Fernerkundung von Gletschern und Eiskappen in Hochgebirgen und Polargebieten im Kontext des globalen Klimawandels

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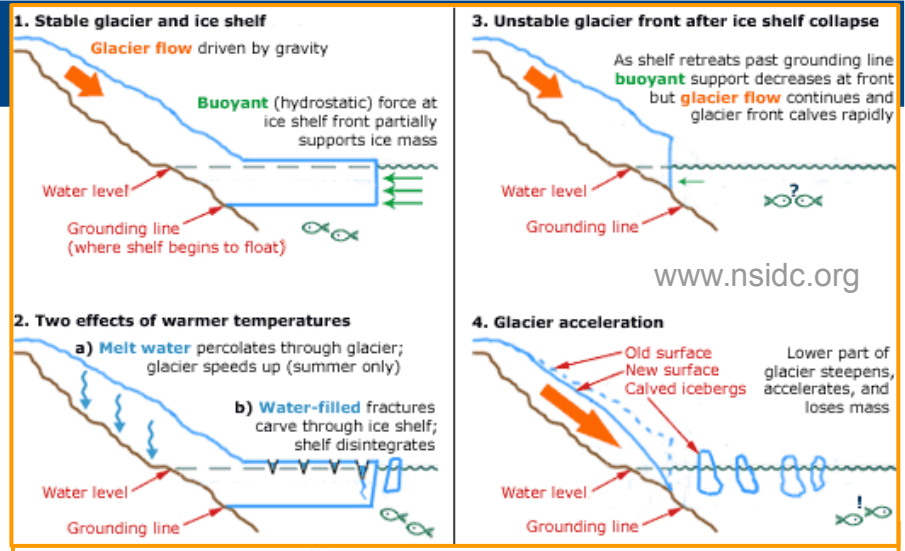
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

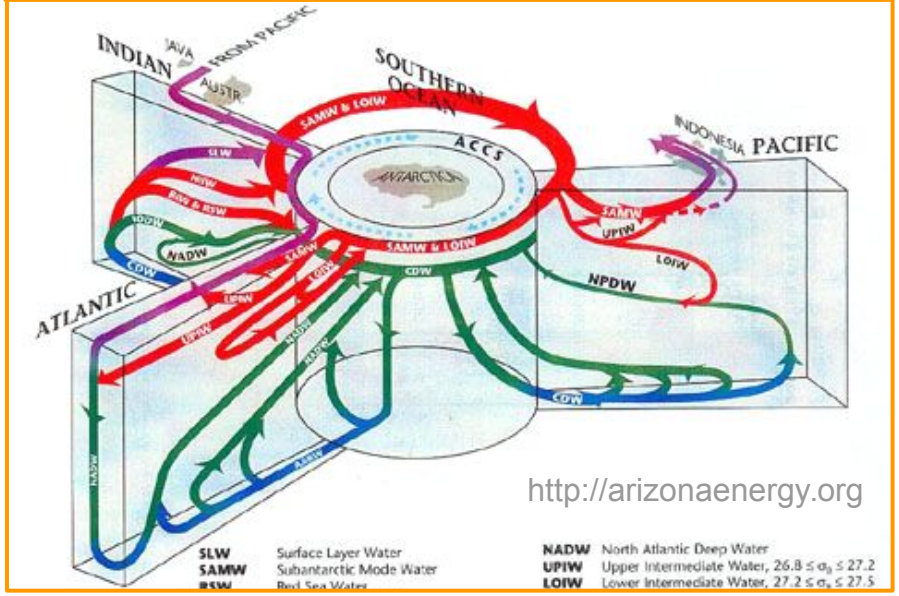
Symposium "Neue Perspektiven in der Erdbeoachtung"
Köln, 26. Juni 2018

Institut für Geographie

Structure & introduction

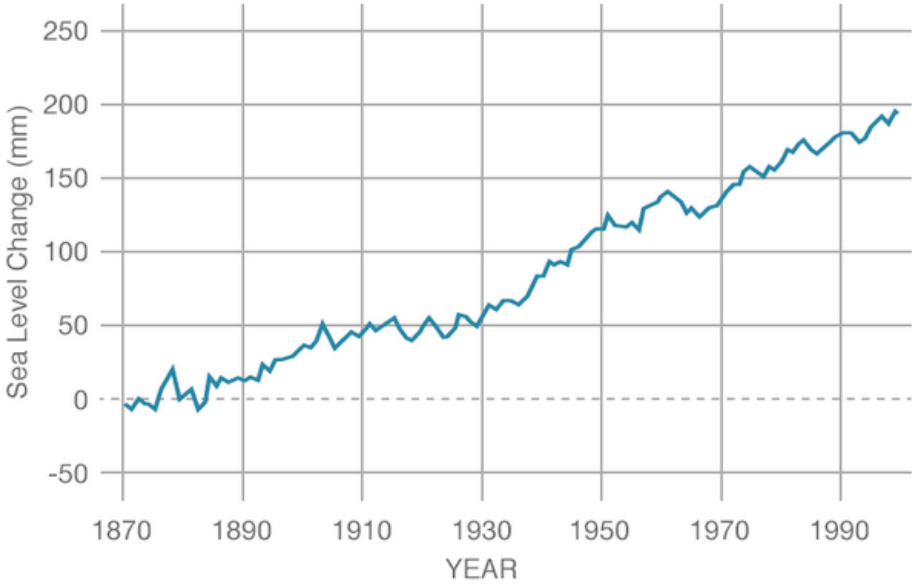
- Relevance of glaciers & ice sheets
  - Polar ice sheets => sea level rise, fresh water & ocean circulation, process understanding
  - High mountains => sea level, water balance and discharge regimes, daily amplitudes & extreme events, irrigation, hydro power, drinking water, tourism => process understanding, glacier volume estimates, cal/val of scenarios computations
- Climate scenarios and polar amplification
- Glaciers, ice caps and ice sheets as ECVs & example products
- Methods to determine glacier/ice sheet mass changes and their difficulties
  - Gravimetric measurements
  - Geodetic mass balances
  - Input-Output / Flux gate approach
- Mass changes of the polar ice sheets
- Impacts in high mountain regions (ex. from South America)



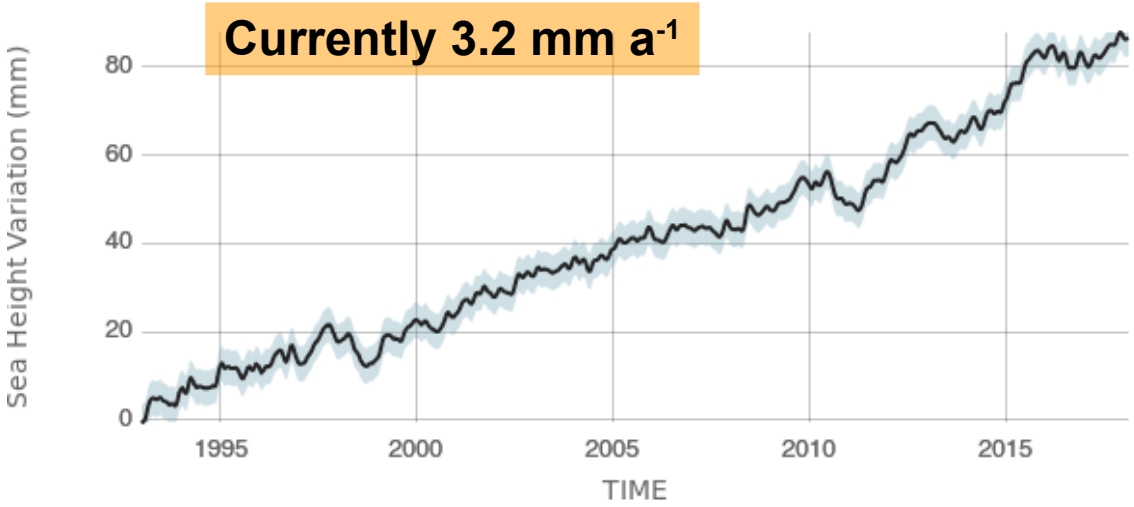


Global sea level rise

Ground data

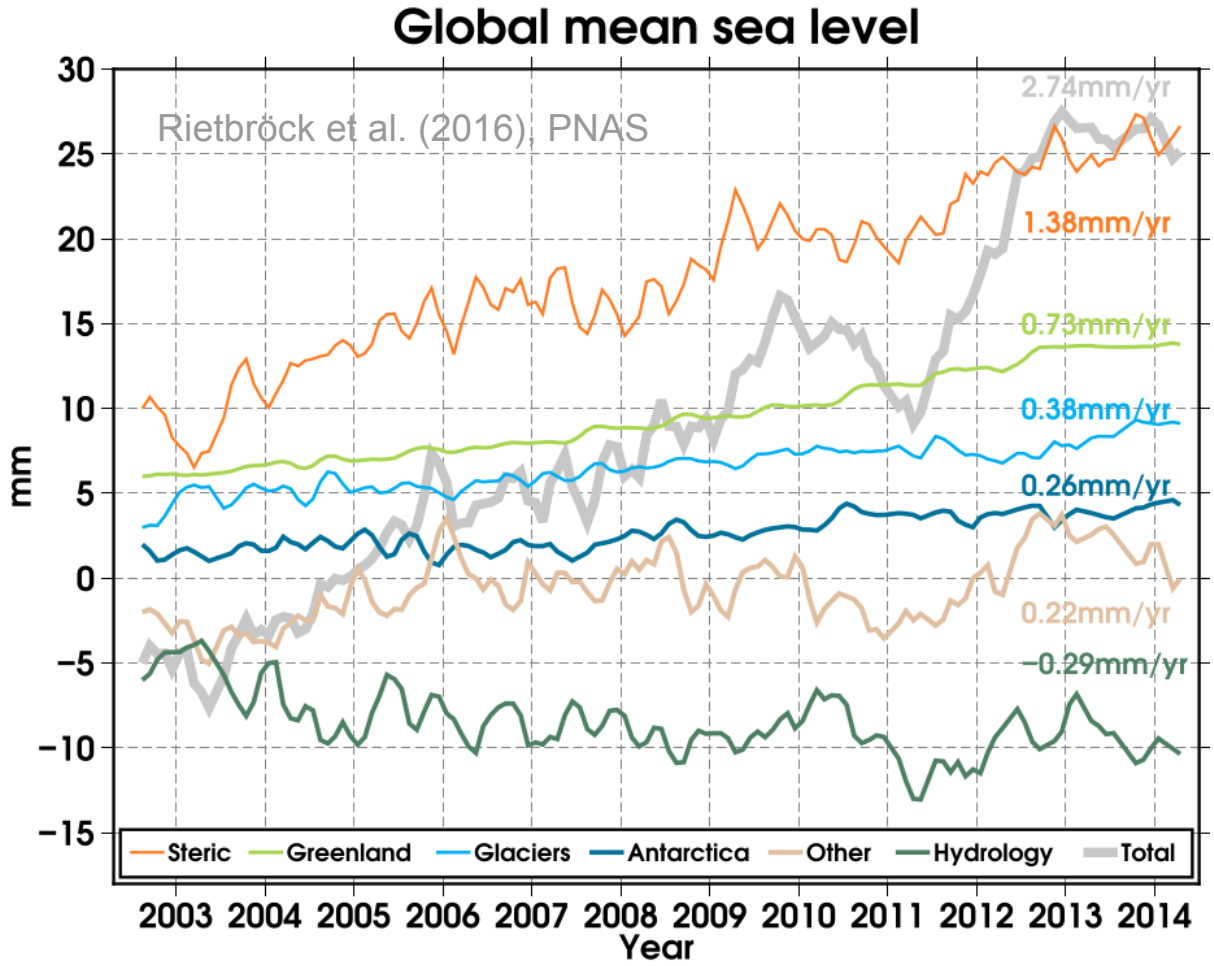


Satellite data



https://climate.nasa.gov/vital-signs/ice-sheets/
22 June 2018

Sea level change and contribution of different drivers (2002-2014)



