

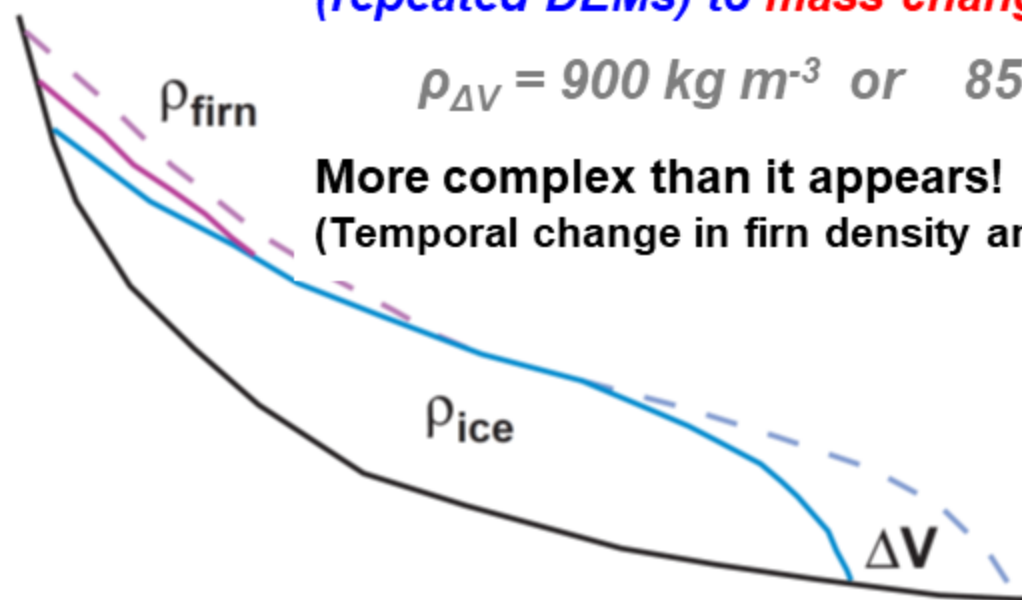
Converting geodetic ice volume to mass change: a global-scale assessment

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How do you convert glacier volume change (repeated DEMs) to mass change?

$$\rho_{\Delta V} = 900 \text{ kg m}^{-3} \text{ or } 850 \text{ kg m}^{-3}$$

More complex than it appears!
(Temporal change in firn density and volume)



A model for surface mass balance, firn density and thickness applied to all glaciers globally

- Estimation of optimal volume-to-mass change conversion factors
- Investigating processes driving departures from reference value

Modelled regional «density of volume change» 2000-2020 in kg m^{-3}

Variable best explaining variance

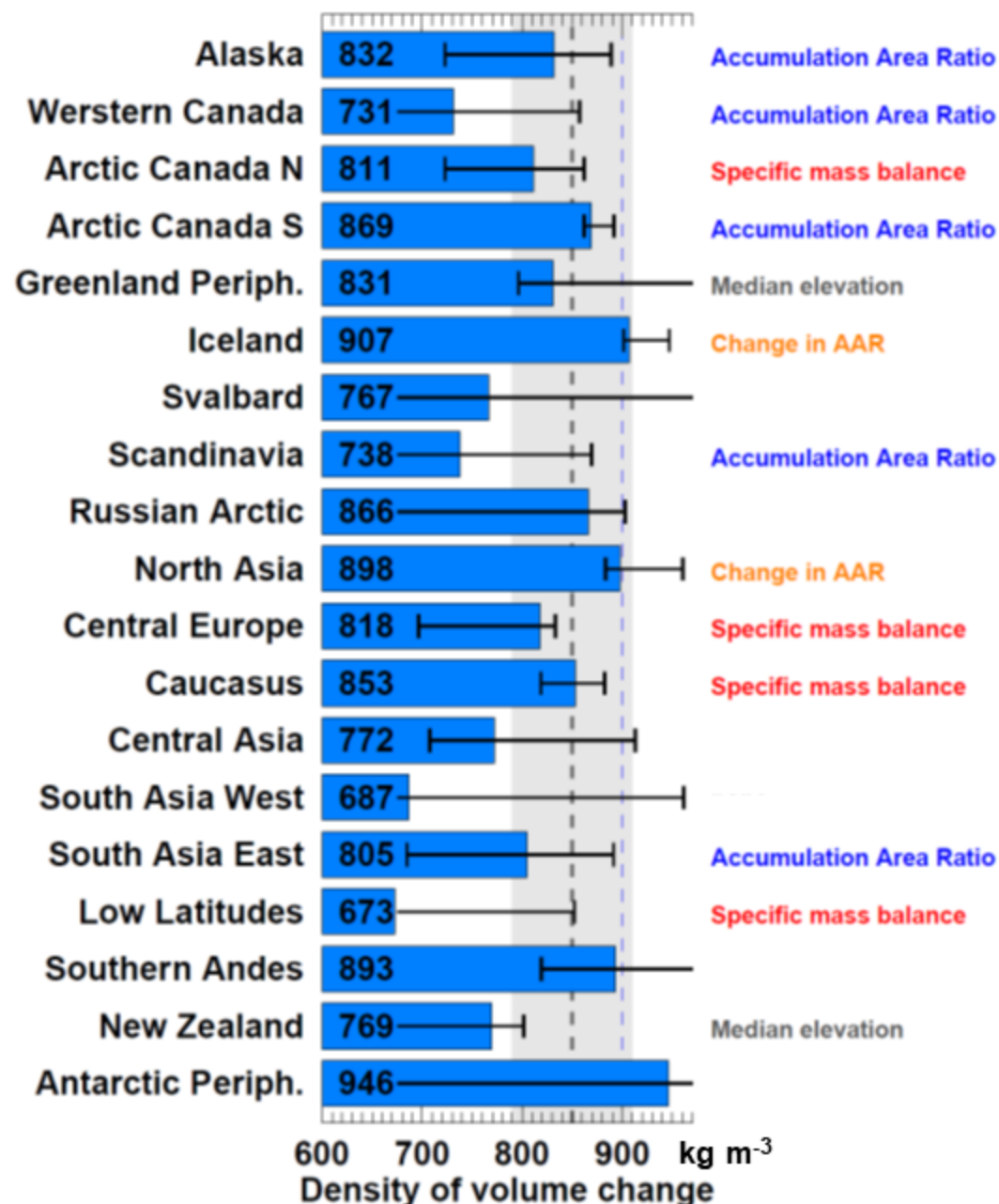


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The problem

Mass change

Volume change

$$\Delta M = f_{\Delta V} \cdot \Delta V$$

(required for
climate studies)

