A globally complete, spatially and temporally resolved estimate of glacier mass change: 2000 to 2019

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Data

All ASTER, ArcticDEM and REMA DEMs intersecting glaciers worldwide:

- Stereo and bias-corrections (*Girod et al., 2017*): 5 million CPU hours
- DEM coverage equivalent to 20 times the land area on Earth

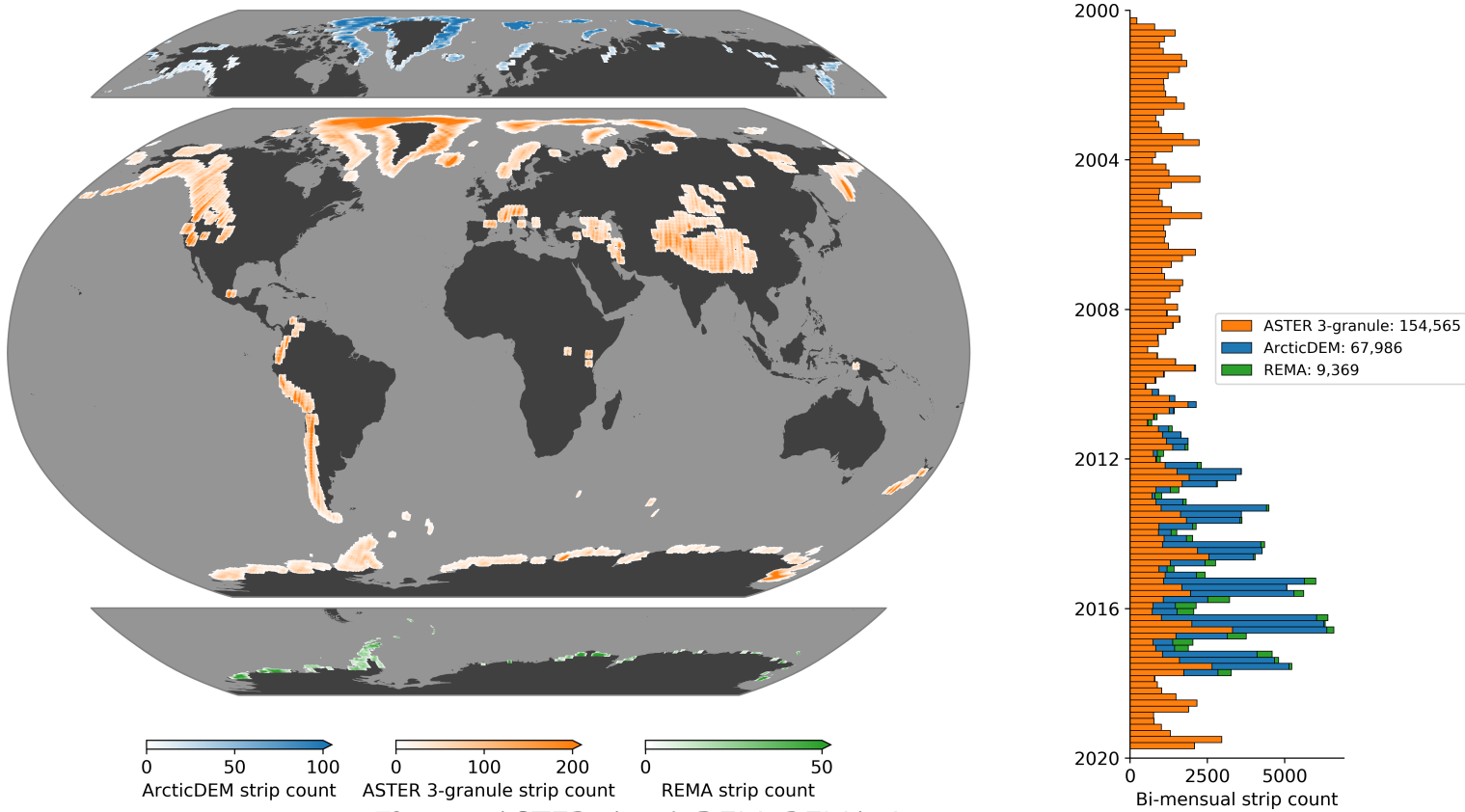


Figure: ASTER, ArcticDEM REMA data coverage

Methods

Continuous glacier surface elevation time series based on Gaussian Process approaches: (*Rasmussen and Williams, 2006*)

- Prior covariances estimated empirically in order to: **remove outliers (filtering), then mitigate effects of seasonality while conserving nonlinear changes (fitting)**

- Half a billion pixels resolved independently at a resolution of 100 m: **99,9% of Earth's glaciers, over 97,4% of their surface with 39 observations in time per pixel on average**

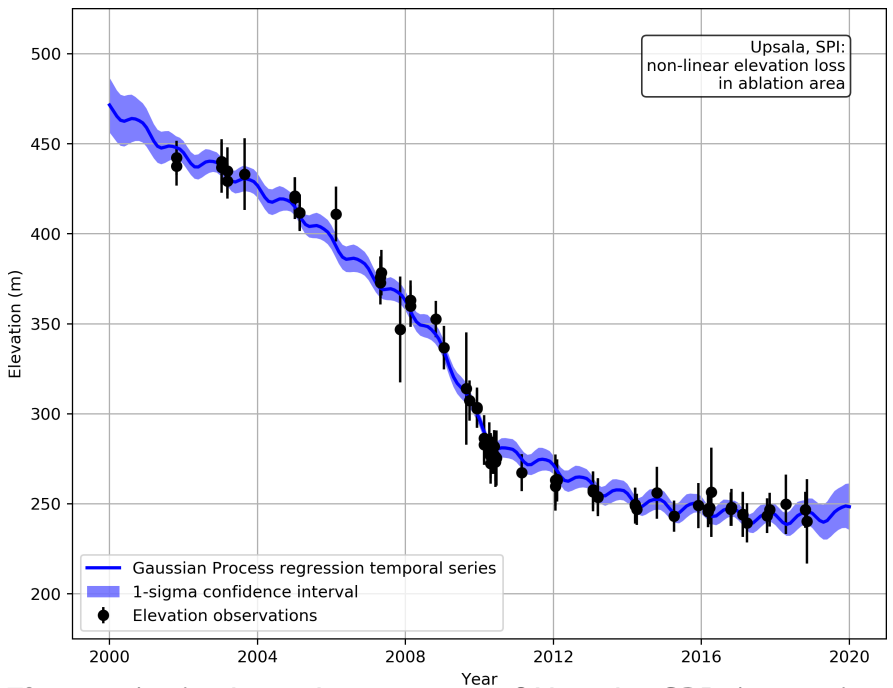


Figure: A pixel on the tongue of Upsala, SPI, Argentina

Validation and uncertainty analysis

All ICESat and IceBridge campaigns on glaciers:

- 25 million high-precision measurements spanning 2003-2019 **intersected at the same points in space and time than our time series**
- Reveal the **absence of elevation change bias in our time series** (<0.01 m yr^{-1} globally), conservative uncertainties and method robustness to multiple variables (low-texture areas, time lag to closest observation)
- Allow the study of the **spatiotemporal correlations structural to our interpolated elevation time series** for rigorous uncertainty propagation when integrating into volume and mass change time series

Region focus: Iceland

Elevation change over the two decades (glaciers + 10 km buffer)