Glacier & ice sheets contribute similarly as steric expansion

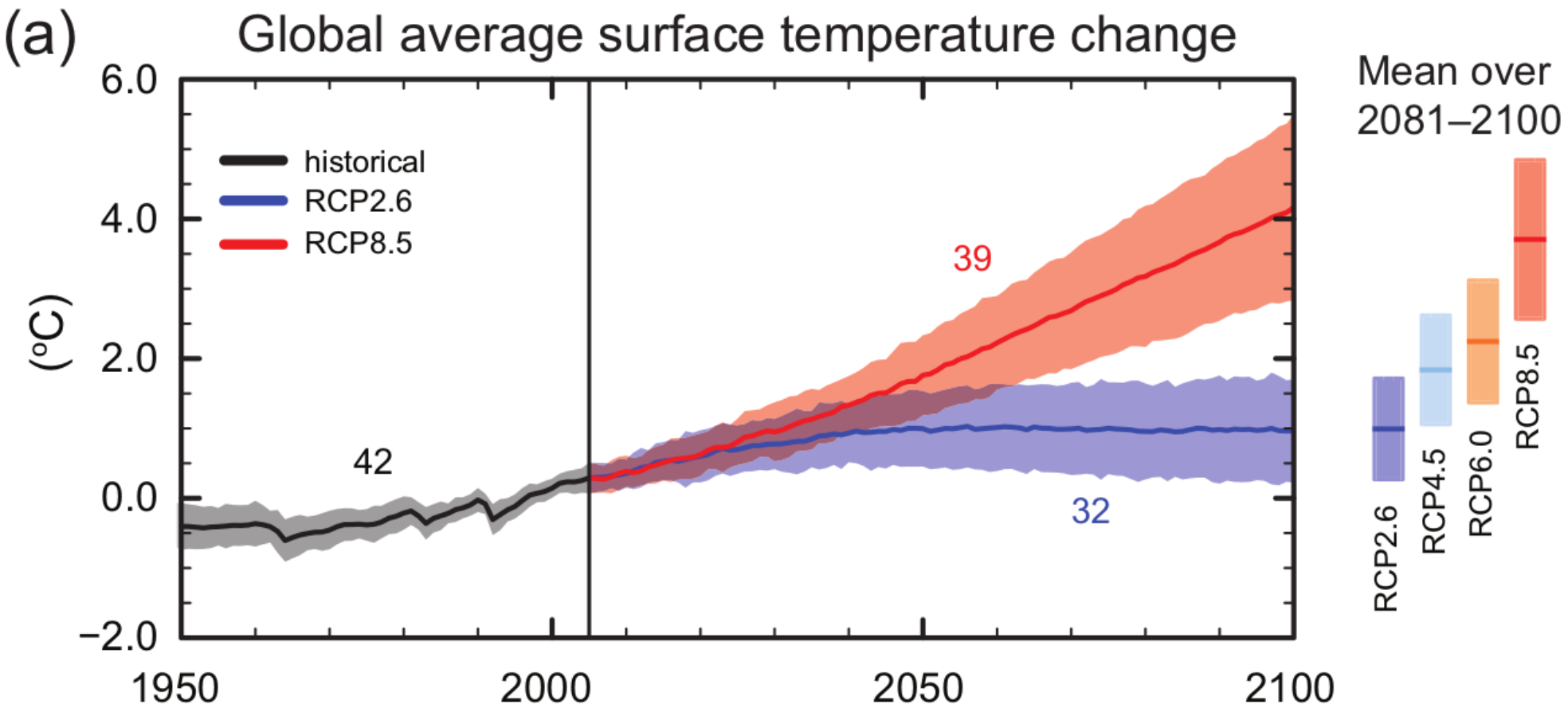
Greenland

Glaciers

Antarctica

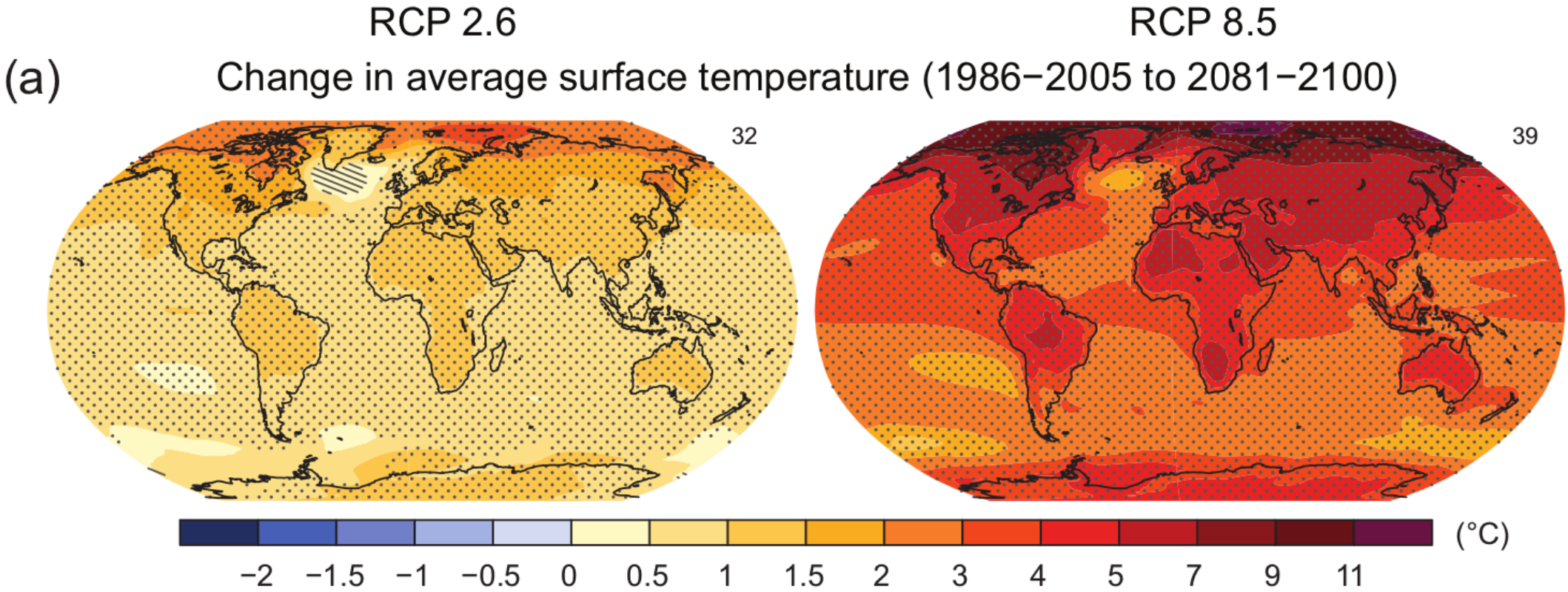
1,37 mm /yr

Global surface temperature trend and scenarios



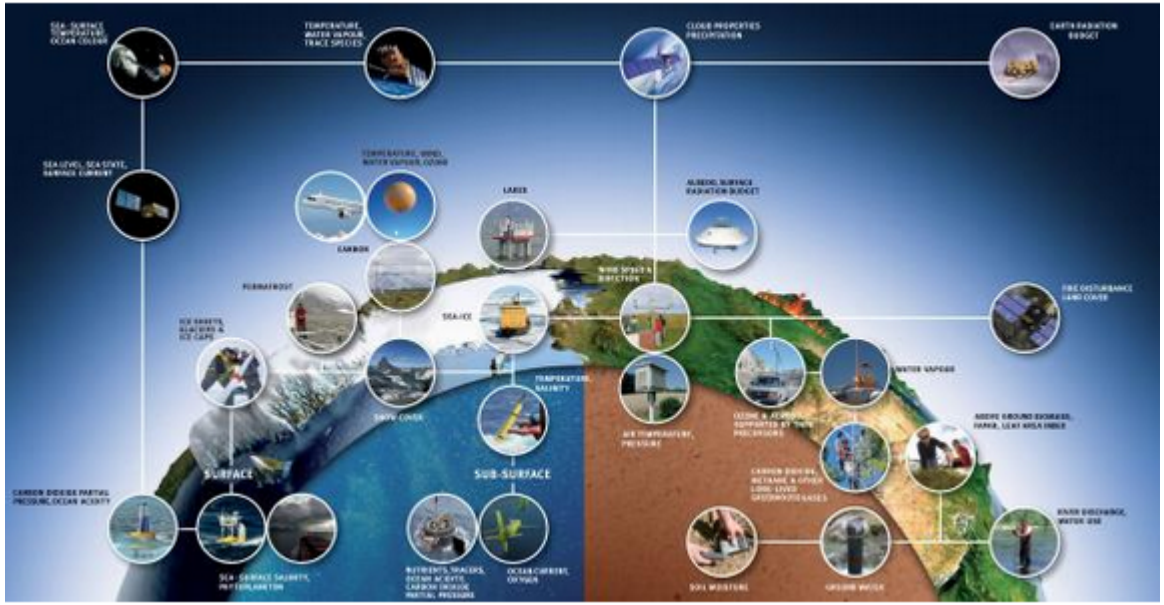
IPCC AR5 (2013)

Polar amplification



IPCC AR5 (2013)

Glaciers & ice sheets – WMO Essential Climate Variables (ECVs)



- An ECV is a physical, chemical or biological variable or a group of linked variables that **critically contributes to the characterization of Earth' s climate**.
- **Relevance**: The variable is critical for characterizing the climate system and its changes.
- **Feasibility**: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

ECV for Glaciers & Ice caps

Product Requirements:

- **Glacier Area:**
  - Frequency: Annual (at end of ablation season)
  - Resolution: Horizontal 15-30 m; Vertical 1 m
  - Required Measurement uncertainty: 5 %
  - Standards/References: IGOS (2009); Paul et al. (2009)
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)
- **Glacier Elevation Change:**
  - Frequency: Decadal
  - Resolution: Horizontal 30 m-100 mx; Vertical 1 m
  - Required Measurement uncertainty: 2 m/decade
  - Stability (per decade unless otherwise specified): 1 m/decade
  - Standards/References: Zemp et al. (2013)
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)
- **Glacier Mass Change:**
  - Frequency: Seasonal to annual (the latter at end of ablation period)
  - Resolution: Vertical: 0.01 m or 10 kg/m2 (at point location)
  - Required Measurement uncertainty: Better than 200 kg/m2/year (glacier-wide)
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)

for Ice sheets

Product Requirements:

- **Surface Elevation Change:**
  - Frequency: 30 days
  - Resolution: Horizontal 100 m
  - Required Measurement uncertainty: 0.1 m/year
  - Stability (per decade unless otherwise specified): 0.1 m/year
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)
- **Ice Velocity:**
  - Frequency: 30 days
  - Resolution: Horizontal 100 m
  - Required Measurement uncertainty: 0.1 m/year
  - Stability (per decade unless otherwise specified): 0.1 m/year
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)
- **Ice Mass Change:**
  - Frequency: 30 days Resolution: Horizontal 50 km
  - Required Measurement uncertainty: 10 km3/year
  - Stability (per decade unless otherwise specified): 10 km3/year
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)
- **Grounding Line Location and Thickness:**
  - Frequency: Yearly
  - Resolution: Horizontal 100 m; Vertical 10 m
  - Required Measurement uncertainty: 1 m
  - Stability (per decade unless otherwise specified): 10 m
  - Entity (Satellite): WGClimate (link is external)
  - Entity (in situ): GCW (link is external)

Glaciers & ice caps

- ICSU
- IUGG
- UNEP
- UNESCO
- WMO

- IPCC

- WGMS
- NSIDC
- GLIMS

Global Terrestrial Network for Glaciers

GTN-G

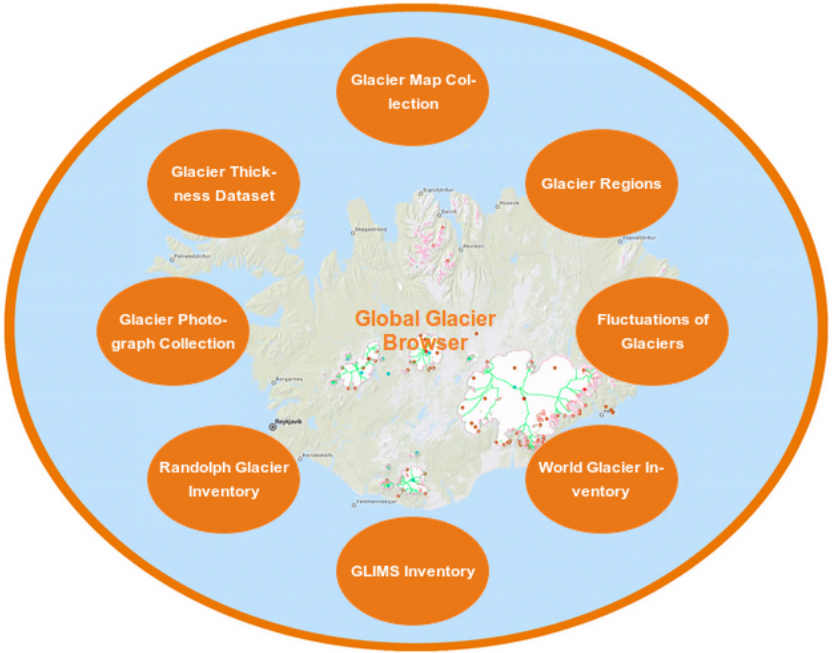
under the auspices of: ICSU (WDS), IUGG (IACS), UNEP, UNESCO, WMO

HOME ABOUT MONITORING STRATEGY NETWORK DATA GUIDELINES CONTACT

welcome

The Global Terrestrial Network for Glaciers (GTN-G) is the framework for the internationally coordinated monitoring of glaciers and ice caps in support of the United Nations Framework Convention on Climate Change (UNFCCC). The network, authorized under the Global Climate/Terrestrial Observing Systems (GCOS, GTOS), is jointly run by the World Glacier Monitoring Service (WGMS), the U.S. National Snow and Ice Data Center (NSIDC), and the Global Land Ice Measurements from Space initiative (GLIMS). More...