(easy to measure)

The conversion factor is poorly constrained and – in almost all cases – accounts for more than just ice density!

volume to mass
conversion factor

$$f_{\Delta V} = \left(\frac{\Delta \rho V}{\Delta V} + \rho \right)$$

Volume change

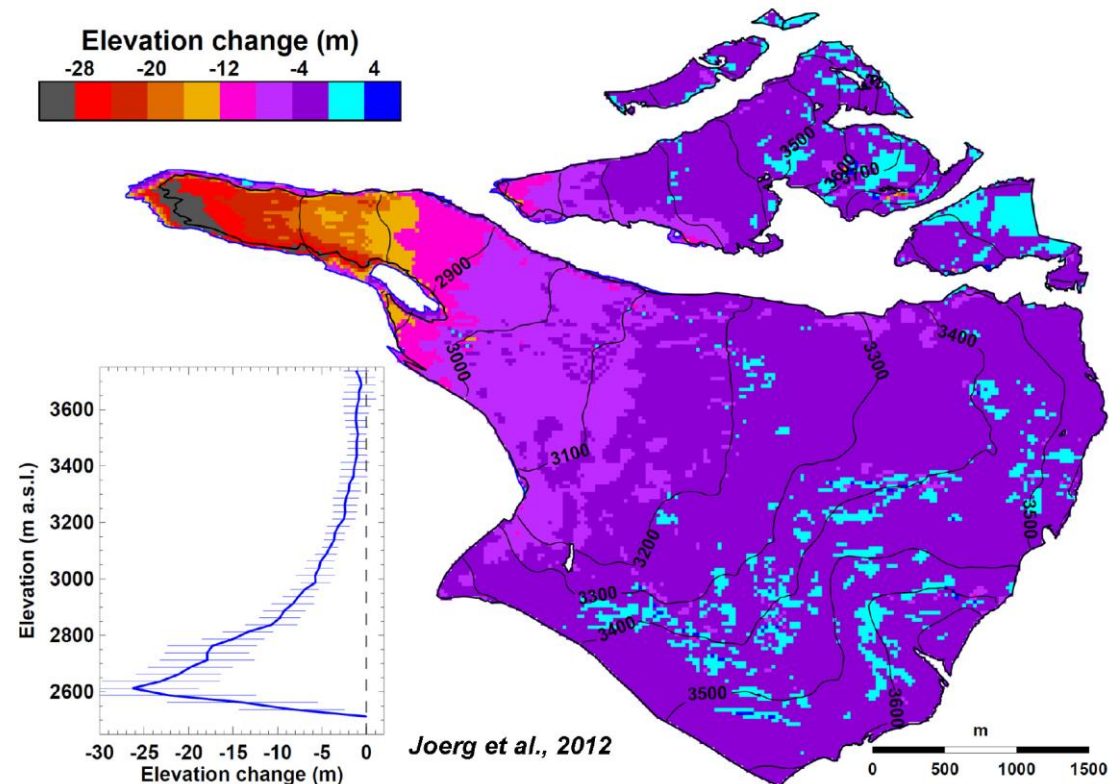
Density CHANGE

Glacier volume

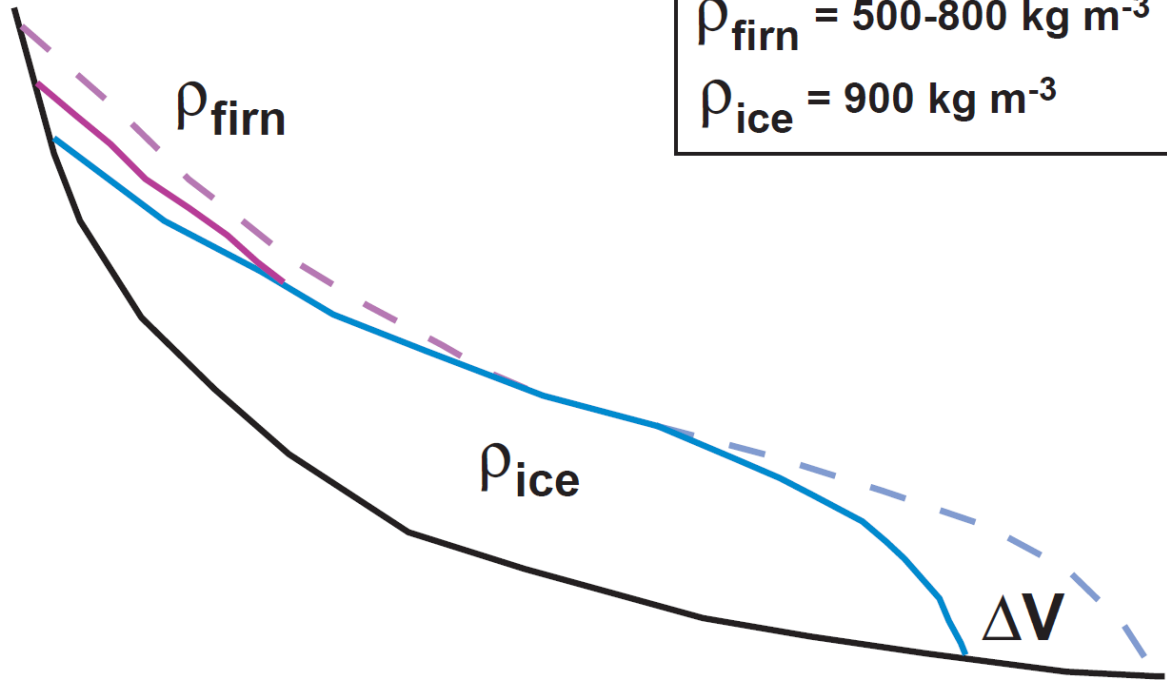
Glacier density

The potential of estimating glacier mass changes from repeated digital elevation models is tremendous and can fully exploits today's spaceborne data set!