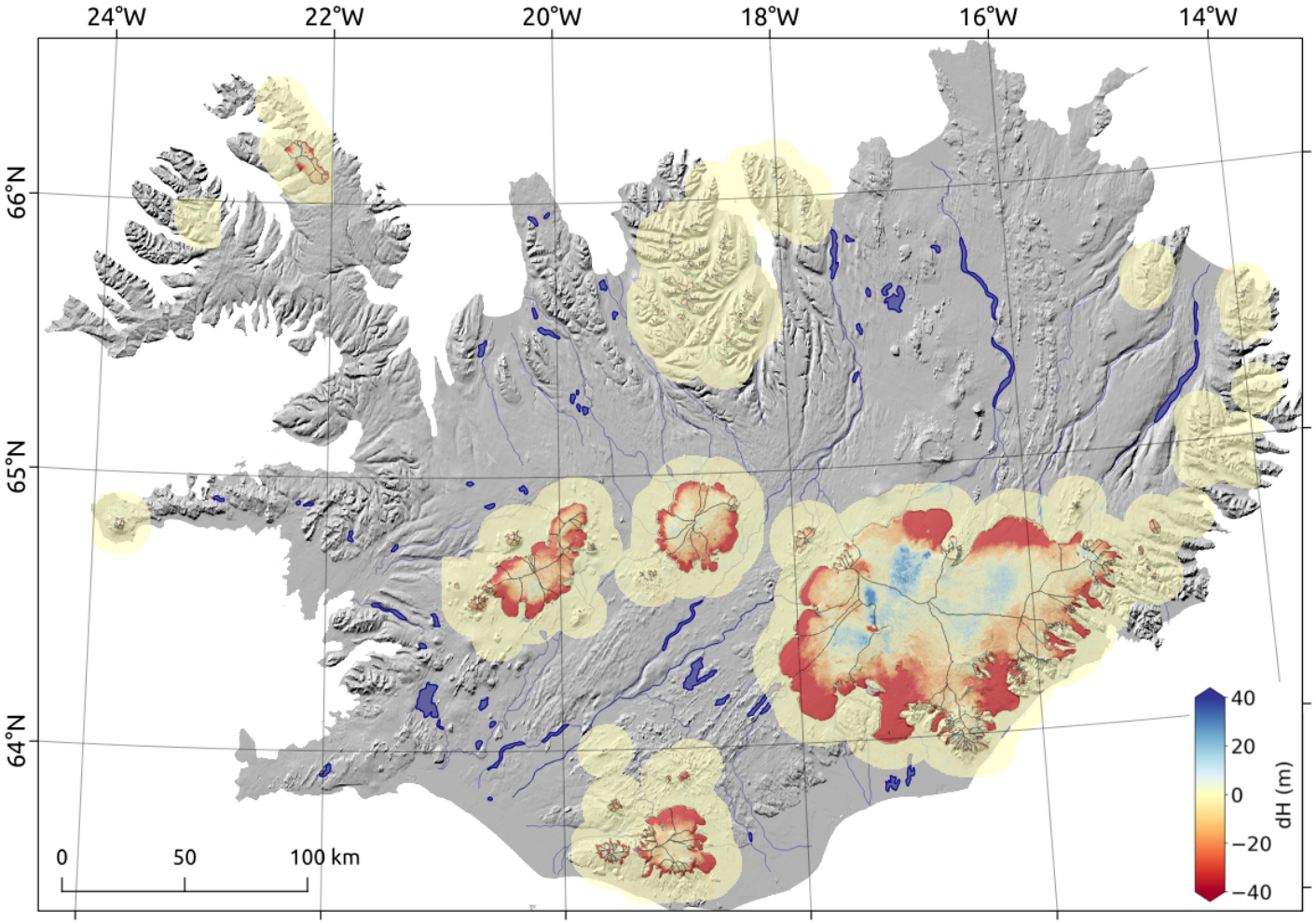
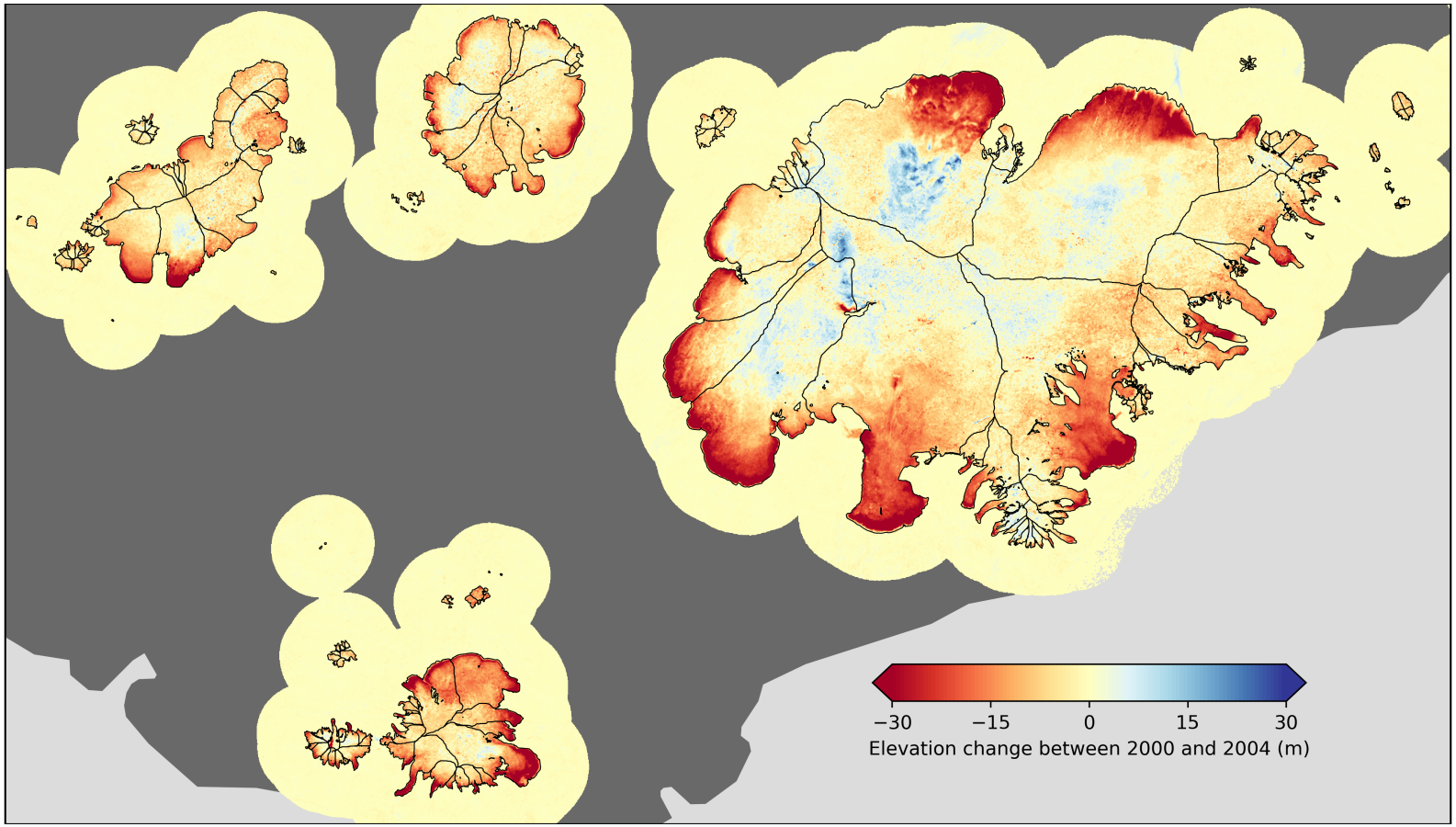


Figure: Iceland elevation change between 2000 and 2019

Region focus: Iceland

5-year elevation change: (visualize retreat + slowdown by switching slides)
2000-2004, 2005-2009, 2010-2014, 2015-2019



