

LONG TERM MONITORING OF AUSTRIAN GLACIERS AS KEY FOR MODELLING FUTURE DEVELOPMENTS

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Overview

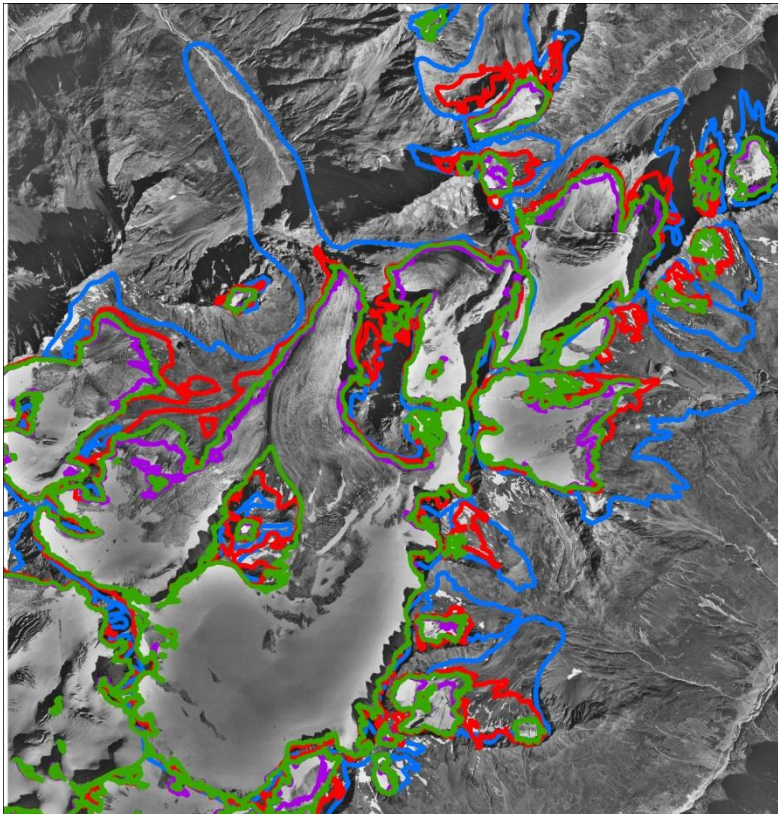
1. Motivation
2. Glacier inventories
3. Mass balance time series
4. Length changes
5. Ice volume
6. Modelling

Motivation

- Climate = long term (min 30 a)
- Climate observations (mean, variability) = long term observations
- Climate changes = changes over long term periods
- Only continuous long term data can show off short term variabilities
- Model development (calibration, validation) requires long term observations

Glacier inventories

- Glacier area (elevation) at time of surveys
- Total area changes (ice thickness, volume/mass changes) over the period between surveys



4 Austrian glacier inventories:

| | | | |
|---------------------|---------------------|---------------------|---------------------|
| ~1850 | 1969 | ~1998 | ~2006 |
| G LIA | GI1 | GI2 | G3 |
| moraines | photo | photo | ALS |
| 941 km ² | 565 km ² | 471 km ² | 415 km ² |
| 100% | 60% | 50% | 44% |

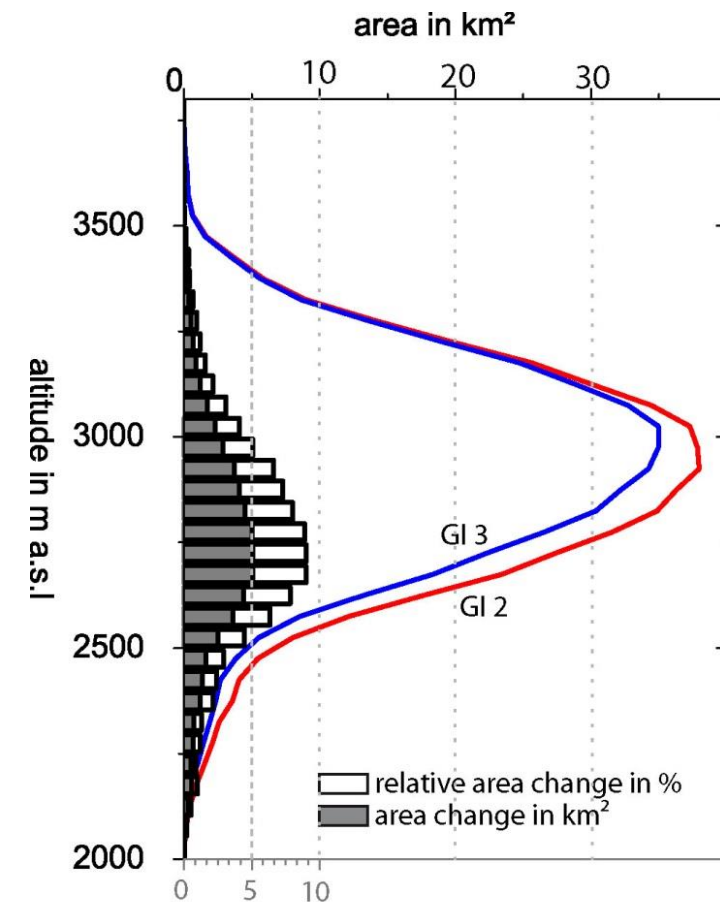
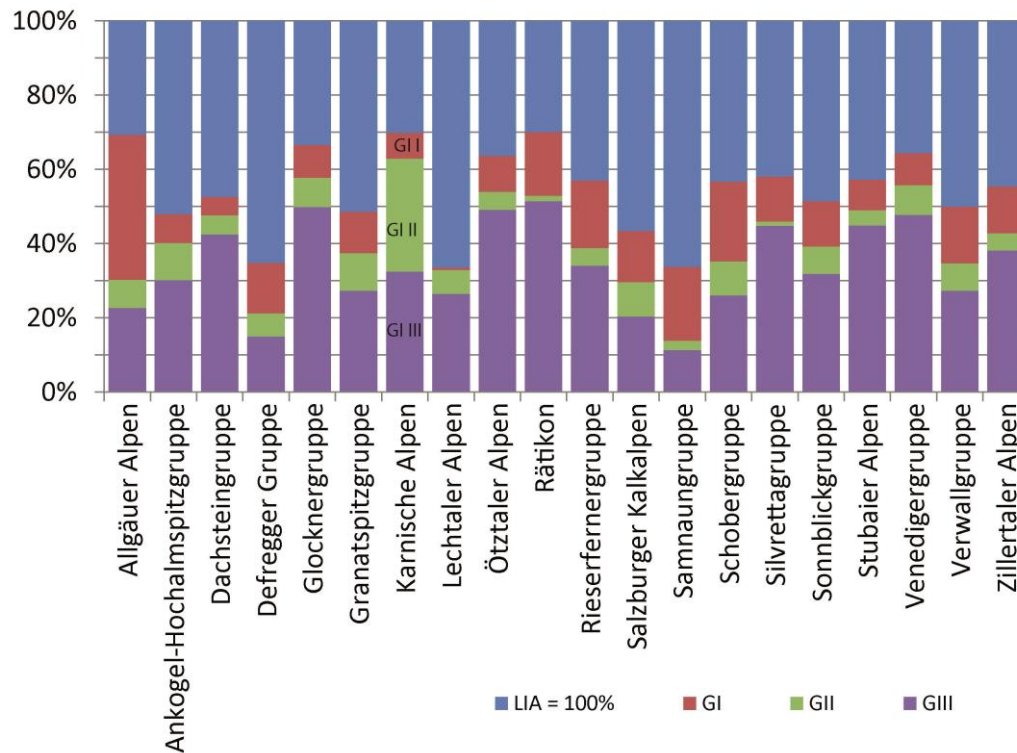
Fischer et al., 2015

<http://www.the-cryosphere.net/9/753/2015/>

<http://dx.doi.org/10.1594/PANGAEA.844988>

Glacier inventories

- regional and temporal variability in area decrease
- elevation dependence of area decrease