This website provides general information on GTN-G and a map-based browser for available glacier data.



Search

QUICK LINKS

Data browser

Data catalogue

ANNOUNCEMENTS

- Glacier Monitoring Session @ AGU 2018!
- Glacier Monitoring Session @ POLAR 2018!
- Glacier Map Collection online!
- more...
- organigram

wgms + + + + GLIMS NSIDC

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Glaciers & ice caps

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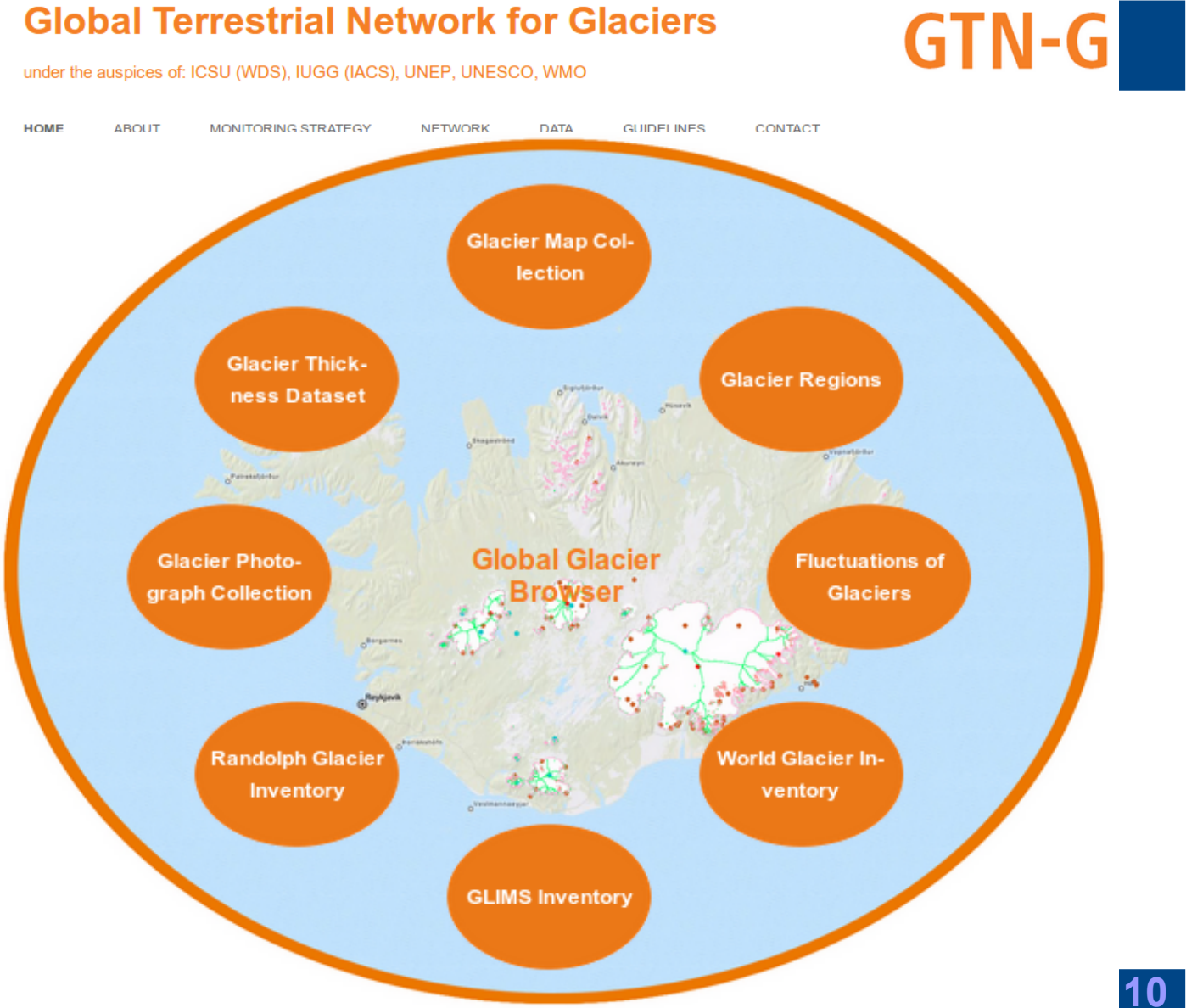
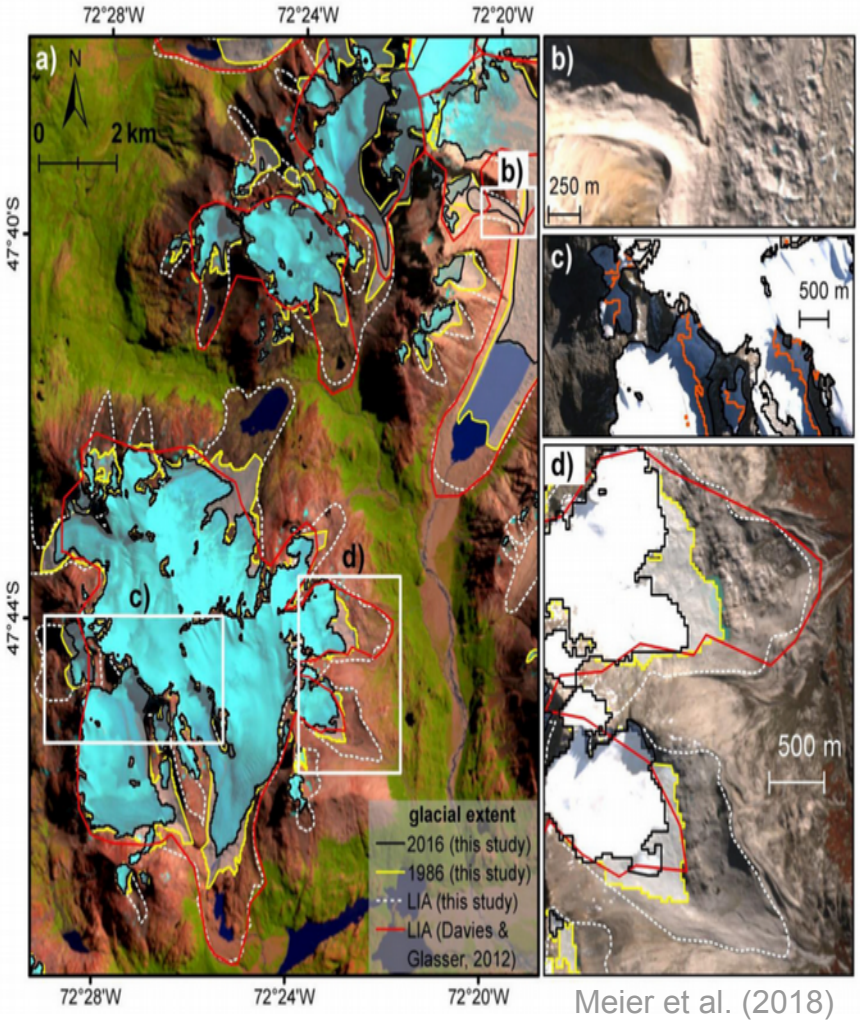


Remote sensing products for glacier research and monitoring

- **Glacier & ice sheet extent**
- **Glacier & ice sheet volume and mass changes**
- *Ice dynamics*
- Grounding line
- Melt status
- Surface properties & albedo
- Supra-glacial lakes
- Pre-glacial lake extent
- Internal structures
- Snow density & water equivalent
- Glacier thickness (airborne/groundbased GPR)
- …..



Meier et al. (2018)

Randolph Glacier Inventory – GLIMS (community effort)

Due to a consolidated remote sensing effort, we now know that there are more than 200’000 glacier worldwide.

Inventory is continuously updated, all scientist can submit their data sets.

Standardized methodology and documentation

Used by modellers (future scenarios) and for e.g. ice thickness reconstruction

GLIMS

Randolph Glacier Inventory 6.0

- Home
- More About GLIMS
- Data Access
- Documentation / RC Resources
- Publications and Presentations
- Workshops and Meetings
- Mailing List
- Software
- Contact

Dataset Description

The Randolph Glacier Inventory (RGI 6.0) is a global inventory of glacier outlines. It is supplemental to the Global Land Ice Measurements from Space initiative (GLIMS). Production of the RGI was motivated by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). Future updates will be made to the RGI and the GLIMS Glacier Database in parallel during a transition period. As all these data are incorporated into the GLIMS Glacier Database and as download tools are developed to obtain GLIMS data in the RGI data format, the RGI will evolve into a downloadable subset of GLIMS, offering complete one-time coverage, version control, and a standard set of attributes.

For more details, and for a complete list of contributors, please see the **RGI 6.0 Technical Report** (PDF format). For the glacier regions used see the **GTN-G Glacier Regions**.

Citation

RGI Consortium (2017). Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 6.0: Technical Report, Global Land Ice Measurements from Space, Colorado, USA. Digital Media. DOI: **https://doi.org/10.7265/N5-RGI-60**

Release History

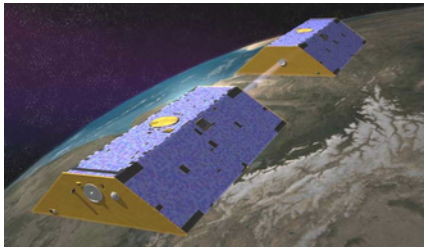
- RGI Version 1.0: released Feb 22, 2012
- RGI Version 2.0: released June 12, 2012. Version 2.0 includes metadata on data sources, outlining techniques and incorporates newly available outlines.
- RGI Version 3.0: released April 7, 2013. Version 3.0 includes identification of all tidewater basins and delineation of glaciers from glacier complexes in nearly all regions.
- RGI Version 3.2: released August 31, 2013.
- RGI Version 4.0: released December 1, 2014.
- RGI Version 5.0: released July 20, 2015.
- RGI Version 6.0: released July 28, 2017.

