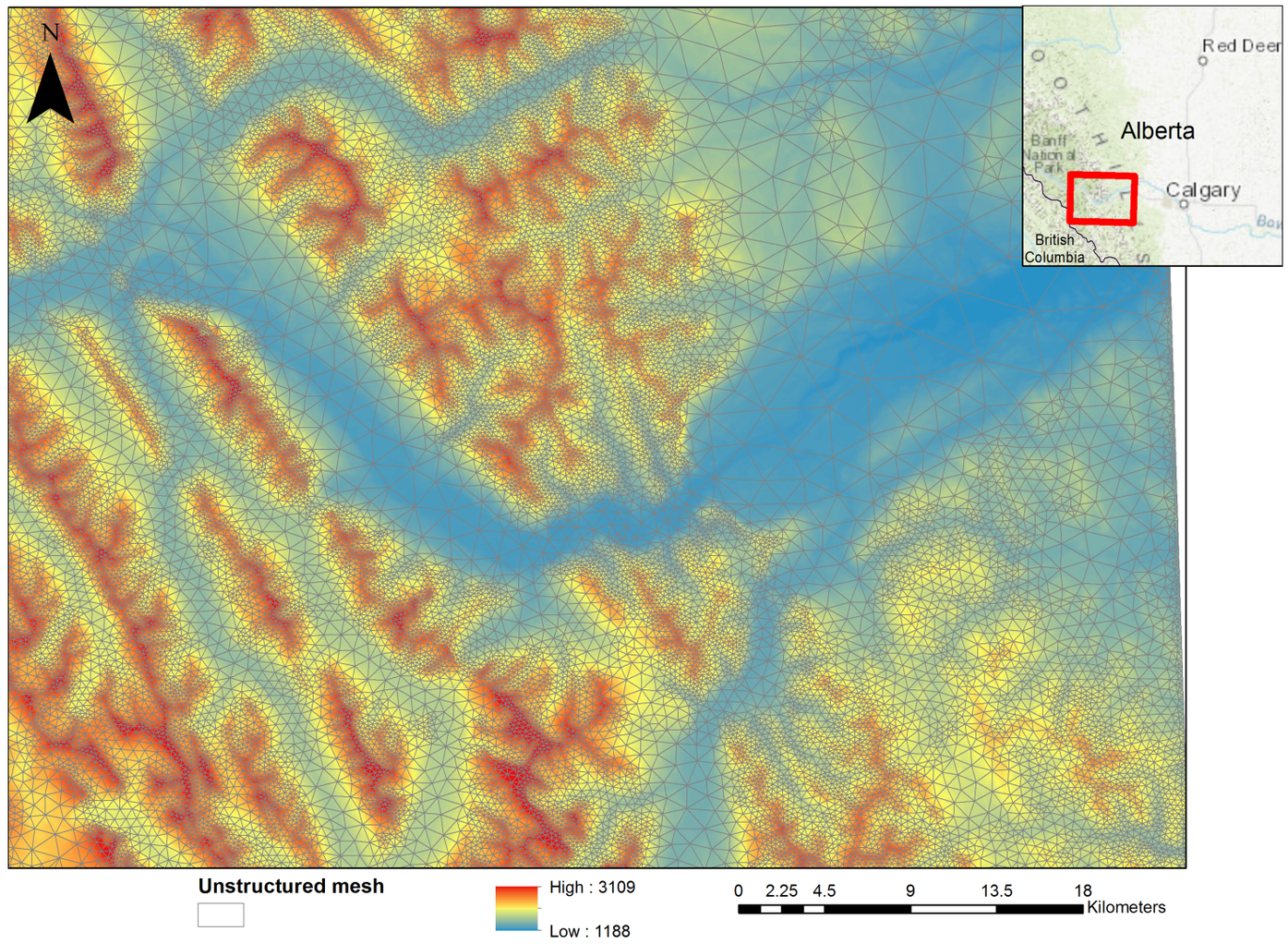
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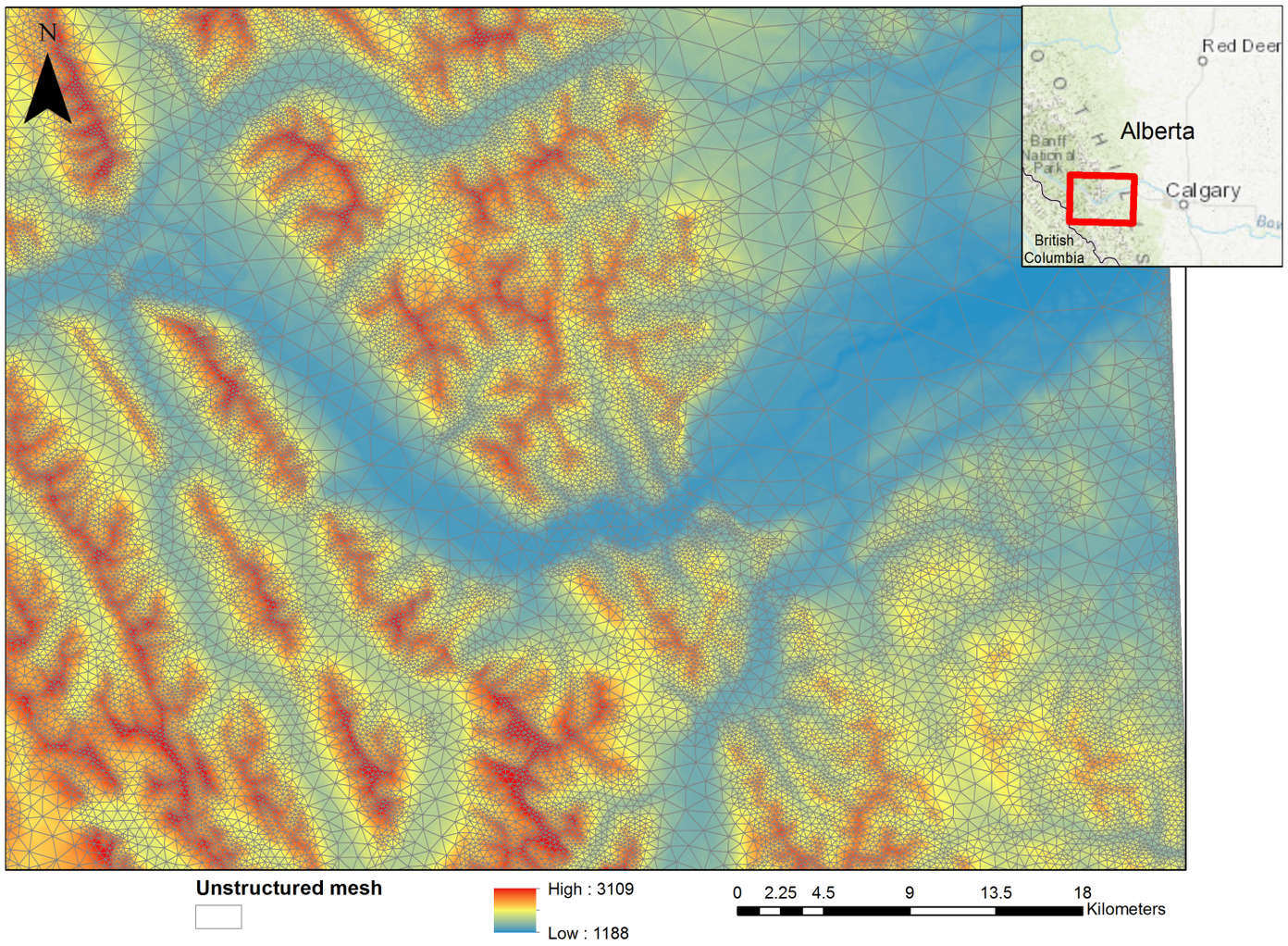
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Canadian Hydrological Model (CHM)

- **Multi-scale, multi-physics** and **variable complexity** model
- **Unstructured triangular mesh** depending on topography and vegetation complexity
- Includes state-of-the-art energy-balance **snowpack schemes**
- Accounts for:
  - **slope** and **aspect**; terrain **shading**
  - **gravitational redistribution**
  - **blowing snow** (redistribution + sublimation)
  - **snow/canopy interactions**

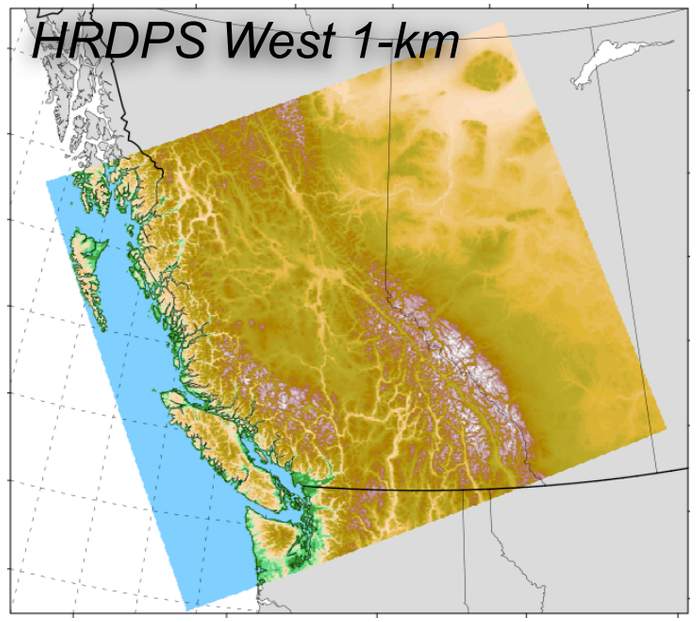


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5-m 3D map of snow depth derived from airborne Lidar over the Kananaskis region (Alberta)
Corresponding CHM mesh (red)

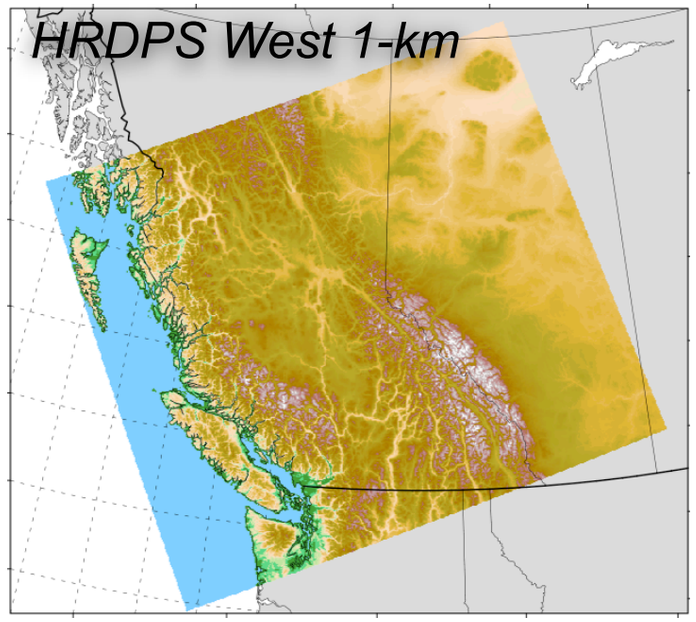
High-resolution driving data

- High-resolution atmospheric data are required to drive CHM
- Use of **ECCC high-resolution products**:
  - High Resolution Deterministic Prediction System (**HRPDS**): **2.5 km** over Canada (+ 1-km over Western Canada)
  - Canadian Precipitation Analysis (**CaPA**) at **2.5 km:** combines HRDPS precip. + radar & gauge measurements



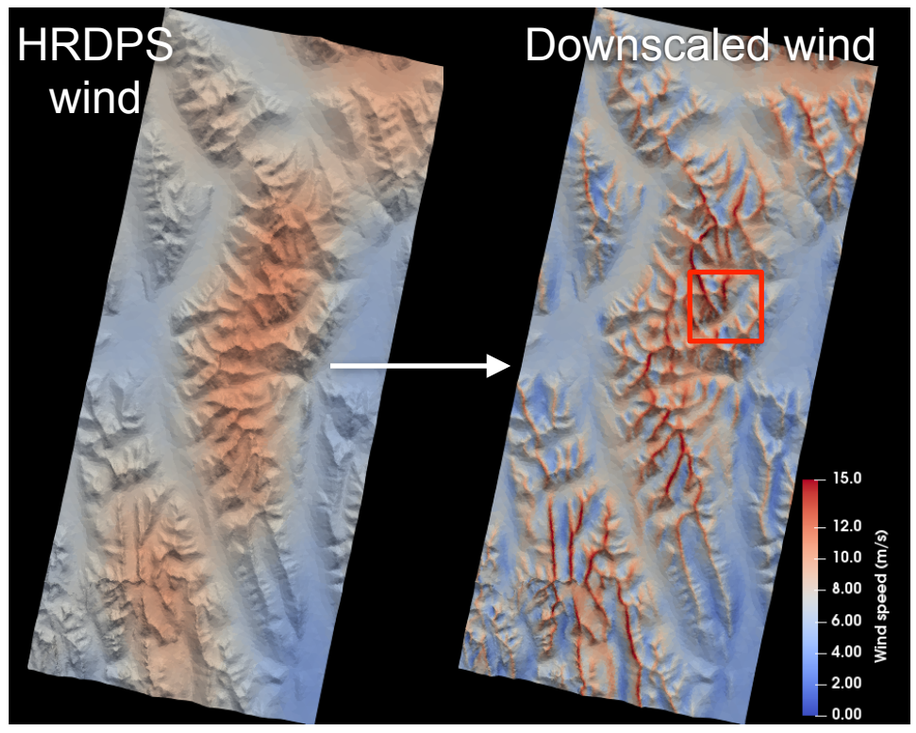
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Development of **innovative downscaling methods**