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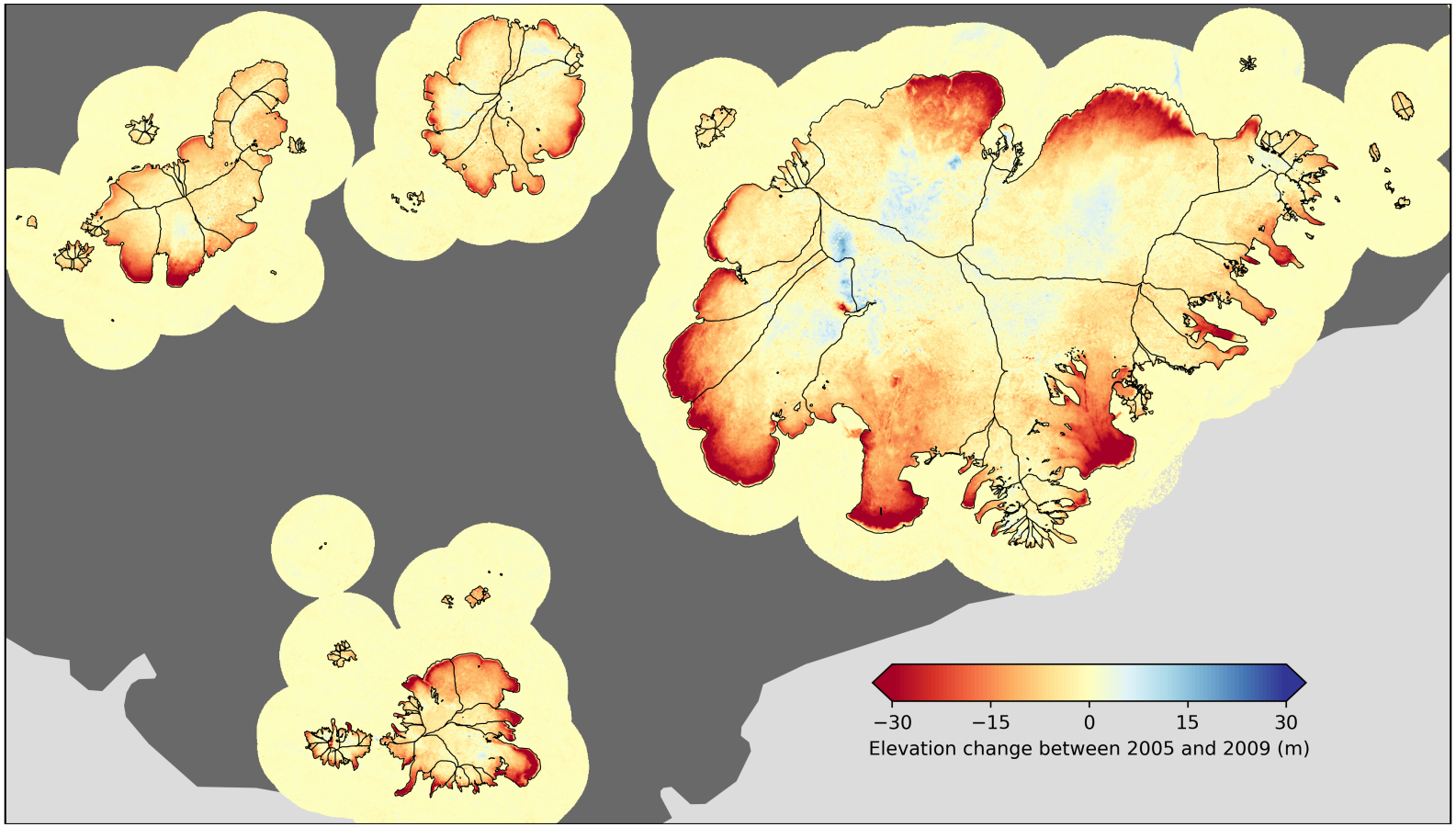

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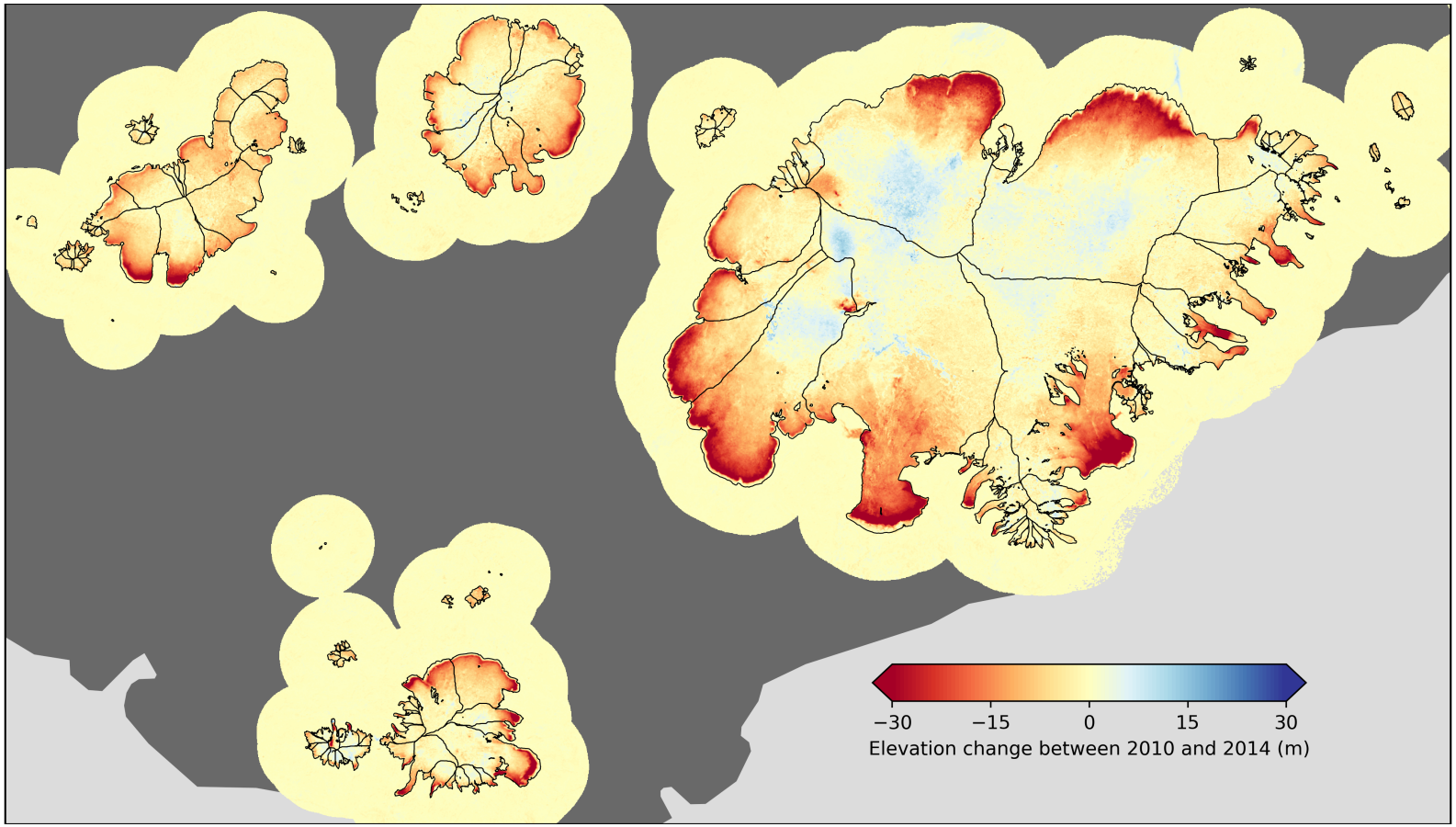

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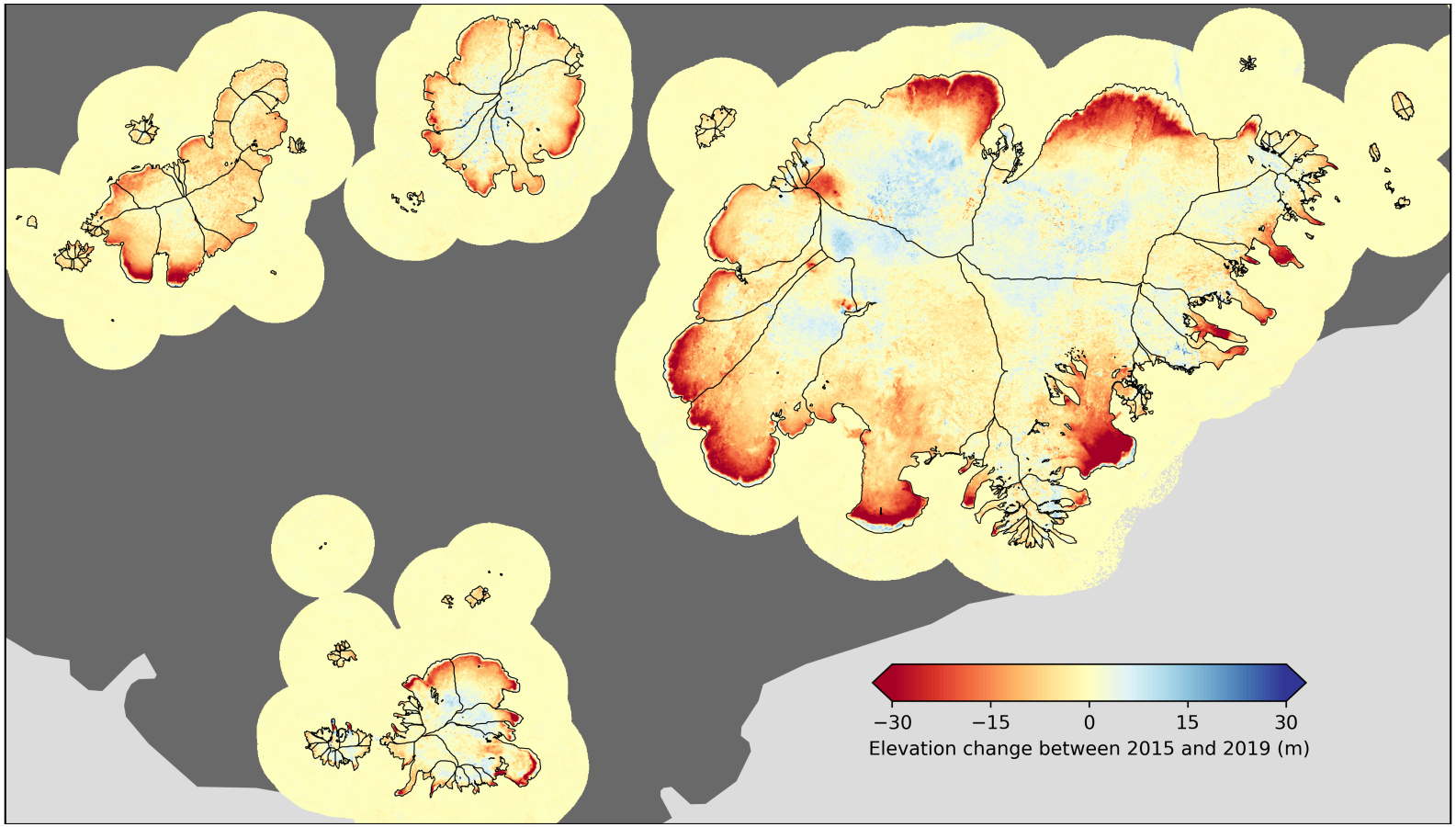