Data Access

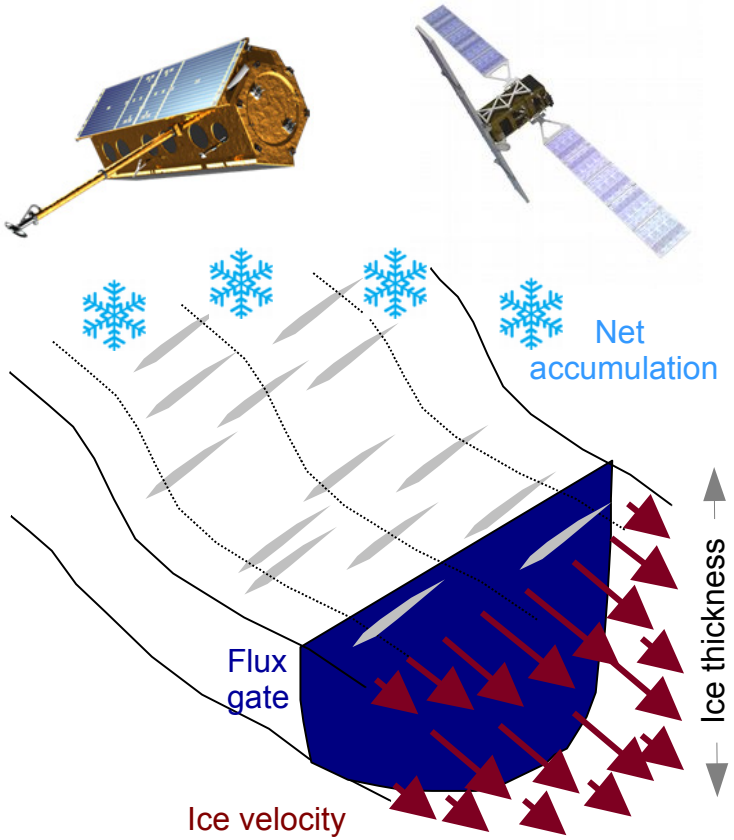
Get the RGI 6.0 (Recommended)

Methods to determine glacier & ice sheet mass changes

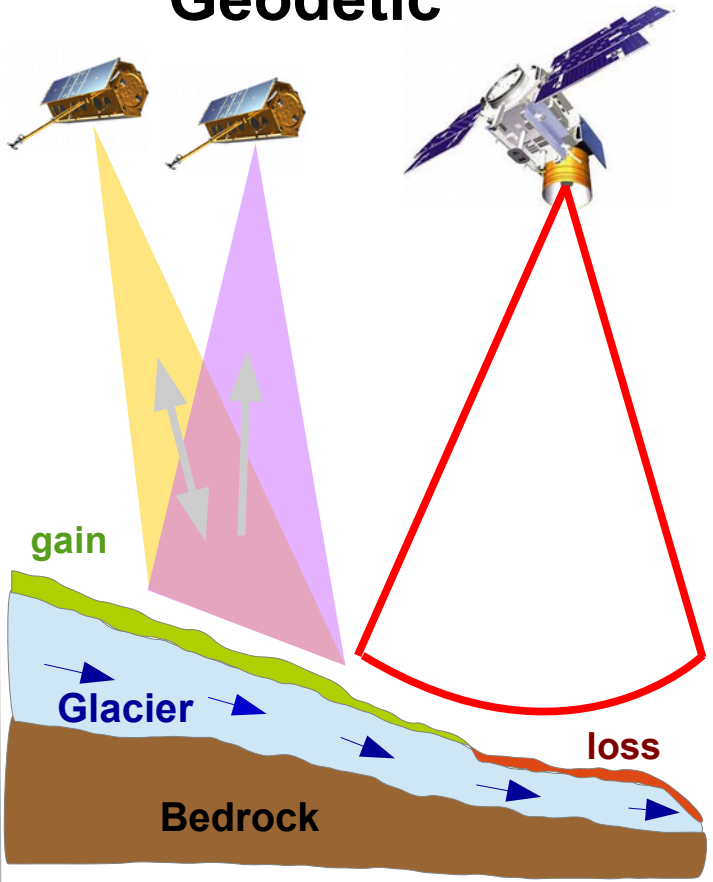
Gravimetry



Input – output



Geodetic



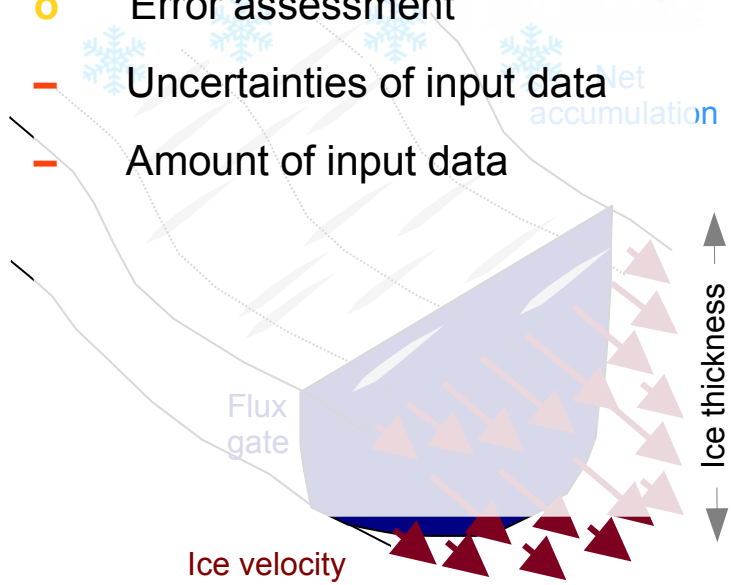
Methods to determine glacier & ice sheet mass changes

Gravimetry

- \+ Direct measurement
- \+ Time series
- – Only regions resolved
- – GIA
- – Size of the region
- – Leakage

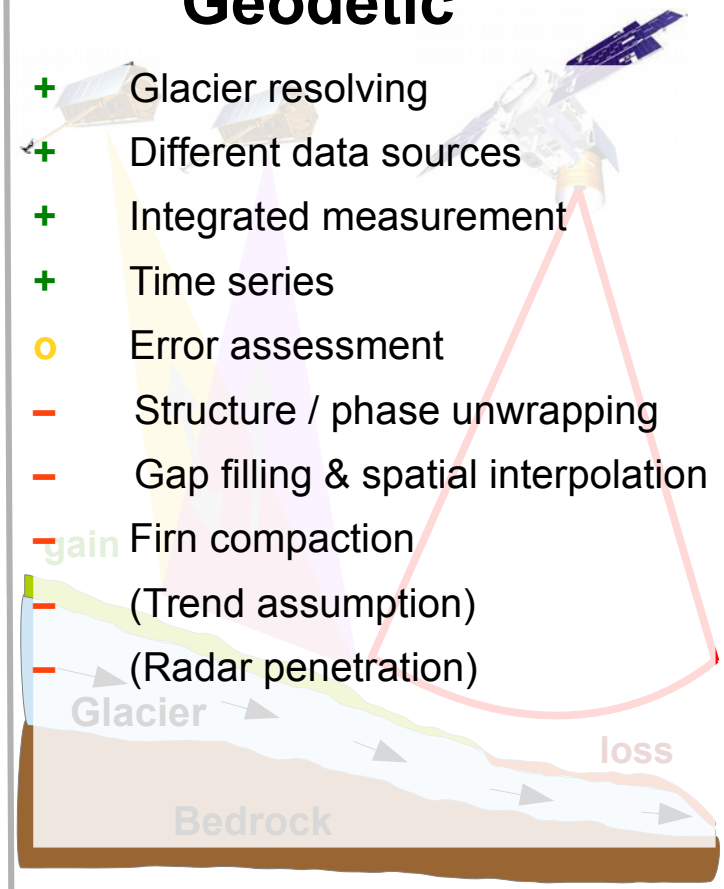
Input – output

- \+ Glacier resolving
- \+ Process information
- \+ Time series
- o Error assessment
- – Uncertainties of input data
- – Amount of input data



Geodetic

- \+ Glacier resolving
- \+ Different data sources
- \+ Integrated measurement
- \+ Time series
- o Error assessment
- – Structure / phase unwrapping
- – Gap filling & spatial interpolation
- – Firn compaction
- – (Trend assumption)
- – (Radar penetration)



Methods to determine glacier & ice sheet mass changes

Gravimetry

- + Direct measurement
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- – Size of the
- – Leakage

Input – output

- + Glacier resolving
- + Process
- +

detic

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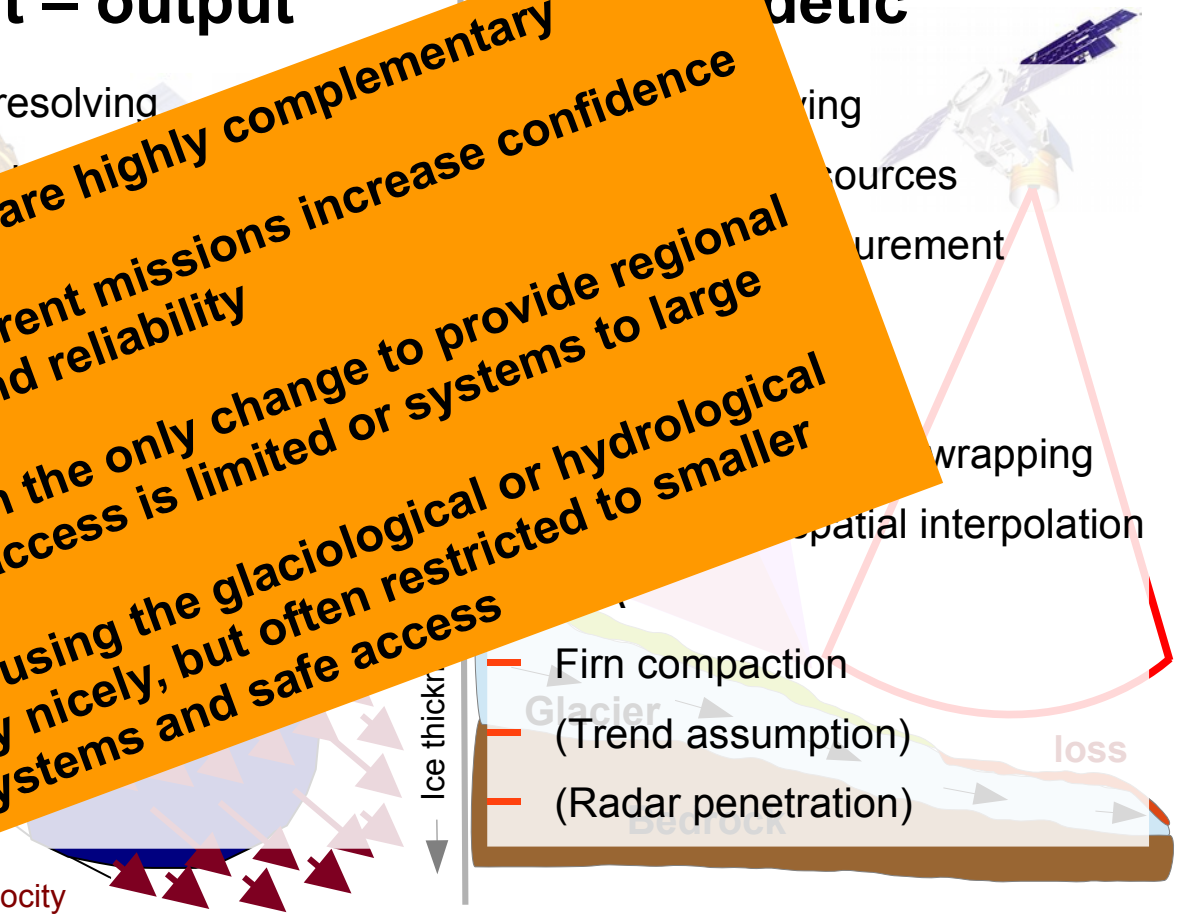
- urement
- wrapping
- patial interpolation

Methods and mission are highly complementary

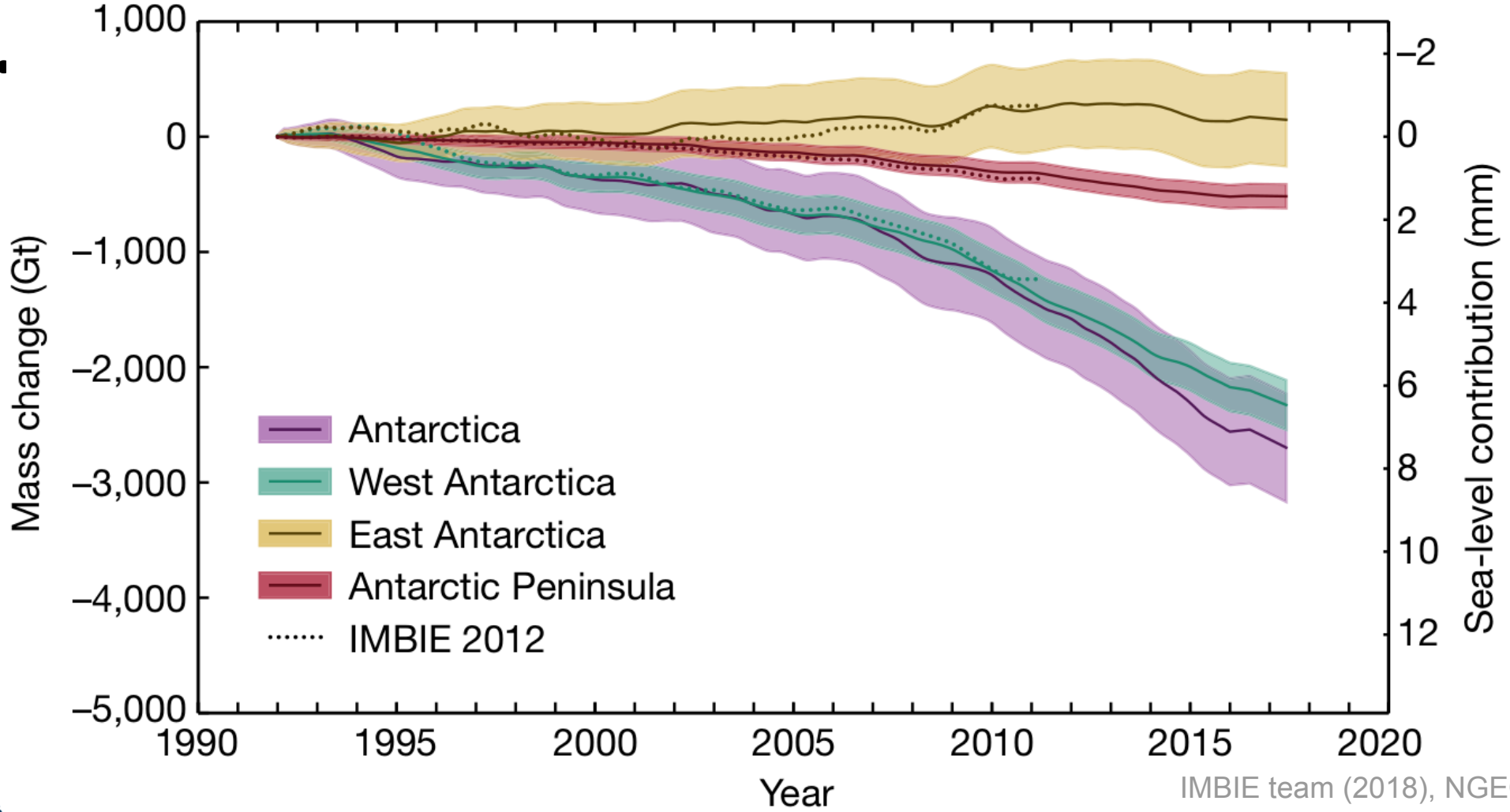
Analysis of data from different missions increase confidence and reliability

