VOLUME CHANGES OF THE GLACIERS IN SCANDINAVIA AND ICELAND IN THE 21st CENTURY

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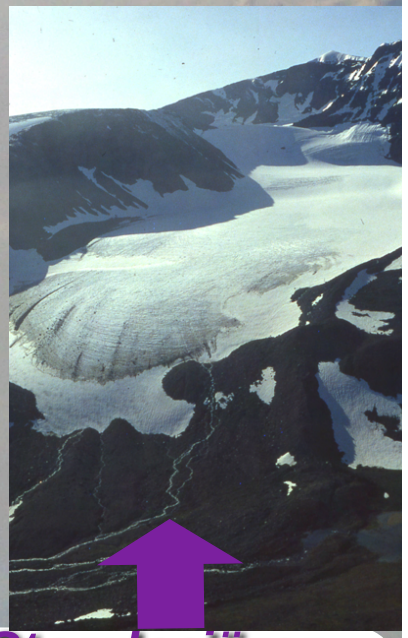
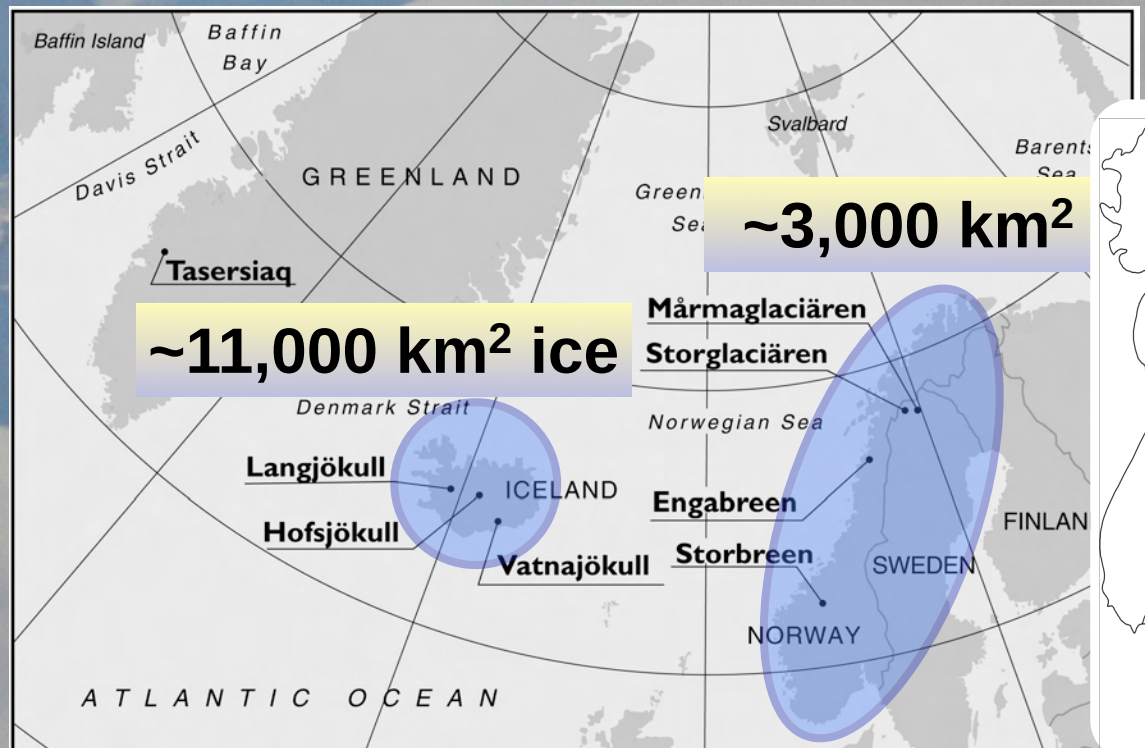
Purpose

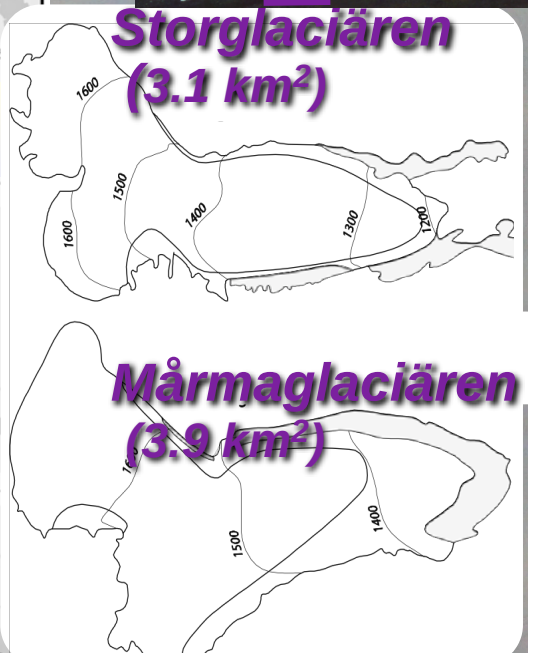
to project the 21st century volume changes of all glaciers in Scandinavia and Iceland

- ***regional estimates***
- ***2 glaciers (Storglaciären, Mårmaglaciären)***

Study area: Iceland, Scandinavia







Data

Climate data, calibration period

- Monthly air temperature: **ERA-40 reanalysis** (0.5°×0.5°), 1958-2001
- Monthly precipitation: **Precipitation climatology VASClimO**, 1951-2000, 0.5°×0.5° (Beck et al., 2005)

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Mass-balance data

- Elevation-dependent mass balance data for individual glaciers

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Glacier data

- **World Glacier Inventory (WGI-XF) dataset** (Cogley, 2009): contains worldwide >120,000 mountain glaciers and >2600 ice caps (area ≥ 0.01 km^2): location, area, highest & lowest elevation complete for Scandinavia
- **Icelandic Inventory** (data from O. Sigurdsson)

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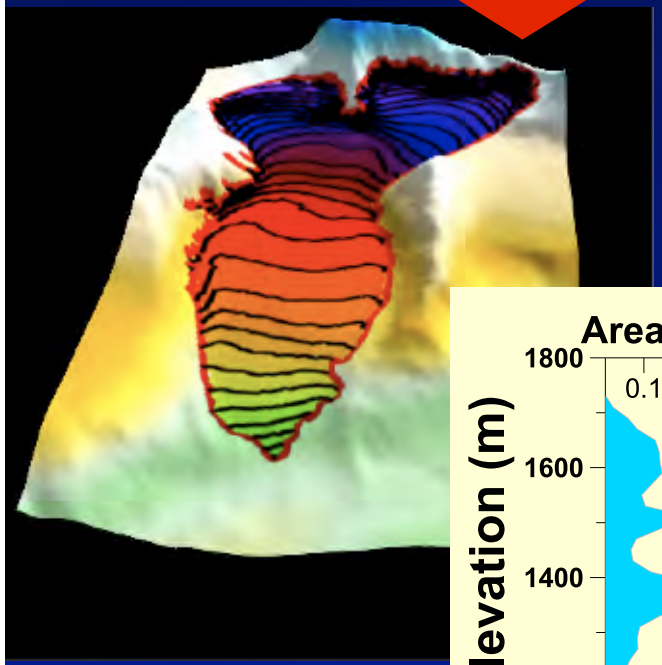
Future projections

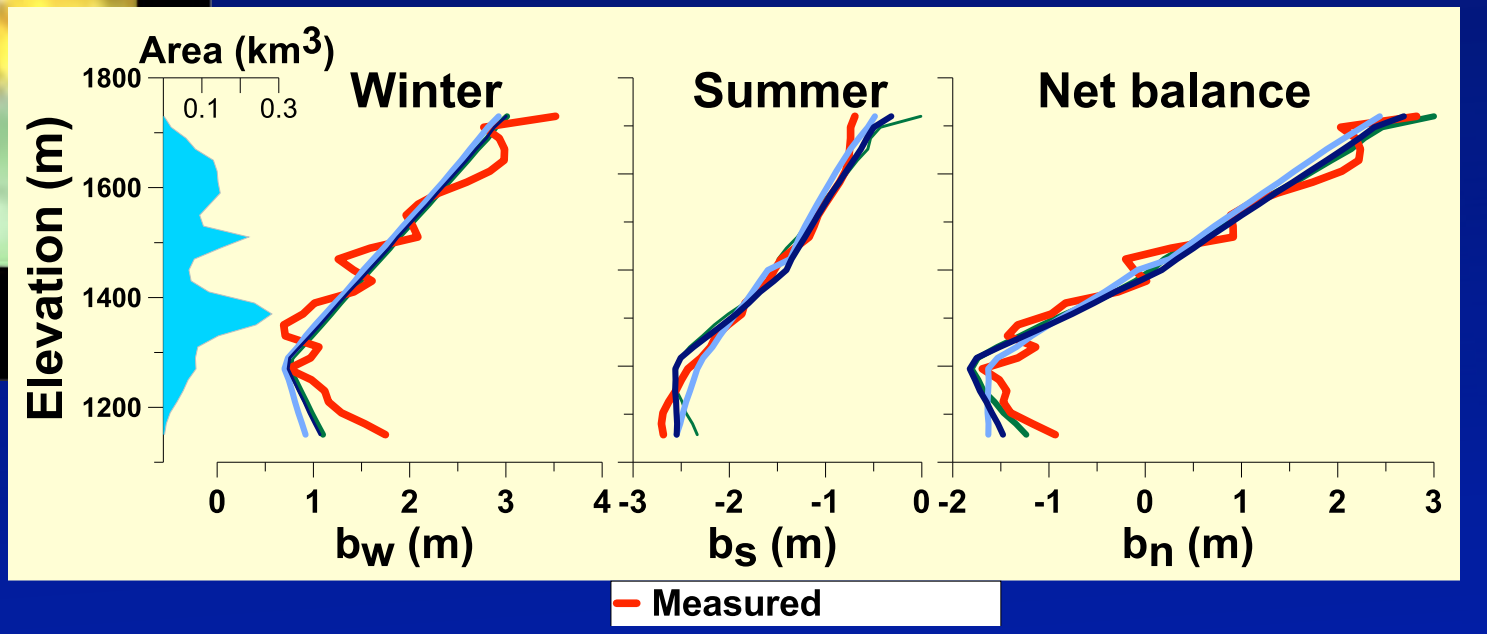
- *Regional analysis*: **10 GCM**, A1B emission scenario
- *Storglaciären, Mårmaglaciären*: **3 CE scenarios**, A1B emission scenario

Methodology

Step 1: Temperature-index mass-balance model

Monthly temperature
Monthly precipitation





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Step 2: Extrapolation of model parameters to all glaciers in Iceland and Scandinavia

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Step 3: Future projections until 2100 for each glacier:
- run mass-balance model
- Volume-area scaling

- **Glacier inventory data**
- **downscaled GCM scenarios**

Glacier retreat

Vernagtferner, Austria

Courtesy of Ludwig Braun

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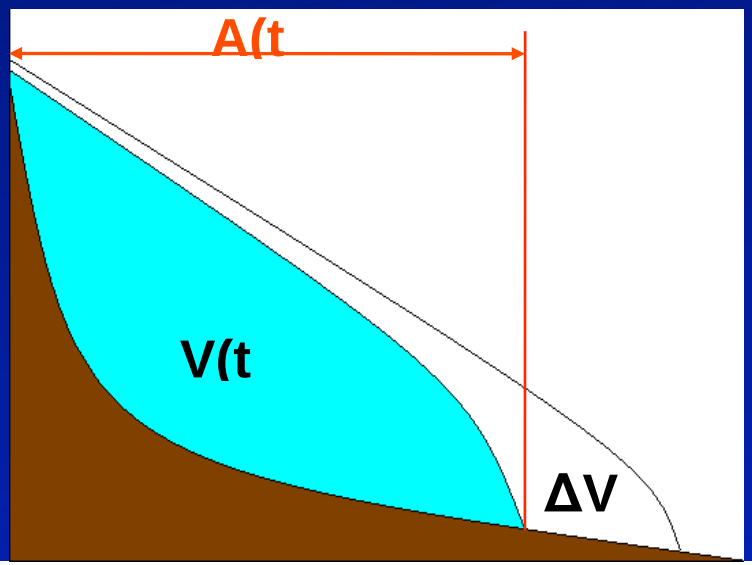
Volume-area-length scaling