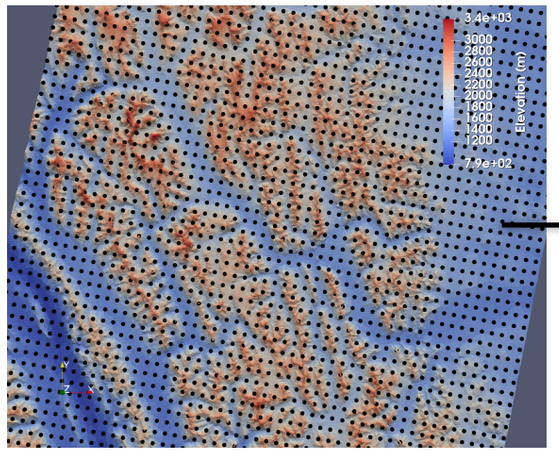
- **Wind field**: combination of HRDPS forecast + library of micro-scale wind fields from a diagnostic model
- Impact for snow hydrology
  - Redistribution by **blowing and drifting snow**
  - Spatial **variability** of **turbulent fluxes** (in particular during **rain-on-snow** events)



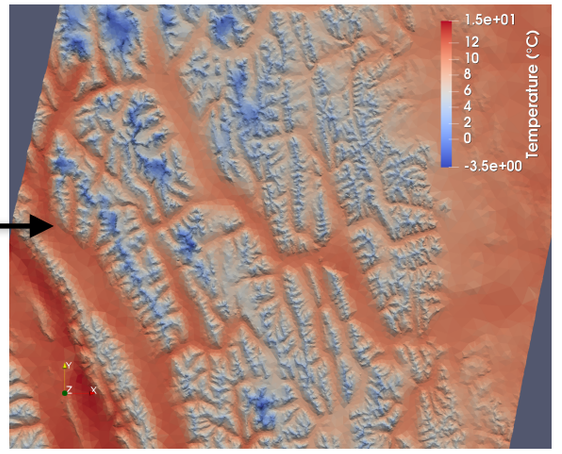
The Snowcast experiment

- CHM over the **upper Bow River basin** (16 000 km²)
- **Atmospheric driving data**: **HRDPS 2.5 km downscaled** to the CHM mesh
- Provide **forecasts** of **SWE, snow depth** and **melt runoff** up to **+ 48h**

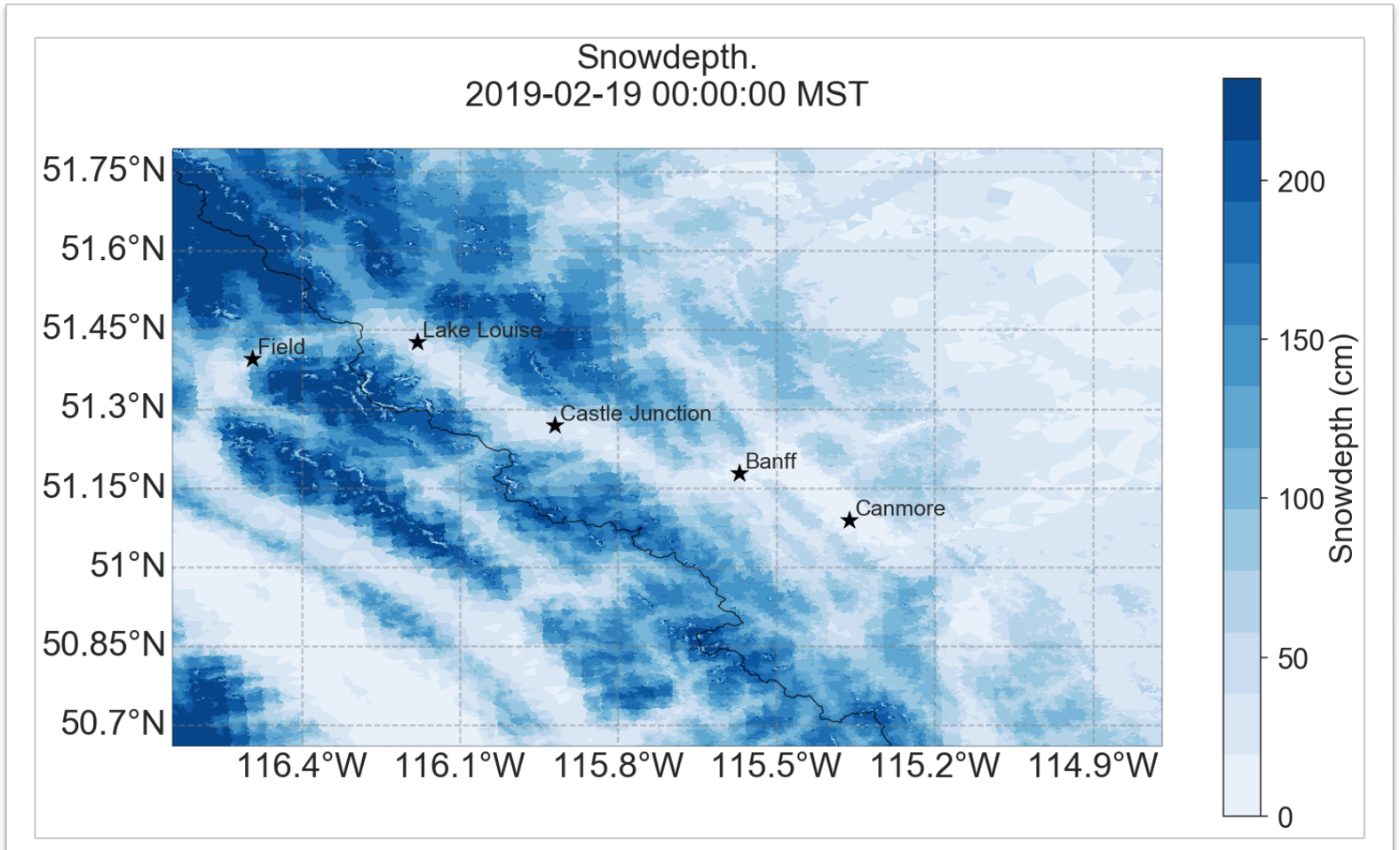
HRDPS points over the Snowcast domain



Downscaling to the CHM mesh



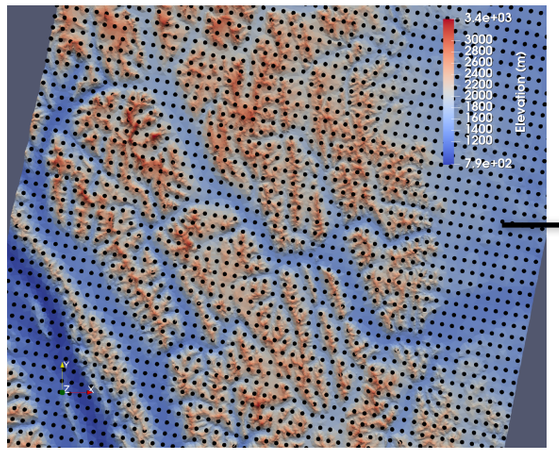
Daily output available at
http://www.snowcast.ca