Remote sensing is often the only change to provide regional assessments since access is limited or systems to large

Field-based studies using the glaciological or hydrological approach link very nicely, but often restricted to smaller systems and safe access

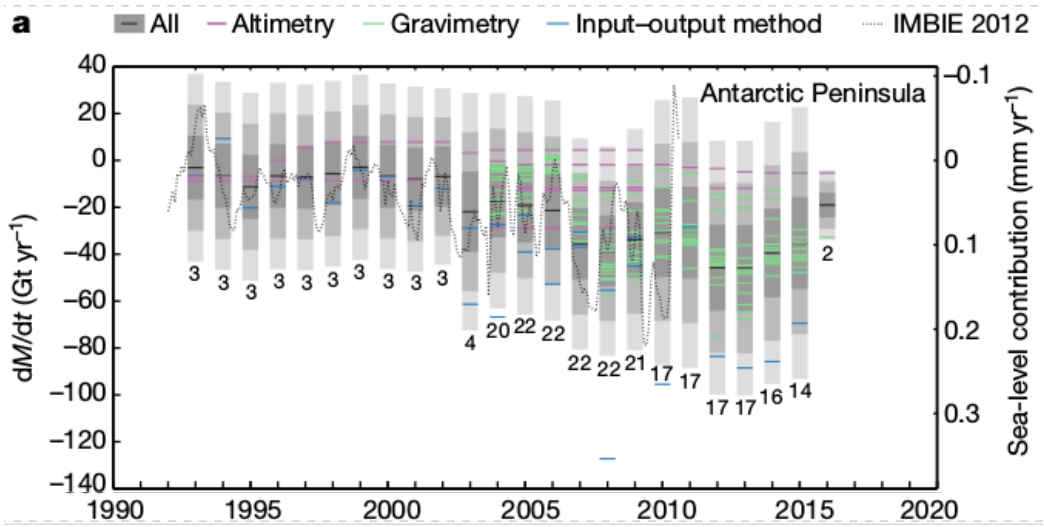


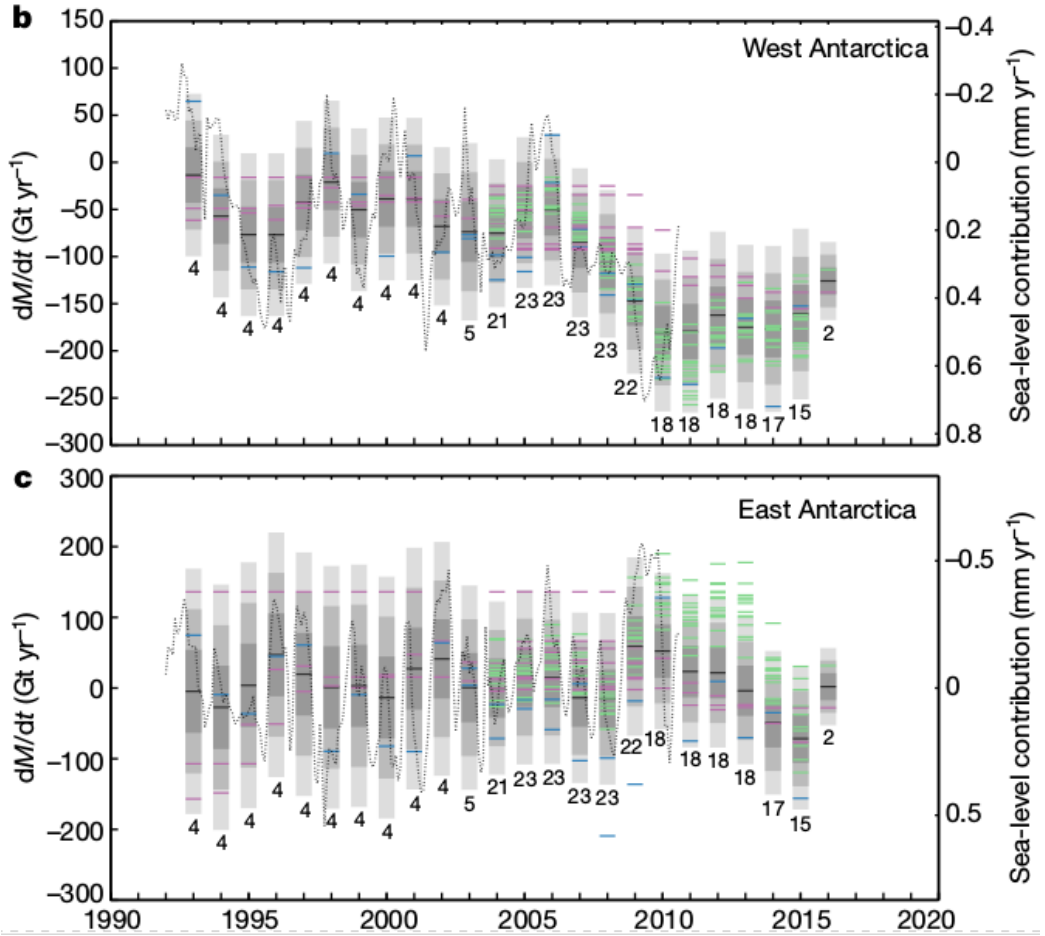
Consolidated Antarctic mass changes



IMBIE team (2018), NGEO

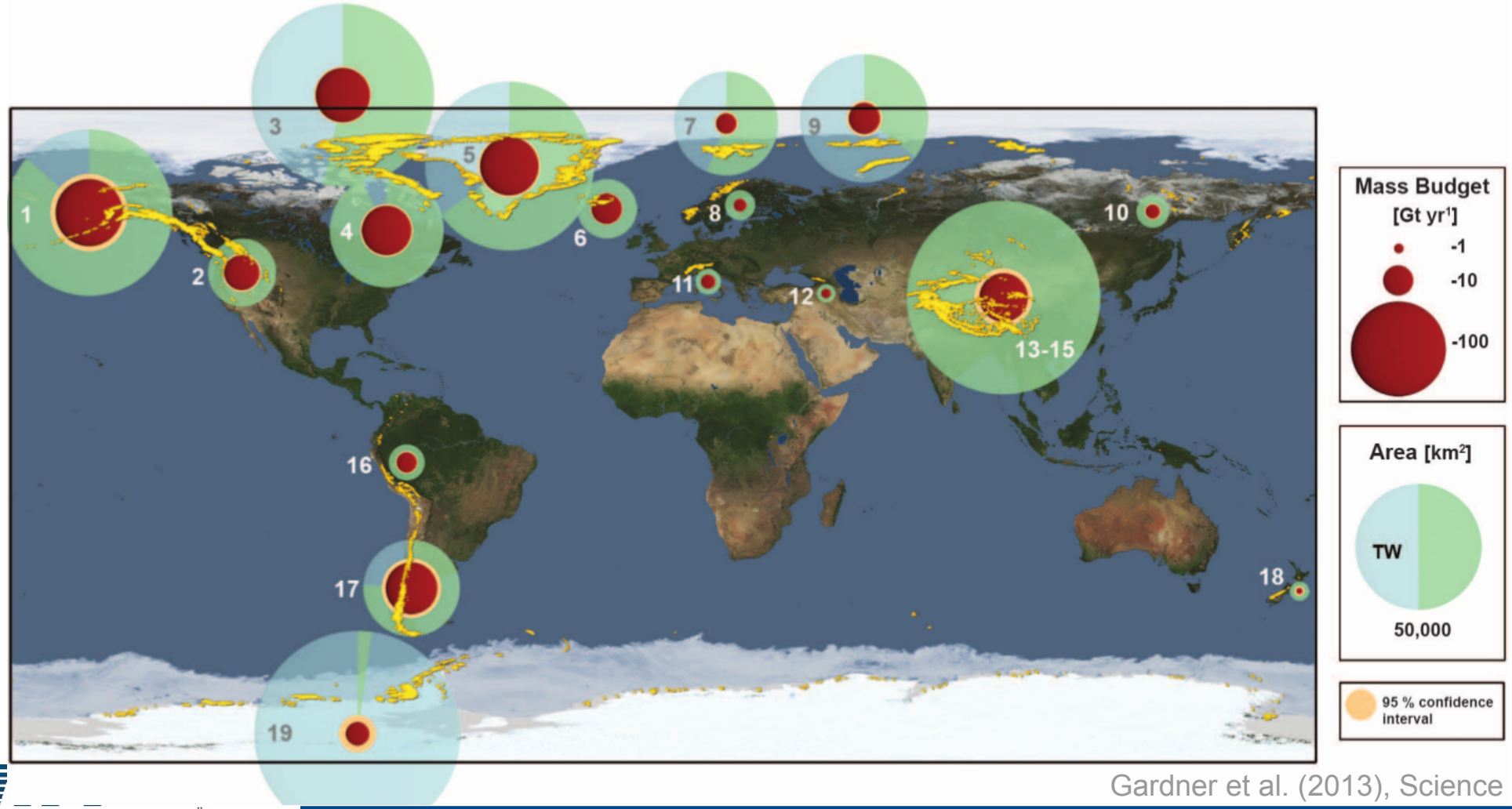
Consolidated Antarctic mass changes





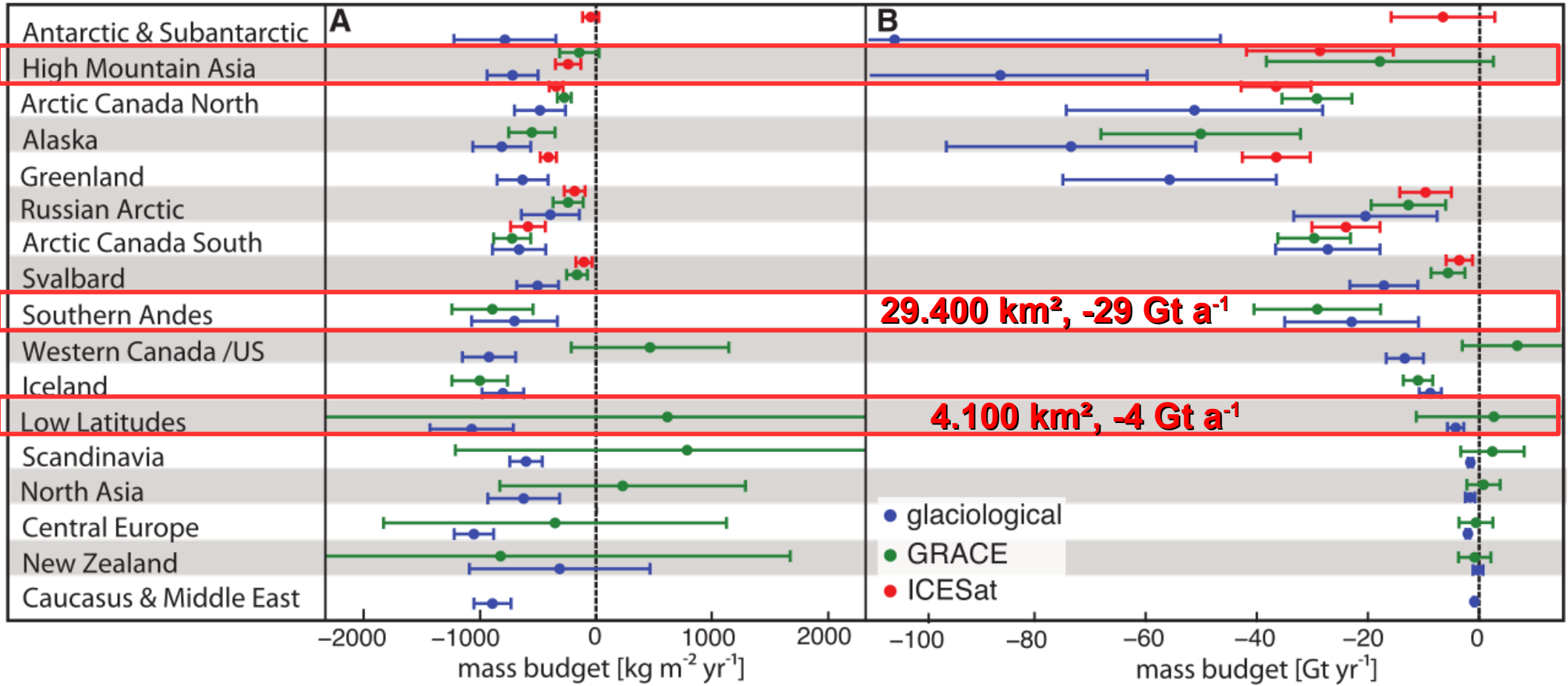
IMBIE team (2018), NGEO

Global glacier mass change estimates



Gardner et al. (2013), Science

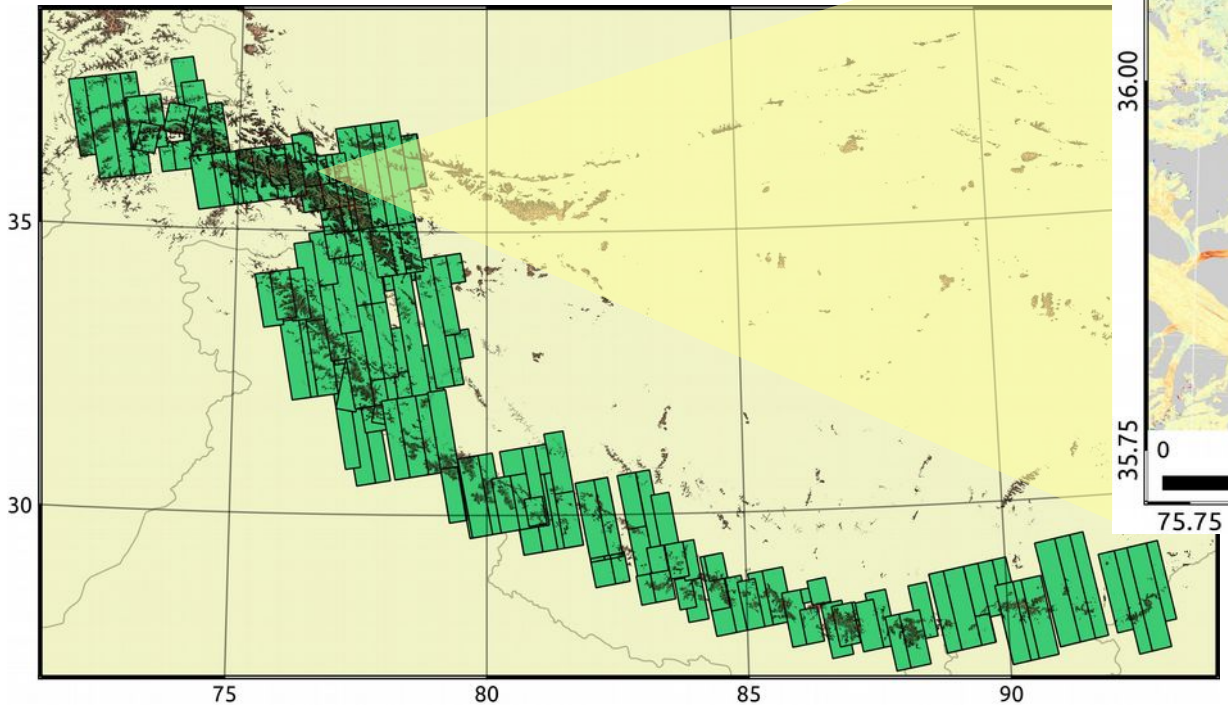
Global glacier mass change assessment from different methods

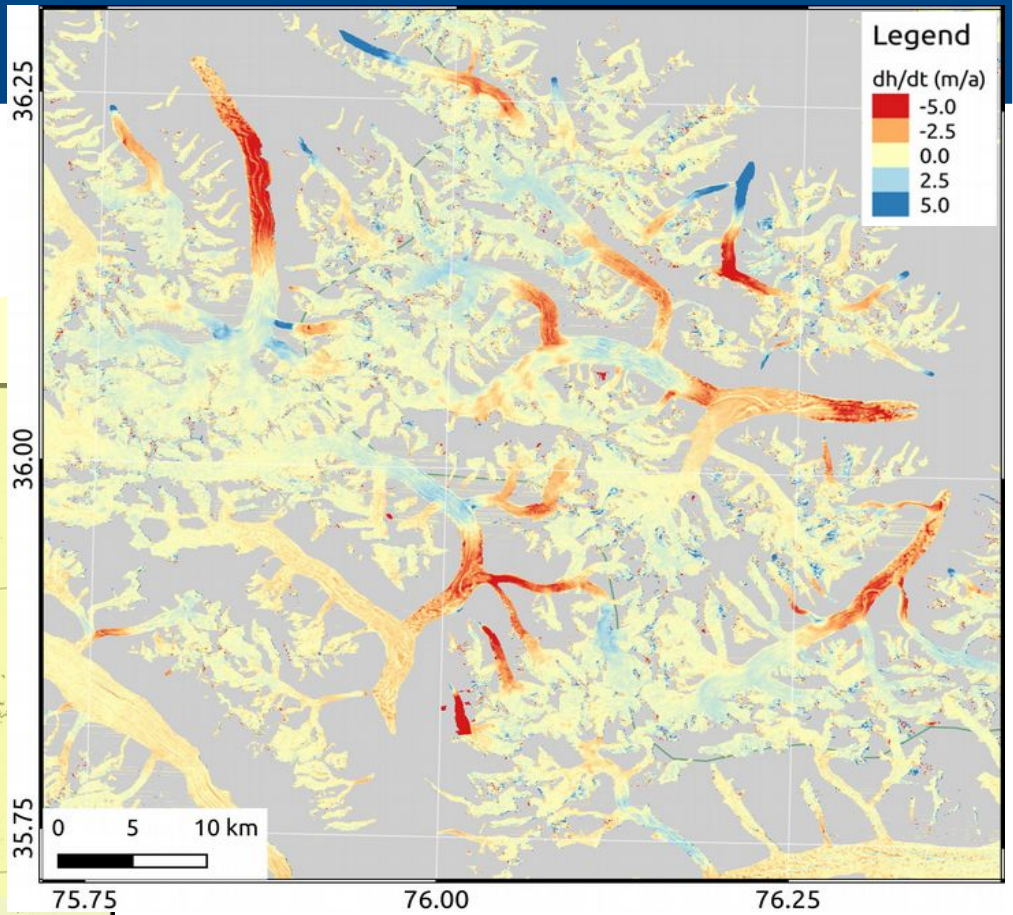


Gardner et al. (2013), Science

Elevation & mass changes HMA

Elevation change dh/dt (m a^{-1})	Volume change dV/dt (km^3 a^{-1})	Mass change dm/dt (Gt a^{-1})
-0.15 ± 0.05	-3.925 ± 0.59	-3.336 ± 0.55





Missions: SRTM – TanDEM-X
Time period: 2000-2012/13
Area measured: 26’172 ± 1’570 km²

Impacts of glacier changes in high mountains