$$V = c\,A^{\gamma}$$



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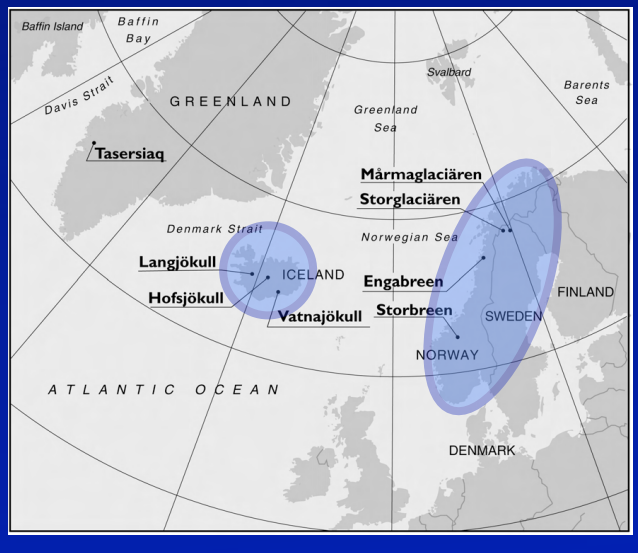
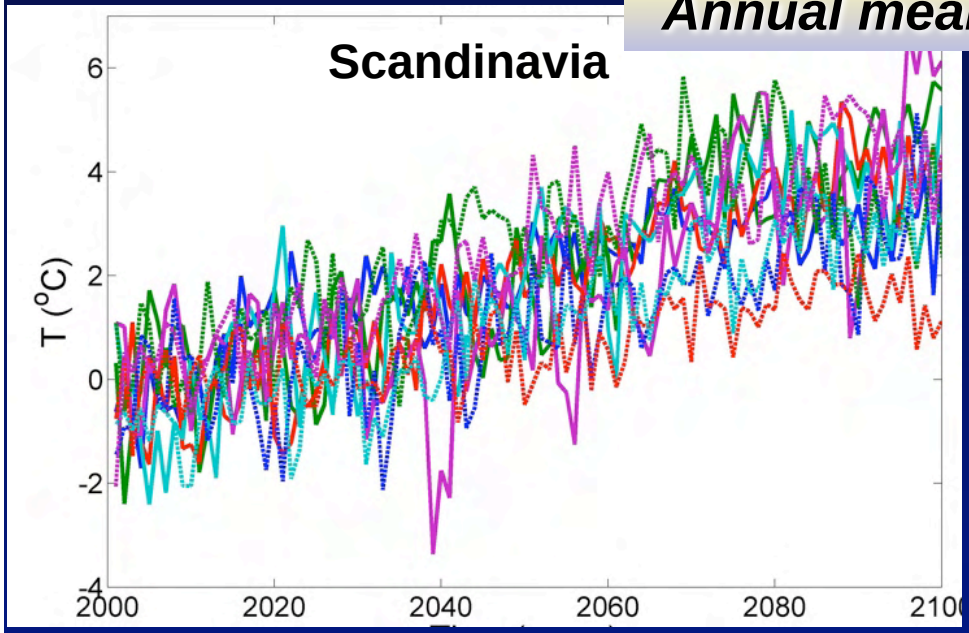
Step 4: Regional estimates of annual volume changes until 2100

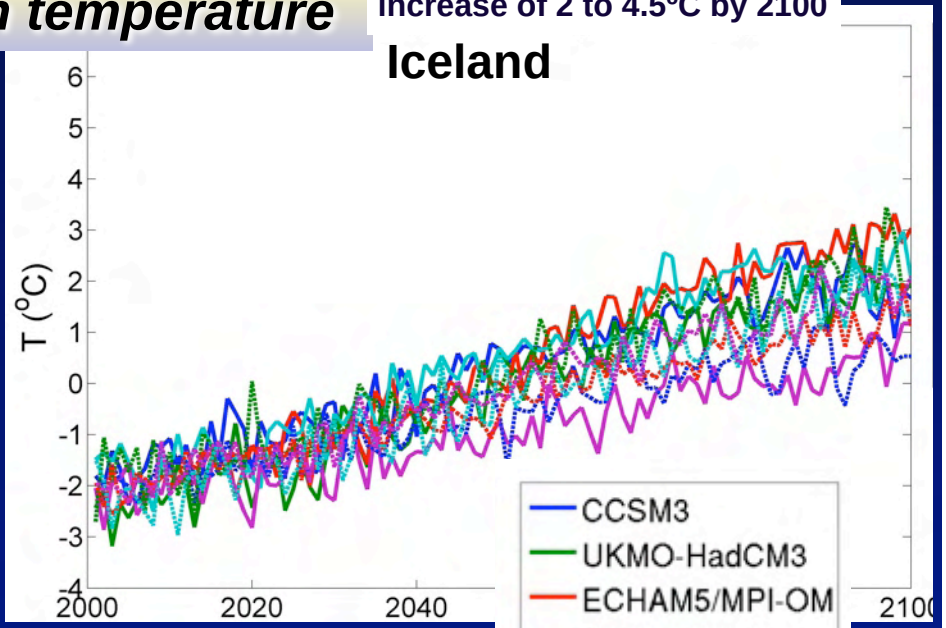


Temperature & Precipitation Projections

Annual mean temperature

increase of 2 to 4.5ºC by 2100





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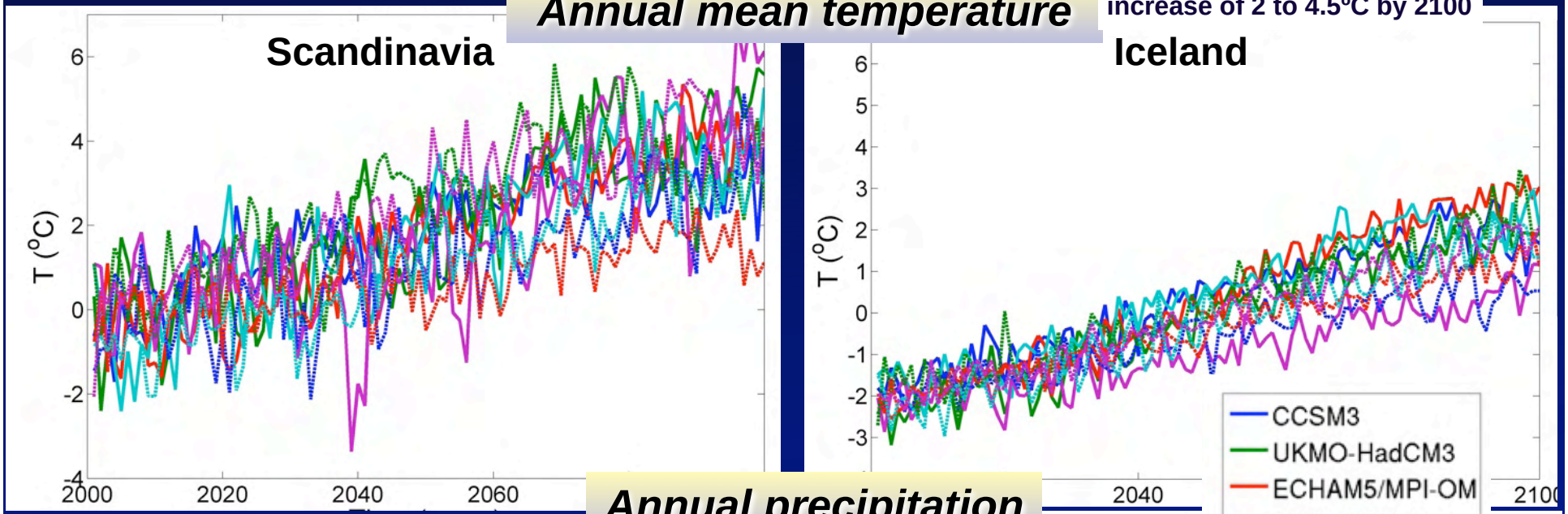
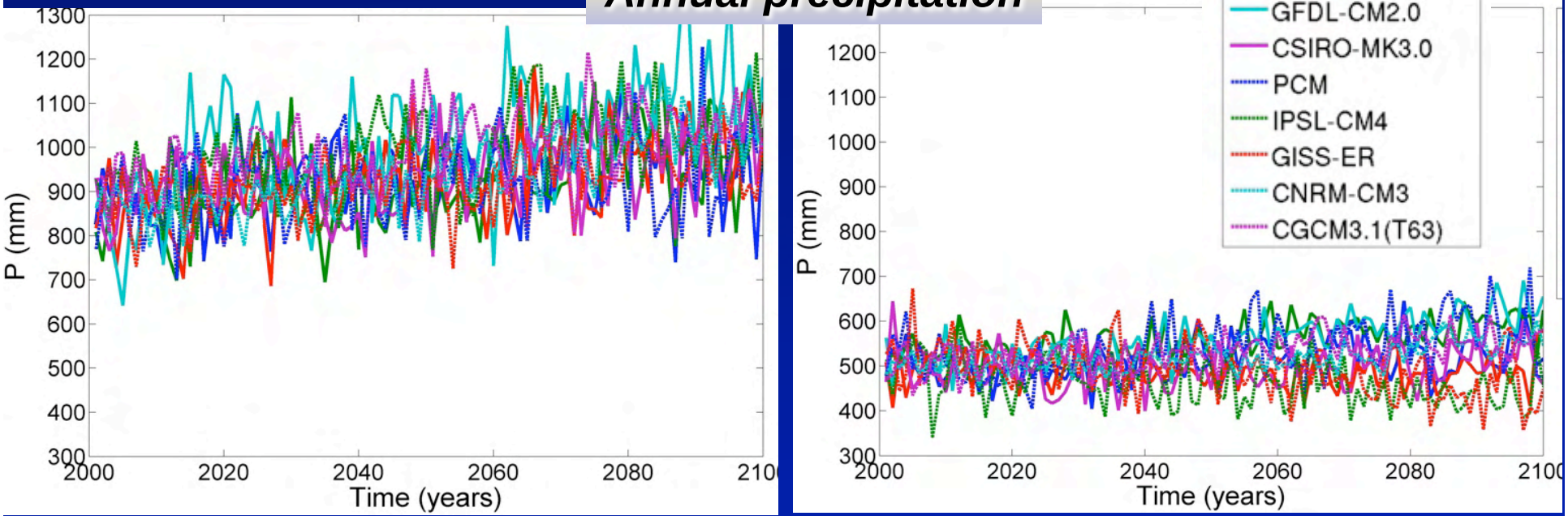
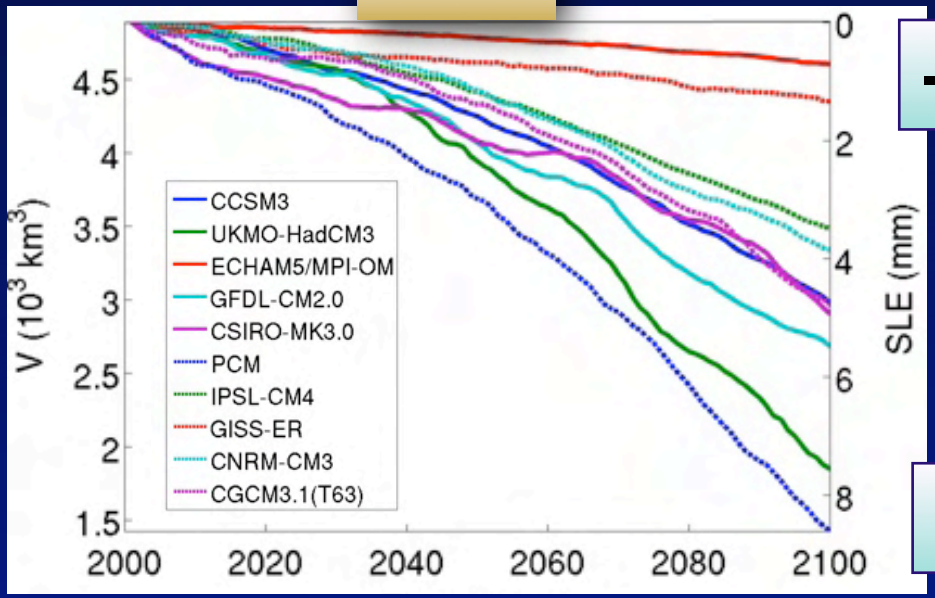