Region focus: Iceland

- **Annual:** large uncertainties (vertical precision, spatiotemporal correlations), density assumption issues
- **5-year periods:** small uncertainties (dominated by density conversion)

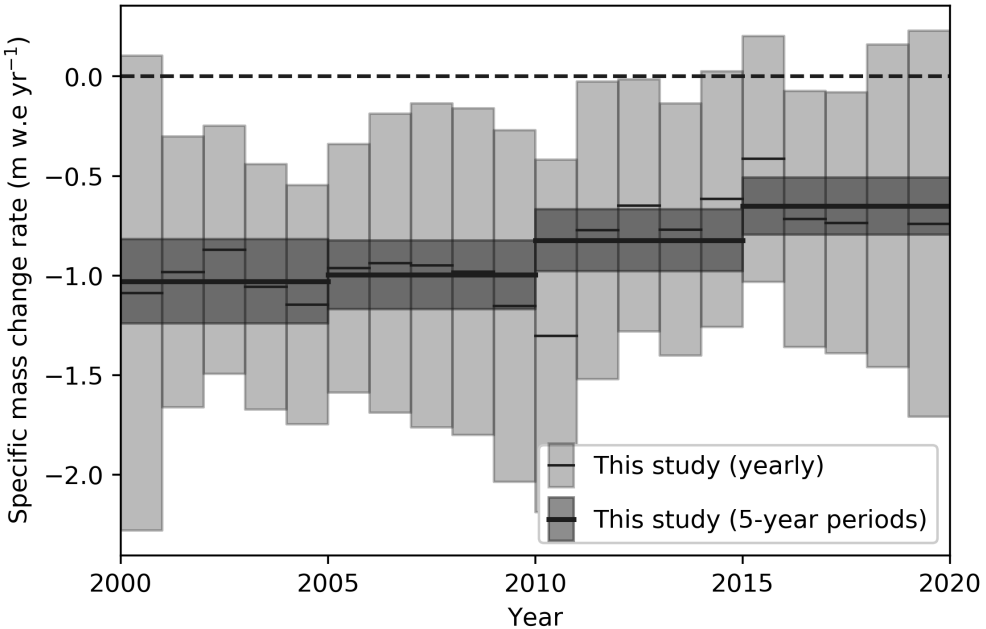


Figure: Iceland specific mass change rate series

Iceland glacier mass change (Gt yr^{-1})			
Period	This study	Other study	Reference
2001-2019	-9.2±0.7	-8.9±0.7	Aðalgeirsdóttir et al., in review
2003-2009	-11.1±0.9	-10±2	Gardner et al., 2013
2003-2009	-11.1±0.9	-10±3	Nilsson et al., 2015
2006-2015	-9.1±0.7	-10±2	Wouters et al., 2019
2006-2015	-9.1±0.7	-7±4	Zemp et al., 2019
2006-2015	-9.1±0.7	-7±3	IPCC SROCC, 2019
2011-2015	-6.8±0.7	-6±1	Foresta et al., 2016

Region focus: Svalbard

Region of massive surges:

- Austfonna basin 3, Northeast (Dunse et al., 2015, McMillan et al., 2014)
- Nathorsbreen, Southwest (Nuth et al., 2019)
- and many others...

Regional estimate in accord with: Schuler et al., in press

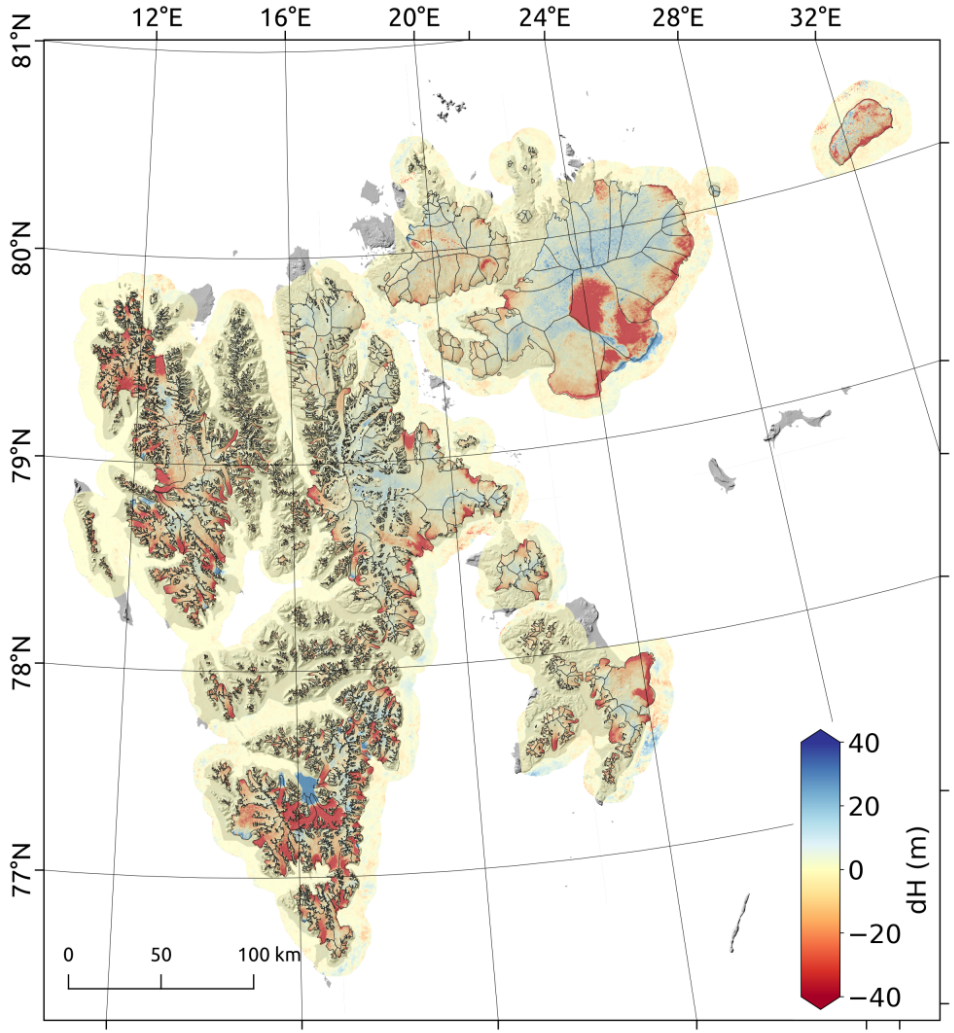
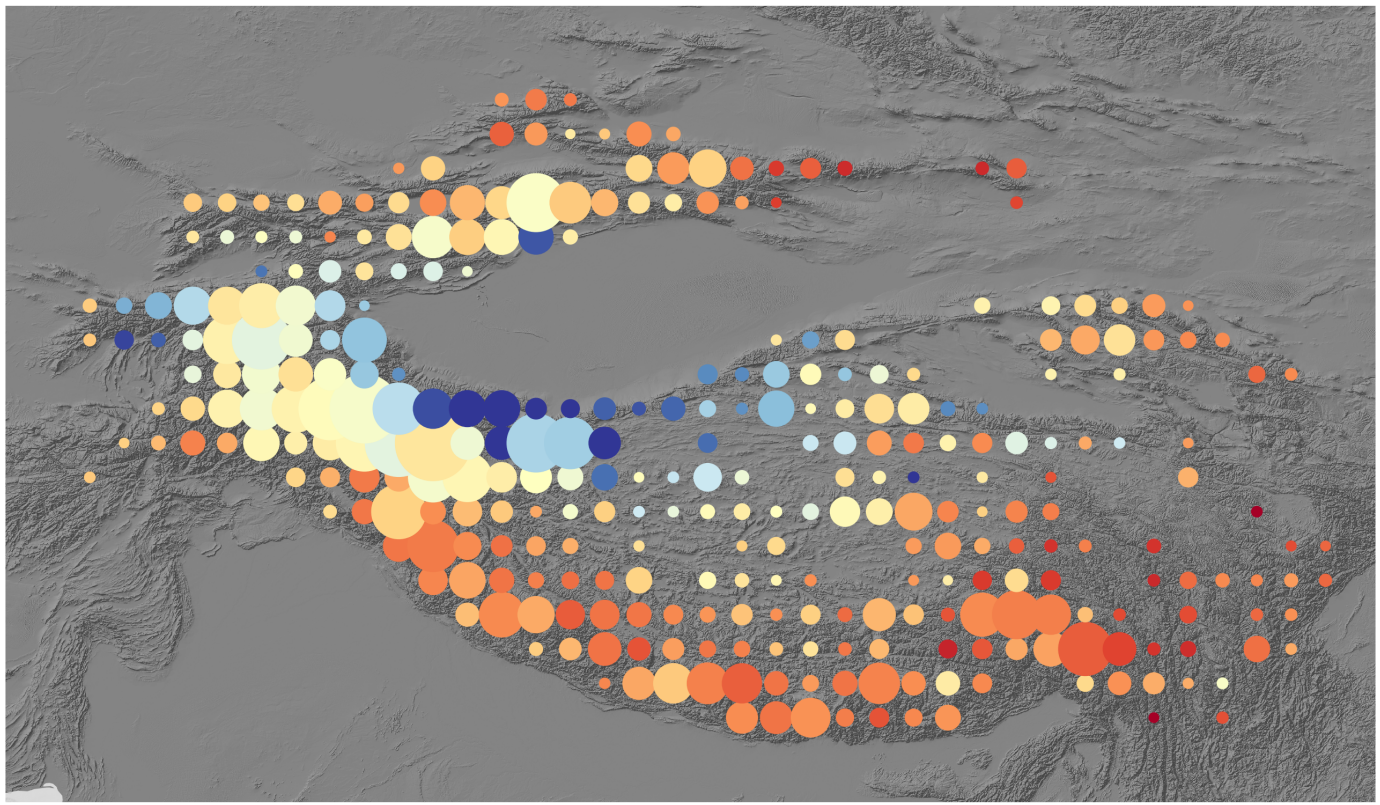