Peru:

- *54% of the energy production from hydropower with 5.4% increasing energy demand per year (Vuile et al., 2018)*
- *Agricultural production in the Cordillera Blanca is strongly relying on irrigation*
- *Mining claims in Peru cover 11% of the country surface => water amount, quality and suspended matter concentration*
- *Production of one ounce of gold requires 25 m³ water in 2008*
- *Glacier hazard & risk: GLOFs and ice avalanches*
- *Downstream ecological impacts*
- *Social and political conflicts resulting from water allocation*

  => At which state are we currently (peak water) and what is glacier volume and mass loss?

Example:
Chavimochic project in the La Libertad coastal region:

- US$ 0.5 Mia agricultural export production by irrigation
- Drinking water of 800.000 people in Trujillo
- Jobs for >60.000 people
- and energy production

All from the Santa river originating from the Cordillera Blanca

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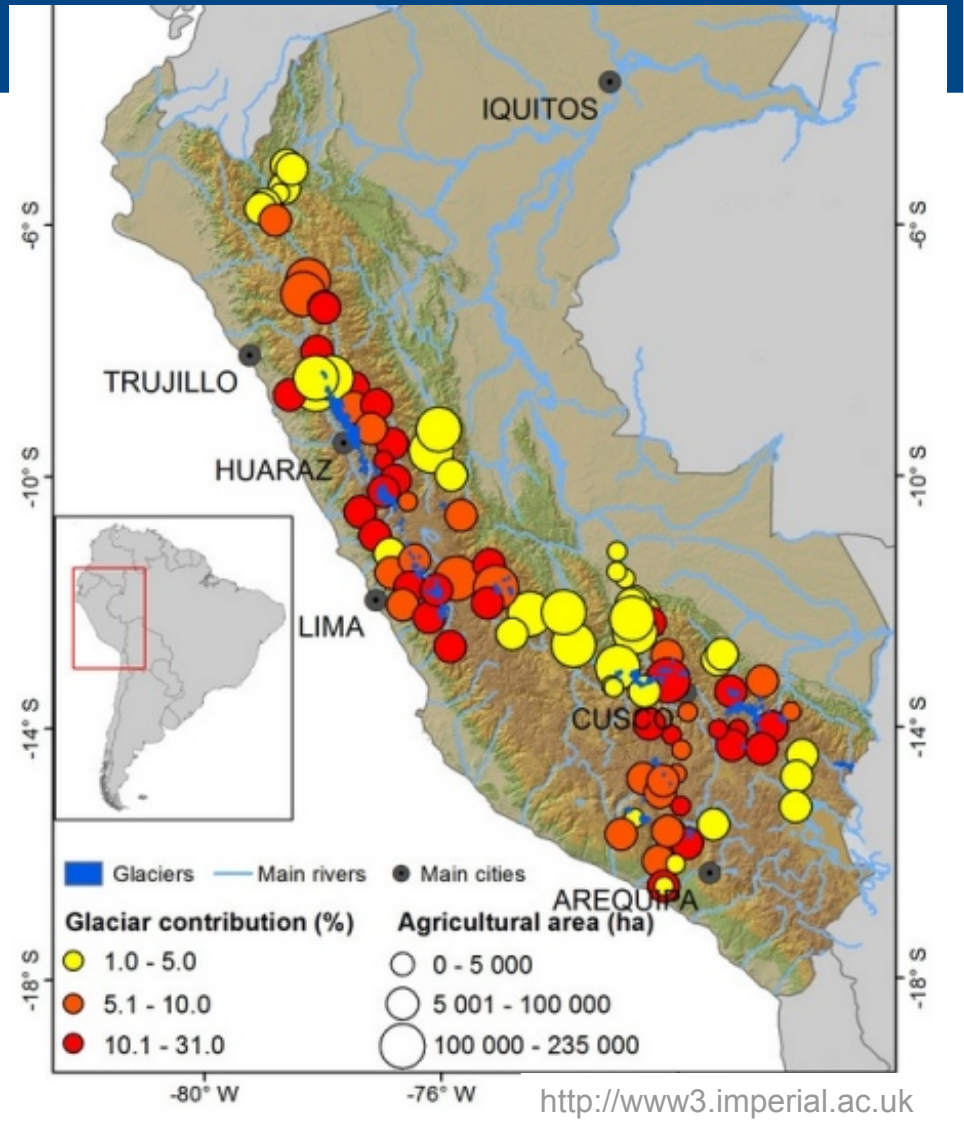
UNISDR
The United Nations Office for Disaster Risk Reduction