Annual precipitation



Glacier Volume Projections

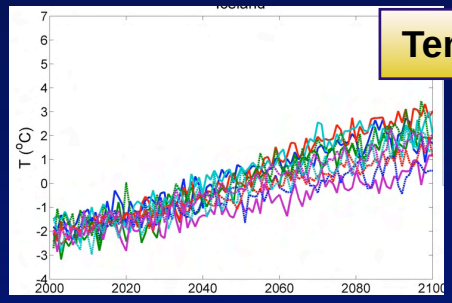
Iceland



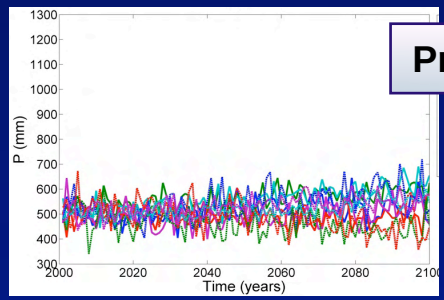
-10%

-70%

Temperature



Precipitation



Glacier Volume Projections

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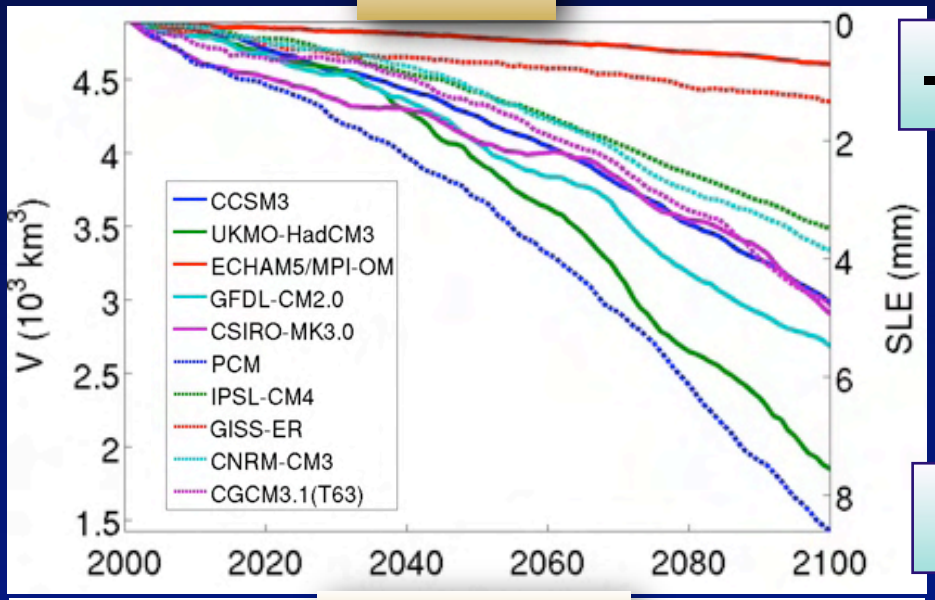

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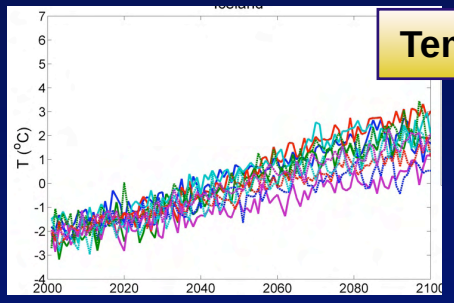
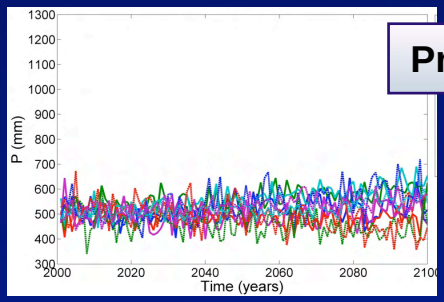
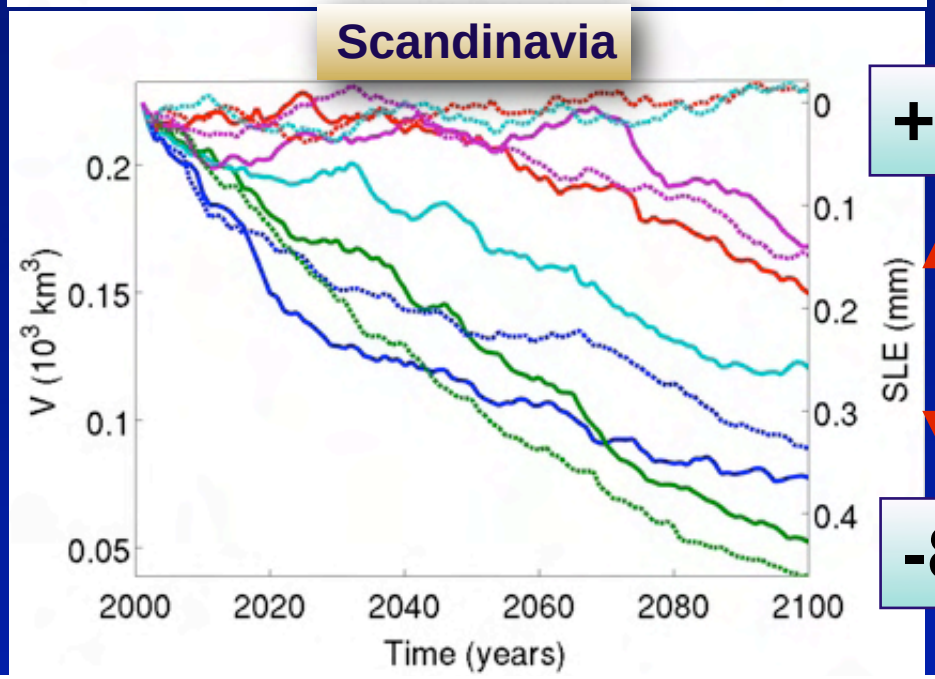


Temperature



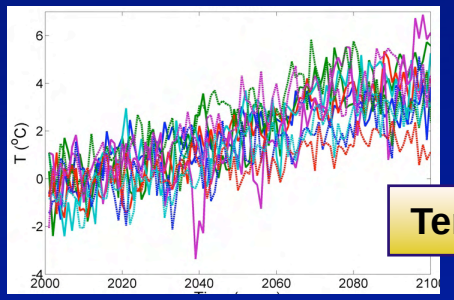
Precipitation

Scandinavia

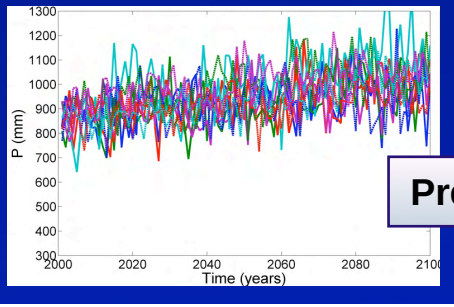


+3%

-80%



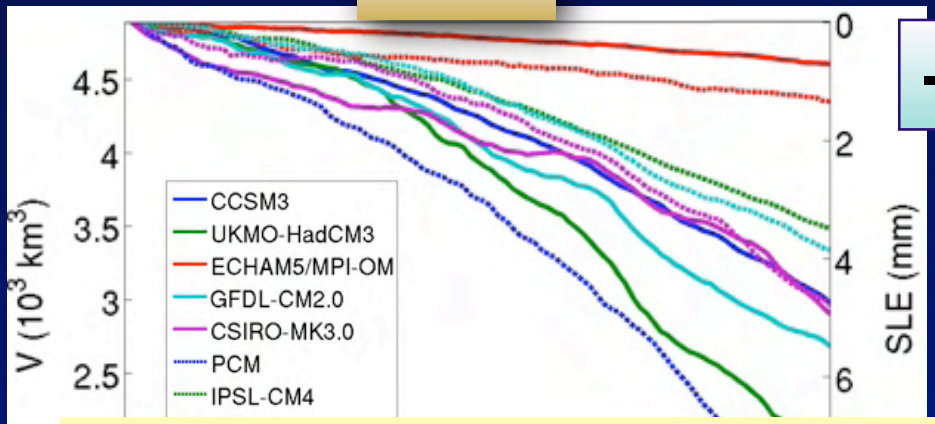
Temperature



Precipitation

Glacier Volume Projections

Iceland



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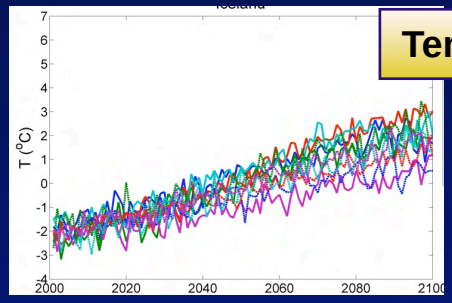
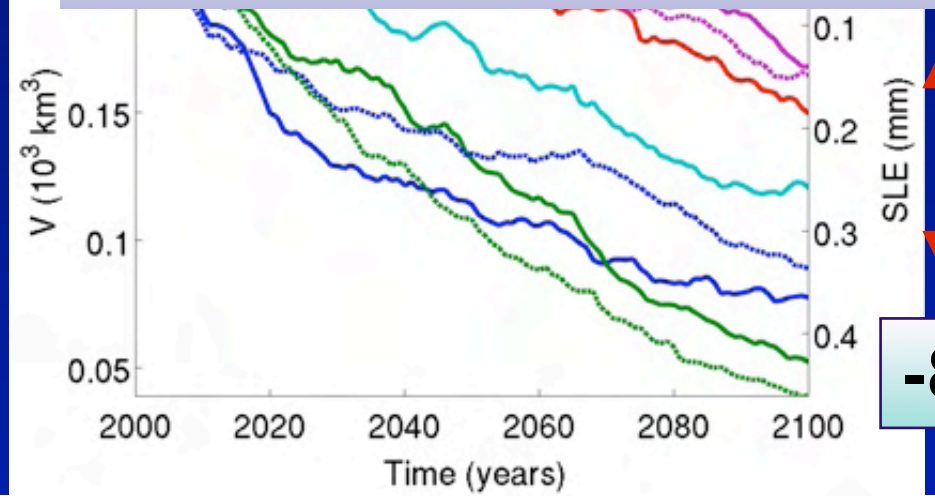


Temperature

Precipitation

Large differences between GCMs
GCMs too coarse ?
--> Do RCMs do a better job?



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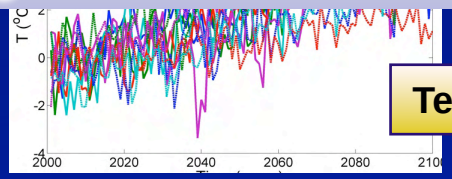
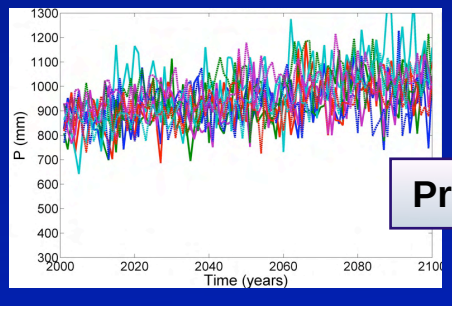
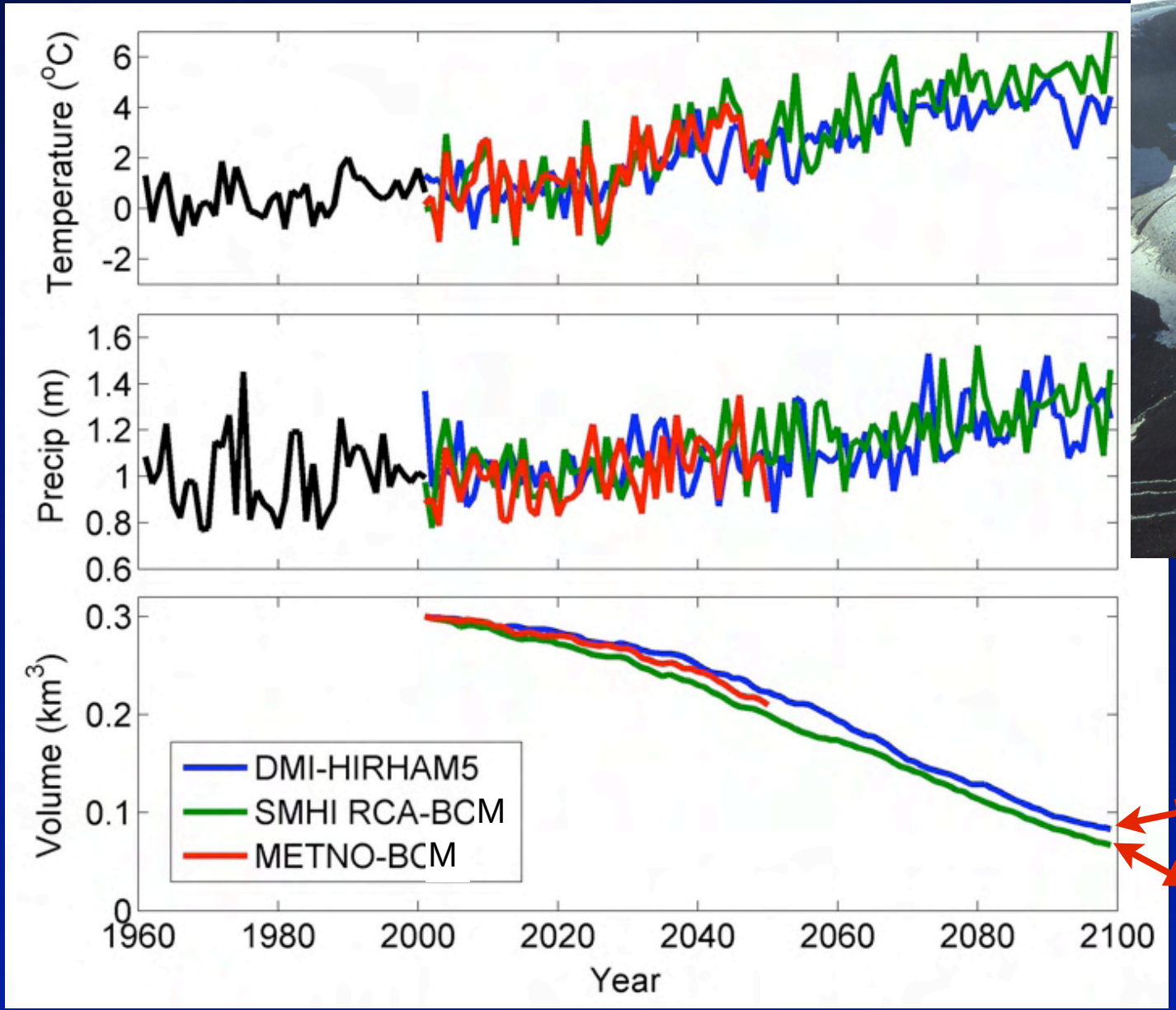