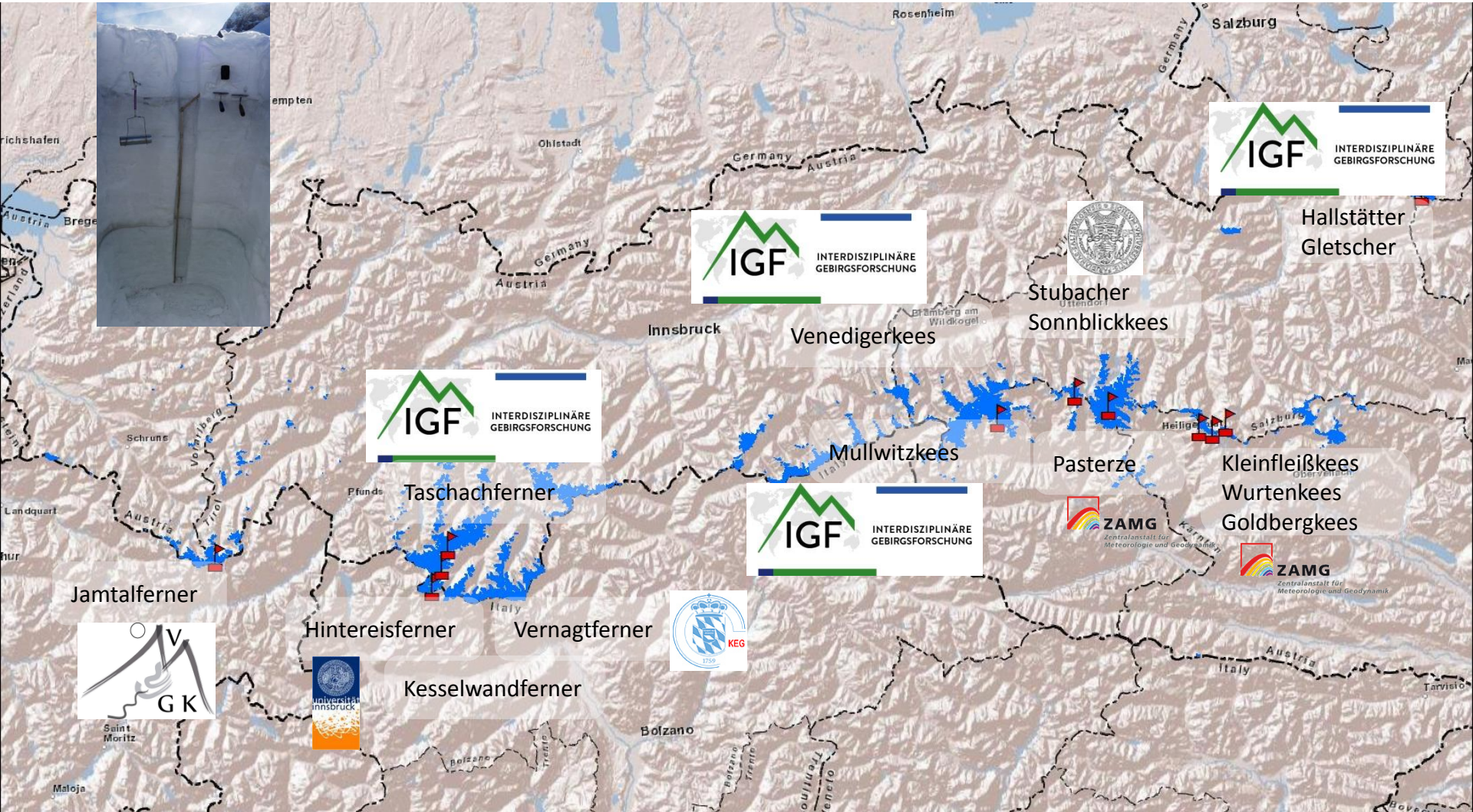
Glacier inventories

- changes in size distribution

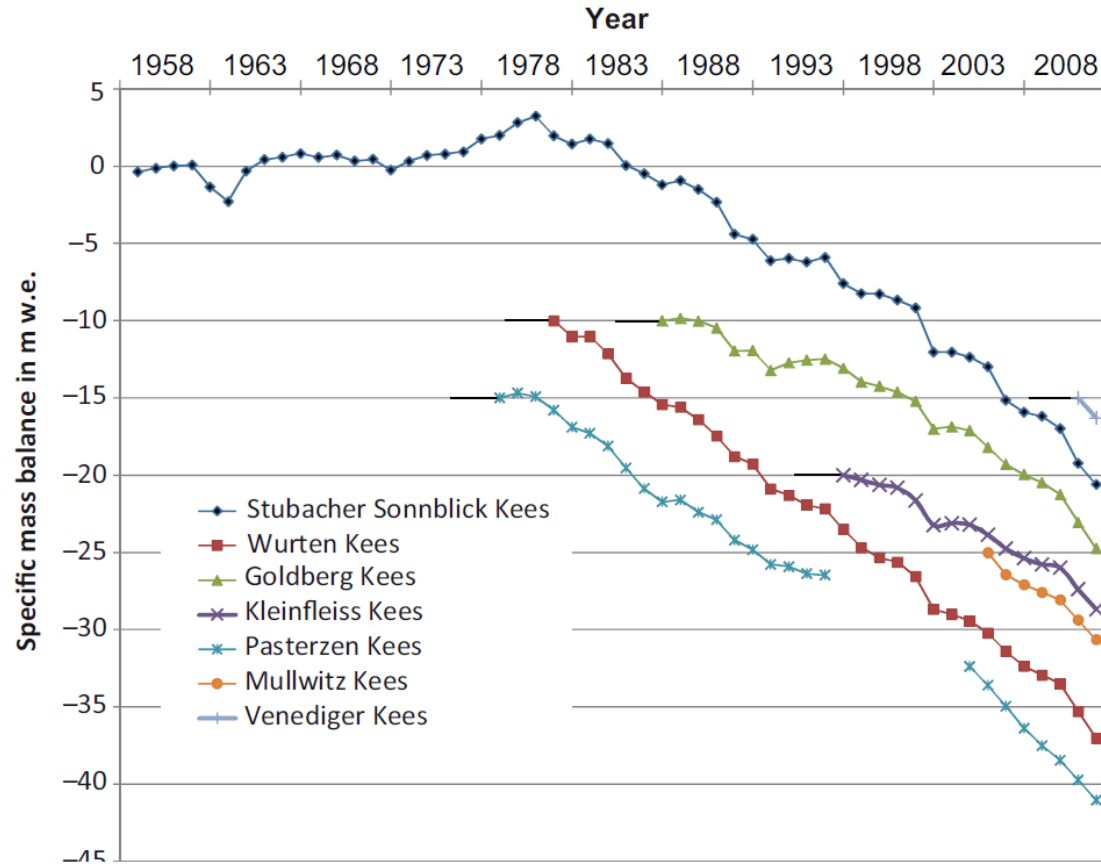
| Size classes (km ²) | < 0.1 | 0.1 to 0.5 | 0.5 to 1 | 1 to 5 | 5 to 10 | > 10 | Total |
|----------------------------------|-------|------------|----------|--------|---------|-------|--------|
| Number of glaciers | | | | | | | |
| in GI 1 | 177 | 401 | 116 | 99 | 11 | 5 | 809 |
| in GI 2 | 401 | 343 | 92 | 79 | 7 | 3 | 925 |
| in GI 3 | 450 | 307 | 77 | 77 | 8 | 2 | 921 |
| Number of glaciers in % | | | | | | | |
| in GI 1 | 22 | 50 | 14 | 12 | 1 | 1 | 100 |
| in GI 2 | 43 | 37 | 10 | 9 | 1 | 0 | 100 |
| in GI 3 | 49 | 33 | 8 | 8 | 1 | 0 | 100 |
| % of total area in class | | | | | | | |
| in GI 1 | 2 | 17 | 14 | 39 | 15 | 13 | 100 |
| in GI 2 | 4 | 17 | 14 | 41 | 14 | 10 | 100 |
| in GI 3 | 5 | 17 | 12 | 41 | 17 | 8 | 100 |
| Area in class in km ² | | | | | | | |
| in GI 1 | 11.30 | 96.03 | 79.08 | 220.30 | 84.73 | 73.43 | 564.88 |
| in GI 2 | 18.83 | 80.01 | 65.89 | 192.97 | 65.89 | 47.07 | 470.67 |
| in GI 3 | 20.77 | 70.63 | 49.86 | 170.34 | 70.63 | 33.24 | 415.47 |