Figure: Svalbard elevation change between 2000 and 2019

Region focus: High Mountain Asia

Generalized acceleration of thinning: the end of the Karakorum anomaly?

2000-2004, 2005-2009, 2010-2014, 2015-2019



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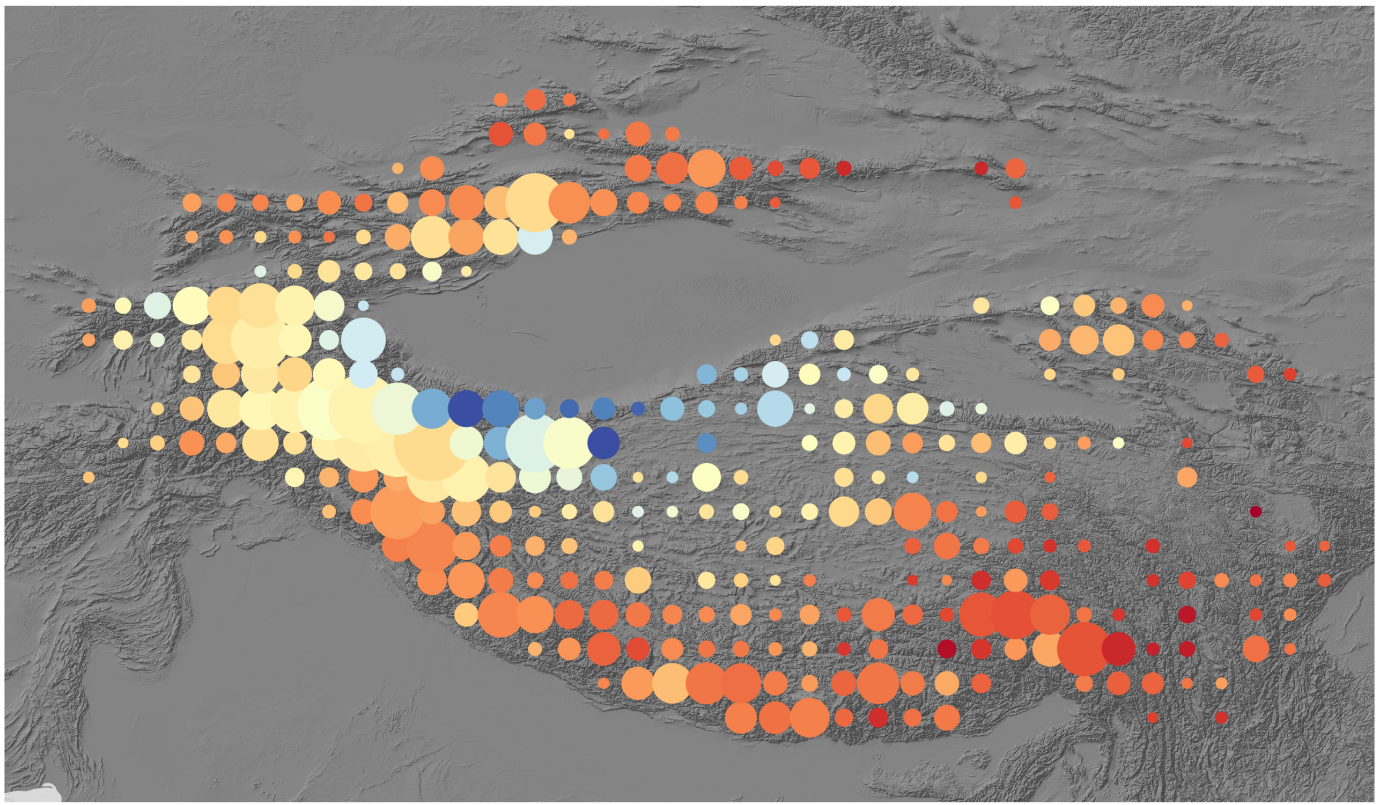

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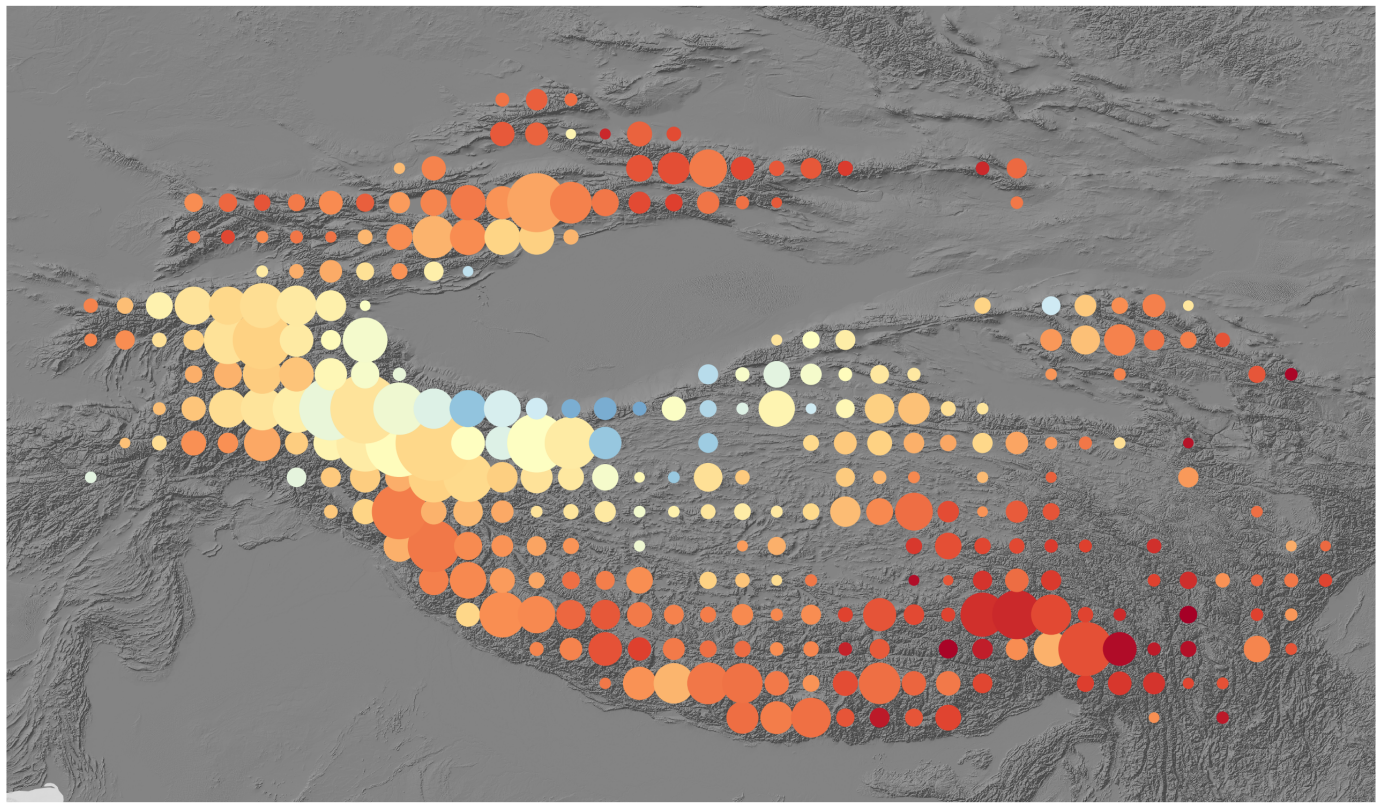