Temperature



Precipitation

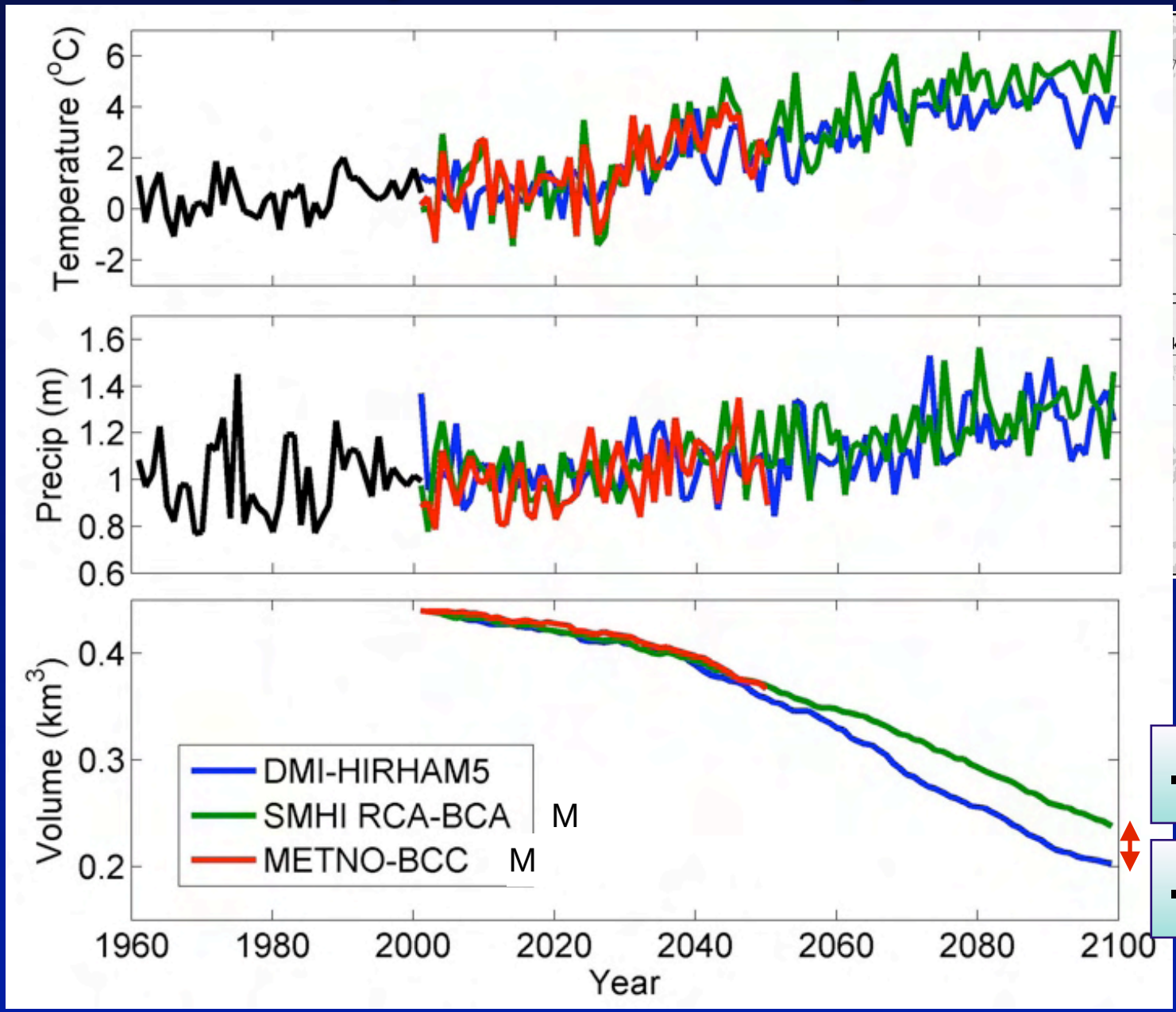
Volume Projections: Storglaciären



-73%

78%

Volume Projections: Mårmaglaciären

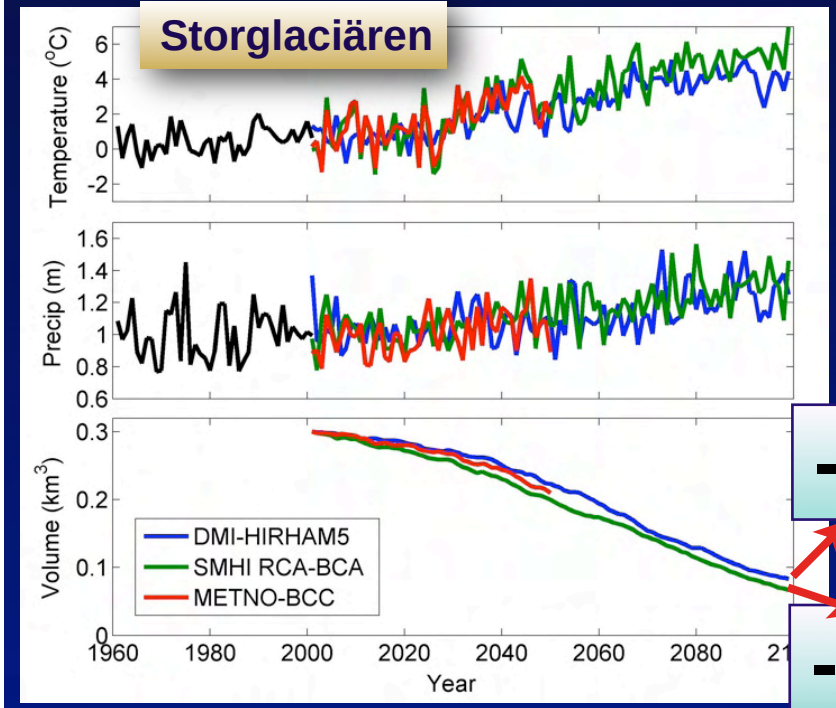


-48%

-50%

Volume Projections

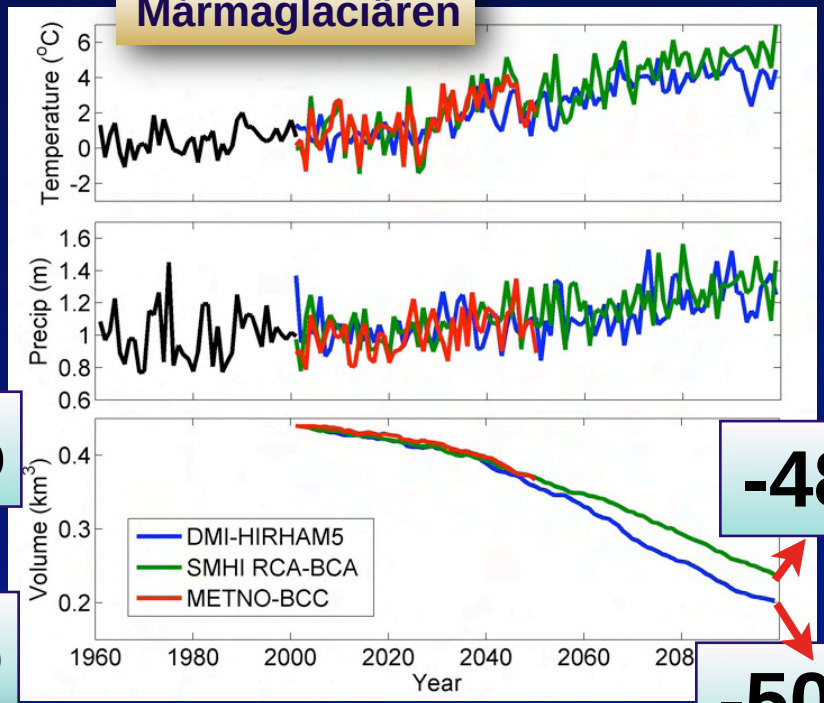
Storglaciären



-73%

-78%

Mårmaglaciären



-48%

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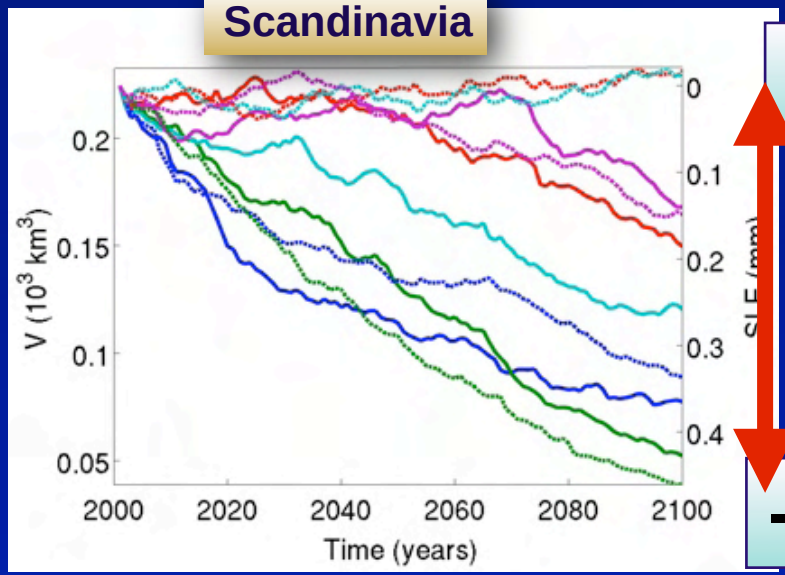
Scandinavia



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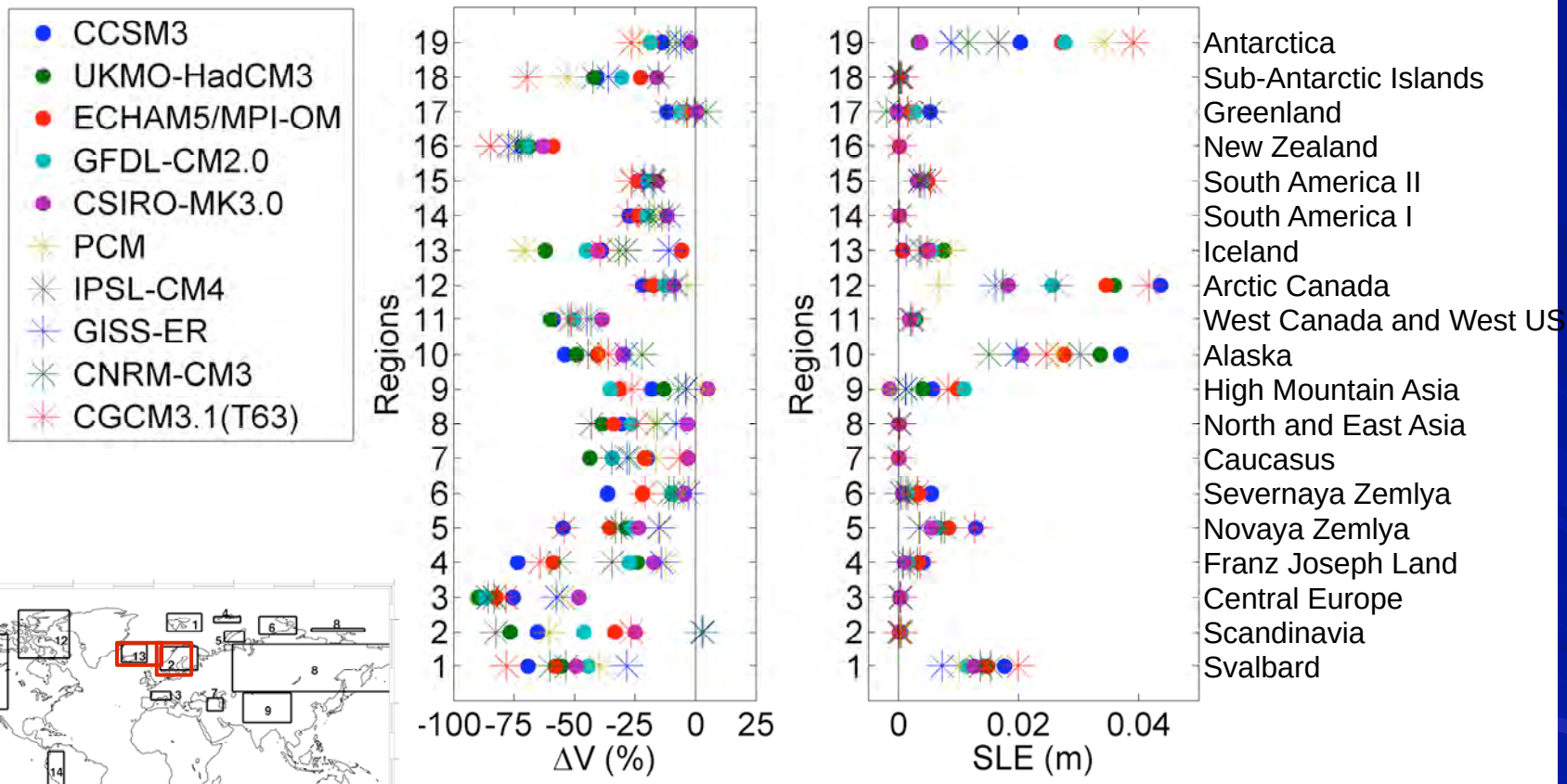
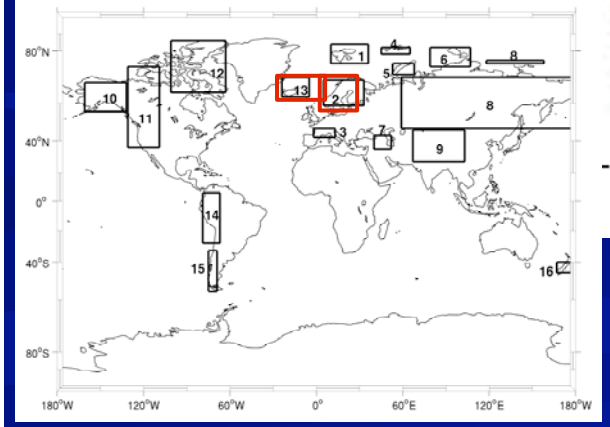
Comparison with all other glacier regions