Mass balance

- Direct glaciological method



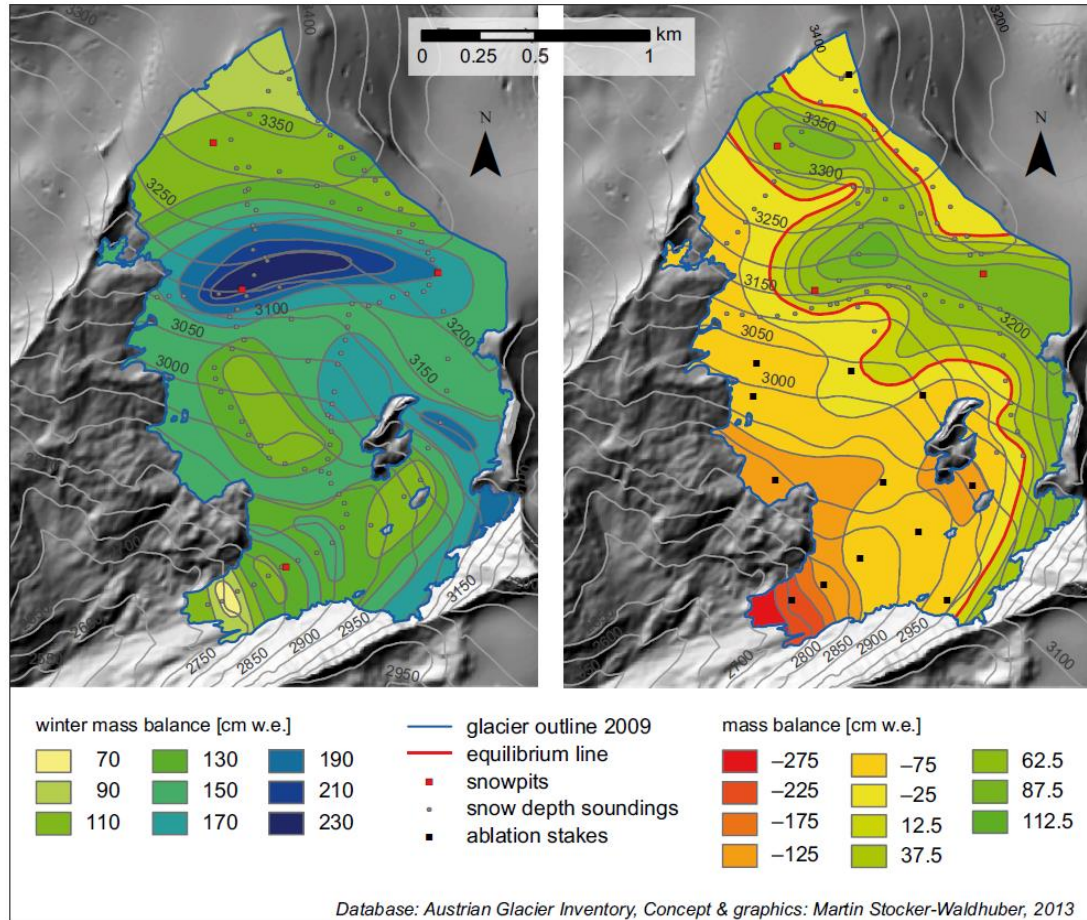
Mass balance



Fischer A., M. Stocker-Waldhuber, B. Seiser, B. Hynek and H. Slupetzky (2014):
Glaciological monitoring in Hohe Tauern National Park. Eco.mont. 6/1, 49-56

Mass balance

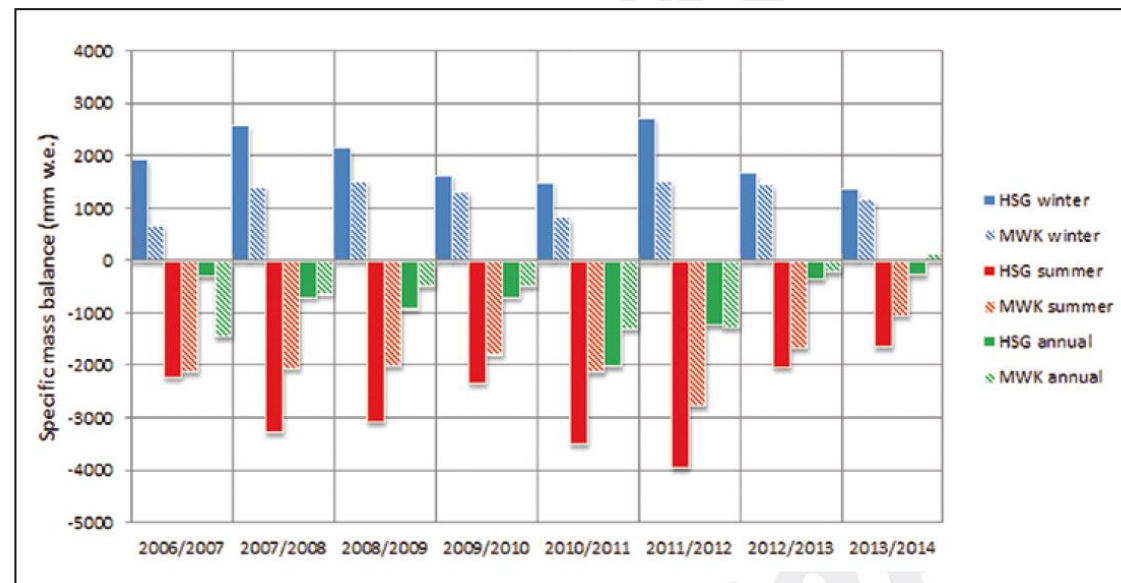
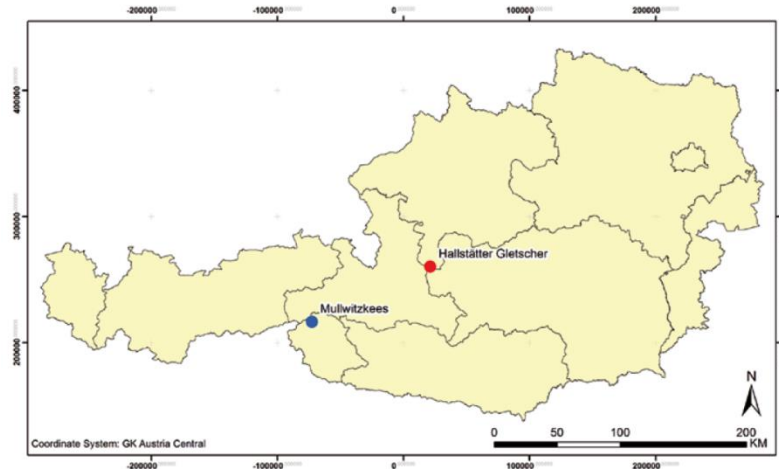
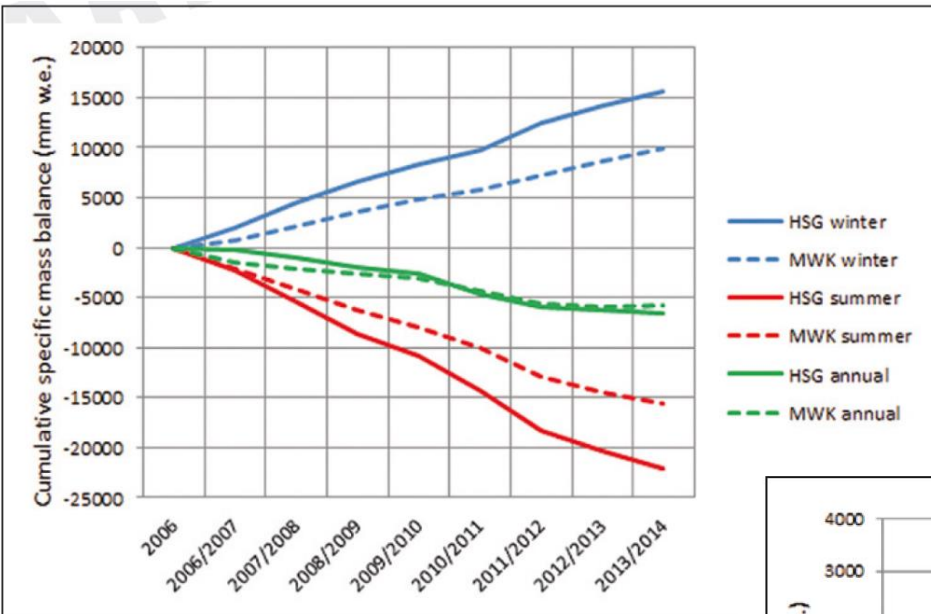
- Winter and summer balance



e.g. Fischer, Andrea; Stocker-Waldhuber, Martin; Reingruber, Klaus; Helfricht, Kay (2015): Glacier mass balances and elevation zones of Hallstätter Gletscher, Dachstein, Austria, 2006/2007 to 2013/2014. *Institut für Interdisziplinäre Gebirgsforschung der Österreichischen Akademie der Wissenschaften, Innsbruck*, doi:10.1594/PANGAEA.806609