However, *glacier volume change* is measured and needs to be converted into *mass change* for impact studies



The problem



«Density of volume change» is not directly measureable! It depends on temporal **CHANGES** in the firn density profile, combined with ice loss in the ablation area.

→ A major and poorly constrained uncertainty component in local to global-scale glacier mass change assessments

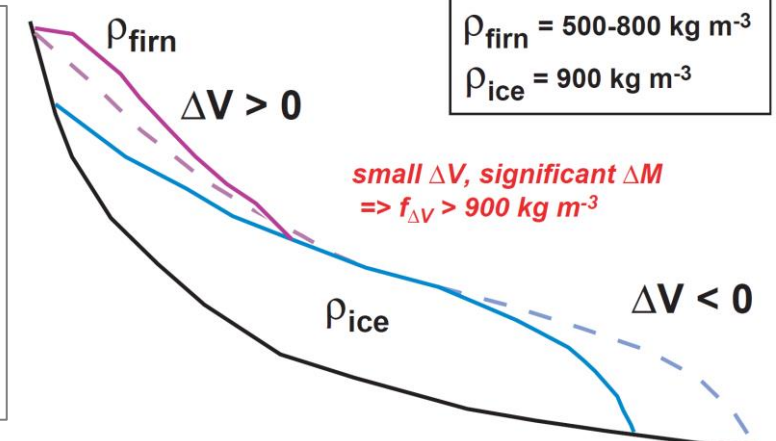
→ A firn model is required, including long-term changes in surface mass balance forcing

Potential for non-intuitive values of the «density of volume change»: In cases with rapid build-up or fast densification of firn, and small volume changes, conversion factors between $\pm$ infinity can occur

Example:

Glacier in slight imbalance with climate (small mass loss) with volume change measured between a normal and higher-than-normal precipitation year:

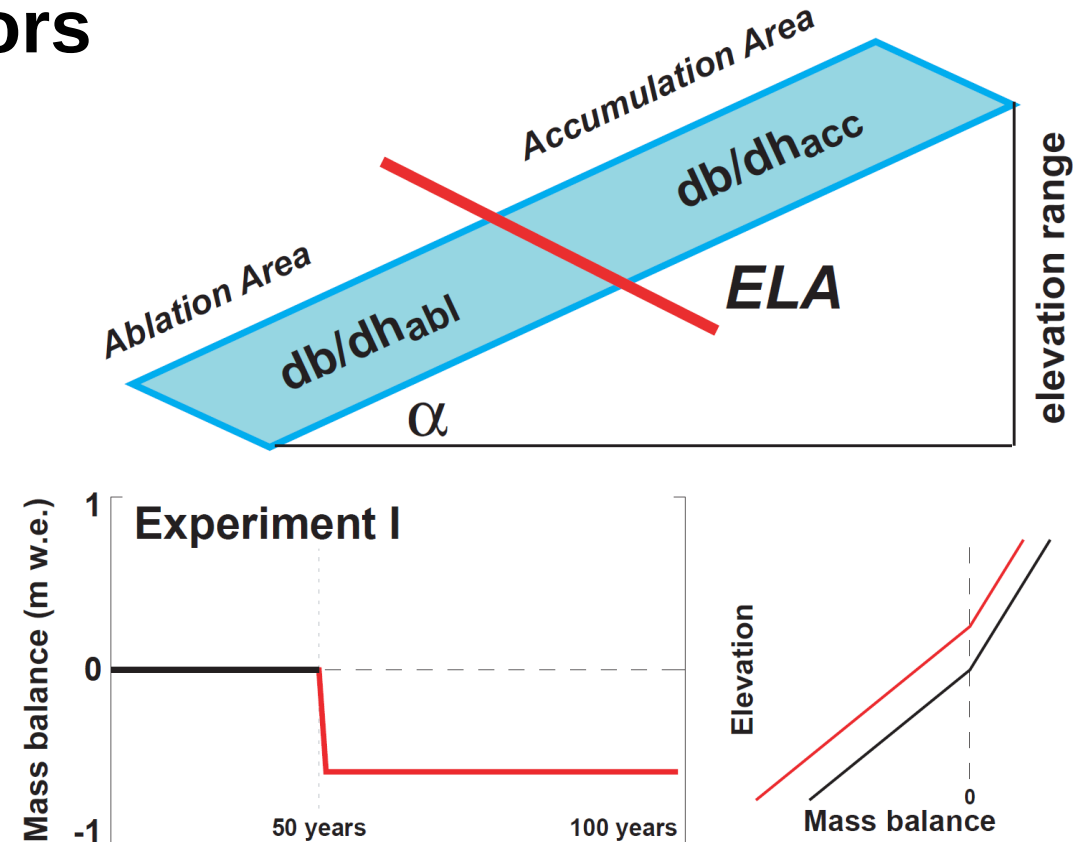
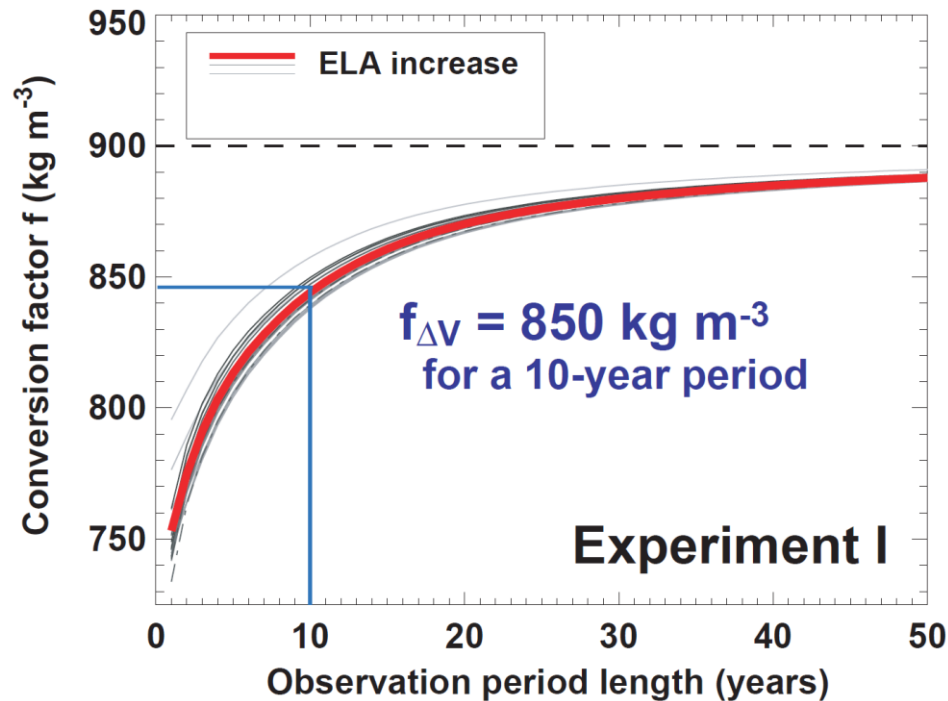
Volume change ~ 0 : decrease in volume due to small imbalance (abl. area) and increase in volume due to higher-than-normal precipitation (acc. area) → compensation
 Mass change < 0 : the volume lost has higher density ($\sim$ ice) than the volume gained ($\sim$ firn)
 Conversion factor = Mass change / Volume change → infinity