Volume reduction and sea-level equivalent (SLE) until 2100 for 19 glacier regions





Radic and Hock, submitted

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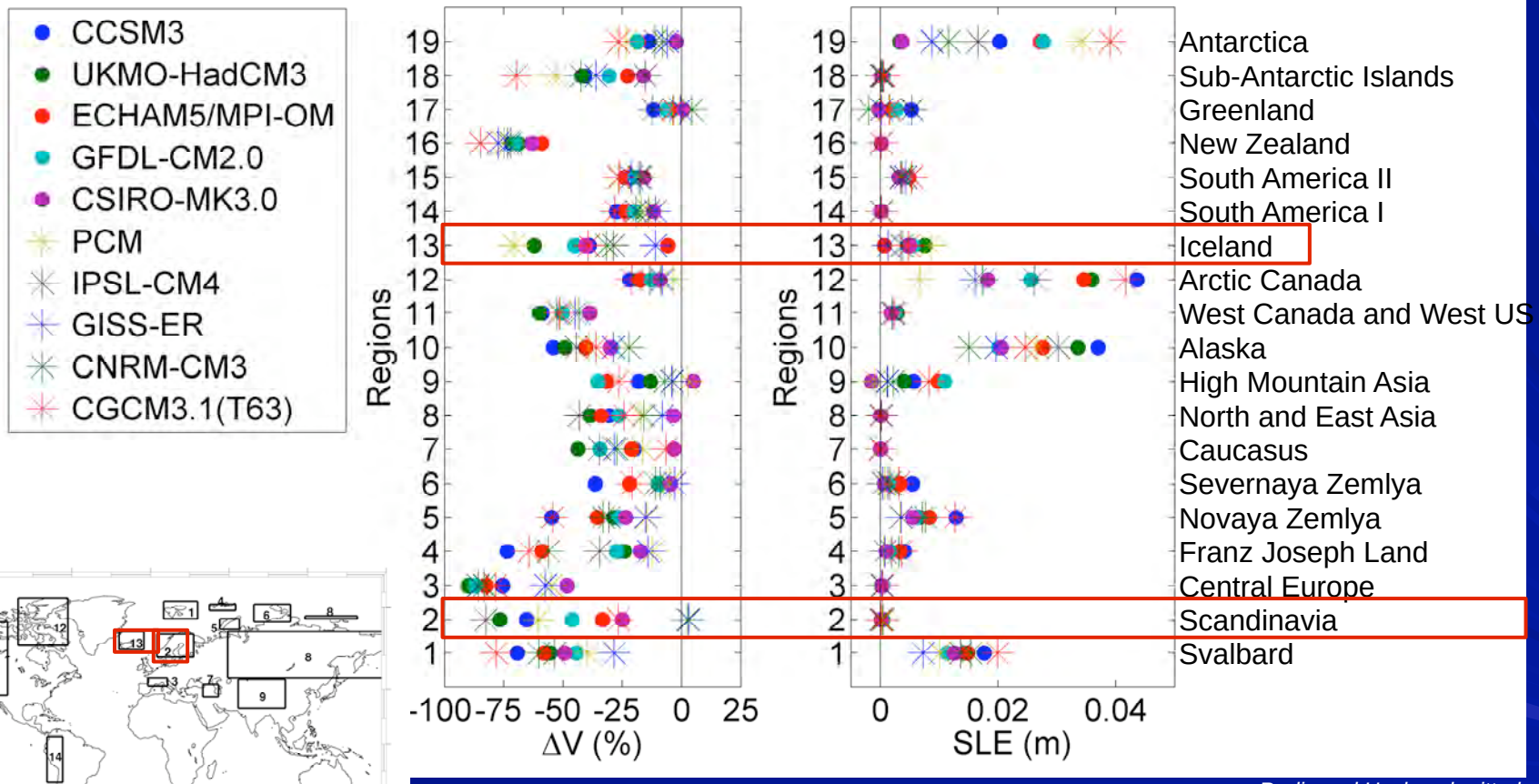

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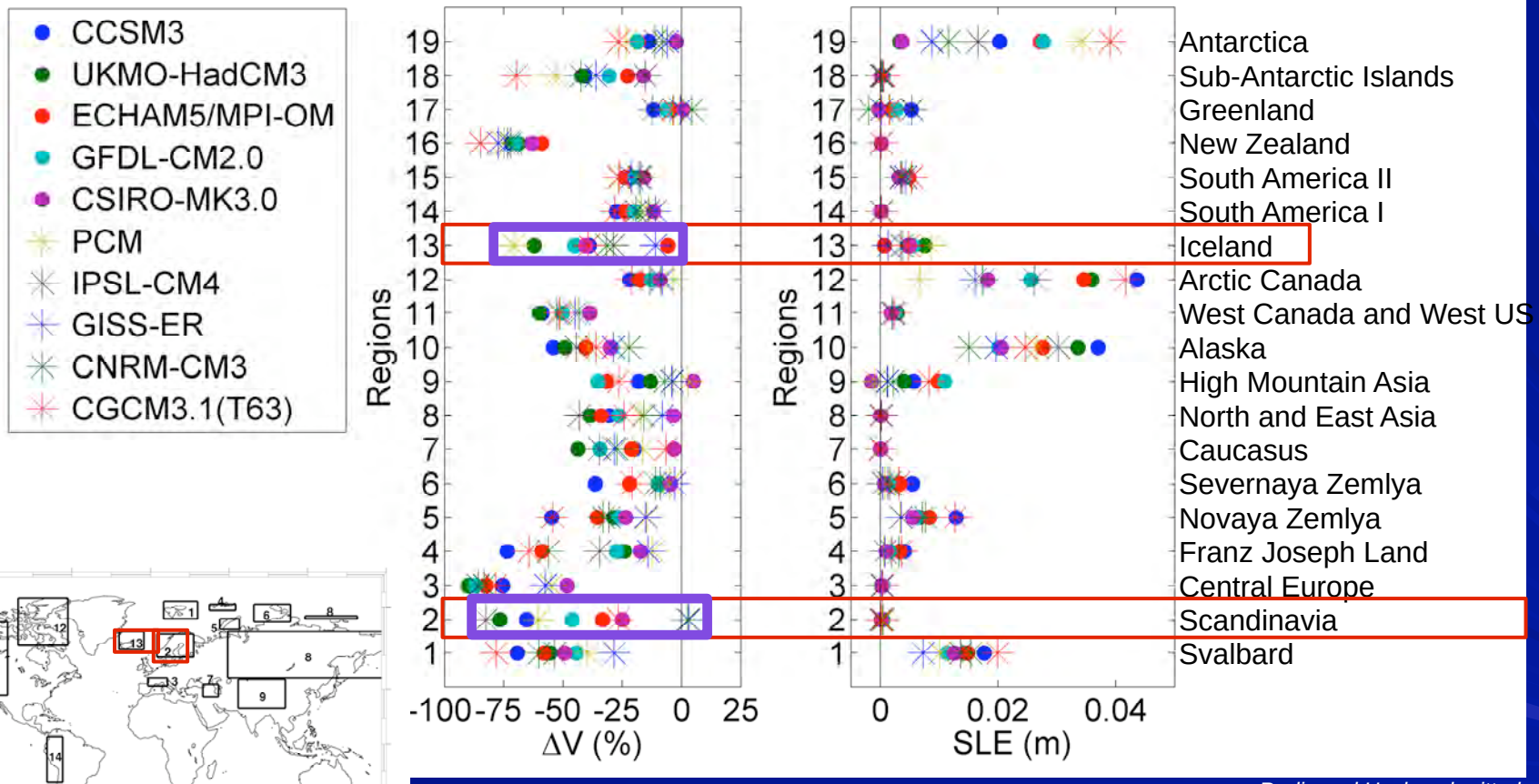

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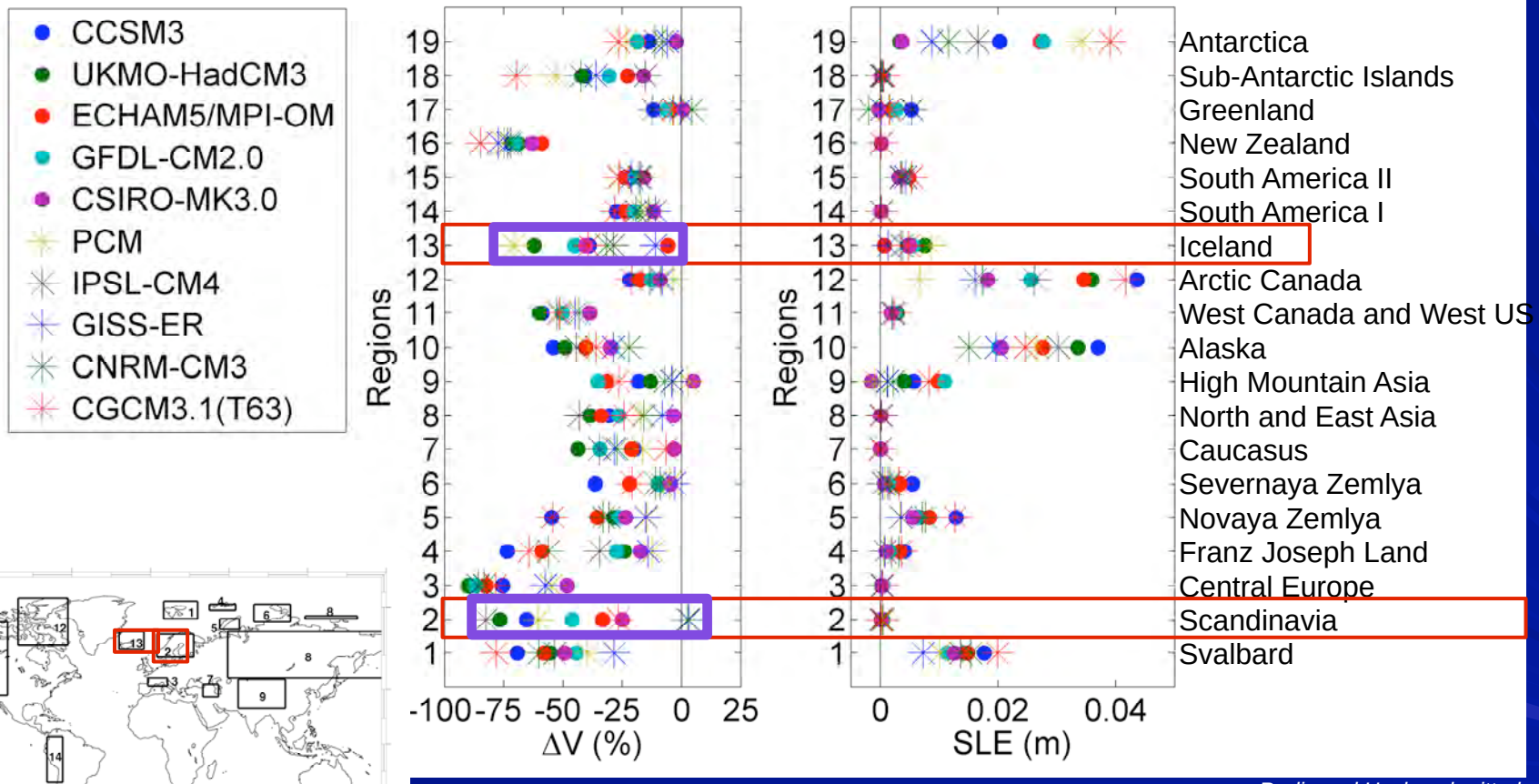
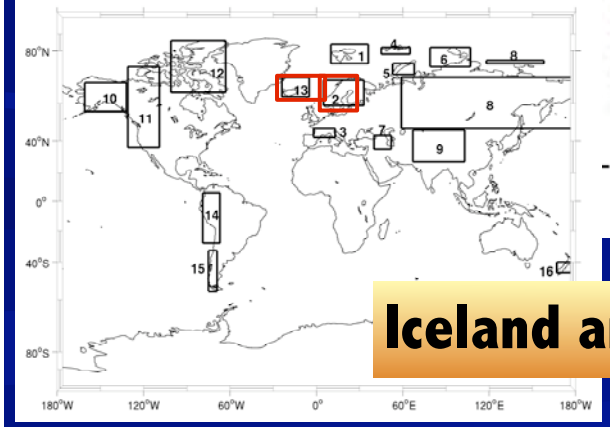