Mass balance

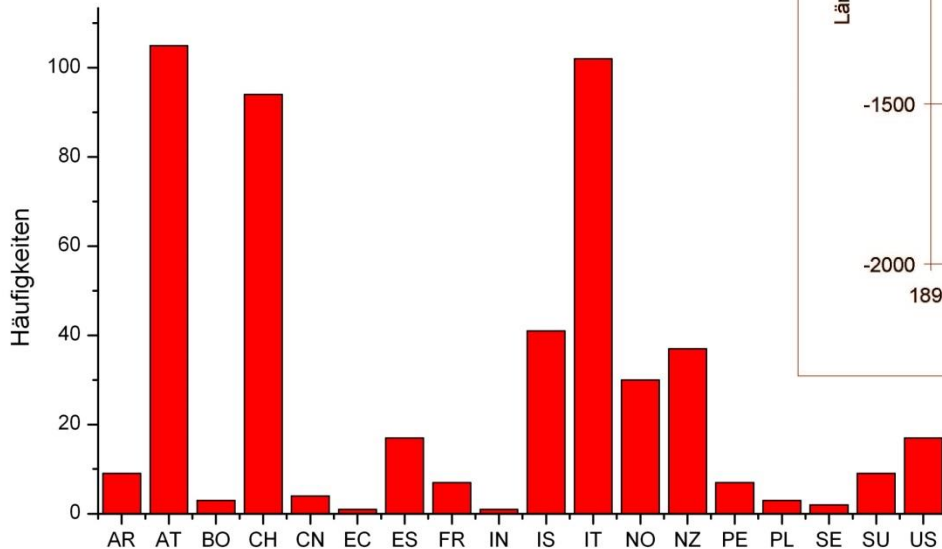
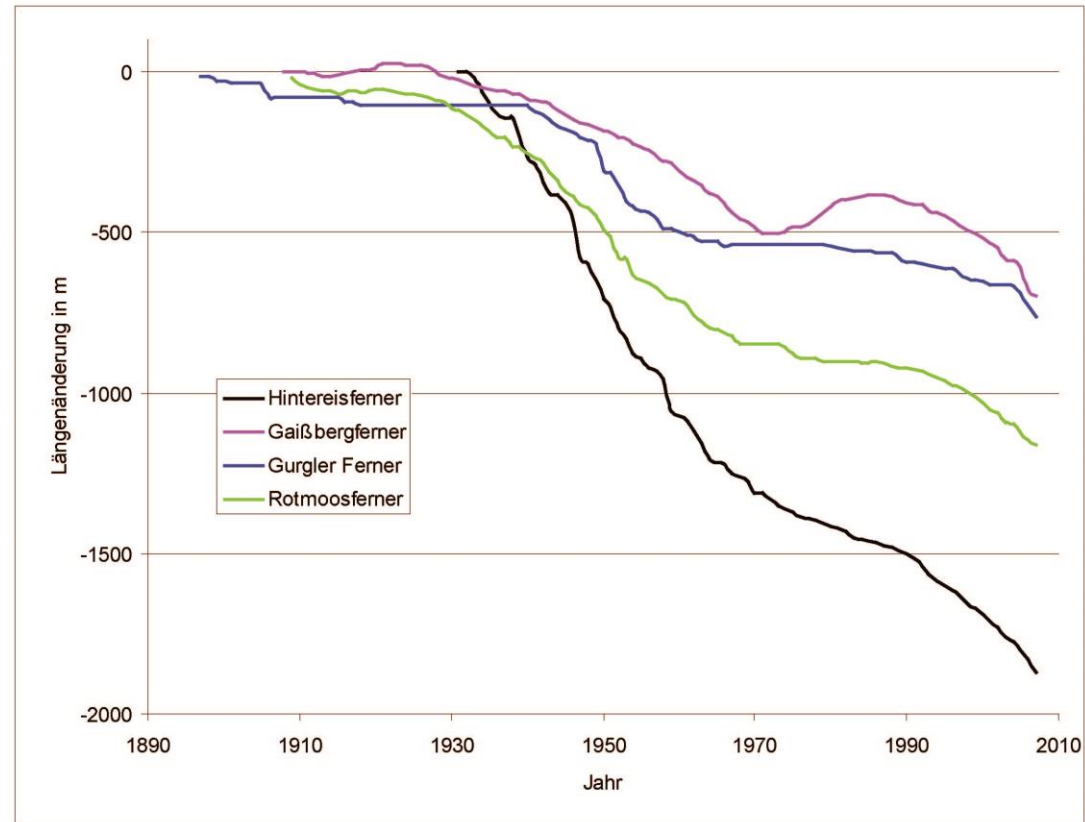
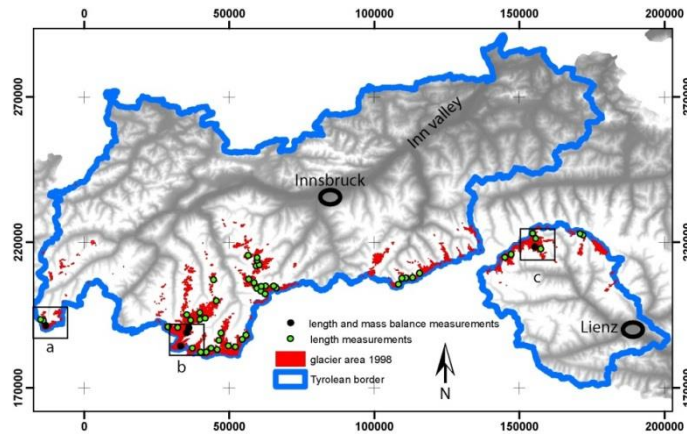
- Regional differences



Stocker-Waldhuber, M., K. Helfricht, L. Hartl and A. Fischer (2015): Glacier surface mass balance 2006–2014 on Mullwitzkees and Hallstätter Gletscher, Austria, *Zeitschrift für Gletscherkunde und Glazialgeologie*, 47, 101-119