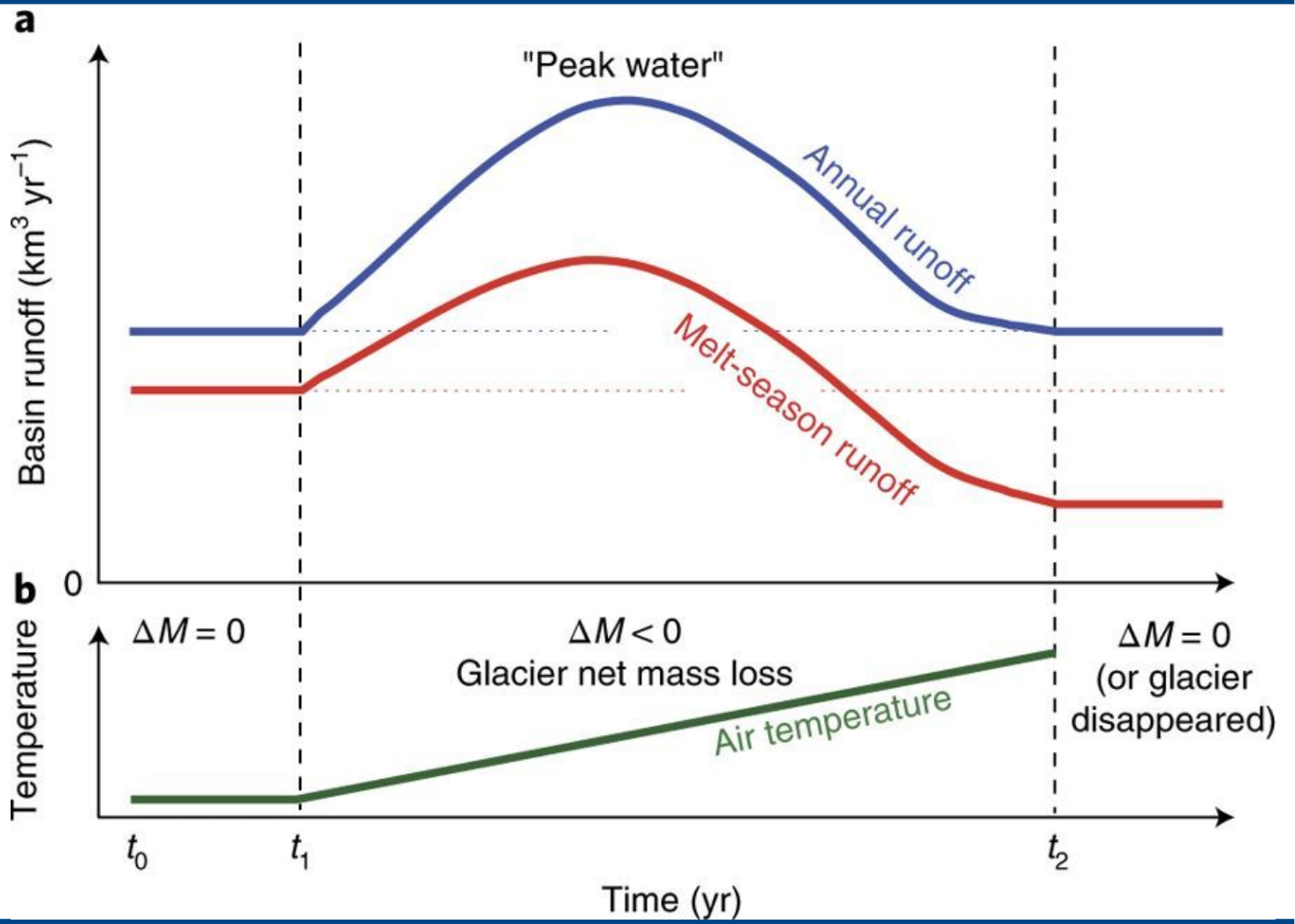
United Nations Office for Disaster Risk Reduction

Glacier discharge & irrigation Peru



http://www3.imperial.ac.uk

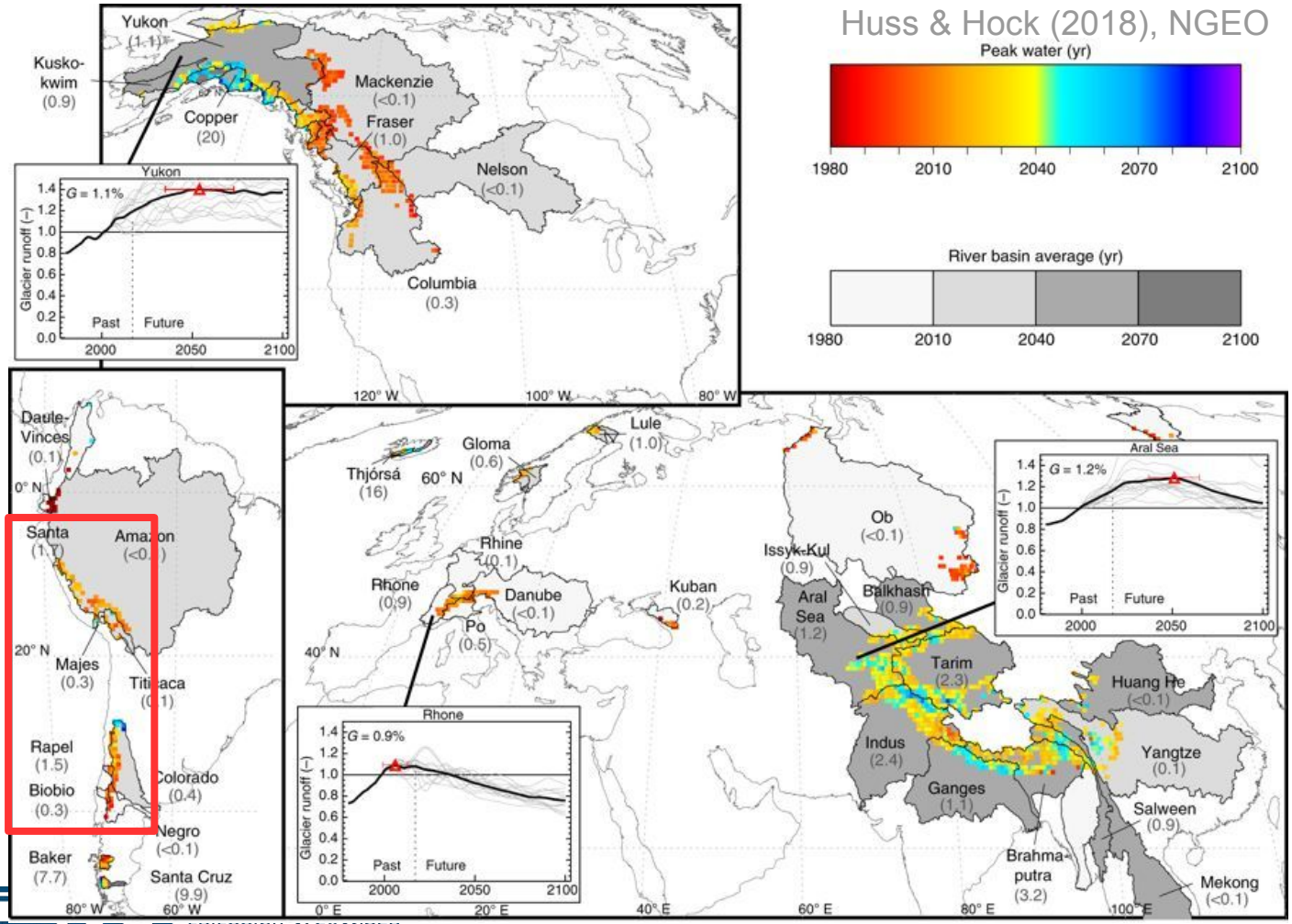
Discharge from glaciers – the “Peak water” effect

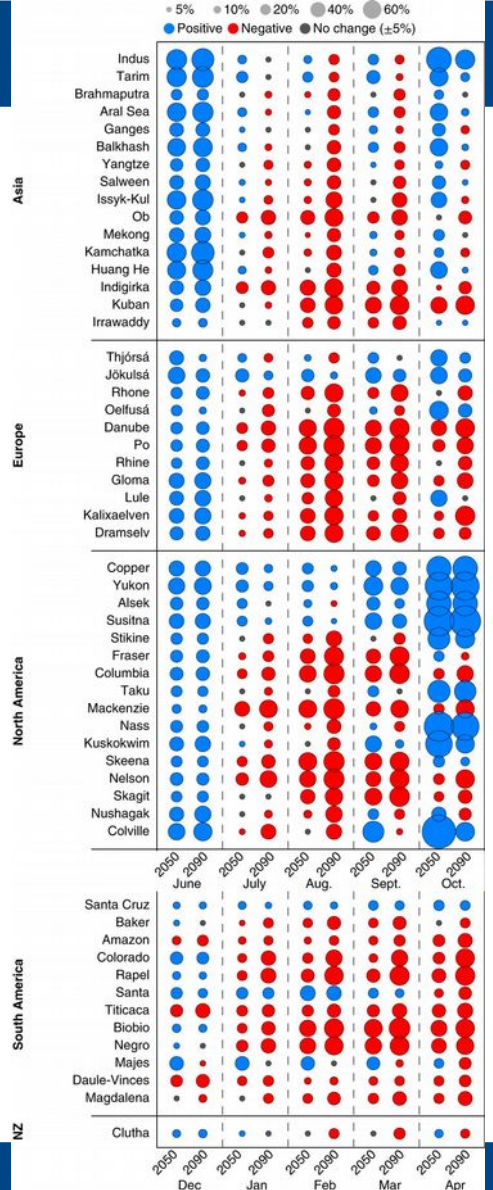


Huss & Hock (2018), NGEO

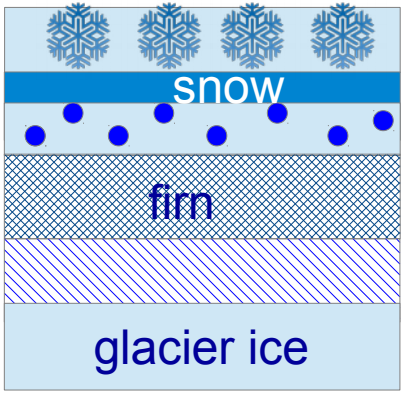
Discharge from glaciers – the "Peak water" effect