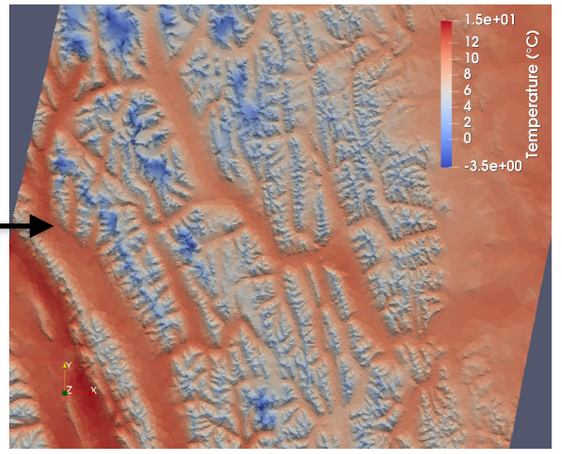
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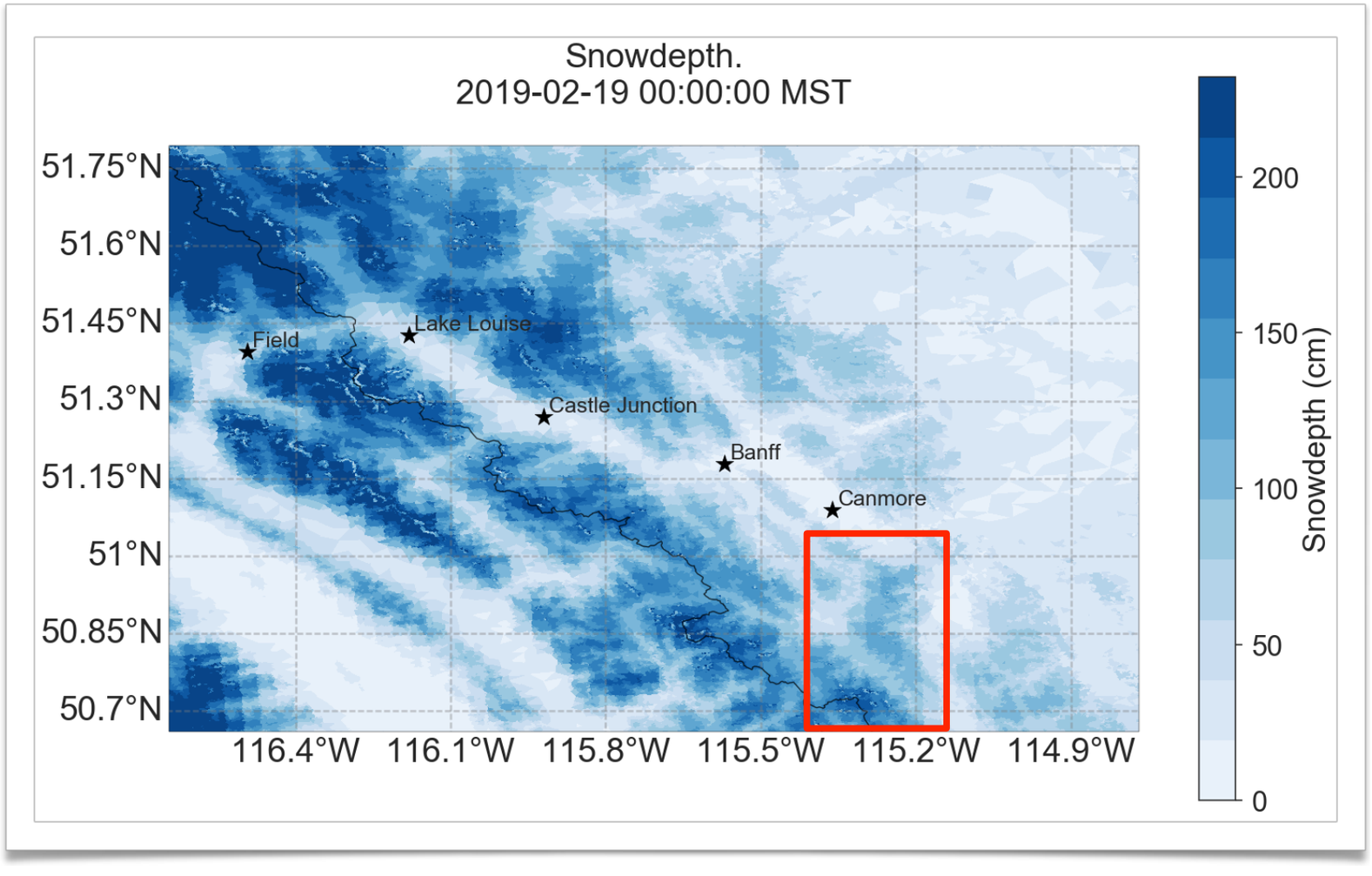
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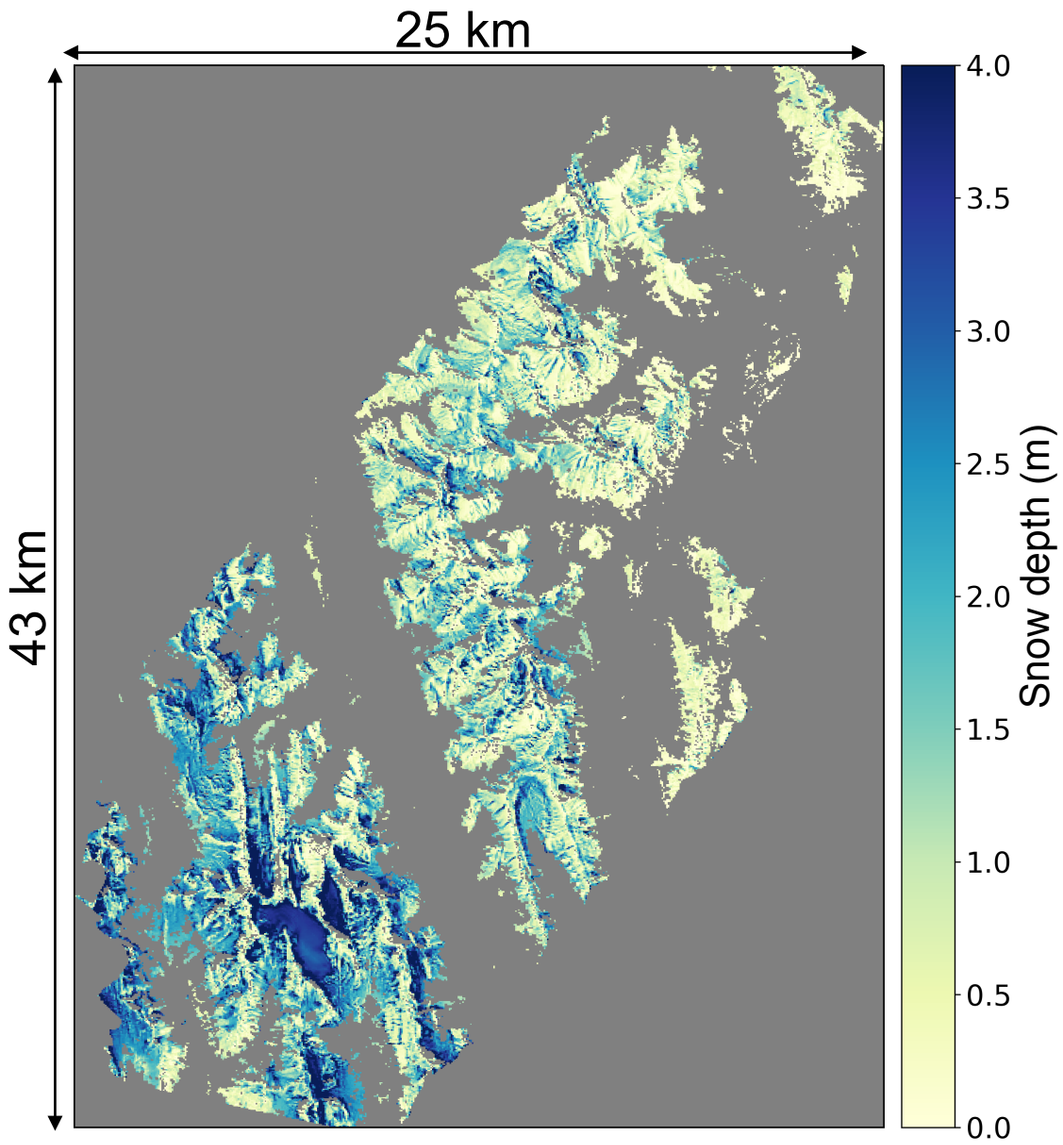
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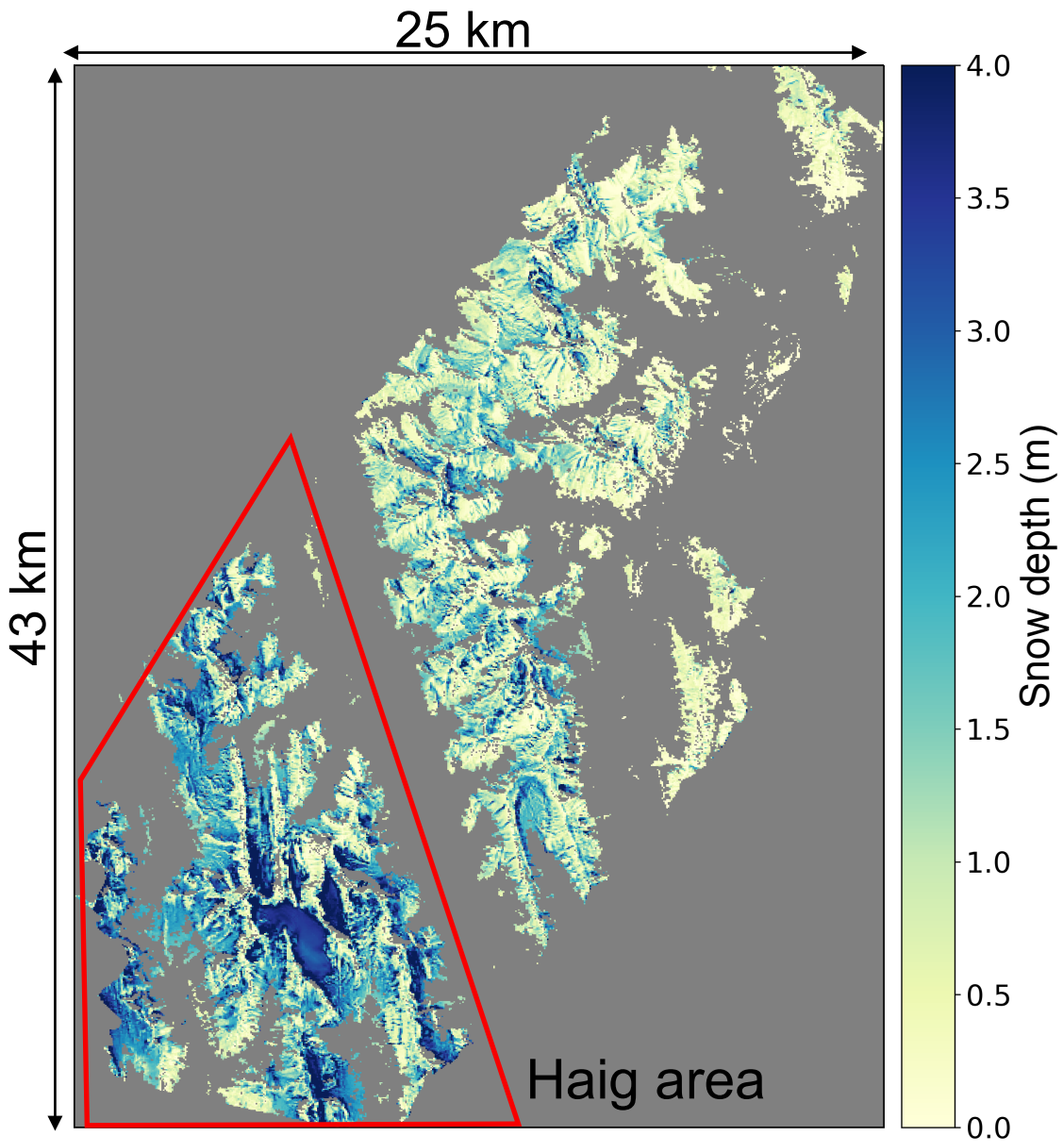


Importance of precipitation forcing



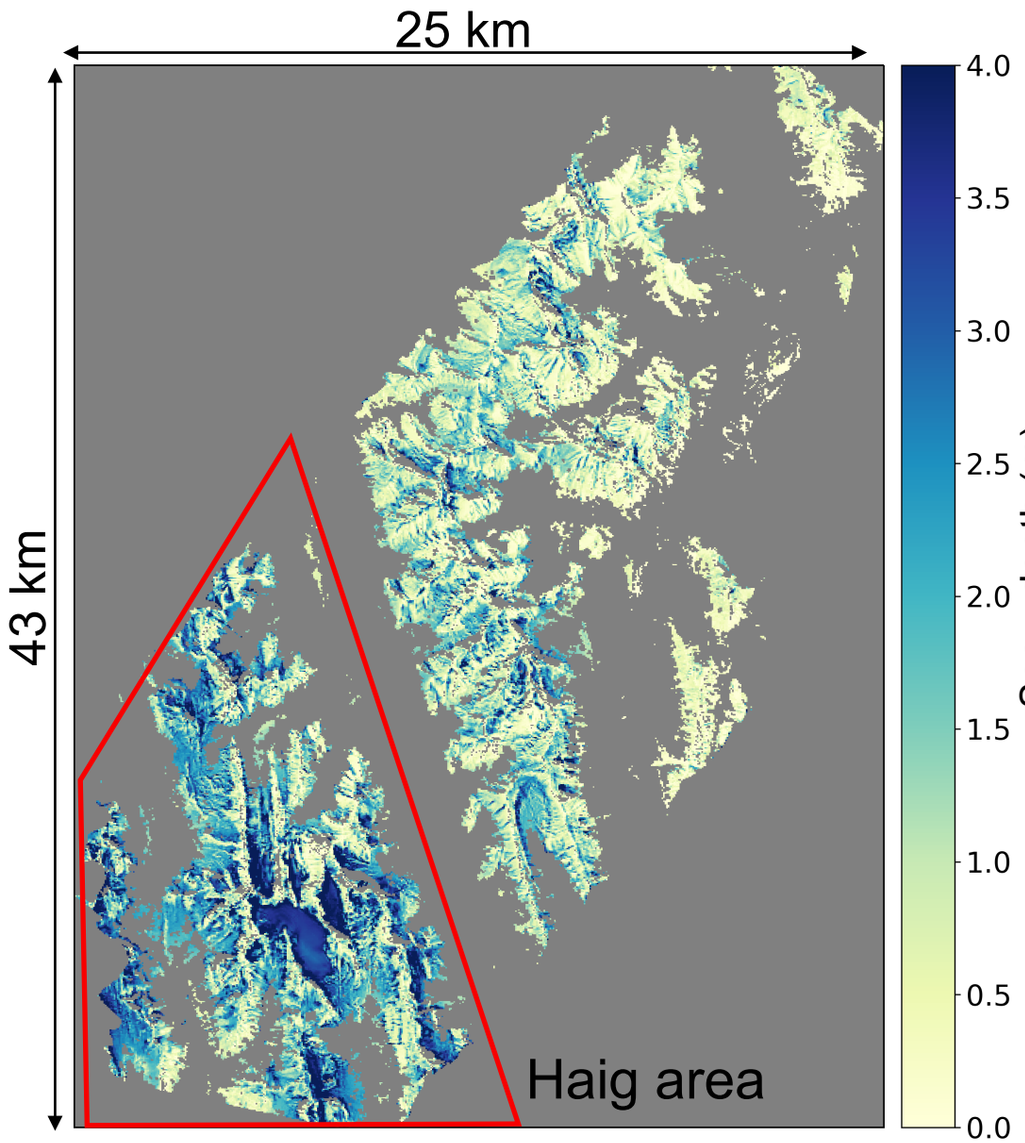
Lidar-derived 50-m map of snow depth on 27 April 2018 (non-forested areas)