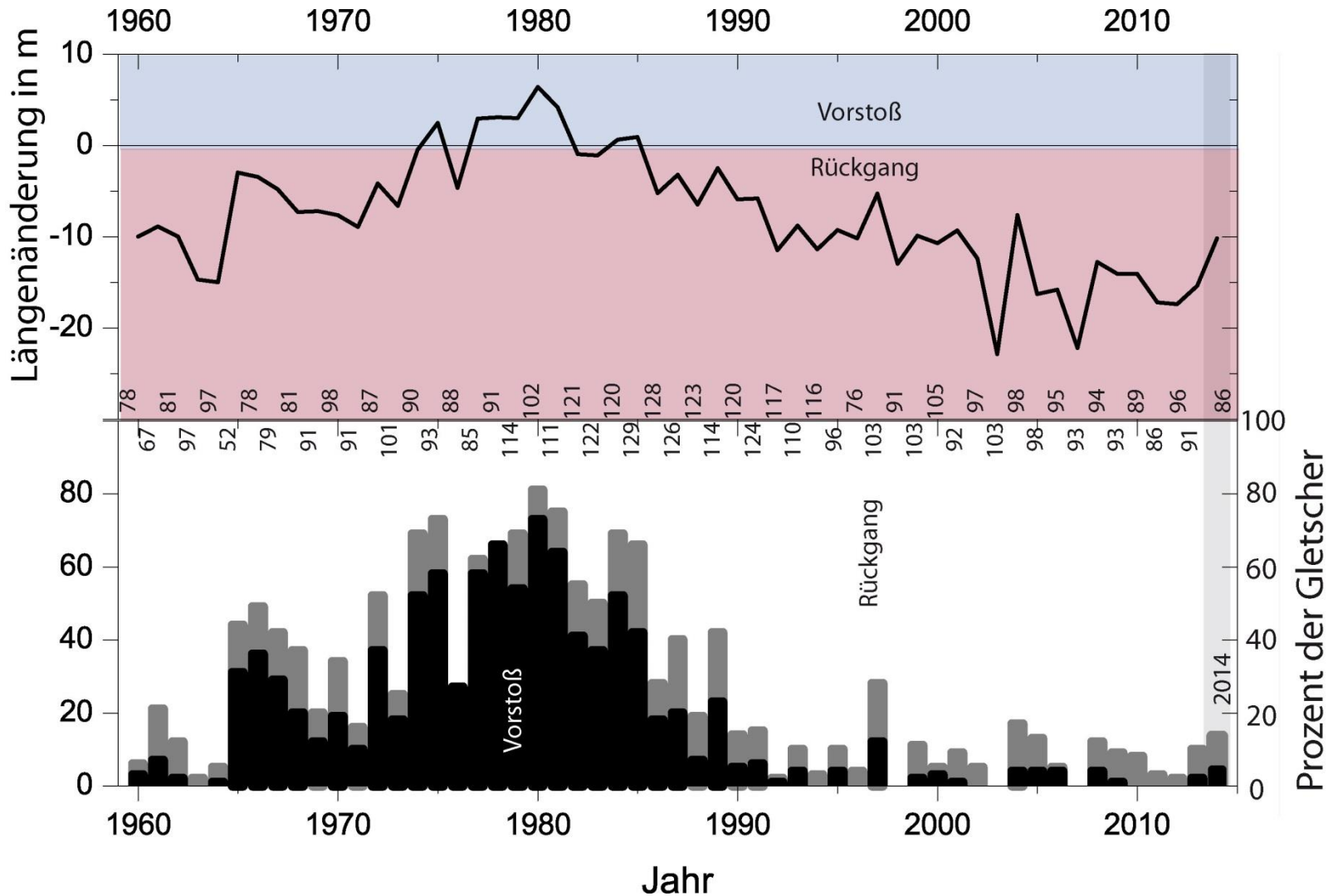
Length Changes

- glacier survey of the Austrian Alpine Club
- more than 100 glaciers in Austria



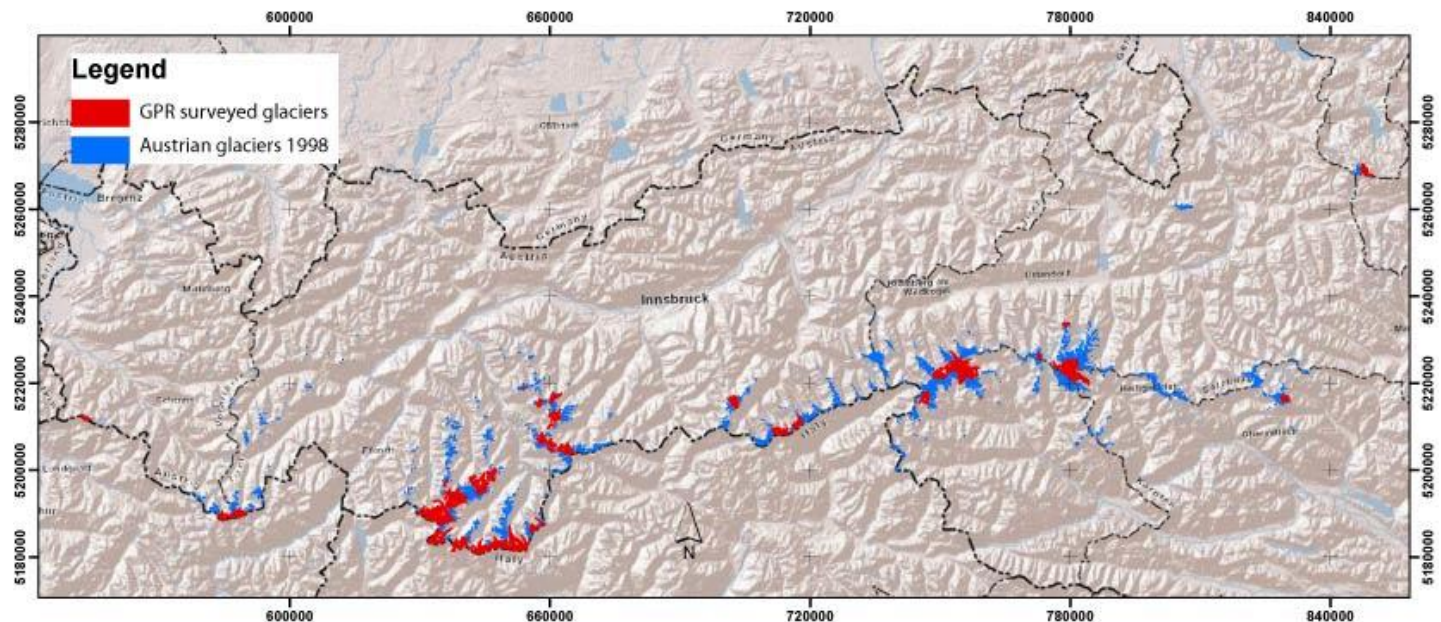
Length Changes

○ Continuous information



Ice volume

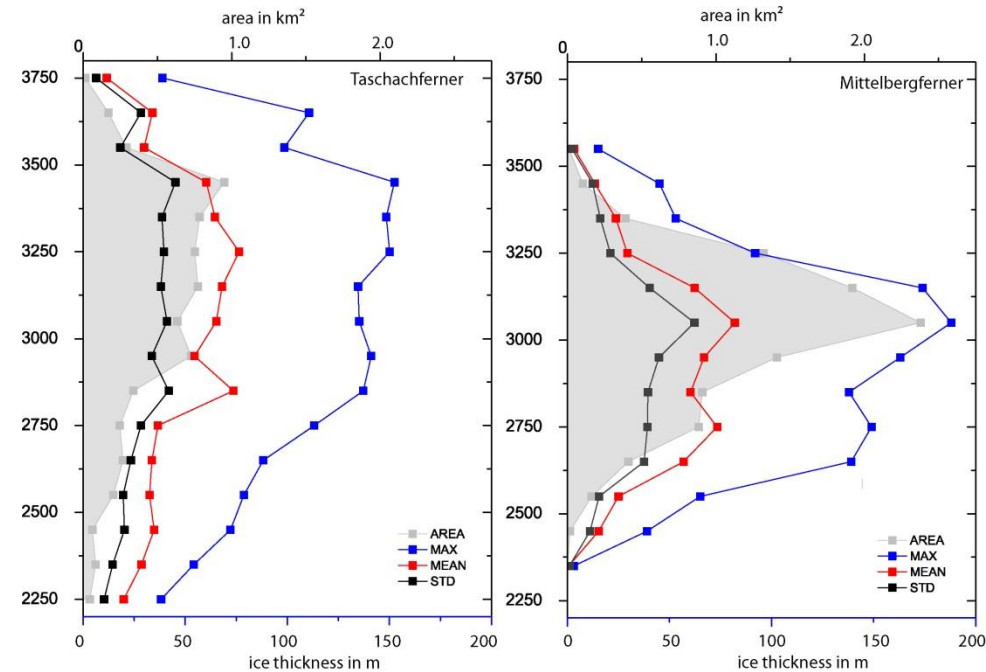
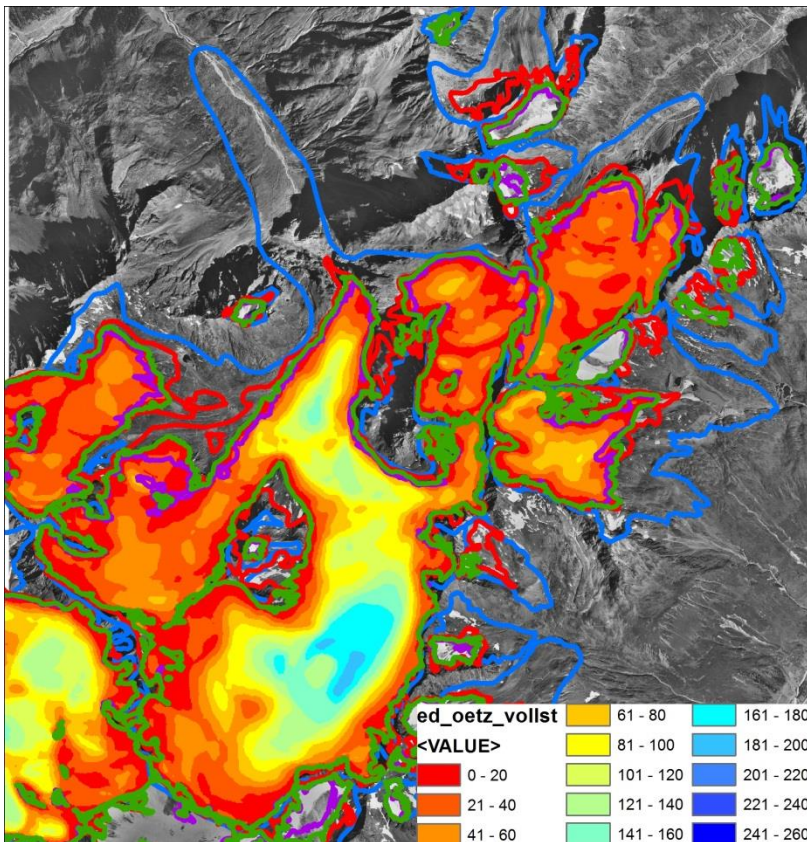
- 64 GPR measured glaciers covering ~ 50% of the total glacier area in GI 2 (225 km²)



Fischer, A., M. Kuhn (2013): GPR measurements of 64 Austrian glaciers as a basis for a regional glacier volume inventory, *Annals of Glaciology*, 54(64), 179–188.