Previous studies on conversion factors

Few dedicated studies so far on volume-to-mass change conversion factors.

Assessment by Huss (2013, The Cryosphere) based on firn density model and **idealized** glacier geometries / mass balance changes.



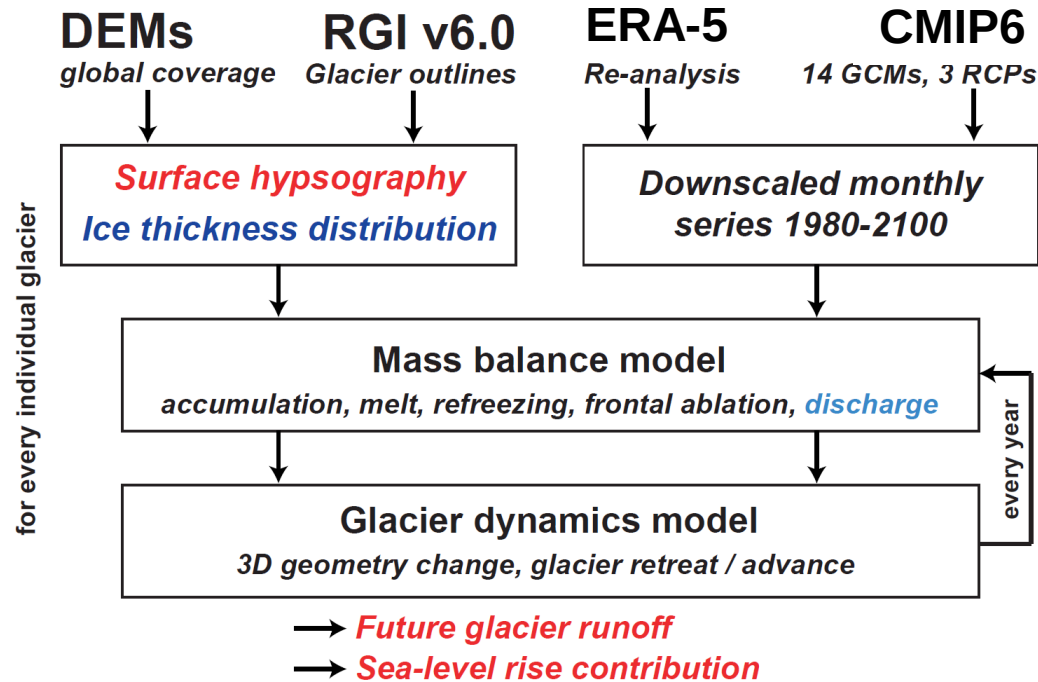
Main findings of Huss (2013):

- A conversion factor of **850 kg m^{-3}** is valid in many cases
- Major deviations from this value for short periods (<3 years), small volume changes, and particular changes in the mass balance gradient