Importance of precipitation forcing



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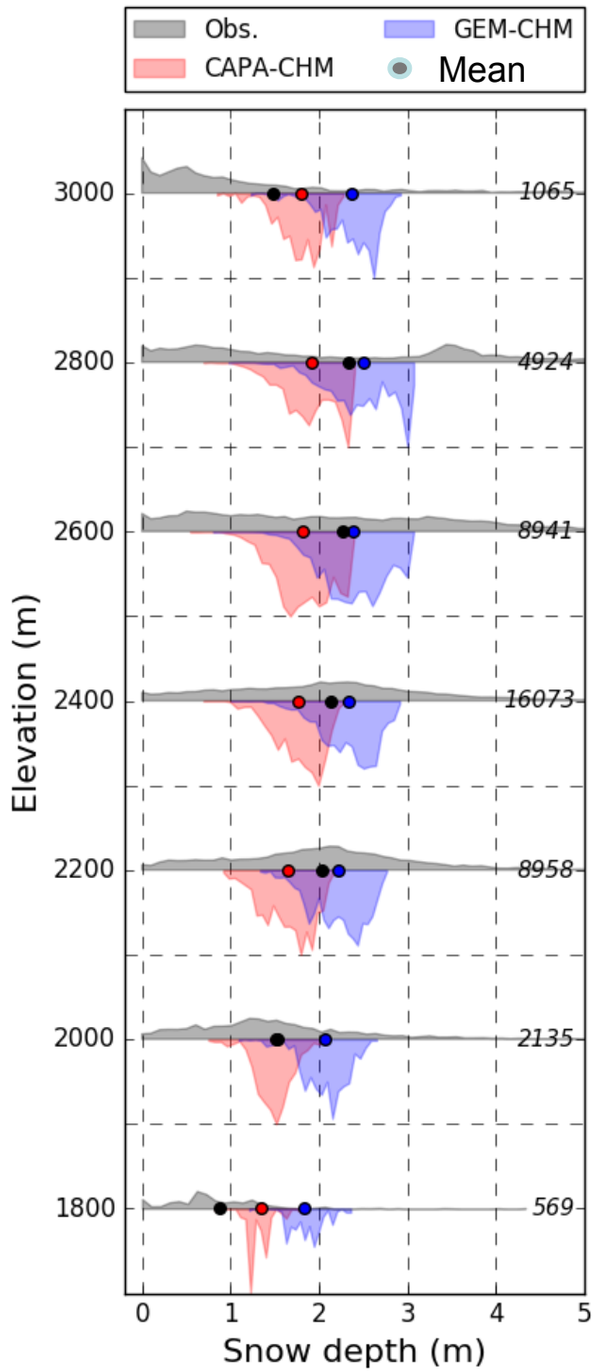
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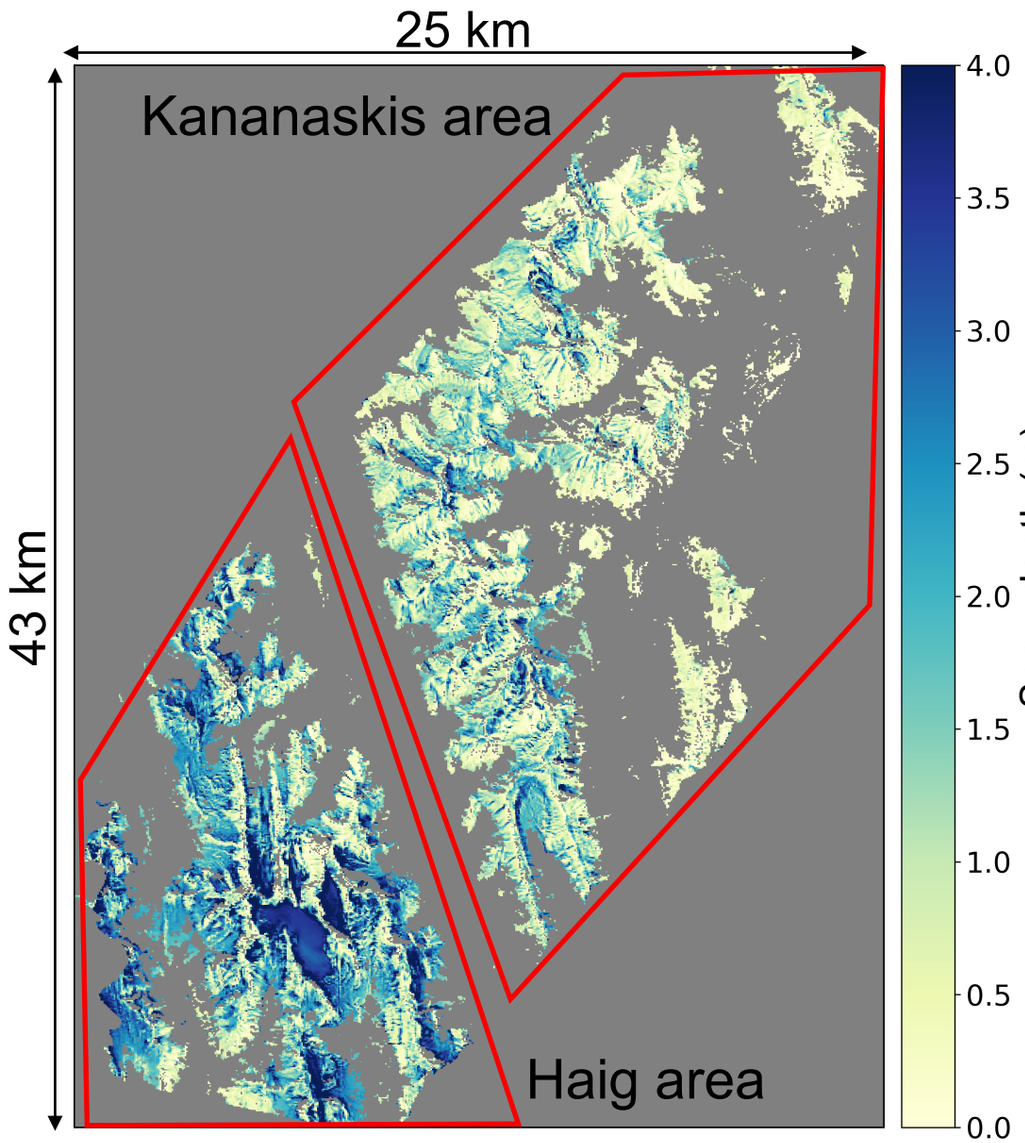
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Snow depth variability per 200-m elevation band

Haig area

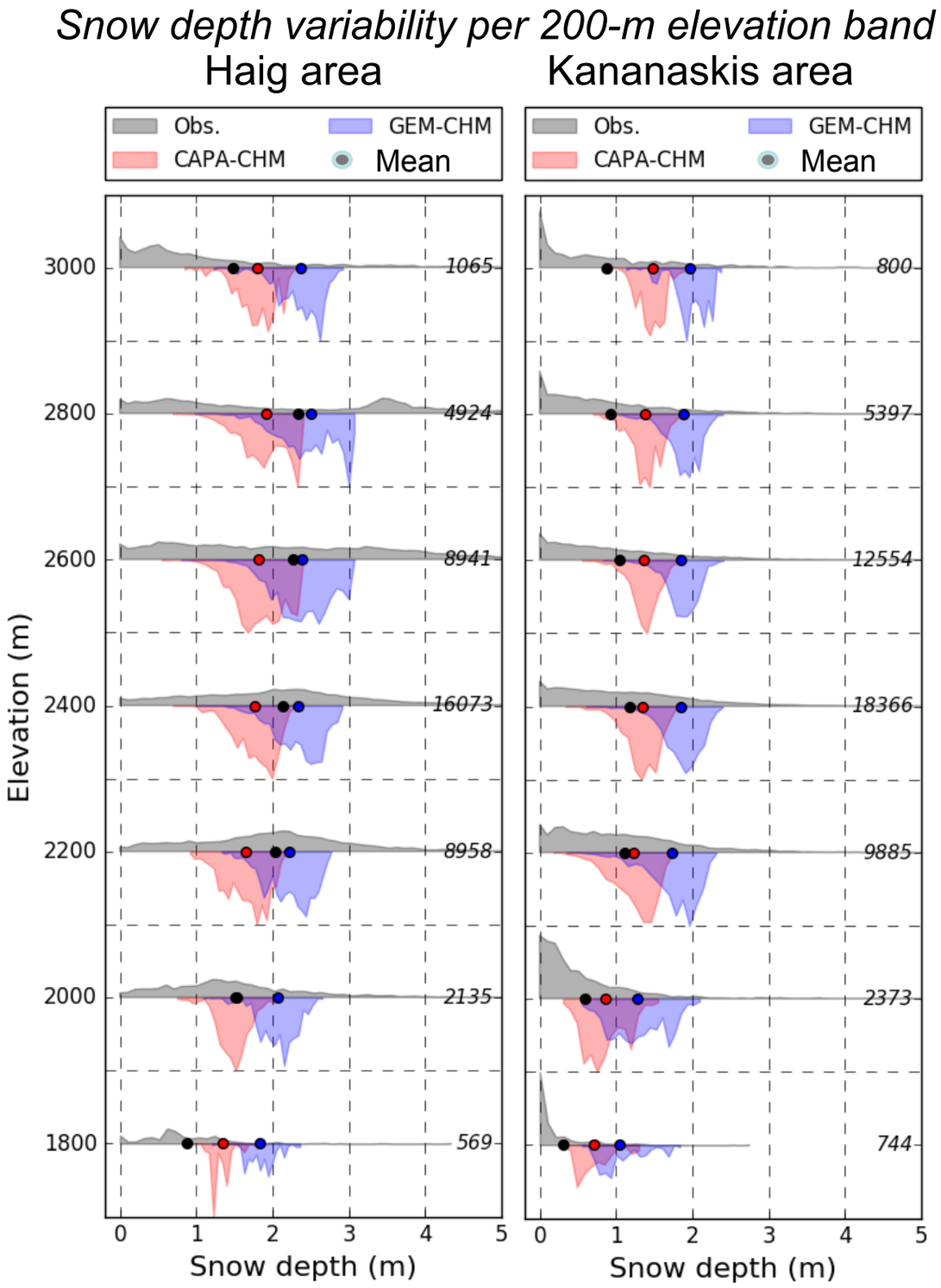


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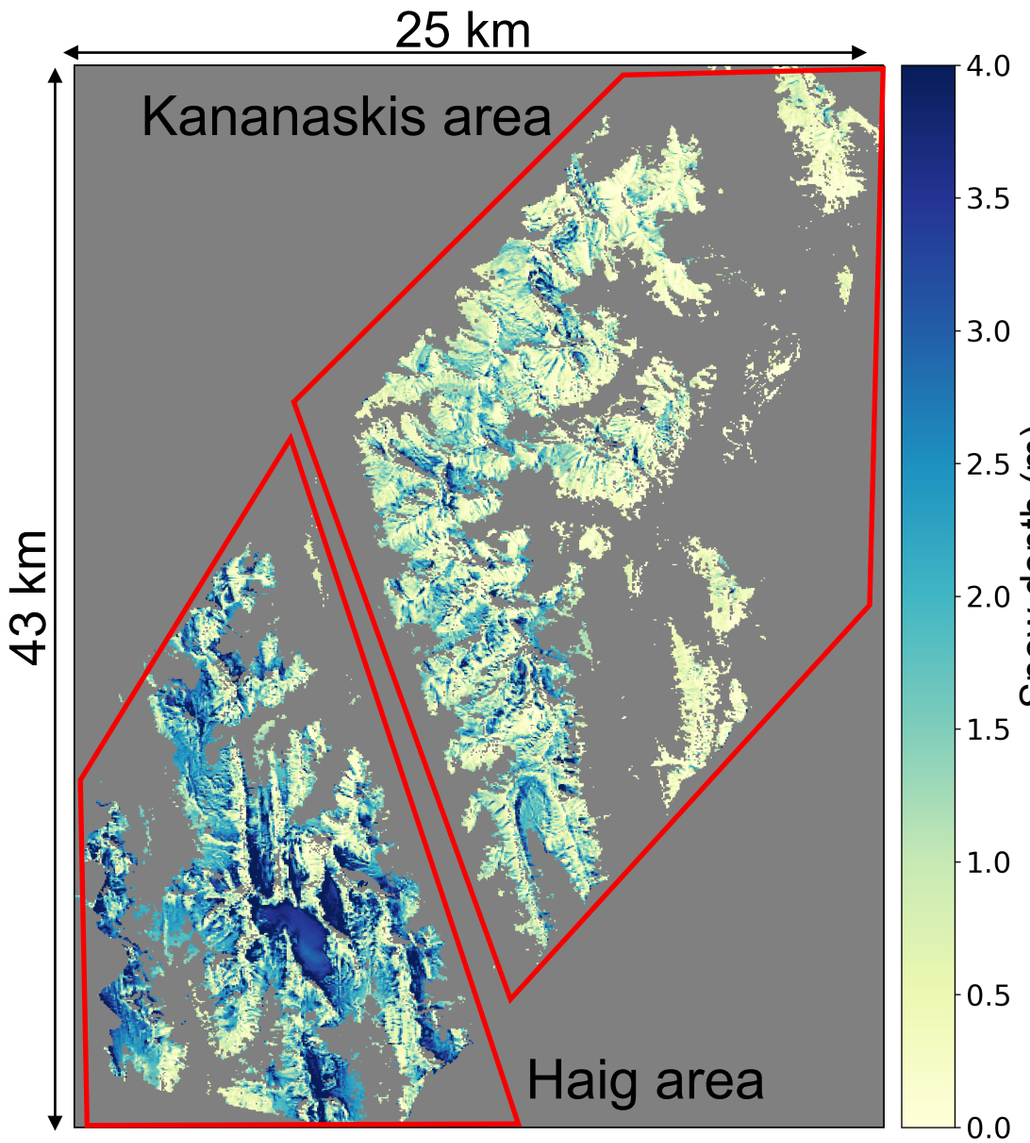