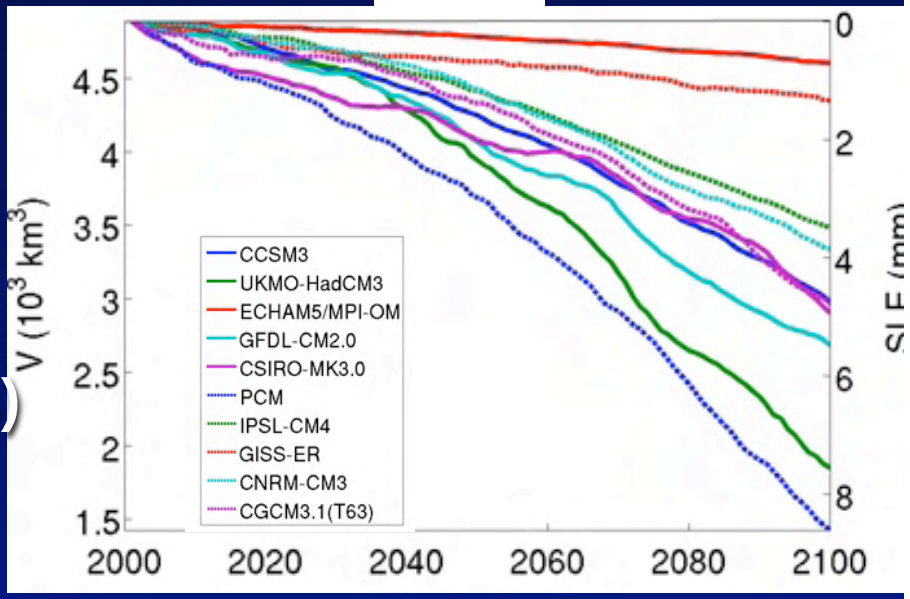
Radic and Hock, submitted

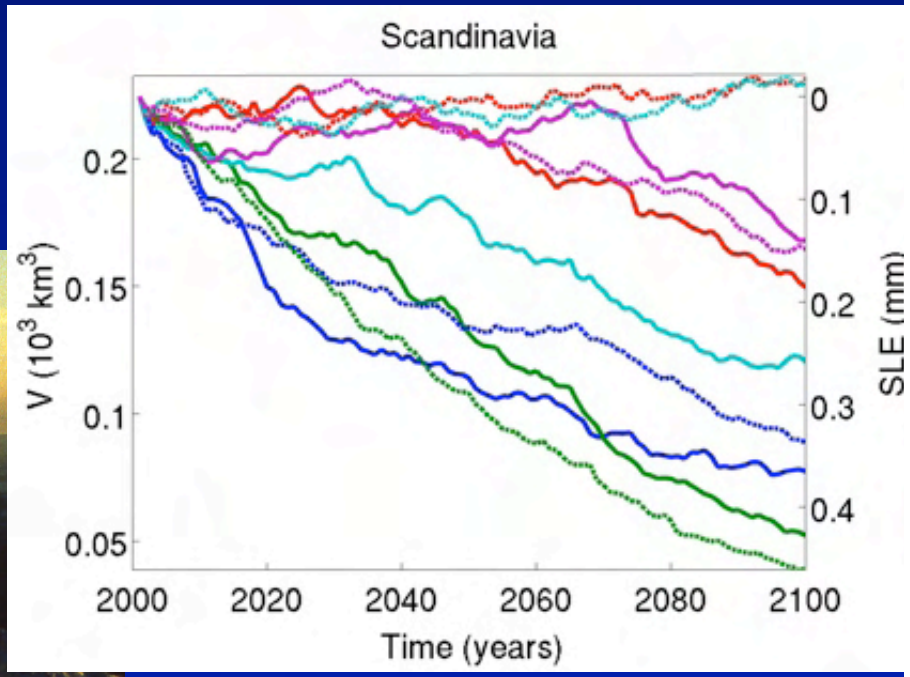
Iceland and Scandinavia show largest spread on Earth

Conclusions

- Most scenarios show a decrease in glacier volume by 2100, roughly by 0 to 80%
- Large uncertainty in the regional projections due to the choice of GCM (larger than in other regions)
- Small differences for the 2 individual glaciers (RCM)
- likely that glaciers will lose a significant fraction of their current mass --> consequences for streamflow (+hydropower)