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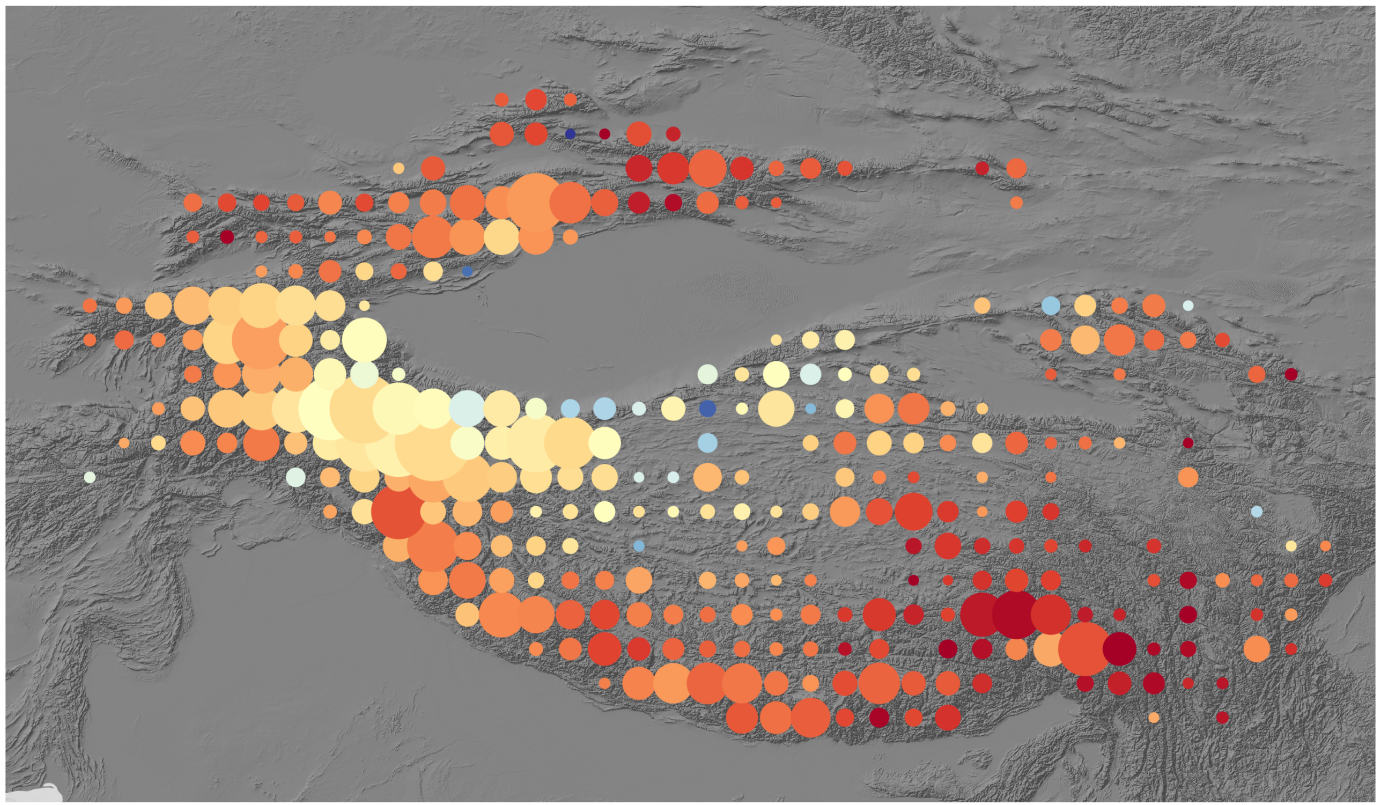

Region focus: High Mountain Asia

HMA mass change estimate:

- Thinning rates triple between 2000-2004 (-0.11$\pm$0.05 m w.e. yr$^-$1) and 2015-2019 (-0.32$\pm$0.05 m w.e. yr^{-1})
- Over 2000-2018, our estimate yields -0.21$\pm$0.02 m w.e. yr^{-1} in good agreement with -0.19 $\pm$0.03 m w.e. yr^{-1} (**Shean et al., 2020**). The fact that our estimate is more negative may arise from the acceleration isolated by our time series that cannot be captured by linear-based approaches.

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Conclusions

Our study presents:

- **A comprehensive surface elevation observational coverage** of 99.9% of inventoried glaciers over 20 years, rendered possible by the massive exploitation and correction of underexploited optical archives
- **A time-continous approach to study Earth's surface elevation** based on statistical modelling methods, validated massively to independent high-precision datasets
- **A spatiotemporal methodology to improve uncertainty propagation to glacier volume and mass change** by accounting for spatial and temporal correlations in glacier elevation estimates

These advances combined make possible this **globally complete, spatiotemporally resolved estimate of glacier mass change for 2000-2019.** Data and further results will be made available at publication. In the meantime, don't hesitate to contact us if you need a snapshot of your favorite glacier :D !

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Appendix snapshot: Eastern Greenland