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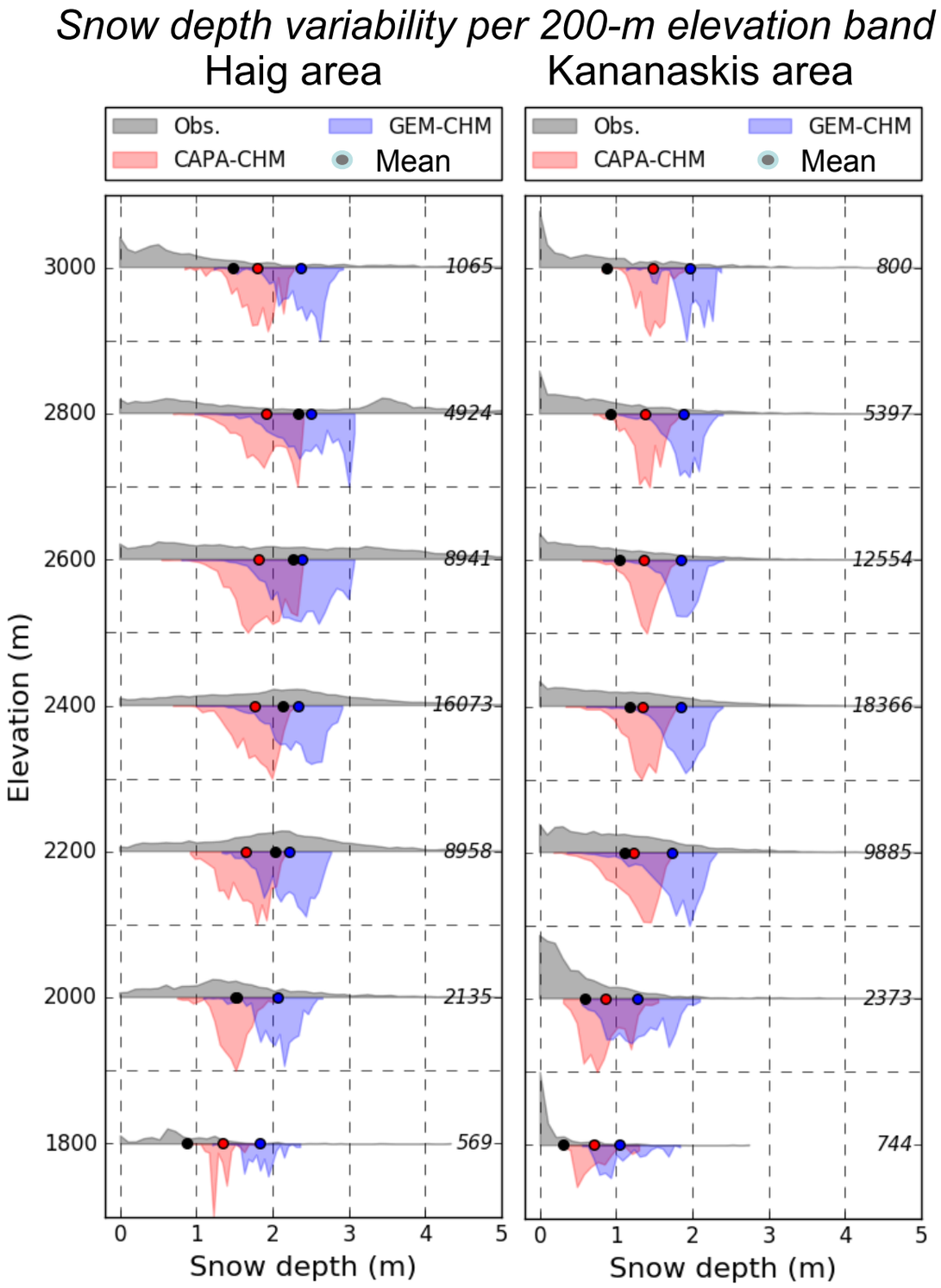


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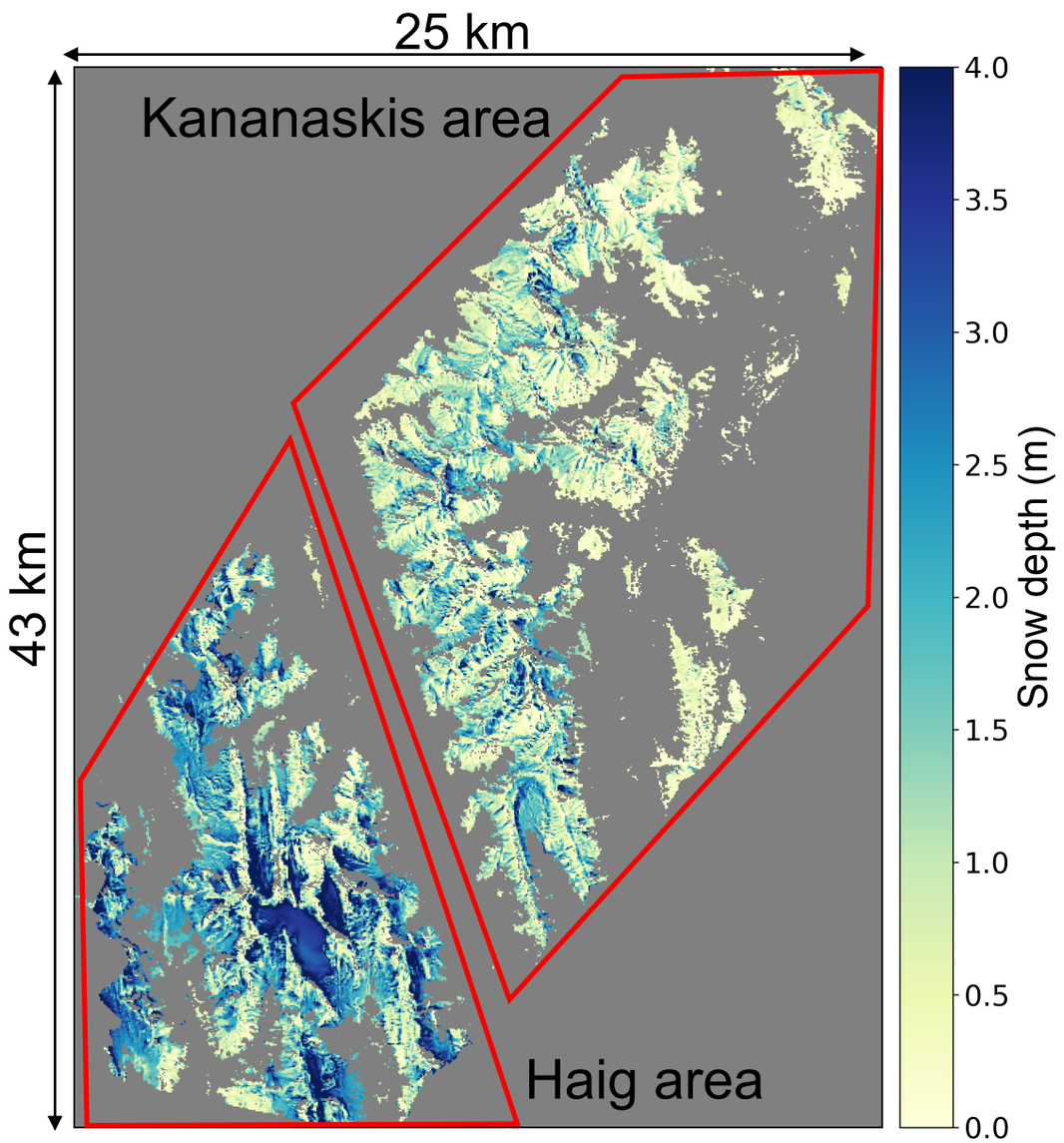
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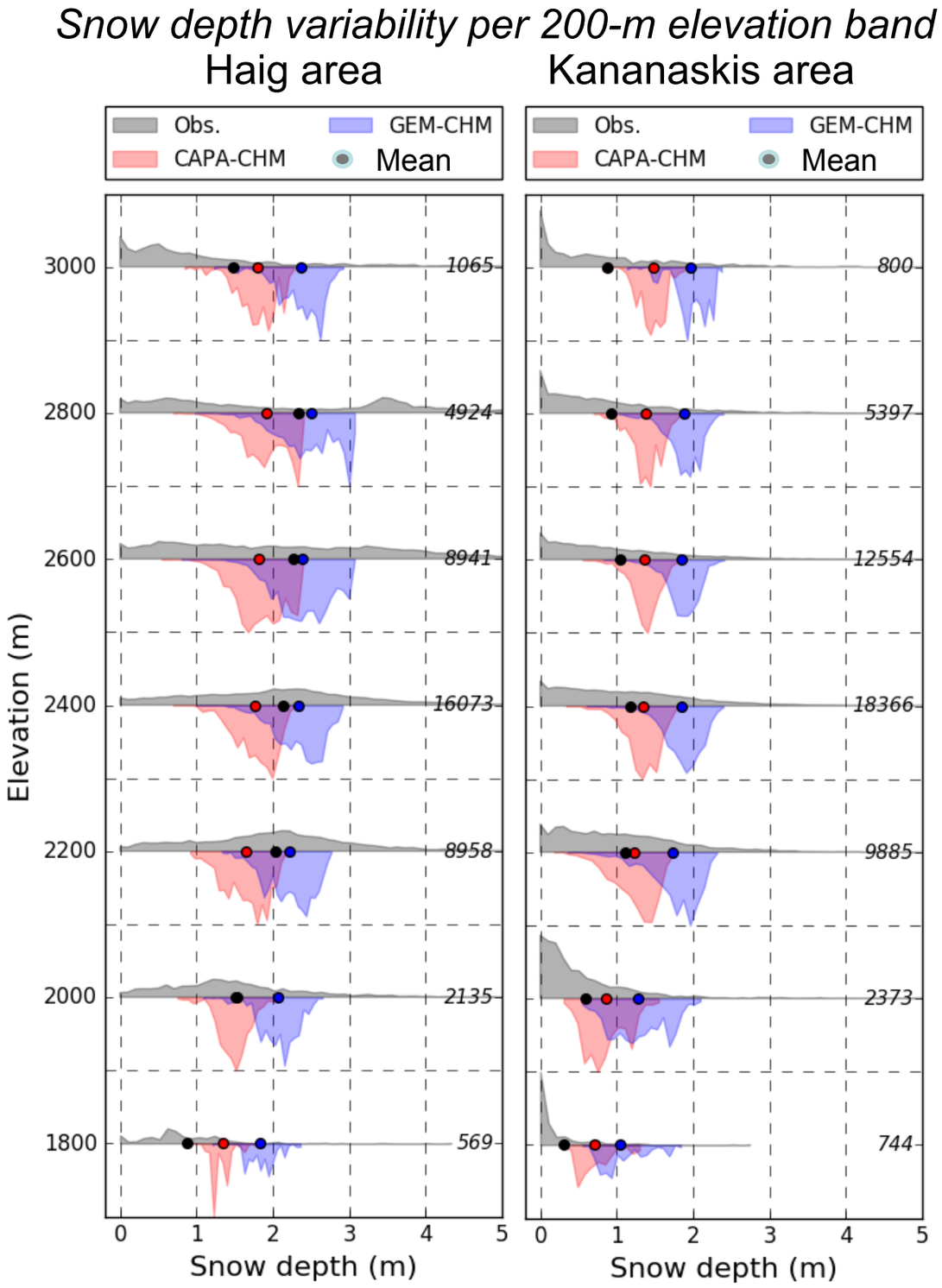
- **High-altitude precipitation** remains one of the **main uncertainty** in mountain snow hydrology