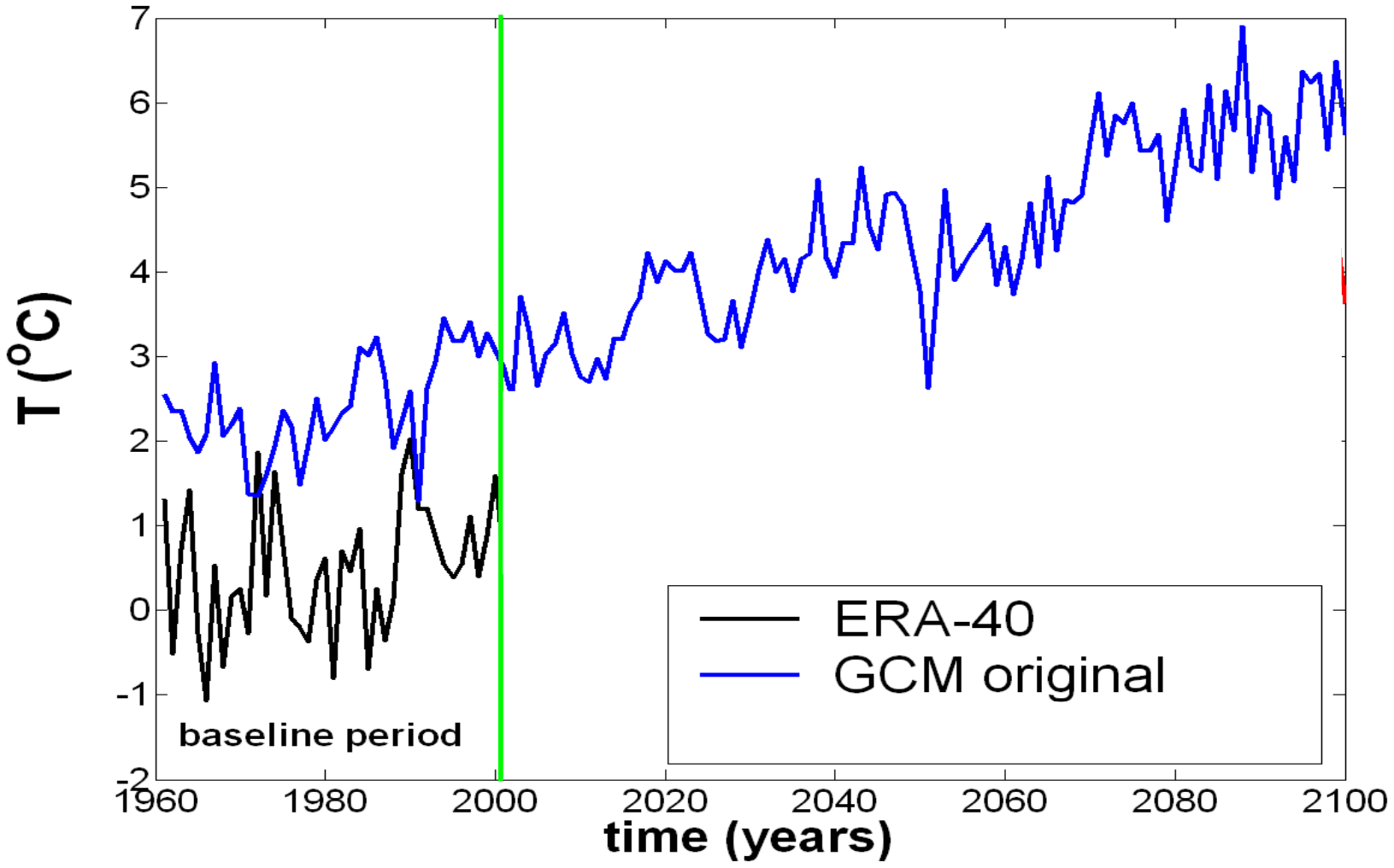
Iceland





Downscaling of RCM and GCMs

'local scaling' with ERA-40



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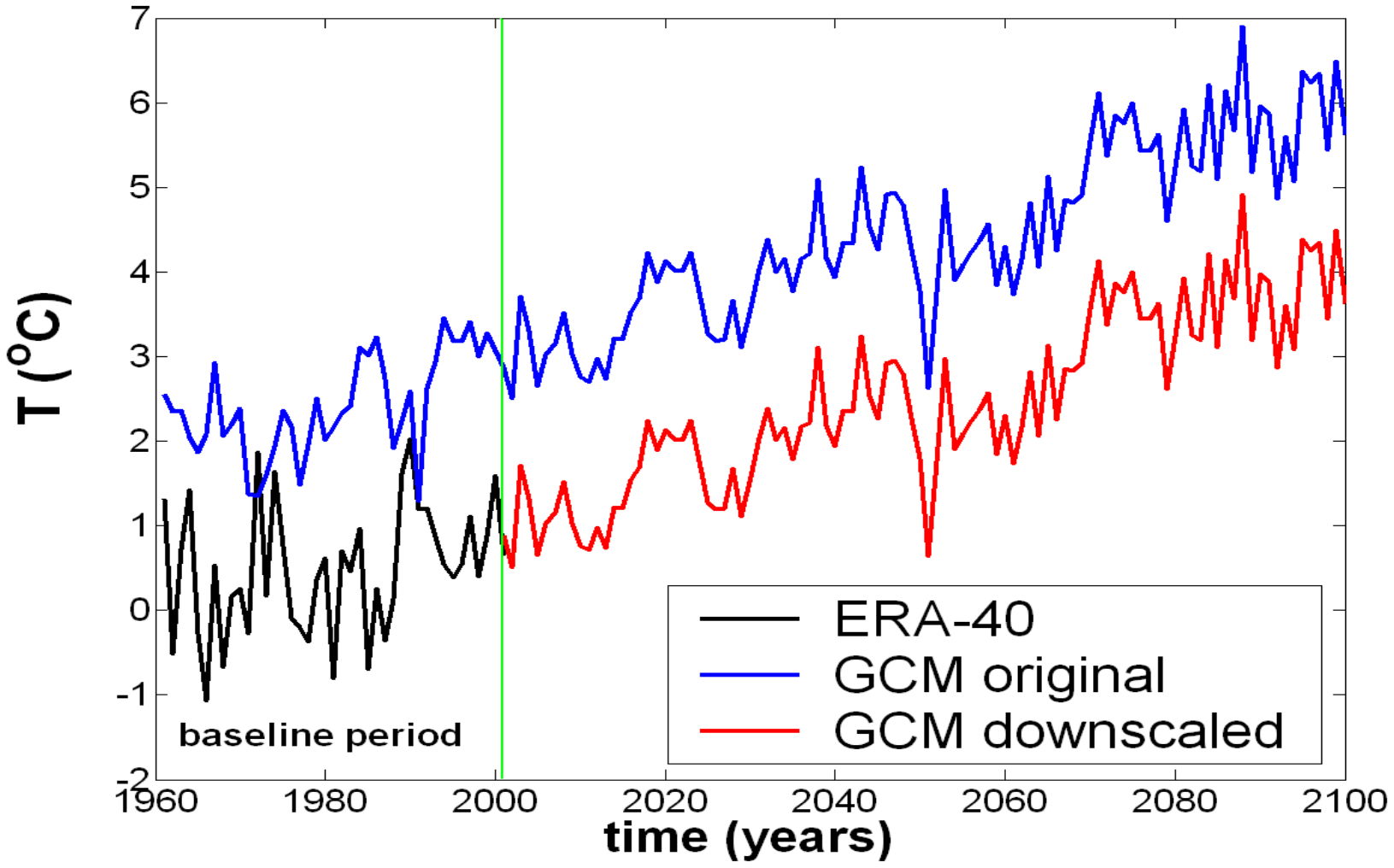
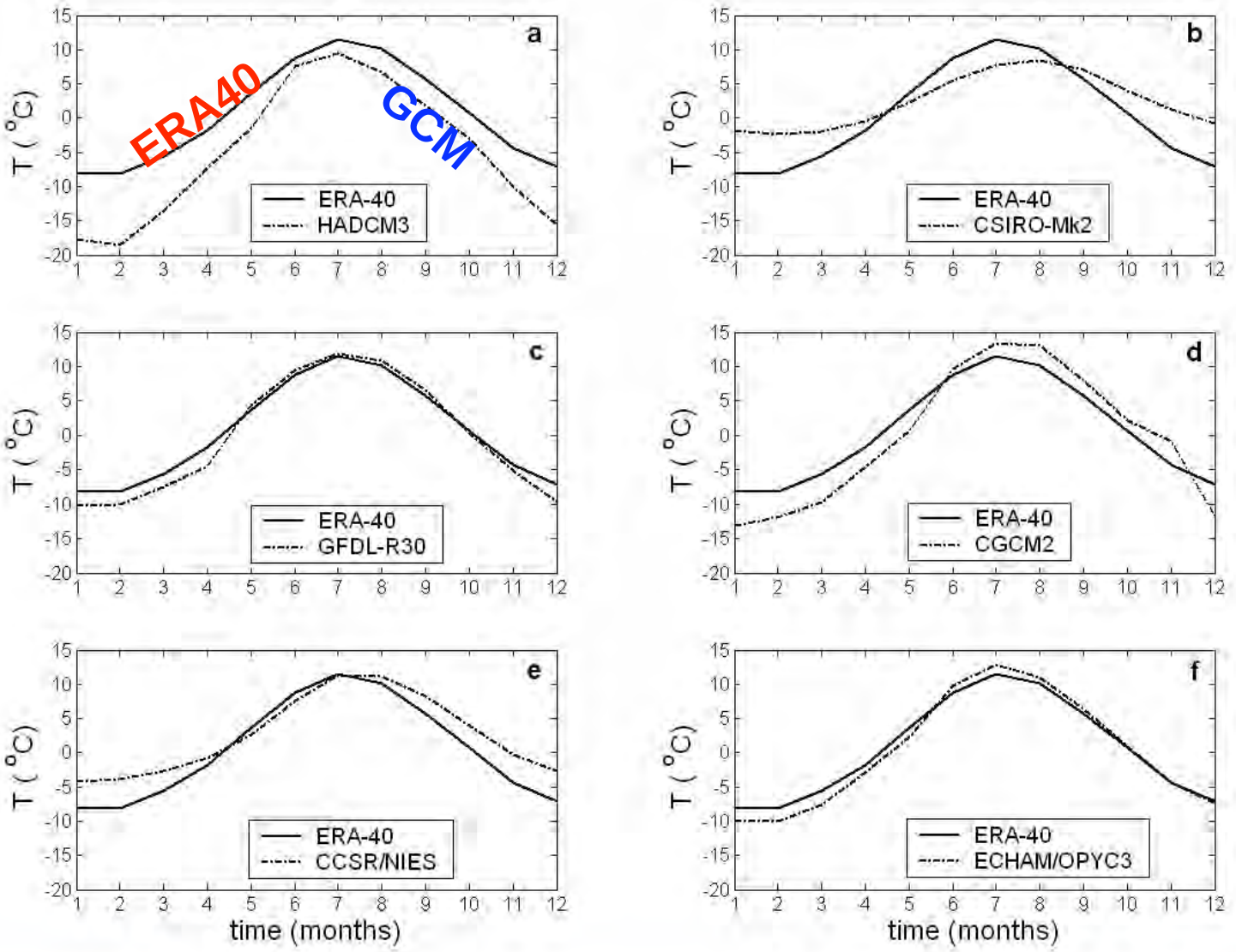


Seasonal temperature cycles averaged over 1961-2001 ERA-40 and six GCMs



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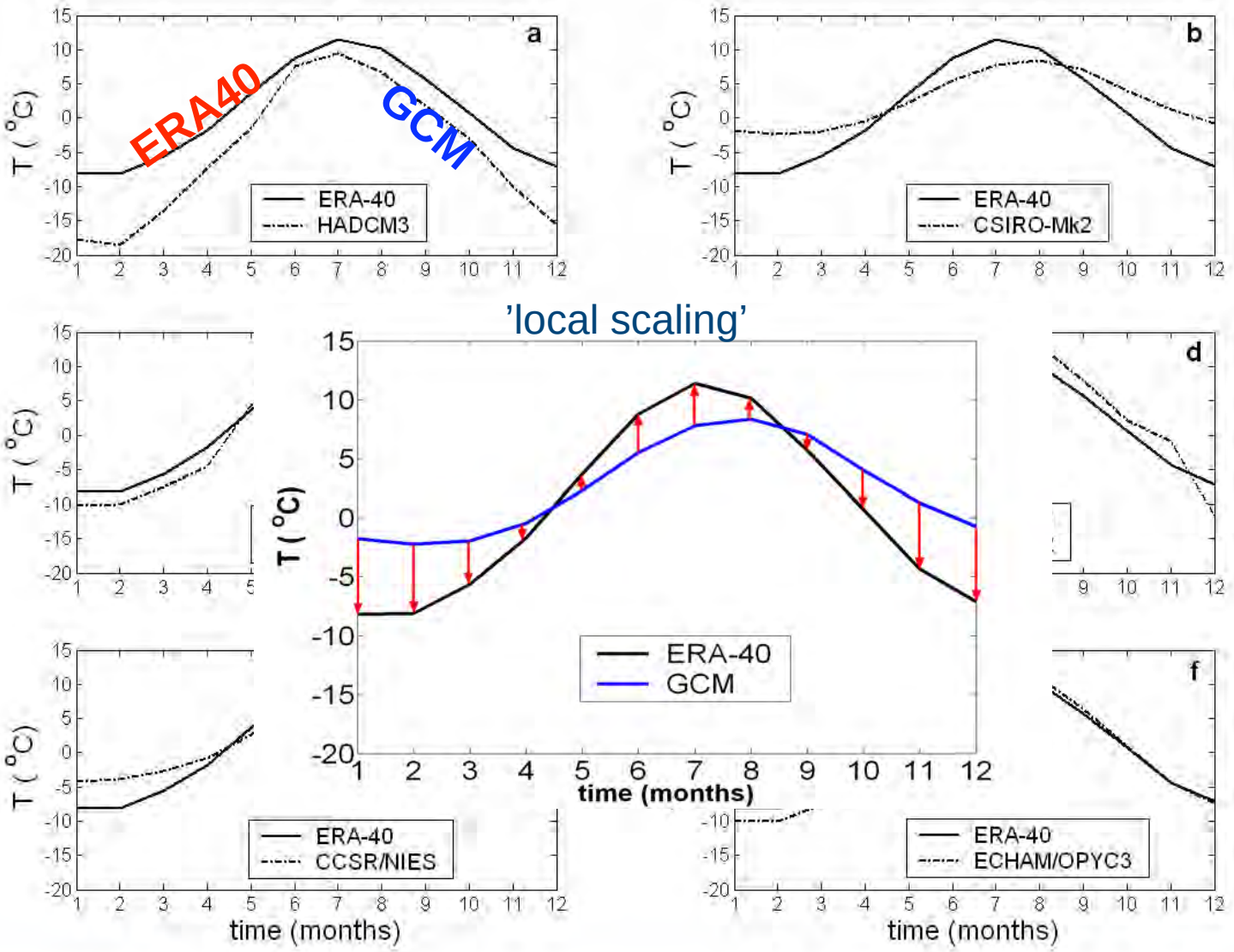
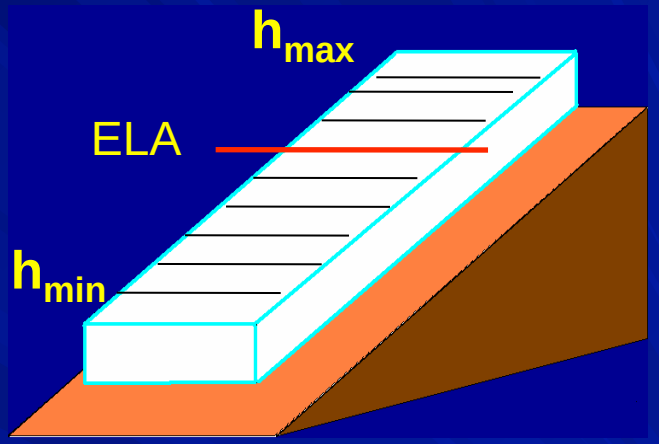


Method

Step 1: Calibrating an elevation dependent mass balance model to 44 glaciers

$$b(h) = -M(h) + C(h) + R(h)$$



Melt

$$M = DDF_{ice/snow}\ T_m^+\ n$$

$$T(h) = T_{ERA} + lr_{ERA}(h_{\max} - h_{ERA}) + lr(h - h_{\max})$$

Snow accumulation

$$C = a_m P_m \quad \begin{cases} a_m = 1, T_m < T_{snow} \\ a_m = 0, T_m \geq T_{snow} \end{cases}$$