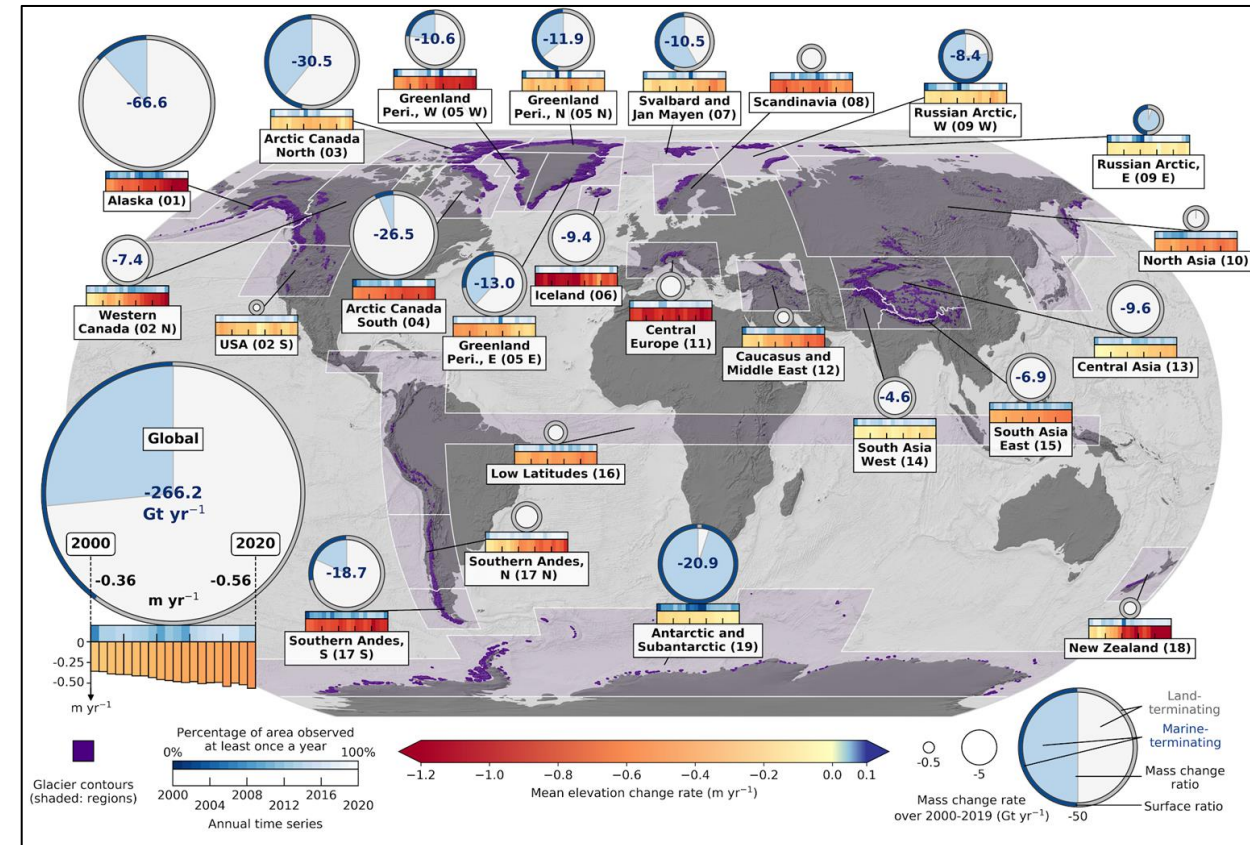
This study - Data and Methods

Infer volume-to-mass change conversion factors for all glaciers globally
2000-2020 (and subperiods) using observed / modelled surface mass balance forcing

Global Glacier Evolution Model (GloGEM)
driving a distributed firn densification model



Complete observational data set of glacier volume changes 2000-2020 (Hugonnet et al., 2021, Nature)

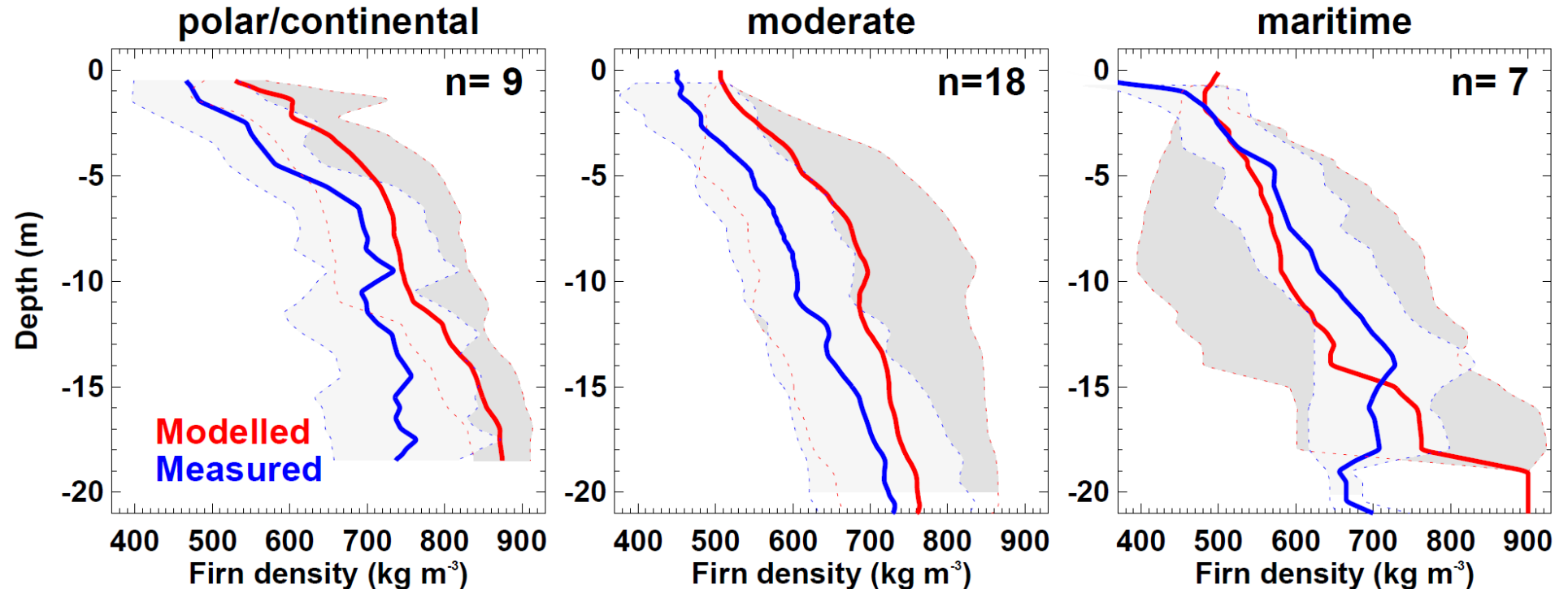


Validation of firn densification

Modelled GloGEM mass balance forcing since 1980 (spin-up before) allows computing annual firn density and thickness changes for all glaciers globally.

Local firn density measured in about 40 profiles in different climatological regions available

Reasonable match of model despite of some overestimation of density



Results

Please note: All results are preliminary!