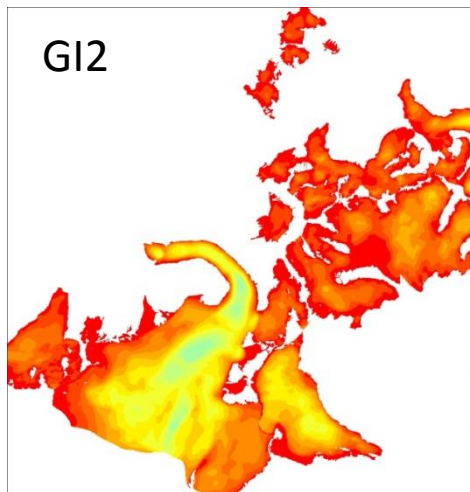
Ice volume

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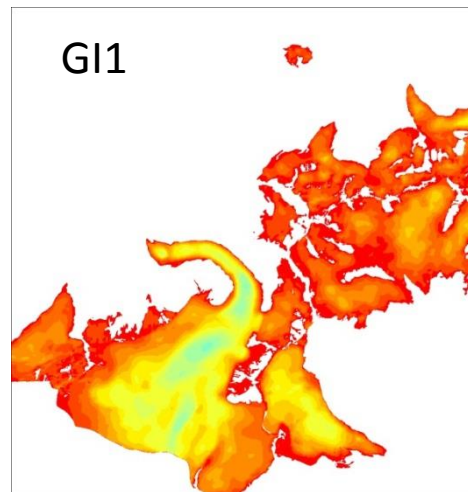


Ice volume

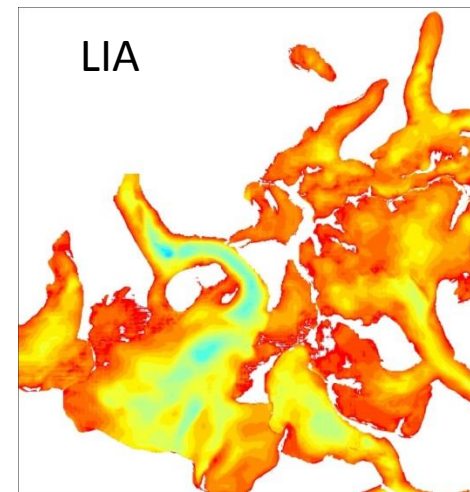
- time series of glacier volume between LIA and today as model test playground



ice thickness GI 2



ice thickness GI 2
+
Surface elevation
change GI1-GI2



ice thickness GI 2
+
Surface elevation
change LIA-GI2

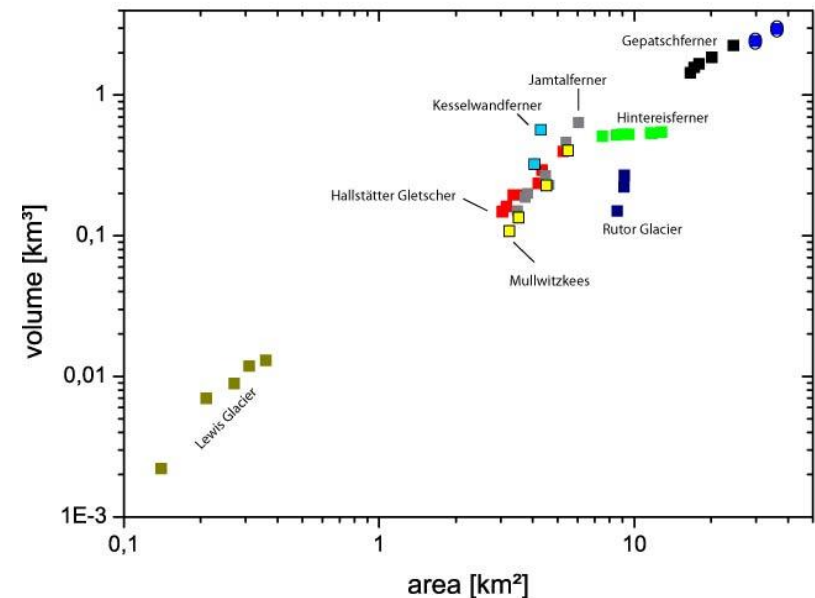
Ice thickness
(m)



Ice volume

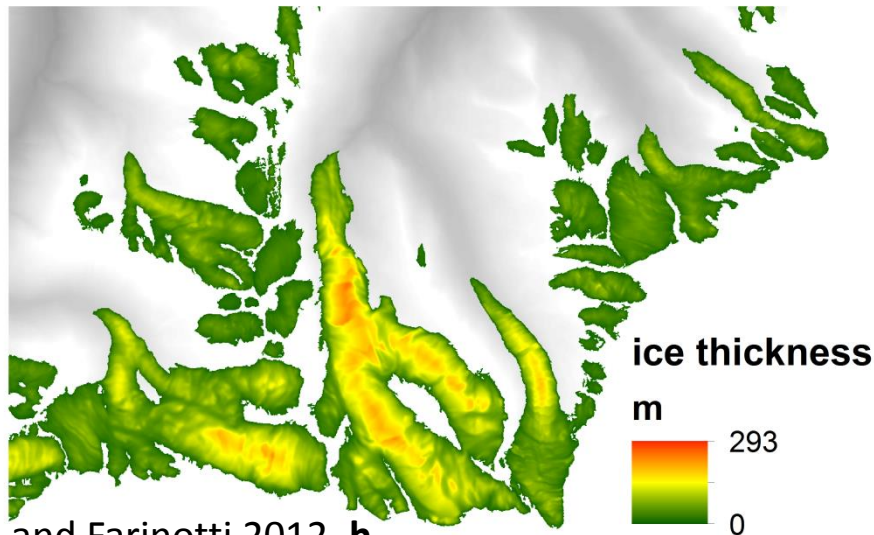
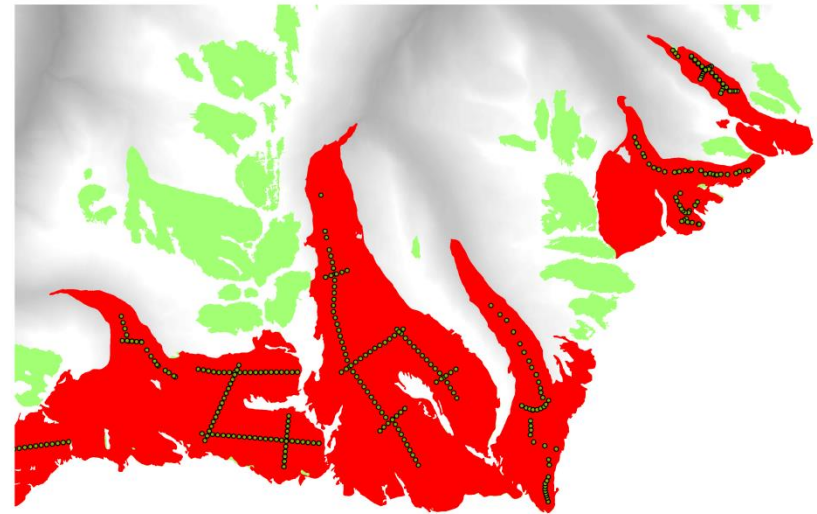
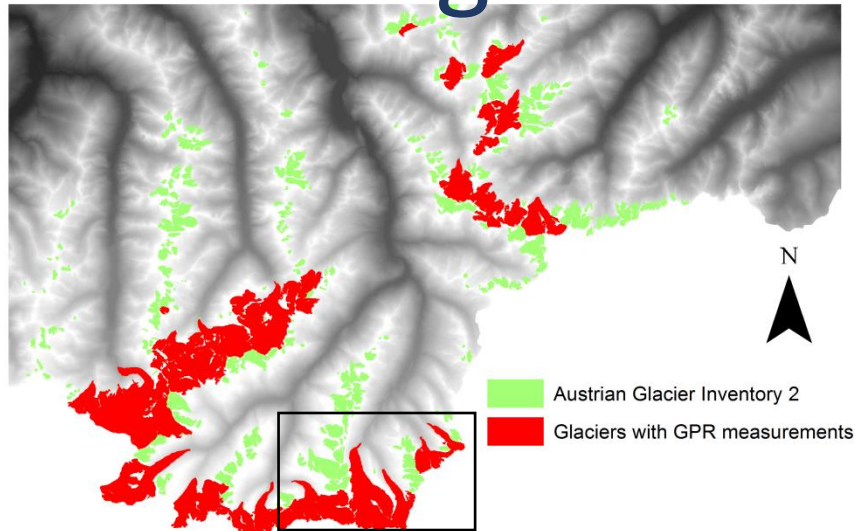
- ice thickness, volume and area do not show the same course of decrease

| | area | mean ice thickness | volume |
|------|-----------------|--------------------|-----------------|
| | km ² | m | km ³ |
| LIA | 358 | 90 | 32 |
| 1969 | 248 | 60 | 15 |
| 1998 | 225 | 53 | 12 |
| | % | % | % |
| LIA | 100 | 100 | 100 |
| 1969 | 70 | 66 | 46 |
| 1998 | 63 | 59 | 37 |