Importance of precipitation forcing



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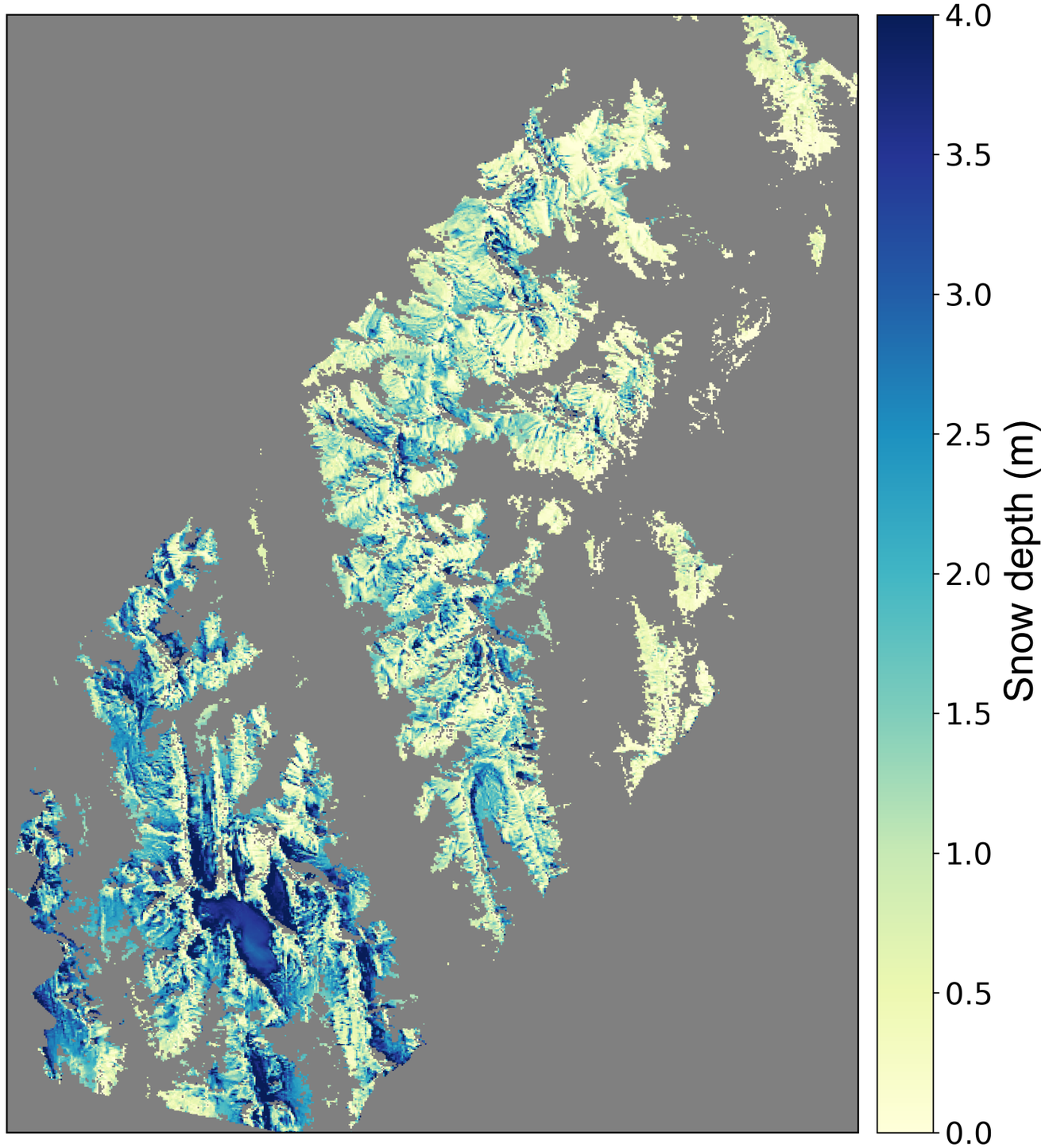
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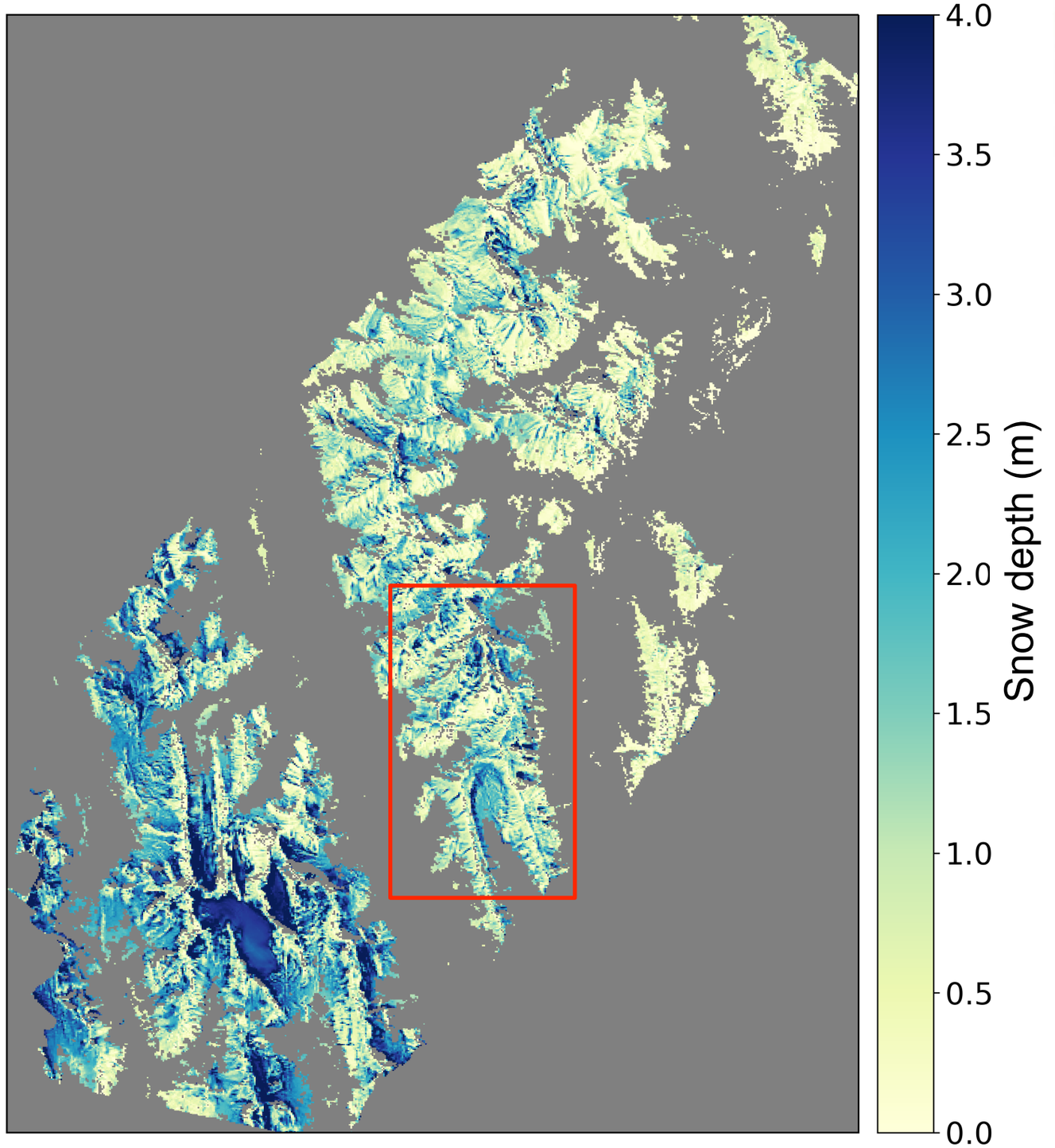
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- **CaPA 2.5 km** presents some potential but **improvements** are needed, in particular, need to incorporate **more stations** from **provincial networks**.