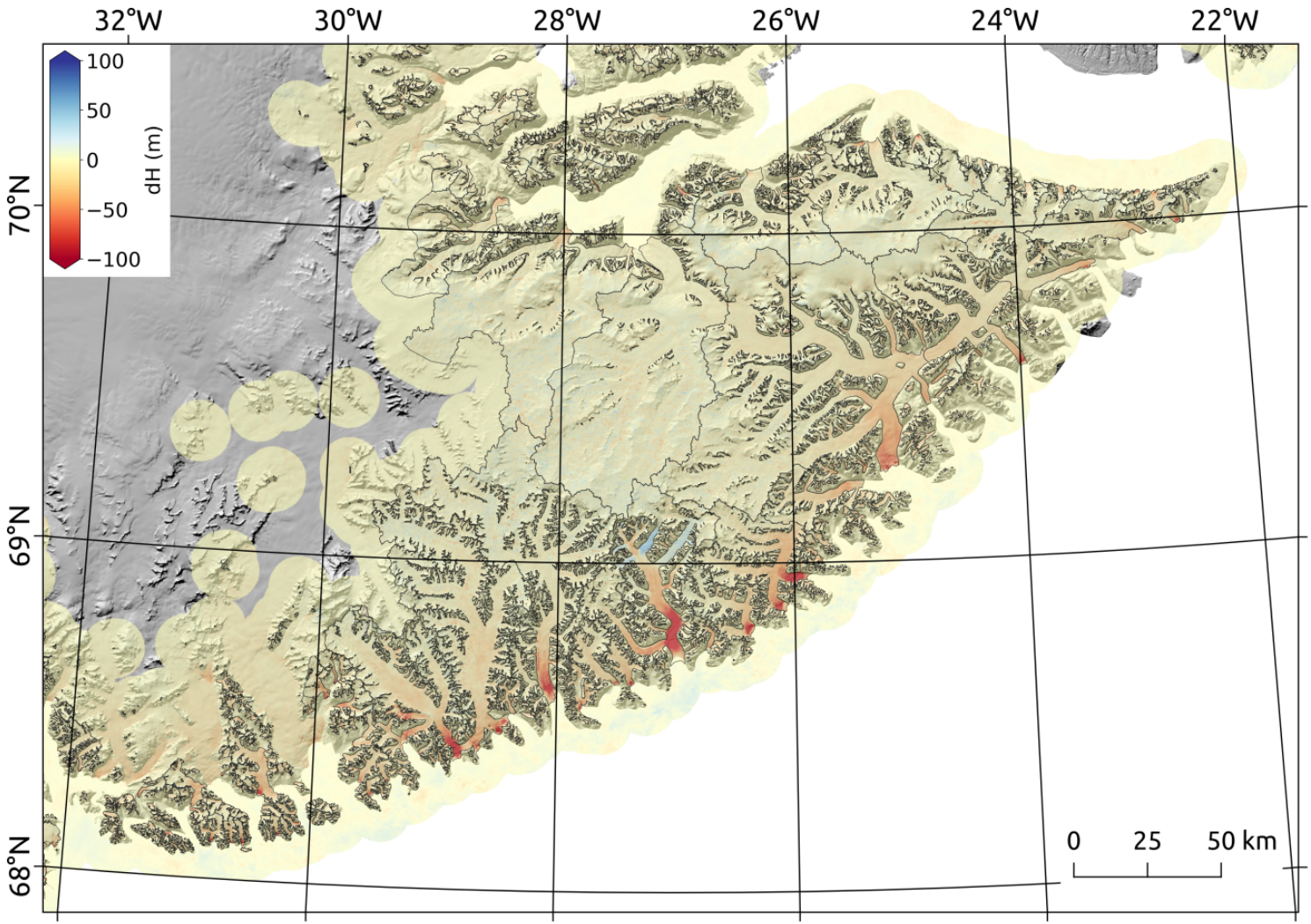

Figure: Eastern Greenland elevation change between 2000 and 2019 (with glaciers connected to ice sheets)