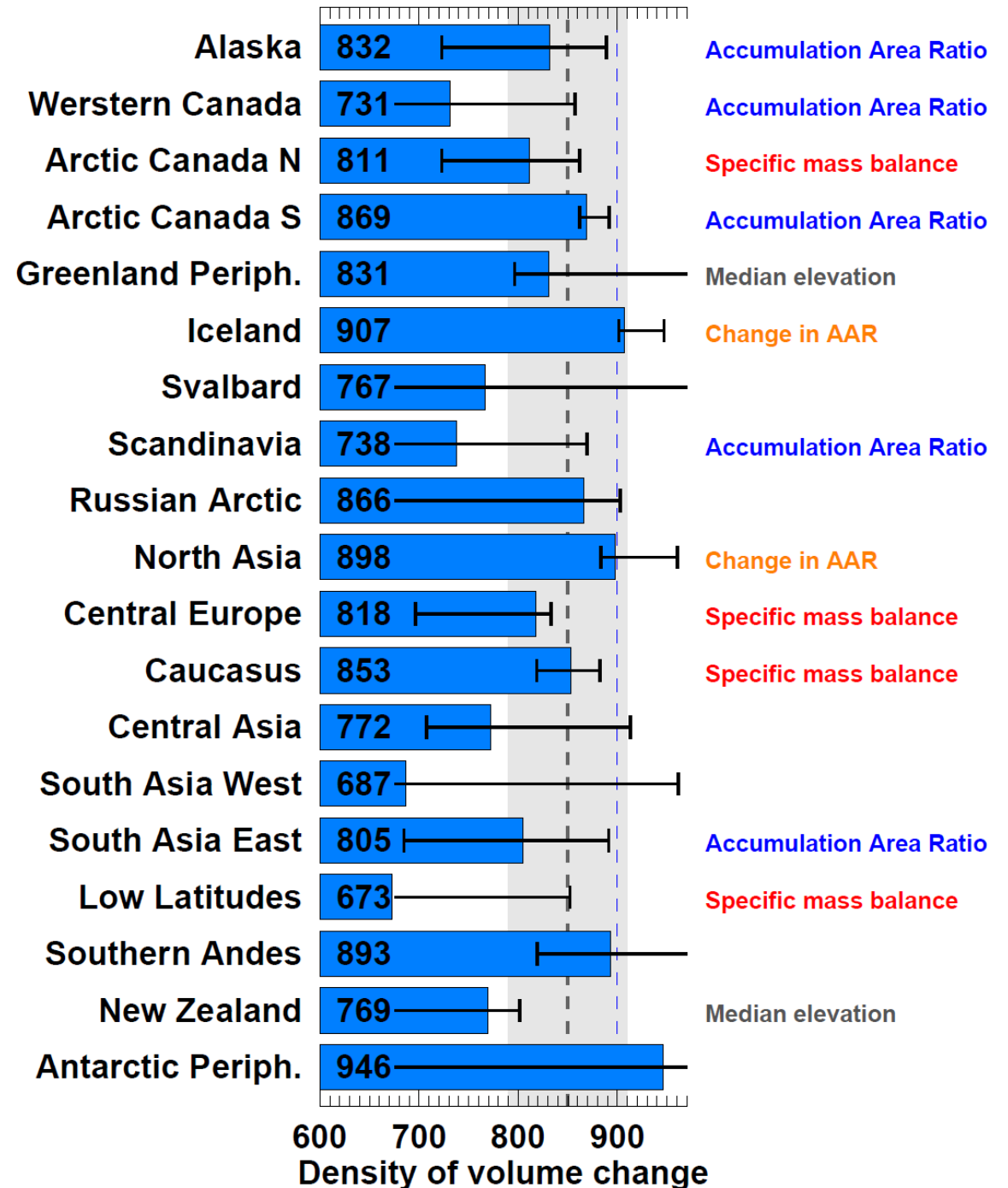
2000-2020:
«Density of volume change»
≈700 - 900 kg m⁻³

The often used assumption of
850 ± 60 kg m⁻³

Is valid for many cases, but noteworthy departures are possible (e.g. South Asia West, Antarctic Periphery, etc.)

Variables best explaining glacier-specific differences in the conversion factors:

- Accumulation Area Ratio
- Specific mass balance
- Change in AAR
- ...