$$P(h) = k_P P_{ERA} \left\lfloor 1 + d_{prec}(h - h_{\max}) \right\rfloor$$

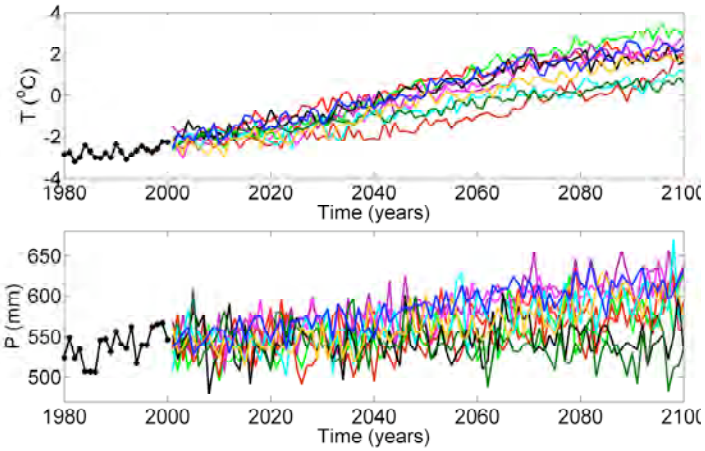
Refreezing

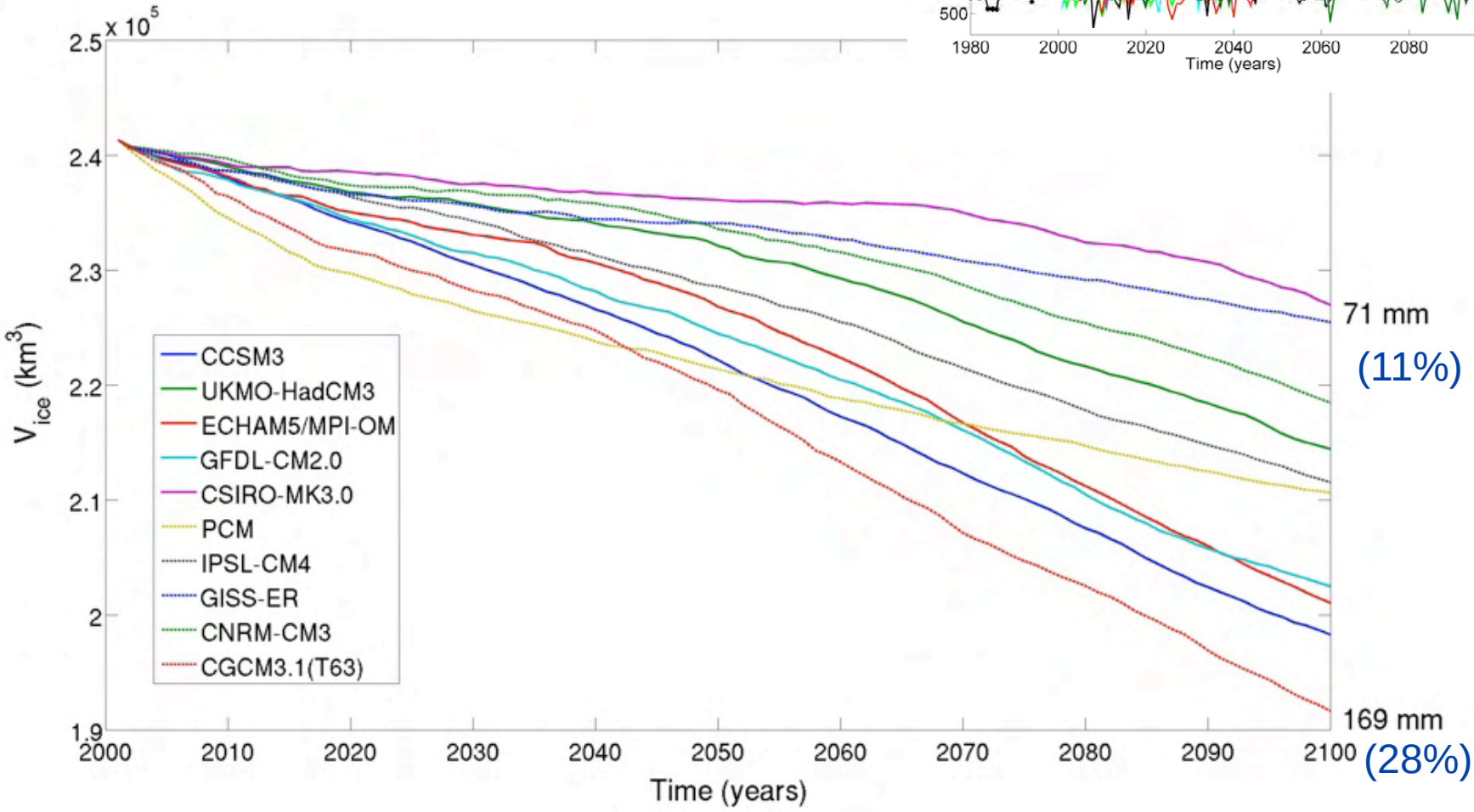
$$R = -0.69\ T_a + 0.0096$$

Woodward et al., 1997

Results

Global volume projections for 21th century





Results

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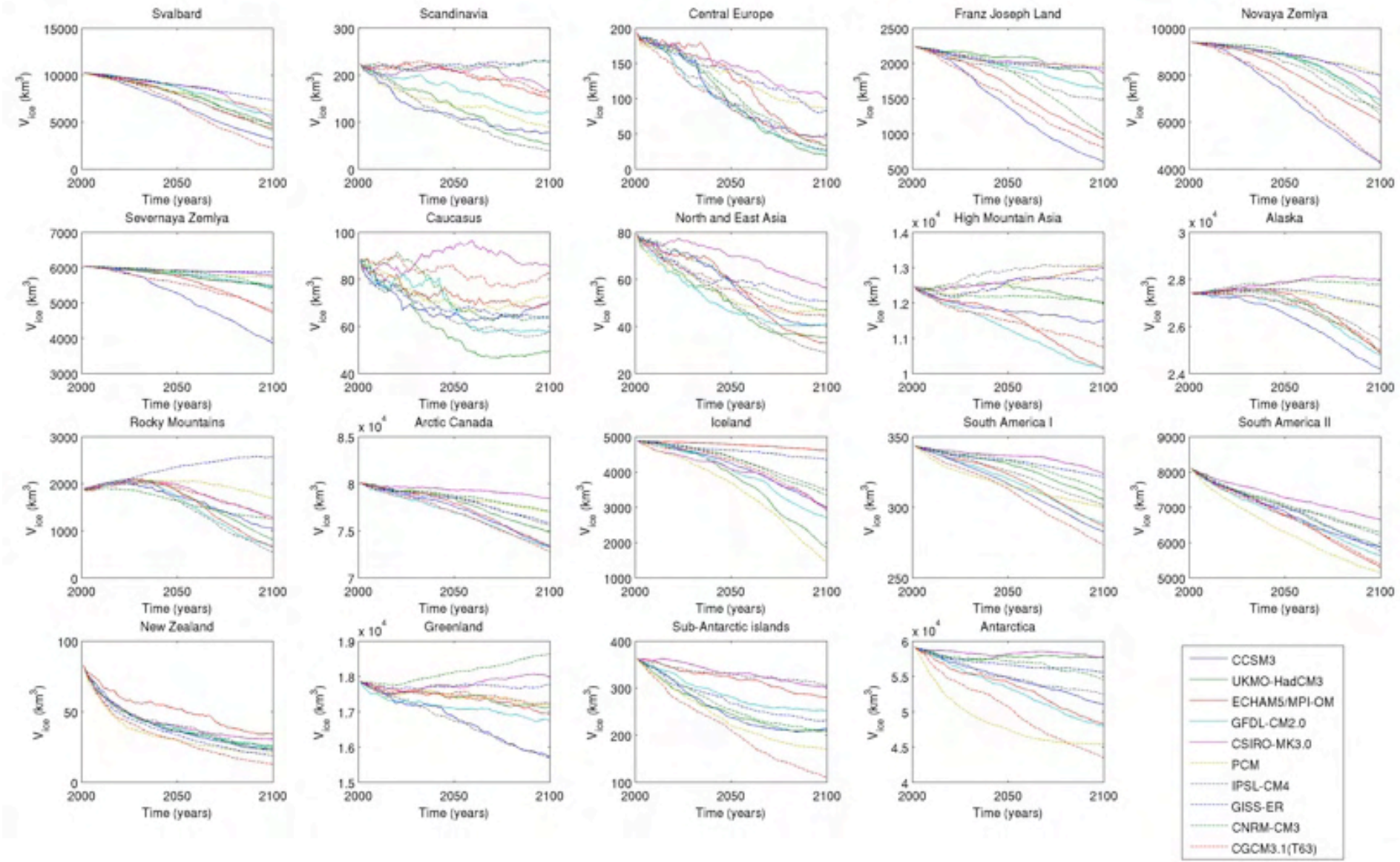
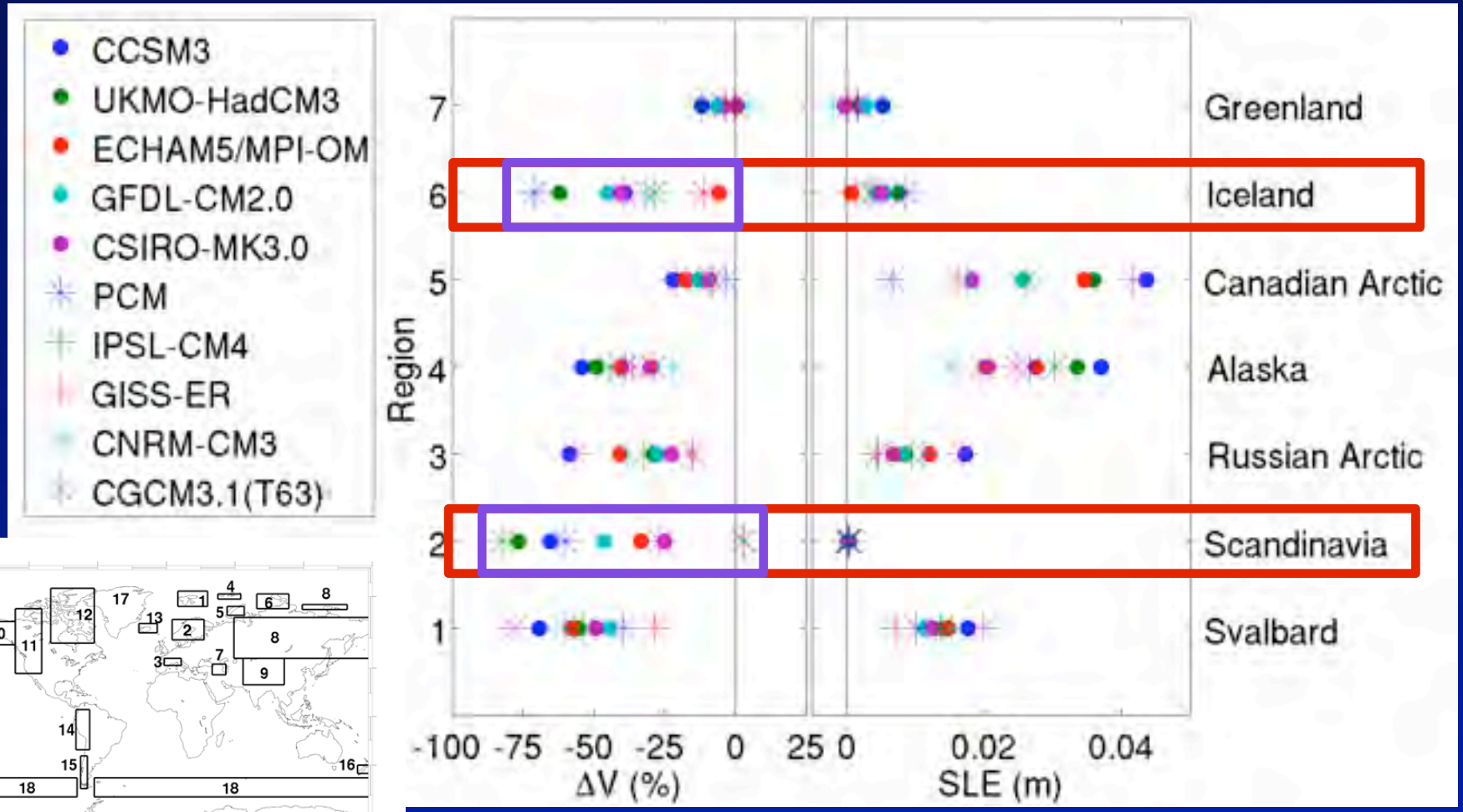


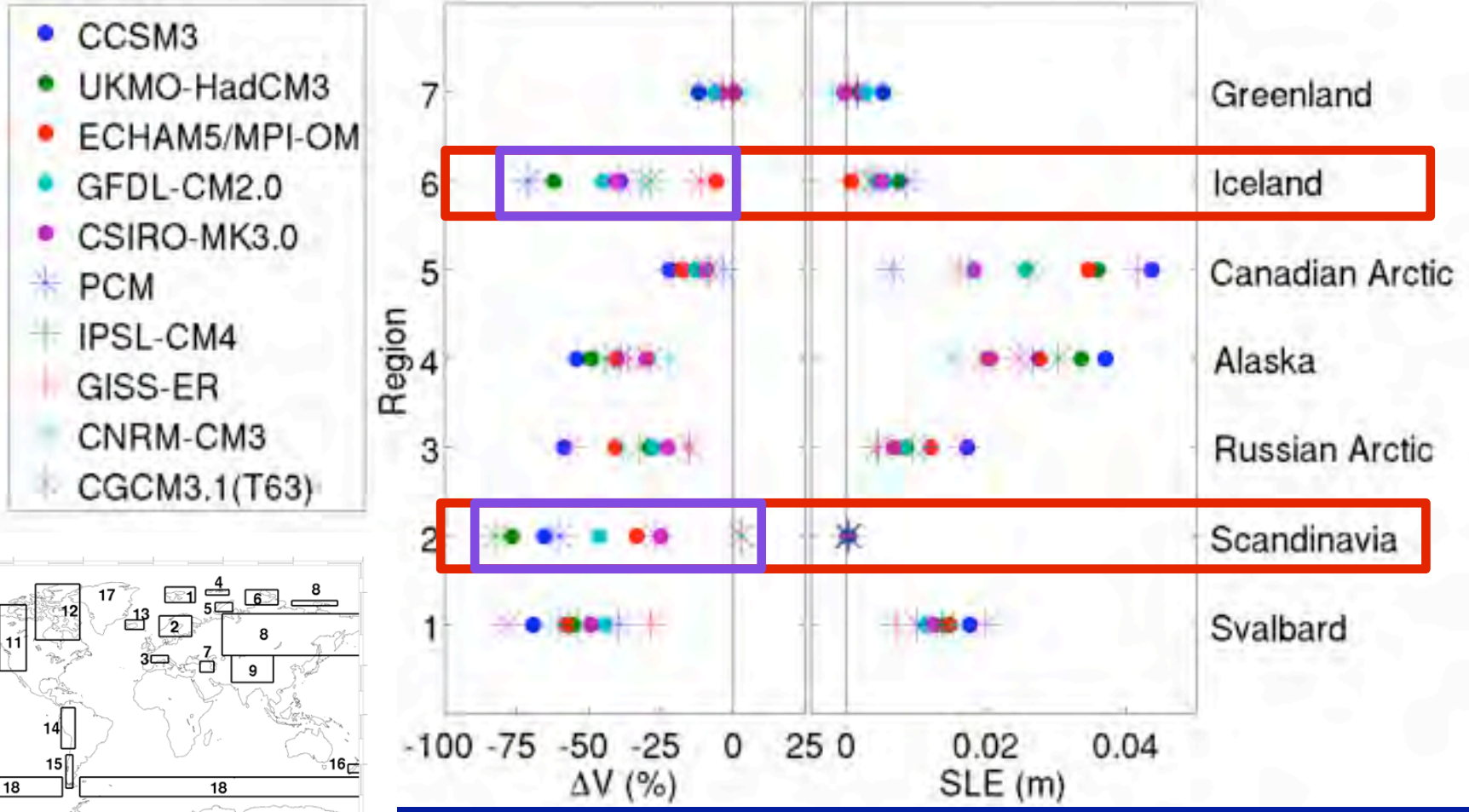
Comparison with other Arctic regions

Volume reduction and sea-level equivalent (SLE) until 2100 for 7 glacier regions



Comparison with other Arctic regions

Volume reduction and sea-level equivalent (SLE) until 2100 for 7 glacier regions



Iceland and Scandinavia show largest spread in the Arctic