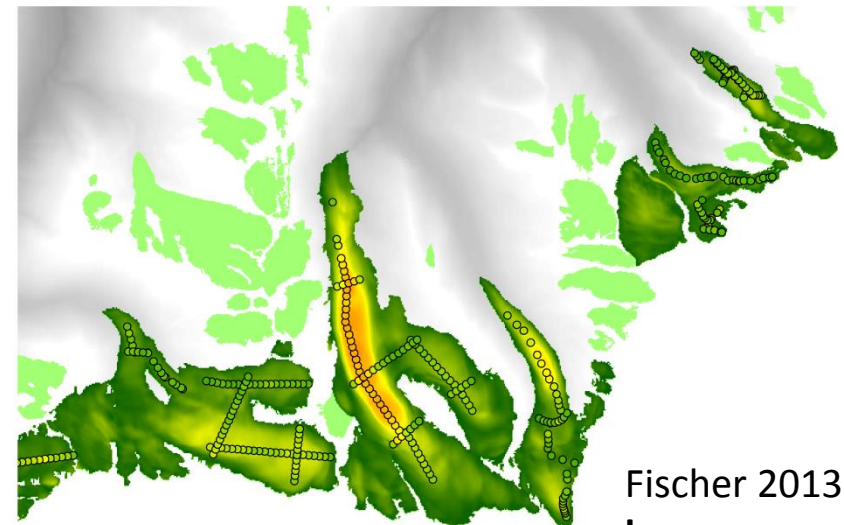


Modelling

- Distributed ice thickness for GI2

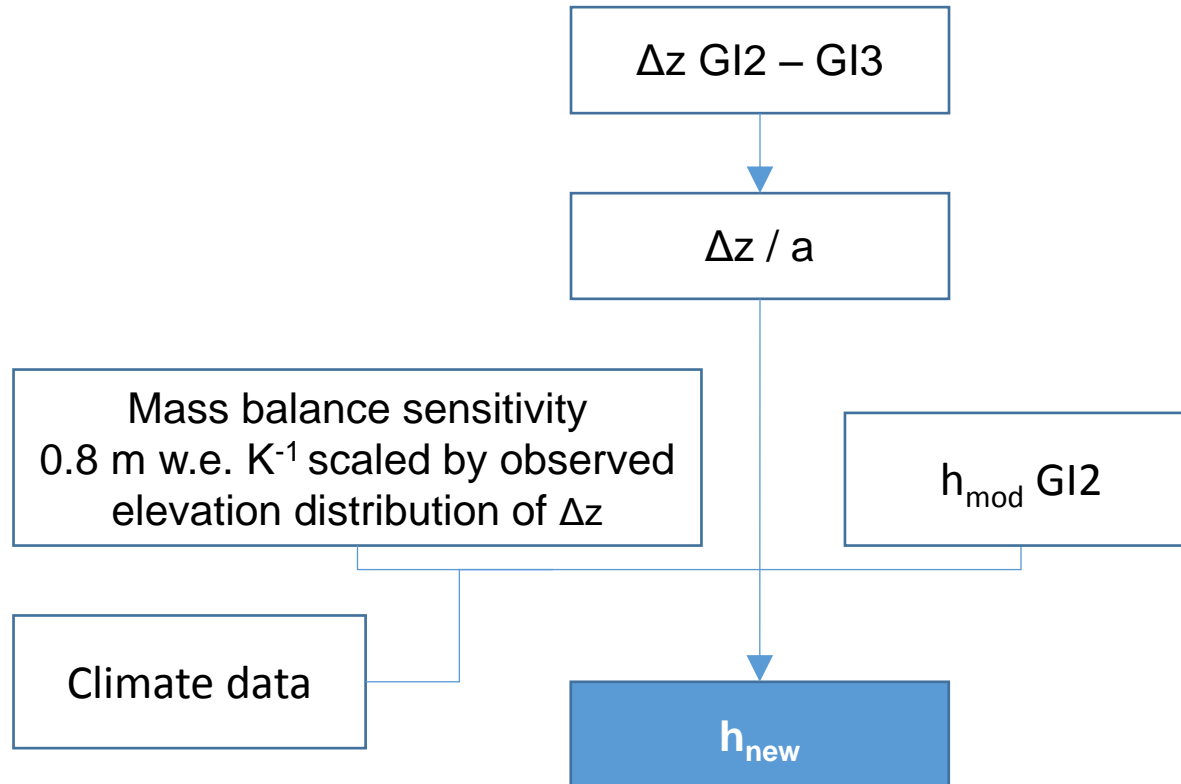


Huss and Farinotti 2012, h_{mod}



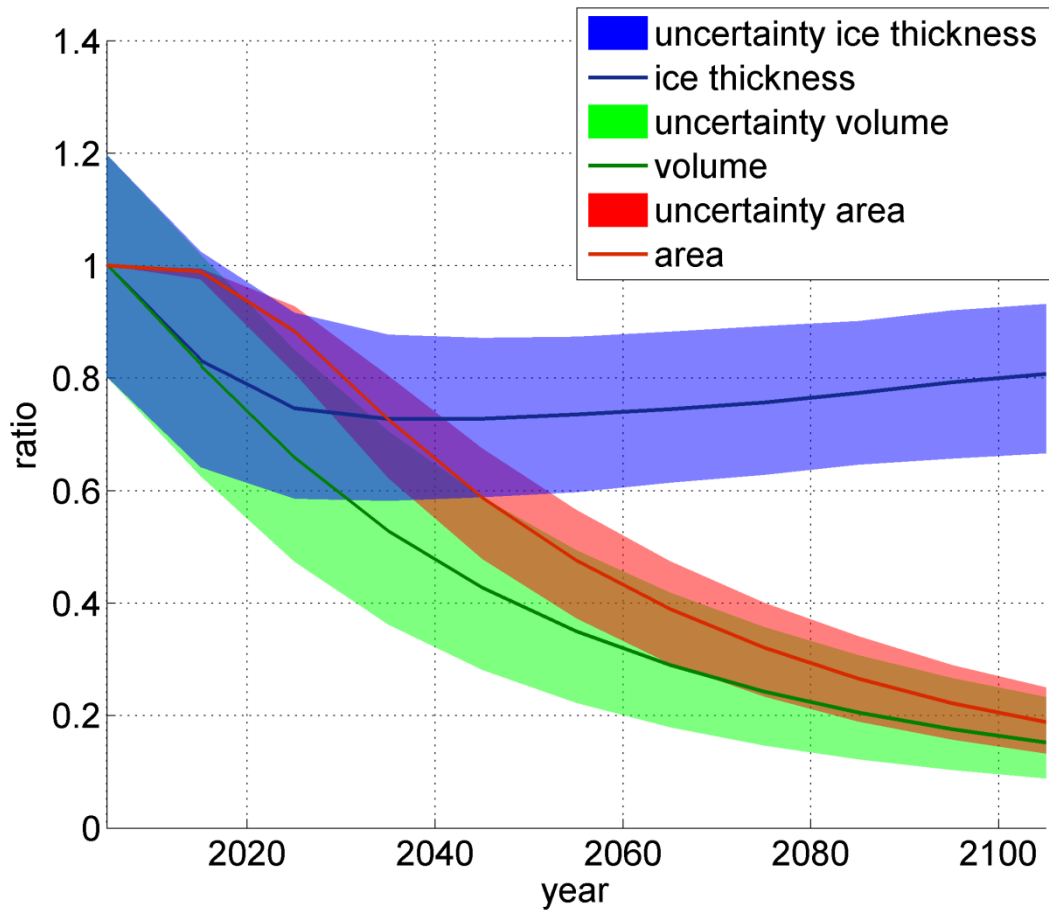
Fischer 2013
 h_{GPR}

Modelling



Modelling

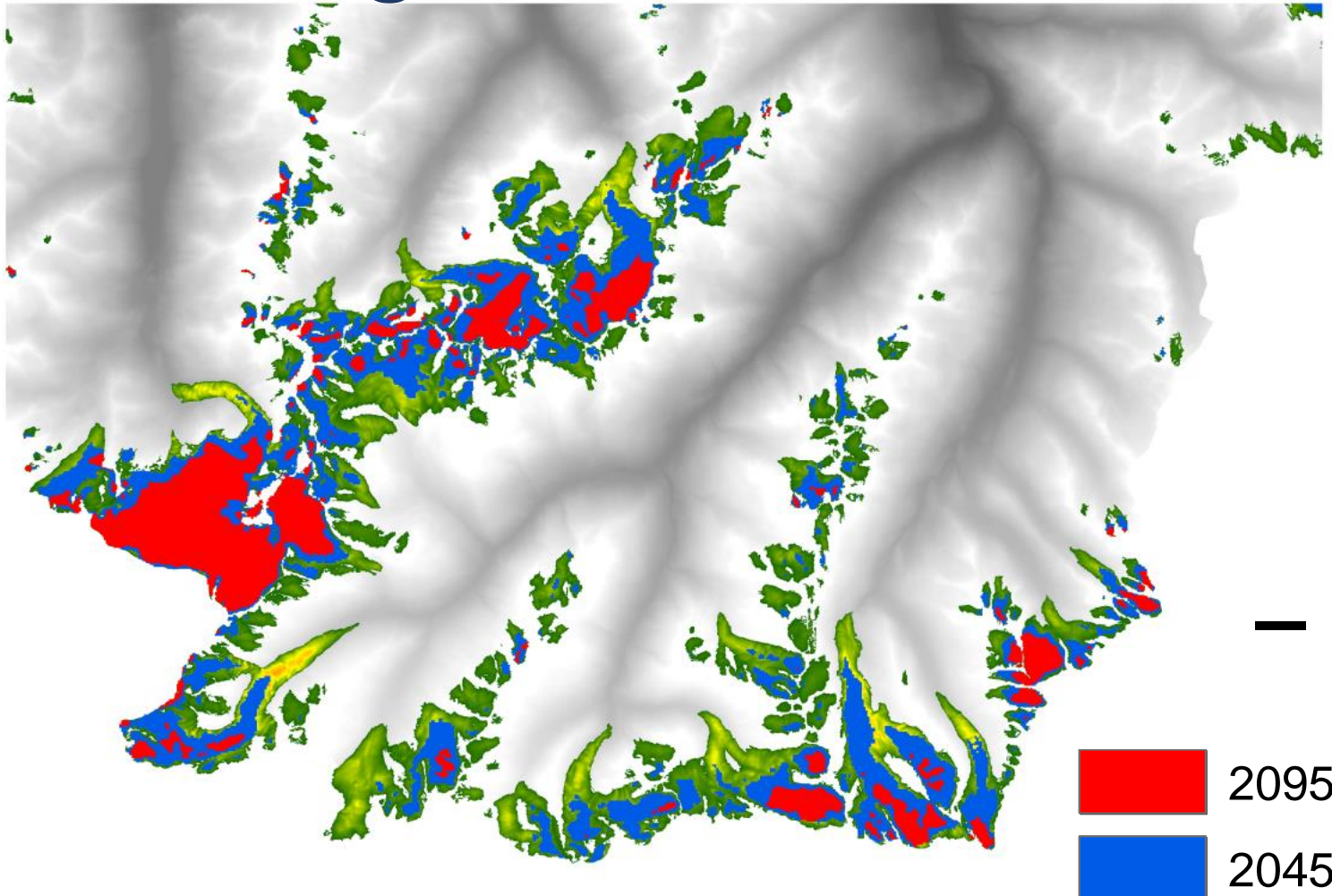
○ Total changes



- Uncertainty range initial ice thickness +/- 20%

Modelling

- distributed changes



Data availability

- <http://www.pangaea.de/>
 - Glacier outlines G LIA, GI1, GI2, GI3, doi:10.1594/PANGAEA.844985
 - Glacier length changes, doi:10.1594/PANGAEA.821823
 - Mass balance, e.g. doi:10.1594/PANGAEA.829950
 - Ice thickness measurements, doi.pangaea.de/10.1594/PANGAEA.849497

- <http://wgms.ch/>
 - Annual reports
 - Fluctuations of glaciers
 - Meta data Browser, <http://wgms.ch/metadatabrowser.html>

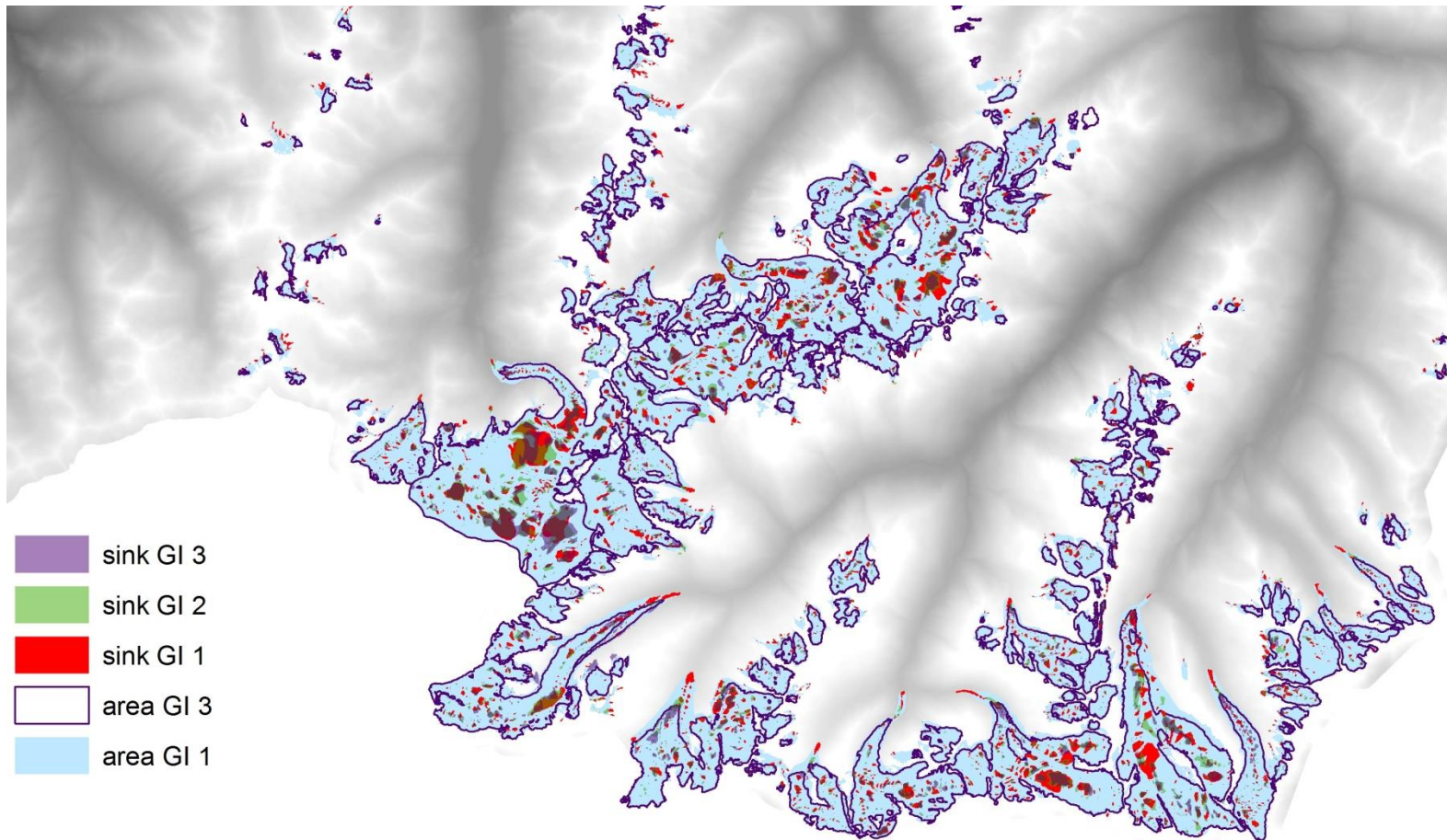
- [Österr. Alpenverein](http://www.alpenverein.at/portal/news/aktuelle_news/2015/2015_04_03_gletscherbericht.php)
 - http://www.alpenverein.at/portal/news/aktuelle_news/2015/2015_04_03_gletscherbericht.php
 - Annual reports on glacier length changes

Summary

1. Continuous data of glacier length ($n \approx 100$) and mass balance ($n \approx 10$) show historically unprecedented glacier melt in last decades
2. Four inventories of glacier area and surface elevations ($n \approx 900$): main area changes at 2750 m a.s.l., high regional variability
3. Measurements of ice thickness and calculated volume at certain time ($n=64$, , 50% of the total area): mean ice thickness decreases from 90 to 56 m (LIA-today)
4. Modelled ice thickness based on inventories
5. Model development based on long term observations

Modelling

- Filled depressions in glacier bed
- Based on different GI surface conditions



- Project *FutureLakes*: <http://www.geomorphology.at/futurelakes.html>