Appendix snapshot: Arctic Canada North

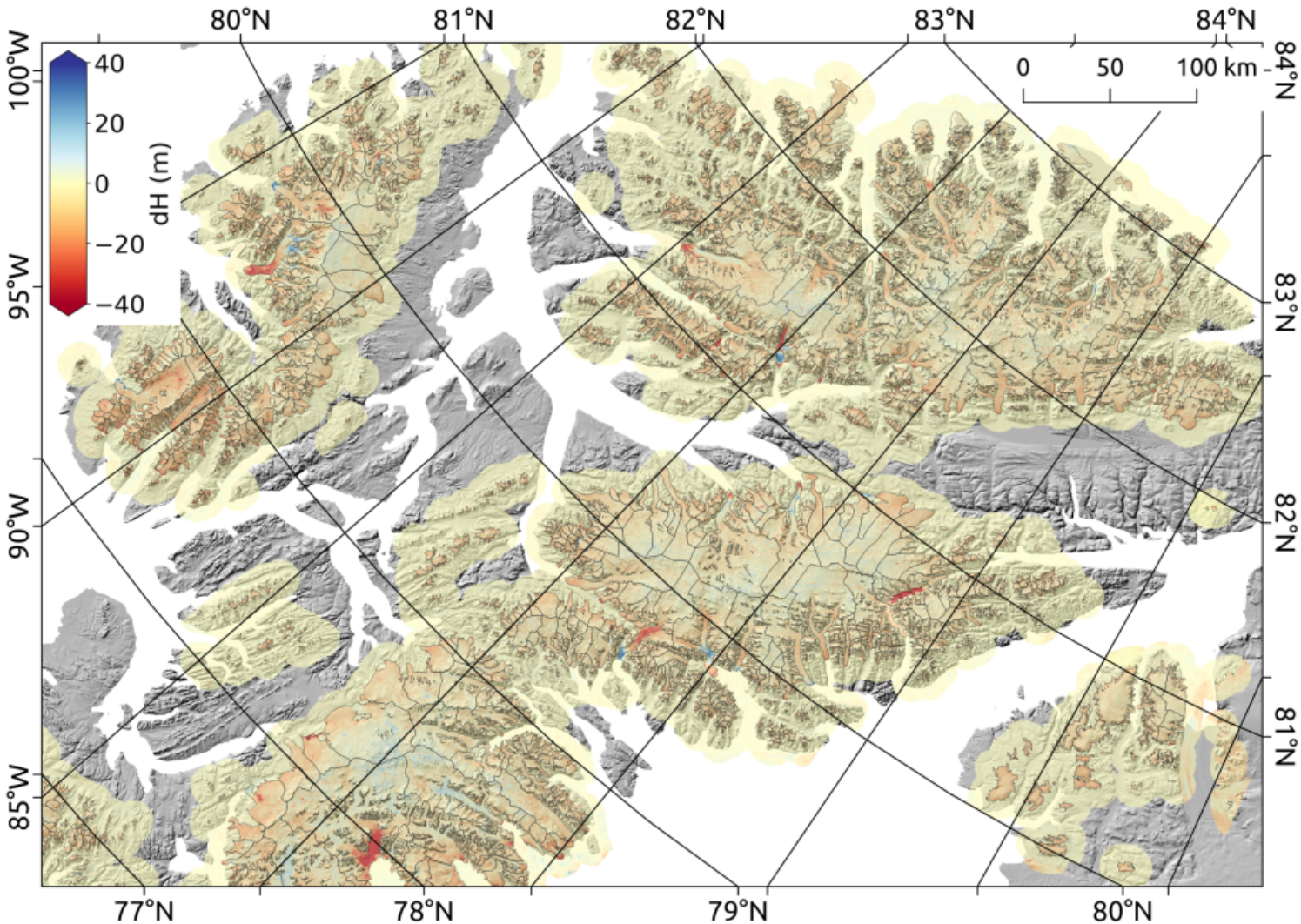

Figure: Arctic Canada North elevation change between 2000 and 2019

Appendix snapshot: Arctic Canada South

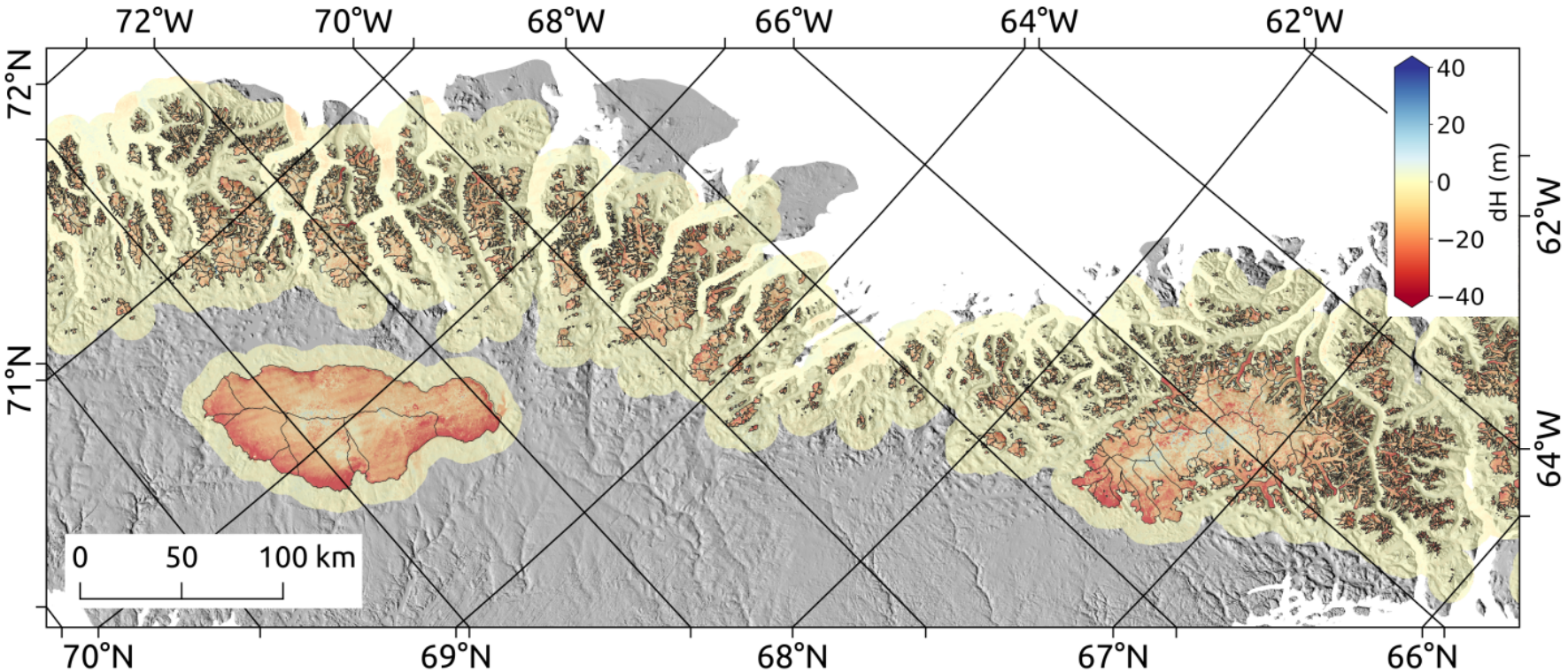

Figure: Arctic Canada South elevation change between 2000 and 2019

Appendix snapshot: Russian Arctic, Novaya Zemlya

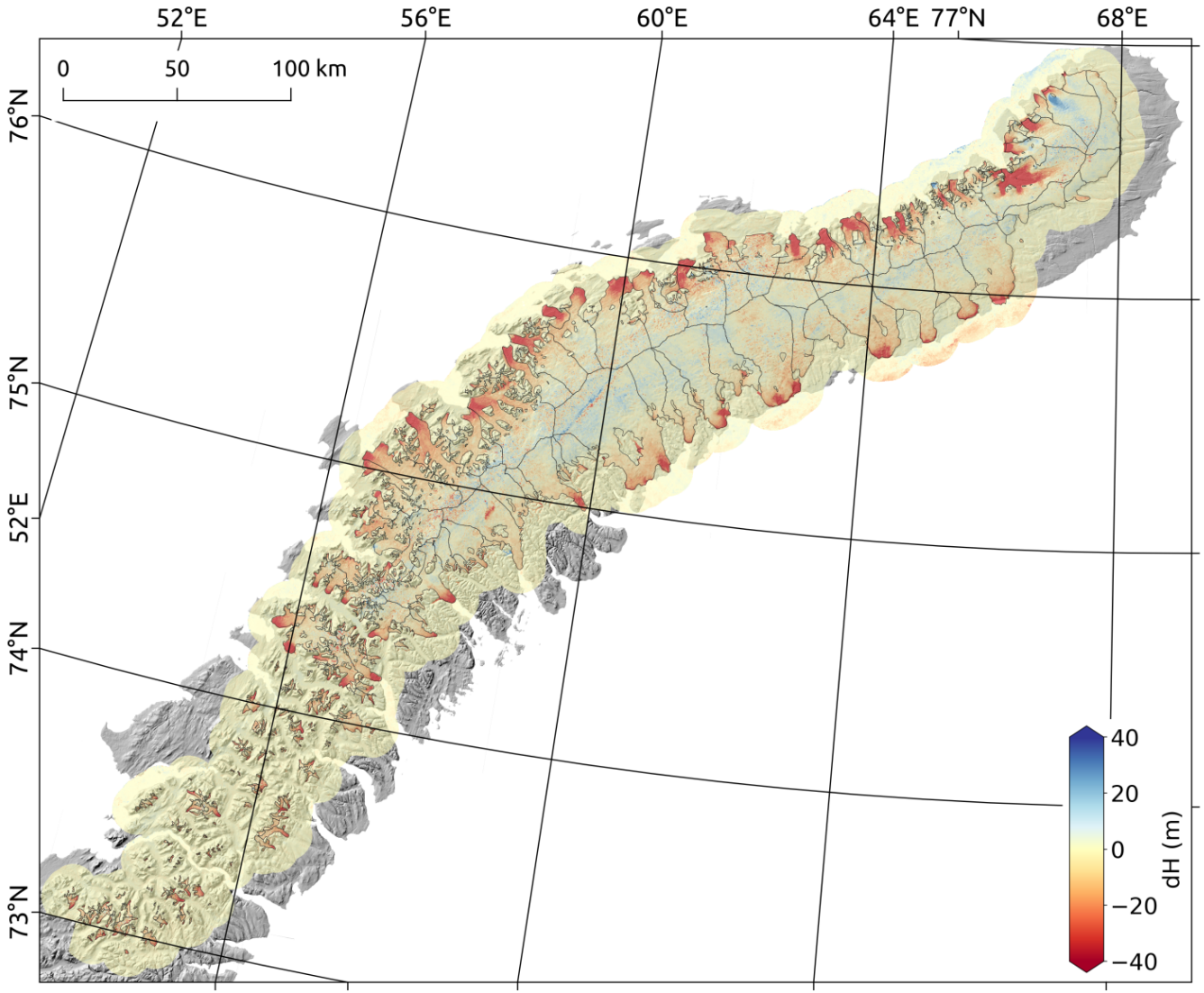

Figure: Novaya Zemlya elevation change between 2000 and 2019

Appendix snapshot: New Zealand

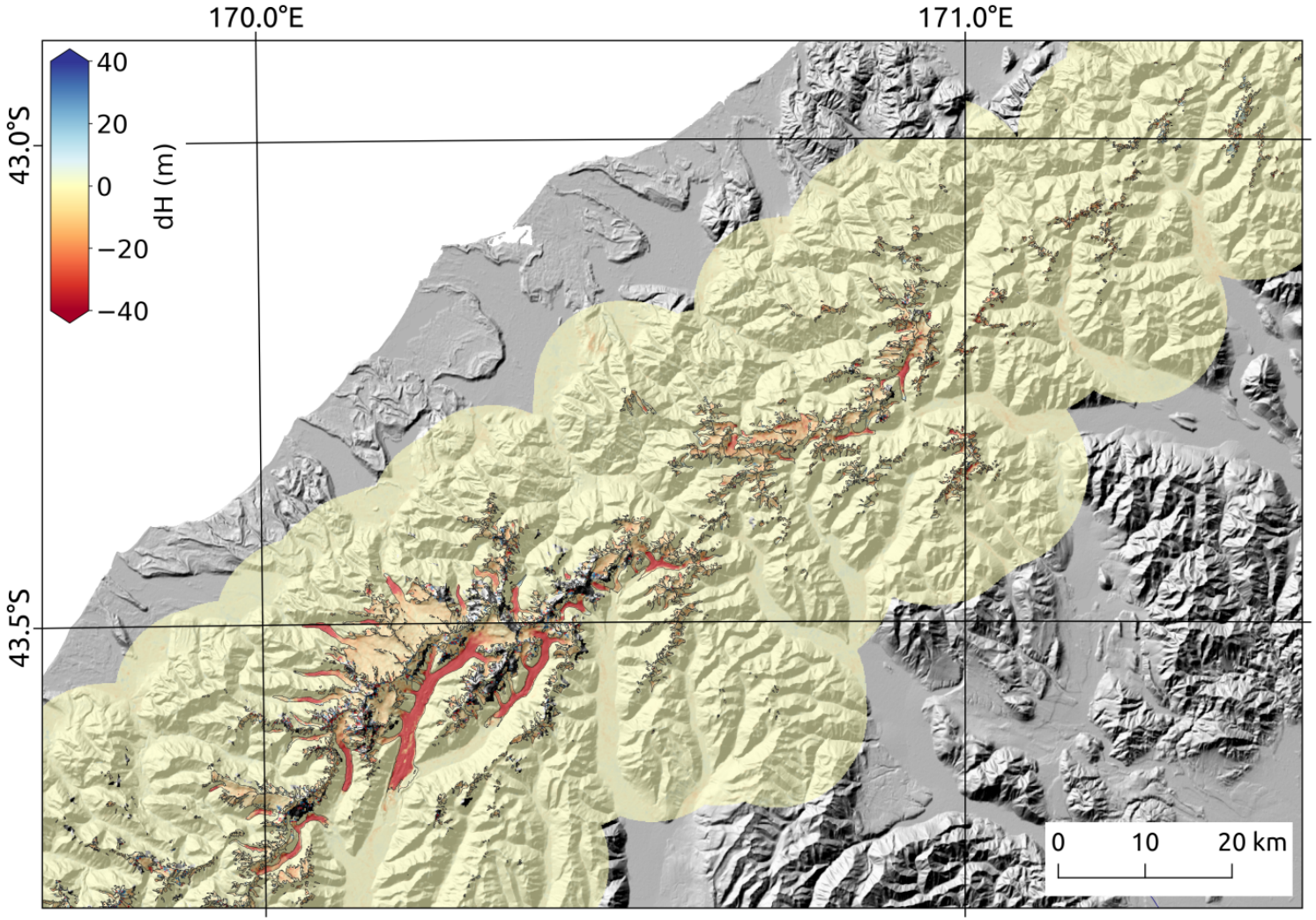

Figure: New Zealand elevation change between 2000 and 2019