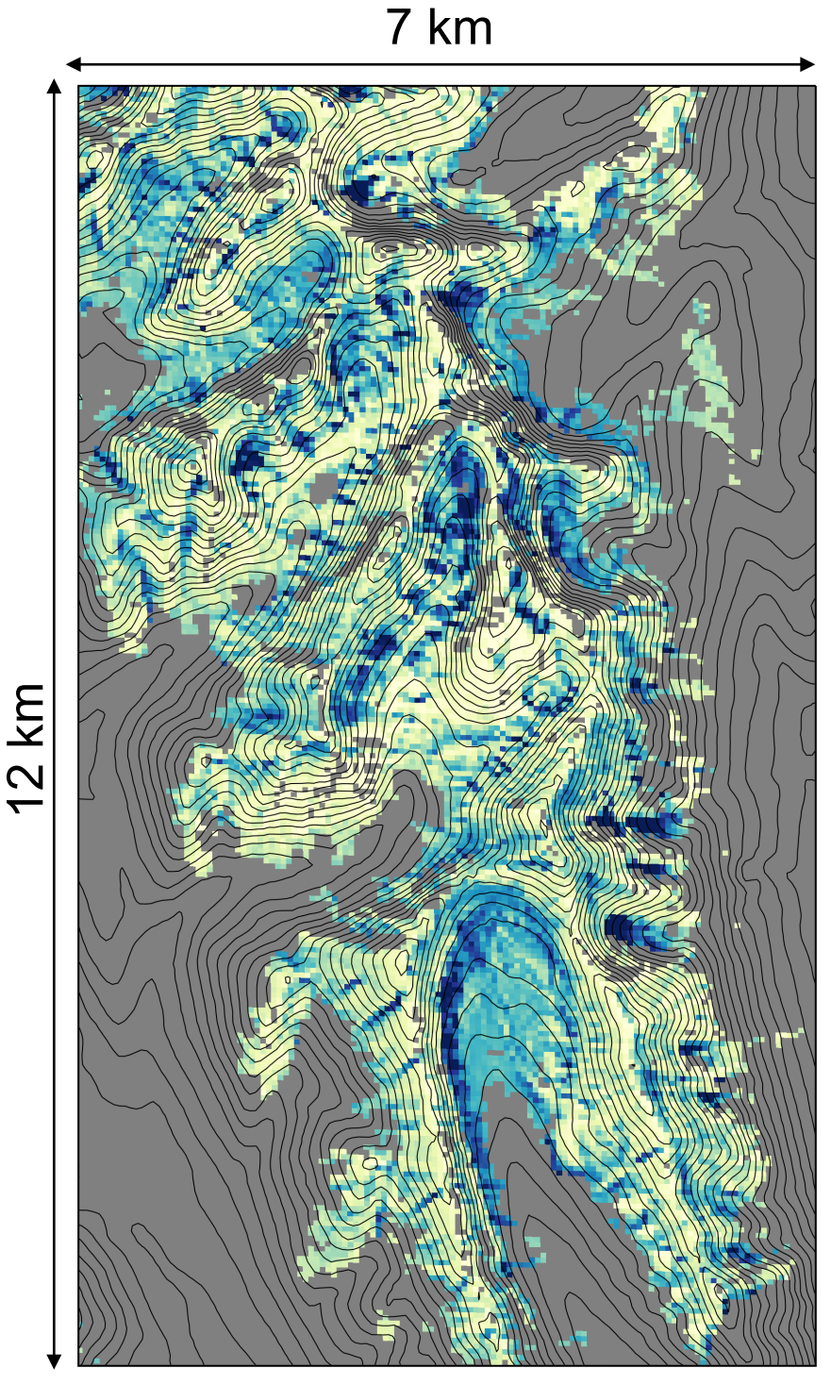
Importance of snow redistribution



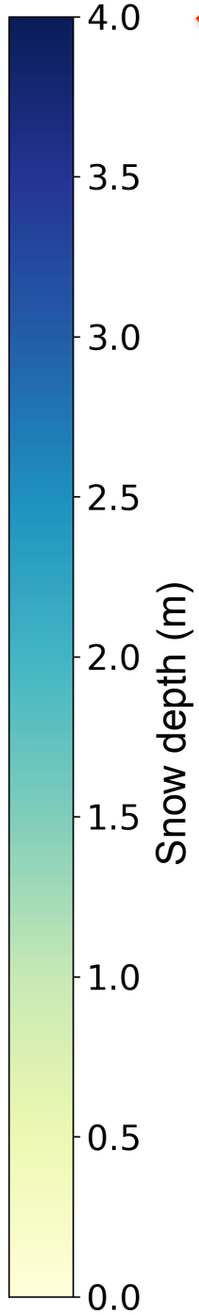
Importance of snow redistribution

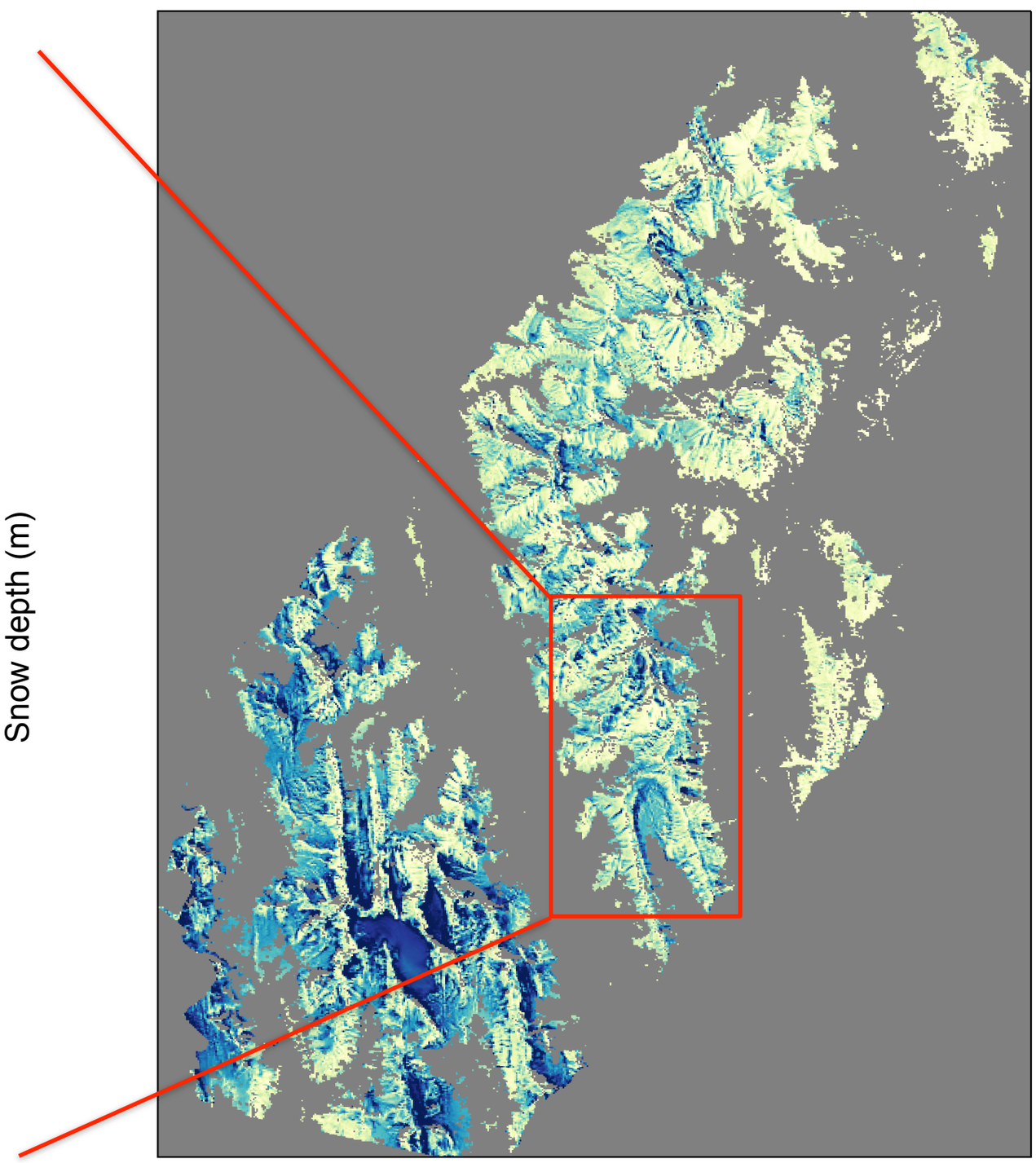


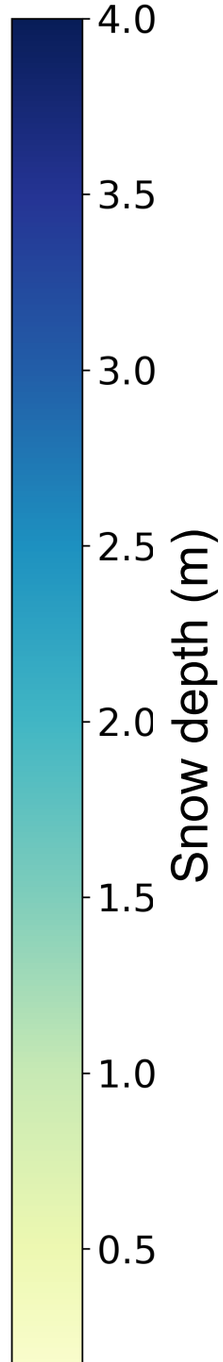
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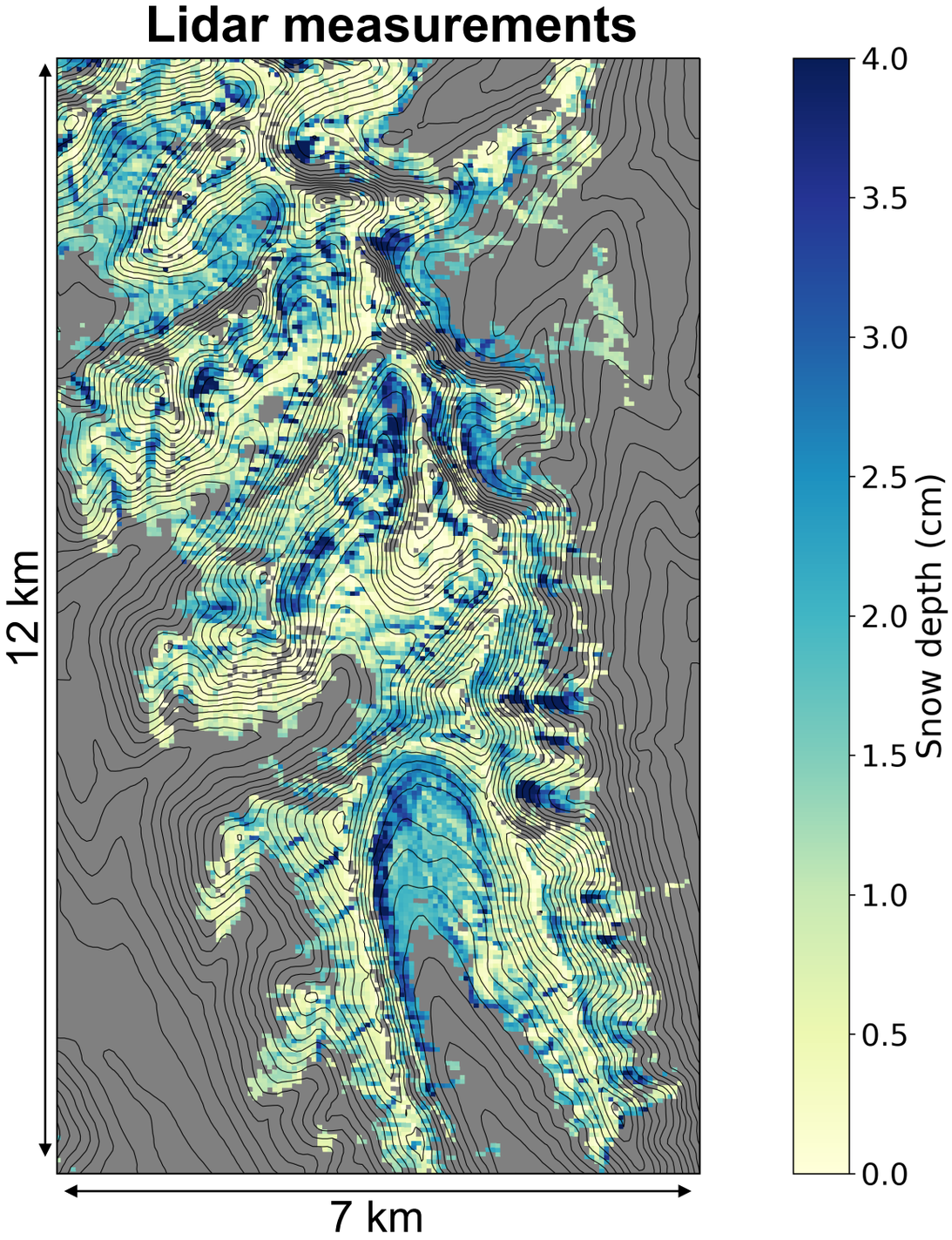
Contour lines every 50 m