Major spatio-temporal variability in conversion factors

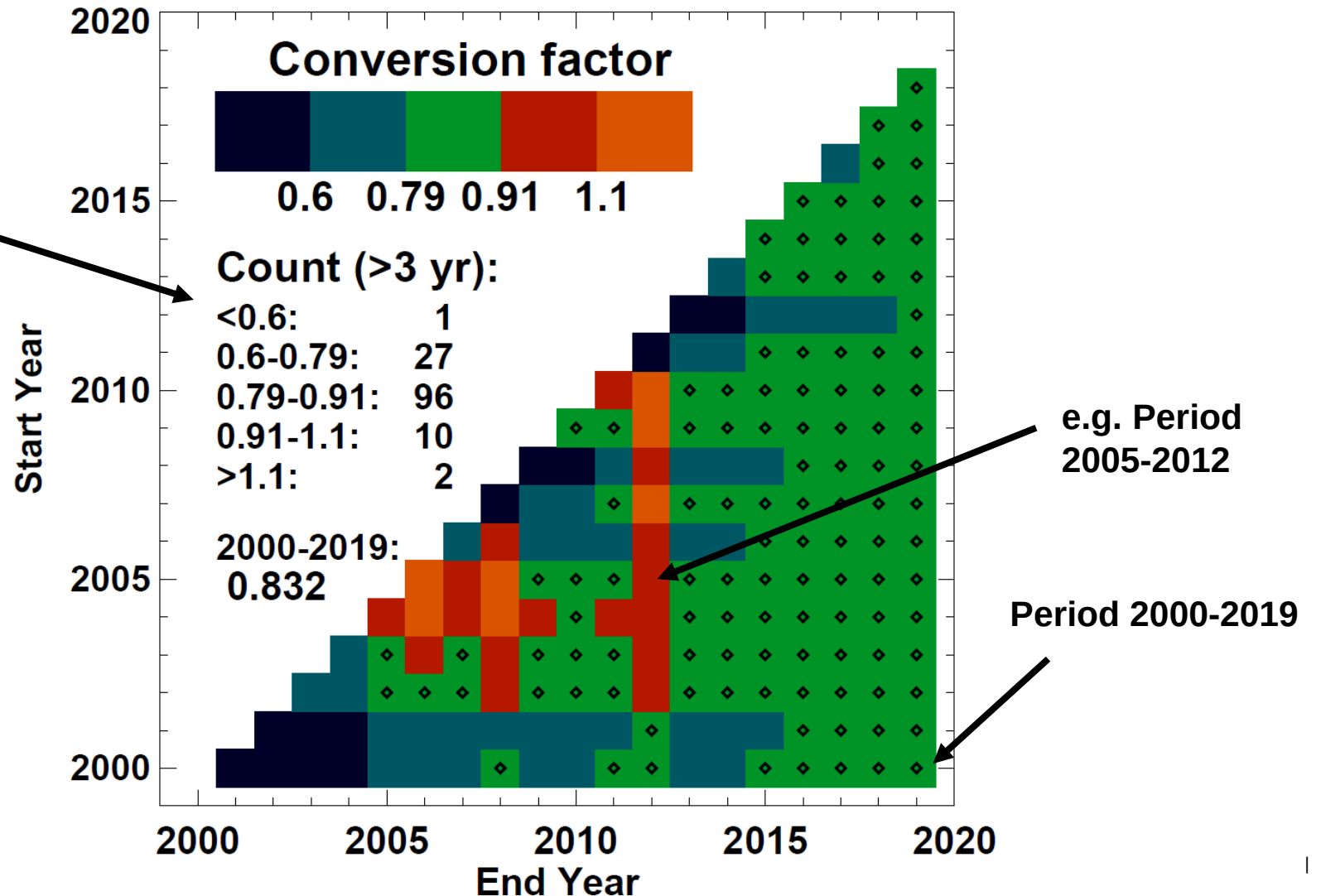
RGI-01 - Alaska

Histogram of conversion factors over all periods >3 years

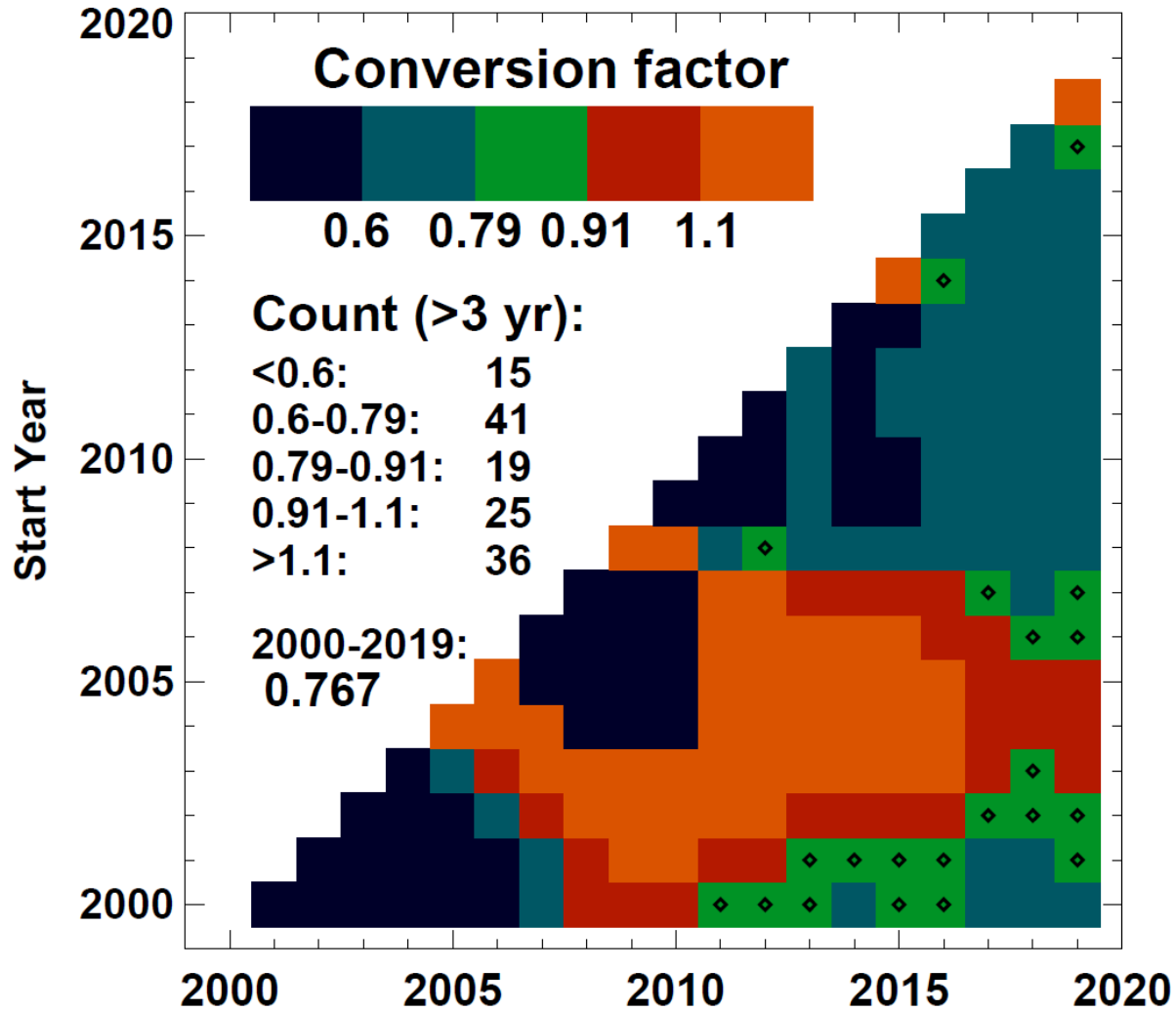
Major variability in conversion factors depending on time period considered!

(due to surface mass balance variability, acceleration / deceleration of mass loss)

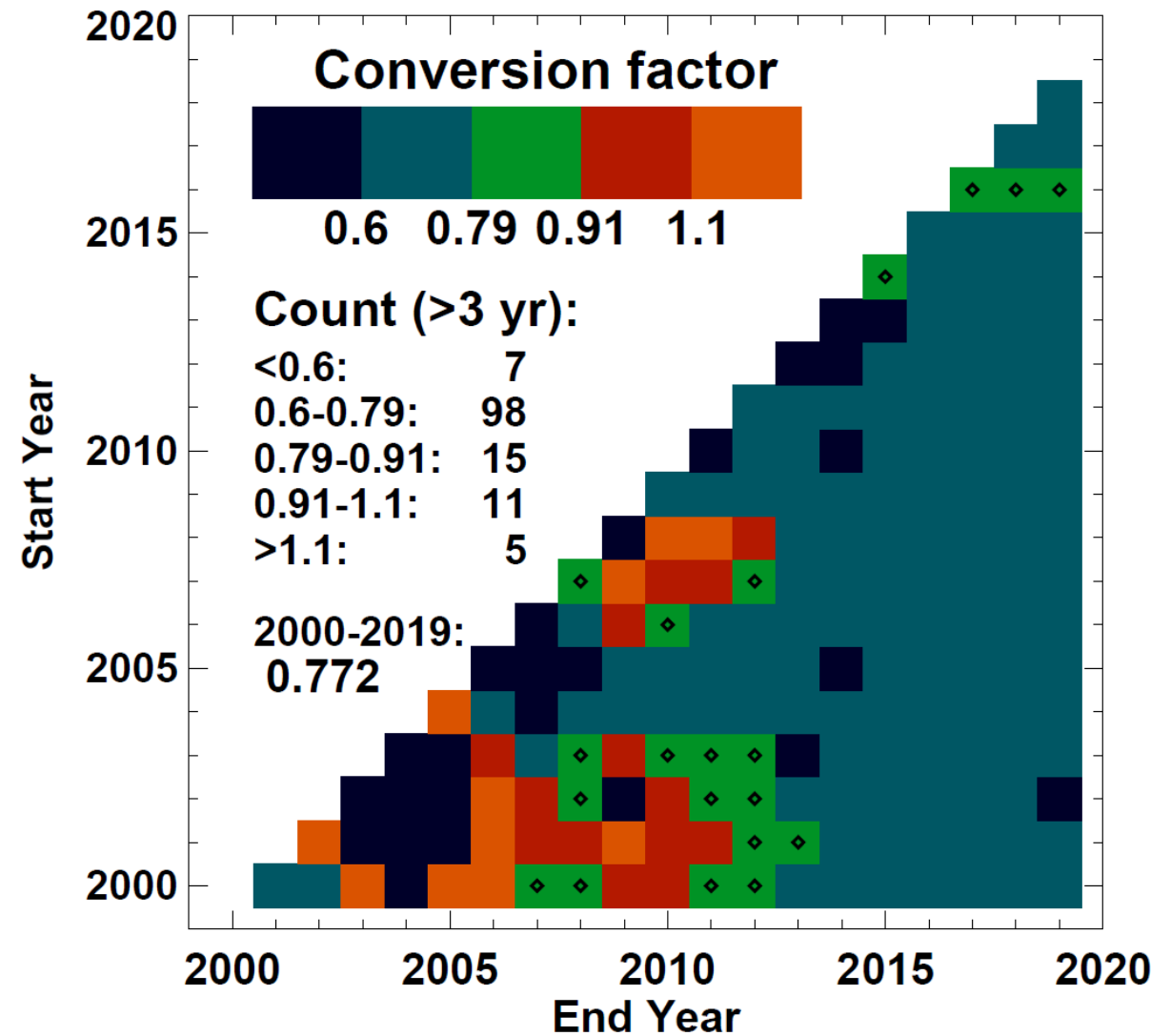
→ The longer the period, the more stable conversion factors get



RGI-07 - Svalbard

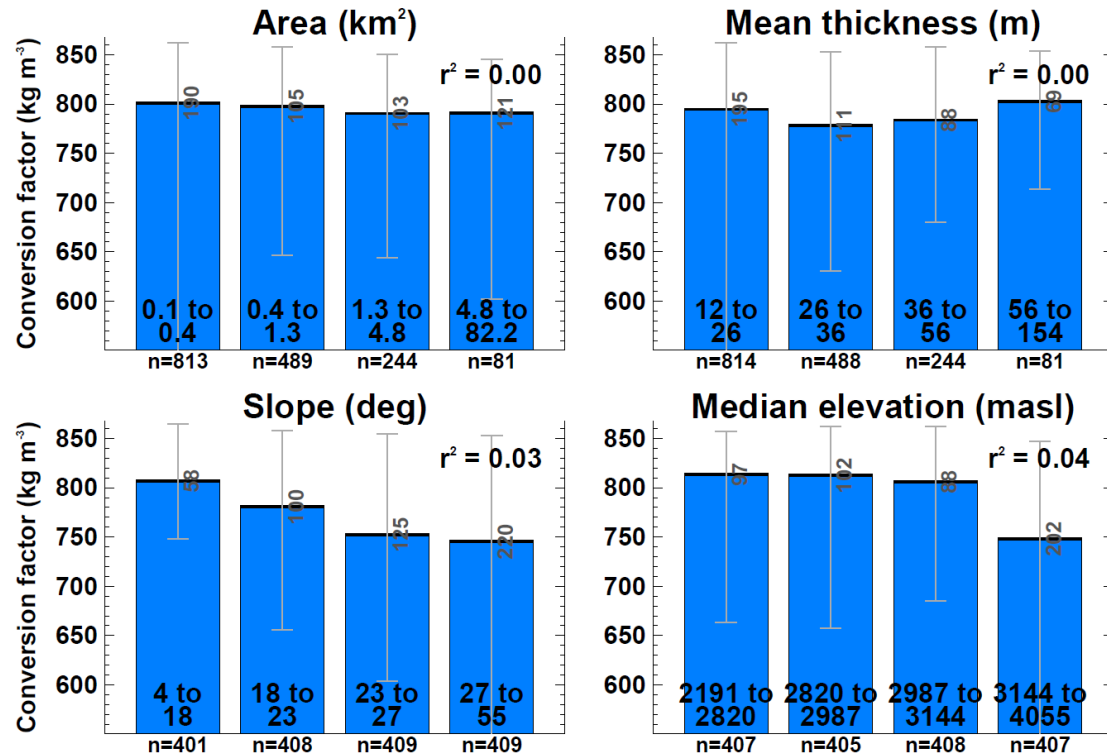


RGI-13 - Central Asia



Factors to explain variance in conversion factors

Correlation of conversion factors
(classified into four groups) with
potential explanatory variables



*Accumulation Area Ratio and Mass balance are the
best variables to estimate glacier-specific conversion
factors*