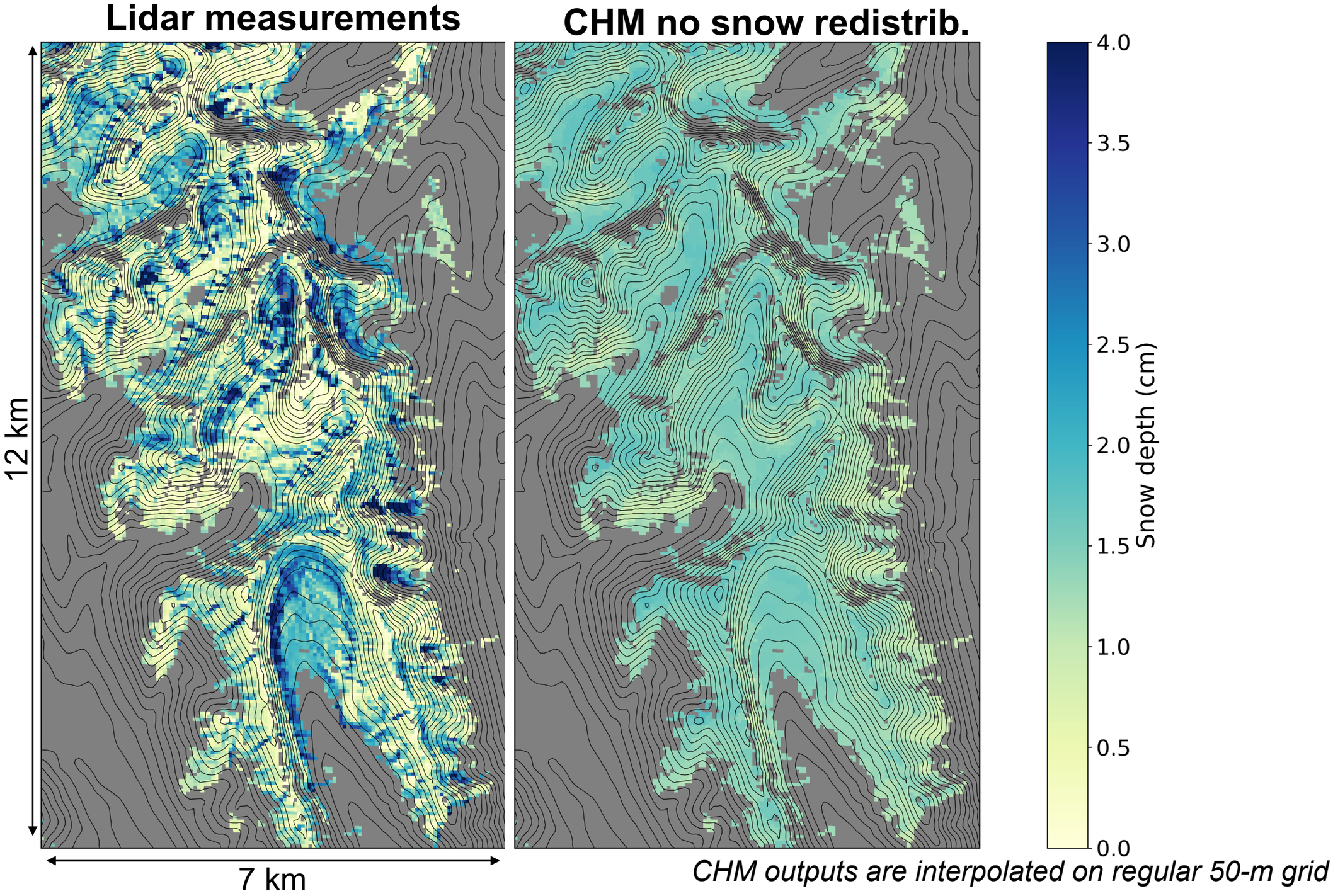




Importance of snow redistribution

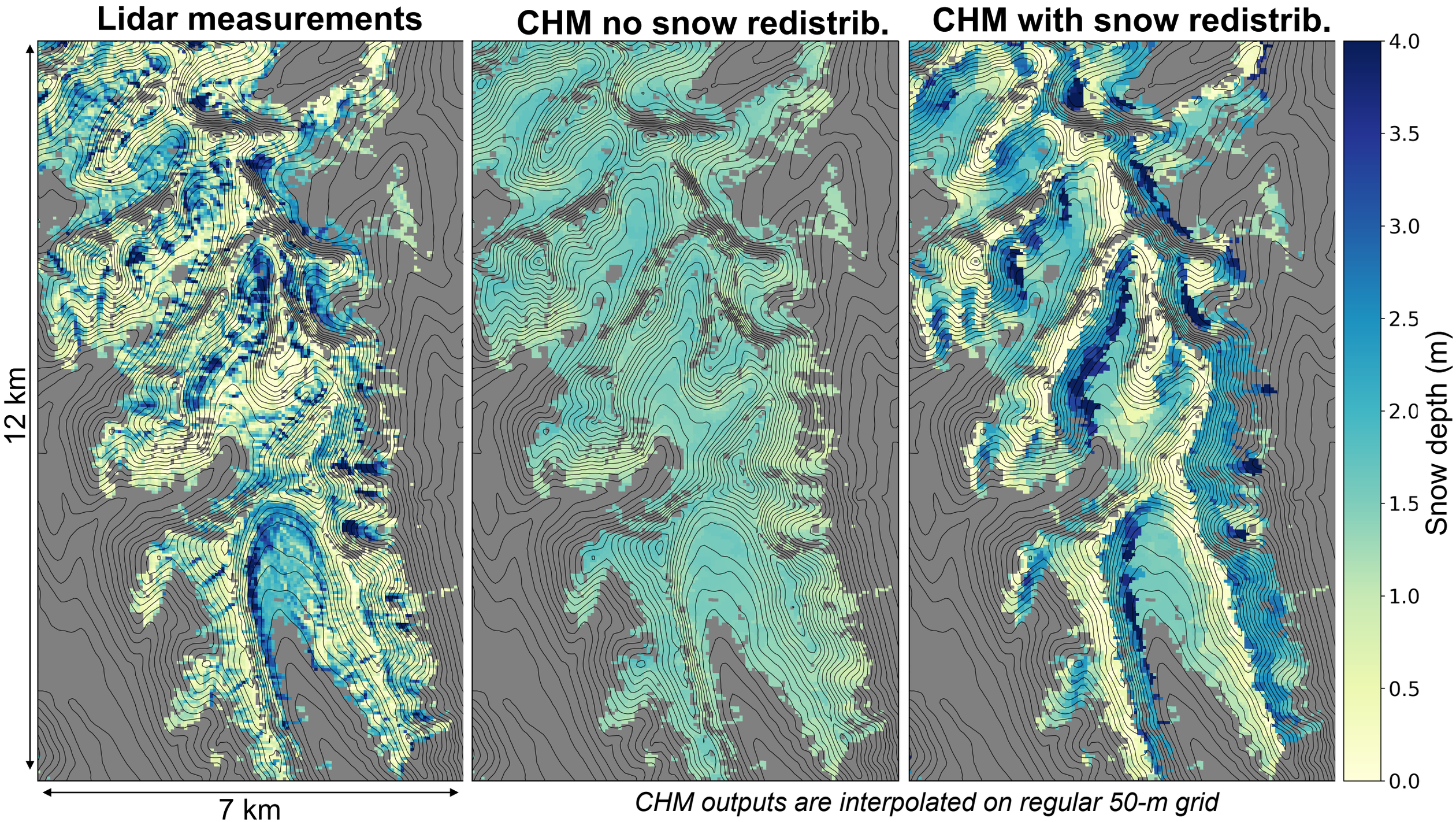


Importance of snow redistribution



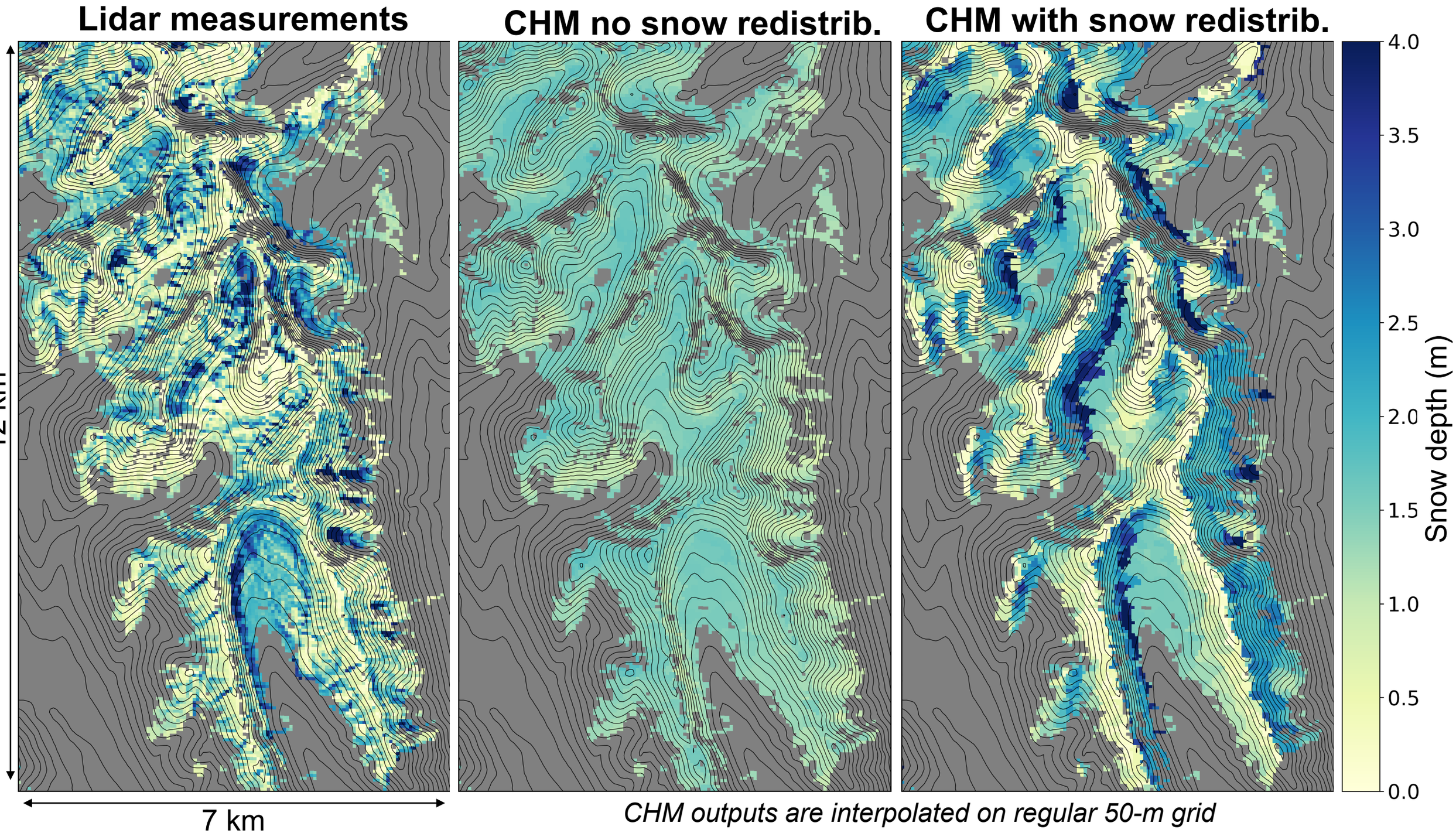
CHM outputs are interpolated on regular 50-m grid

Importance of snow redistribution



CHM outputs are interpolated on regular 50-m grid

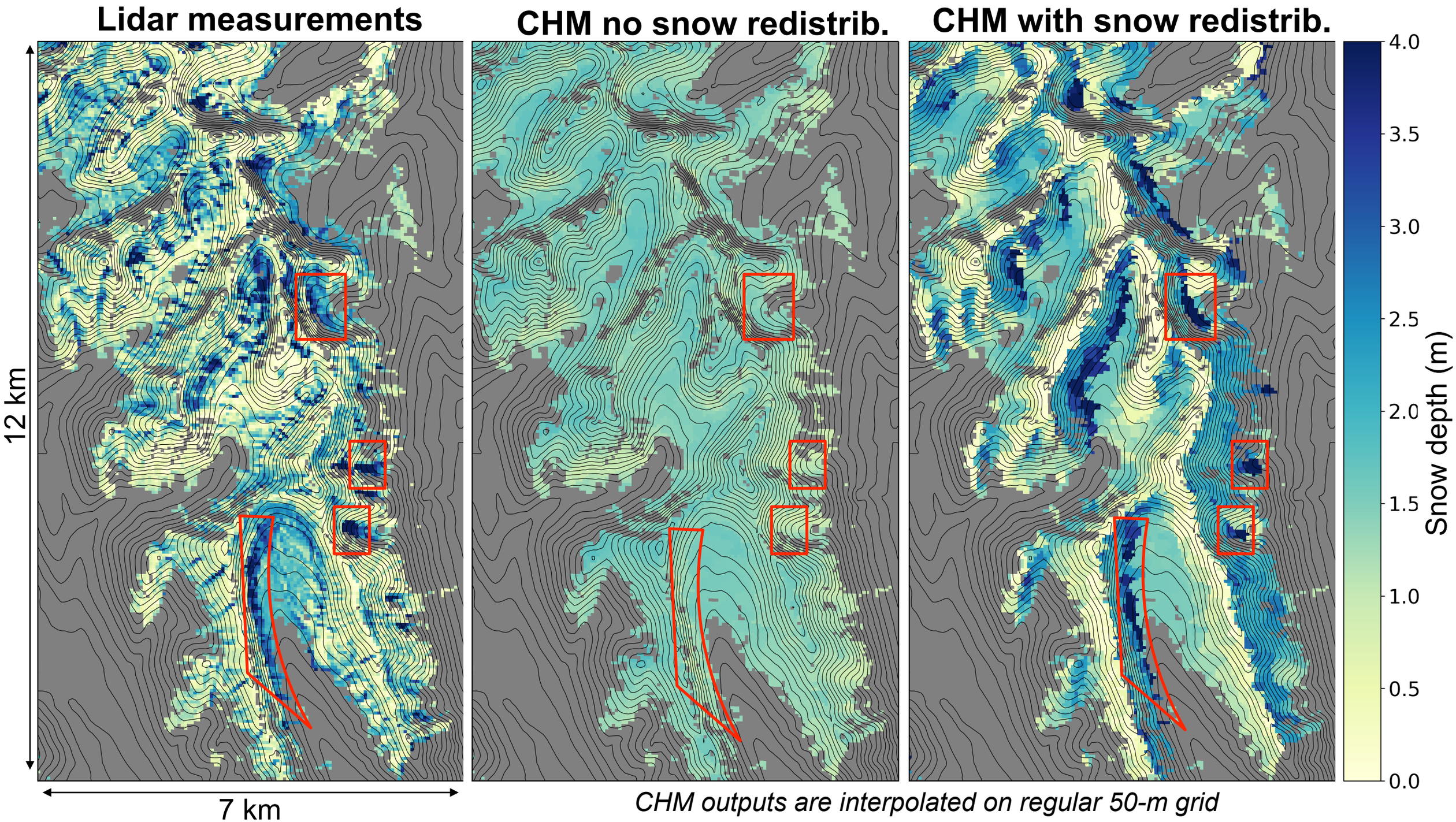
Importance of snow redistribution



CHM outputs are interpolated on regular 50-m grid

CHM captures **many features** of **snow accumulation**

Importance of snow redistribution

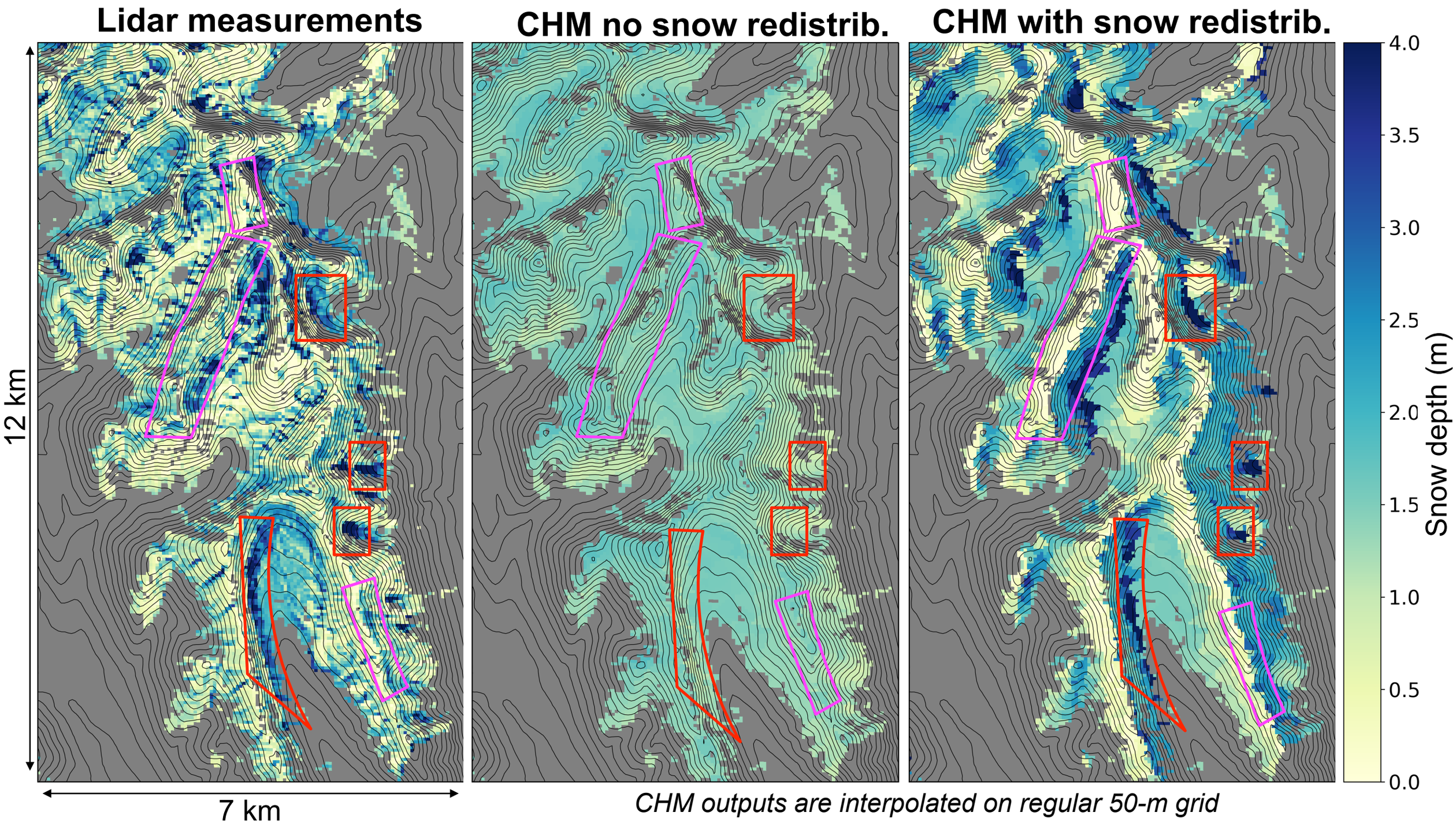


CHM outputs are interpolated on regular 50-m grid

CHM captures **many features** of **snow accumulation**

Avalanche deposition areas

Importance of snow redistribution



CHM outputs are interpolated on regular 50-m grid

CHM captures **many features** of **snow accumulation**

Avalanche deposition areas

Redistribution along crest lines

Conclusion and perspectives

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➢ Development of a **multi-scale snowpack modelling** system in the Canadian Rockies

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- Requires **simultaneous improvements** in **snowpack models** and **atmospheric driving data**

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- **Collaboration:**
  - Better link with ECCC snow analysis
  - Extension of Snowcast to other mountainous and arctic regions of Canada
  - Distribution of Snowcast outputs (SWE, melt runoff, …) for various hydrological applications

Thanks you for your attention!

Questions?