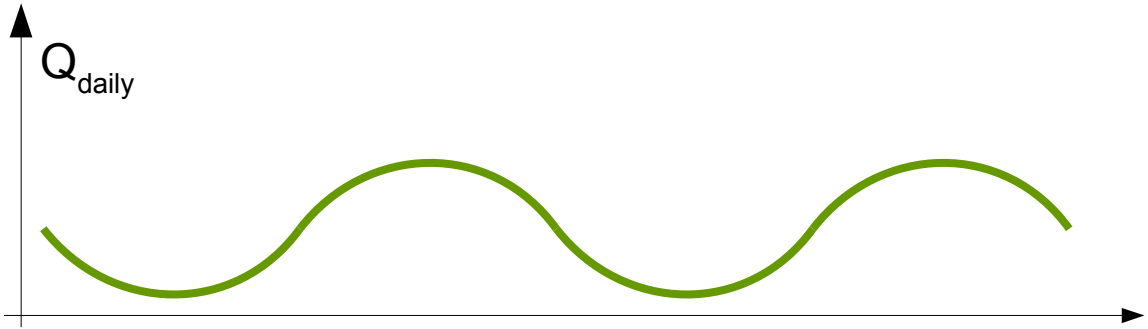
Huss & Hock (2018), NGEO



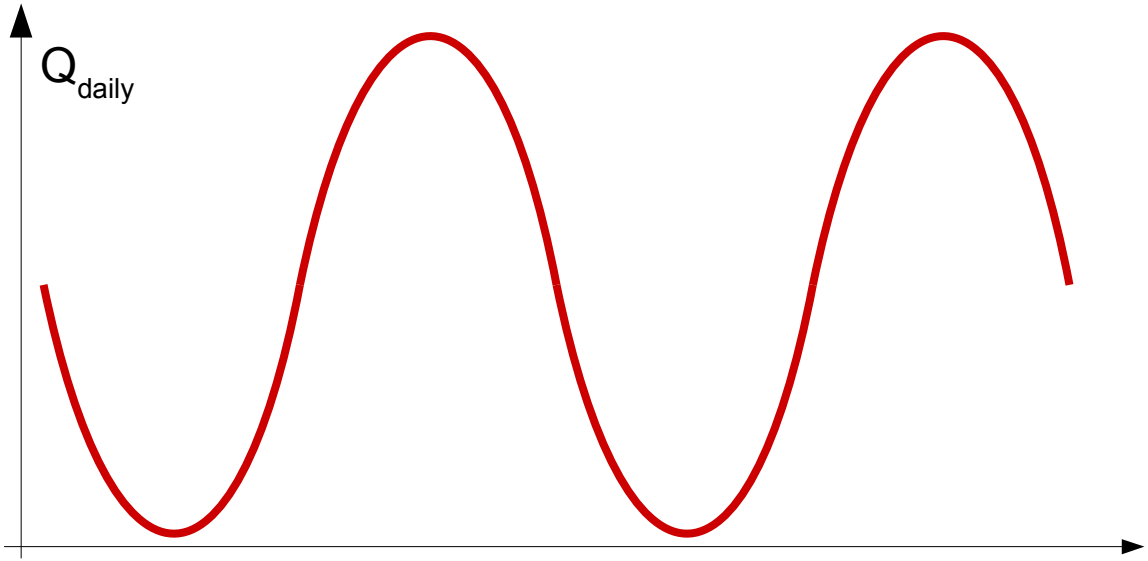


Daily and response to extreme events

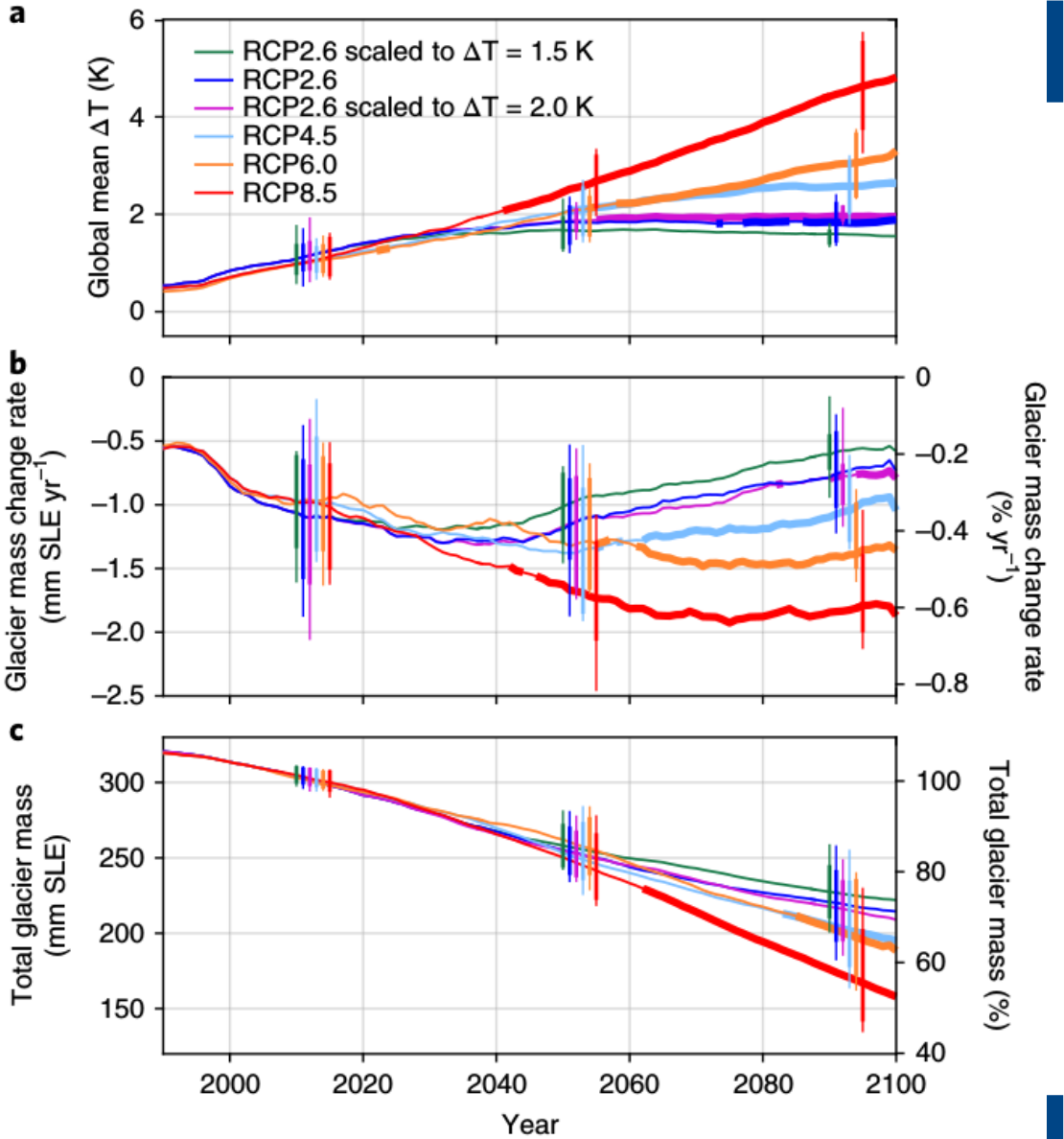




glacier ice

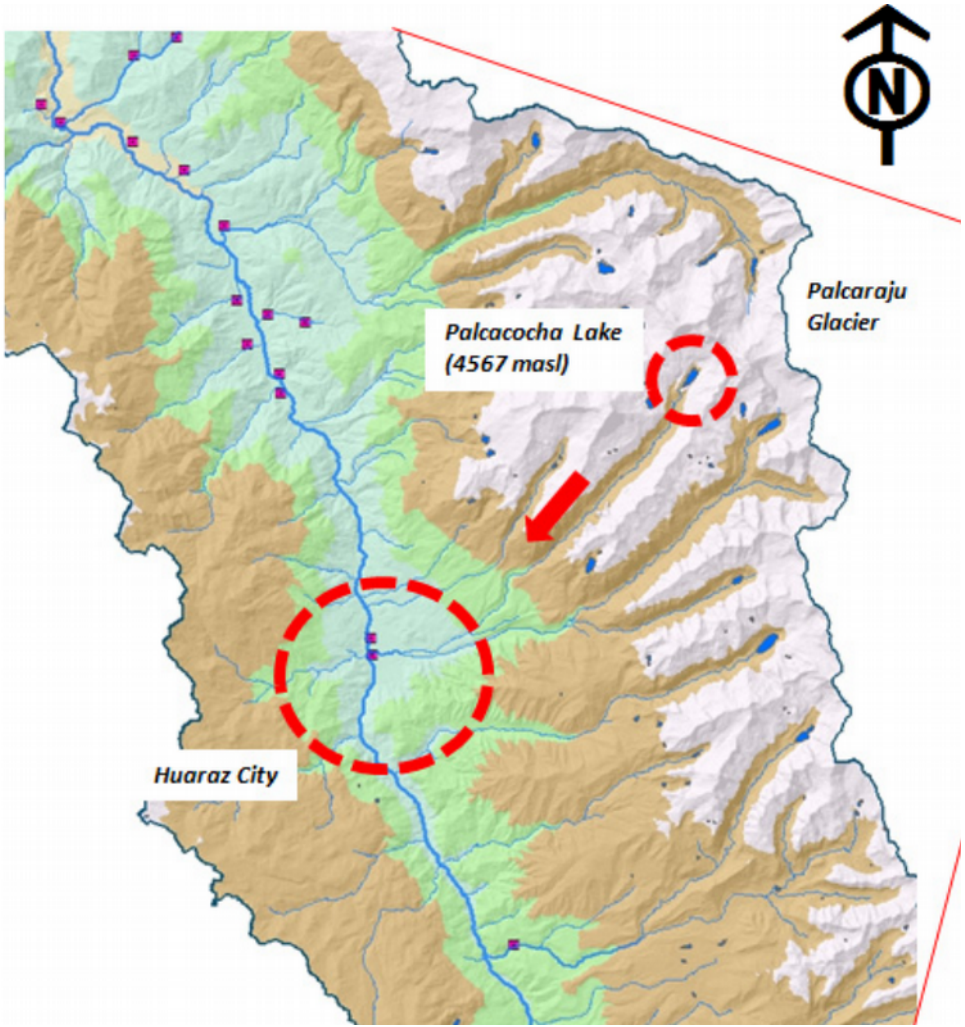


Global glacier equilibrium mass



Marzeion et al (2018), NGEO

Natural hazards: Glacier Lkae Outburst Floods and avalanches



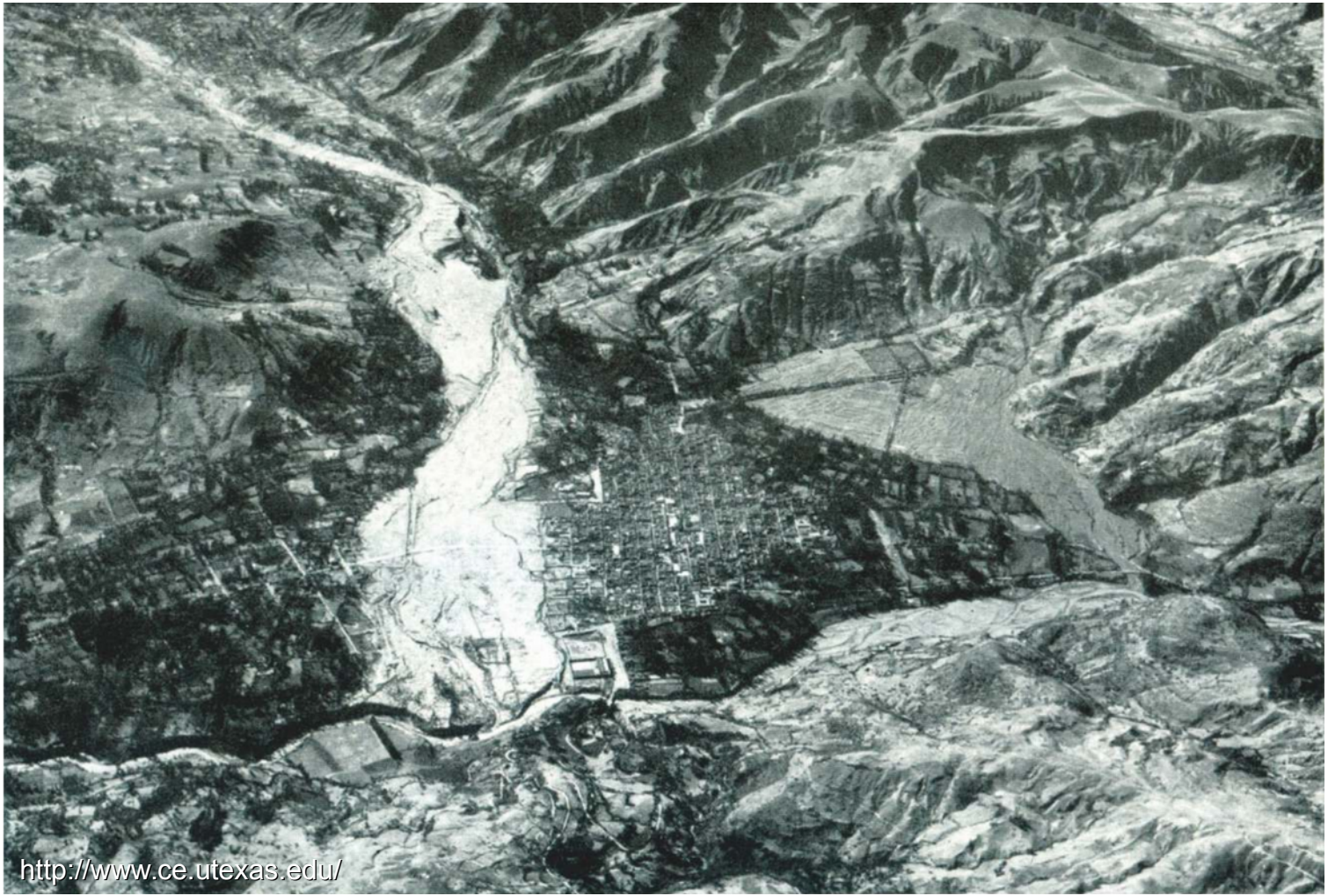
http://www.ce.utexas.edu/prof/maidment/giswr2012/TermPaper/Rivas.pdf

Natural hazards: Glacier Lkae Outburst Floods and avalanches

Huaraz city covered by the 1941 flood after failure of the end moraine causing 5000 casualties

In 2010 a tsunami of 23m was induced by a large glacier calving event destroying 50 homes and a water processing plant

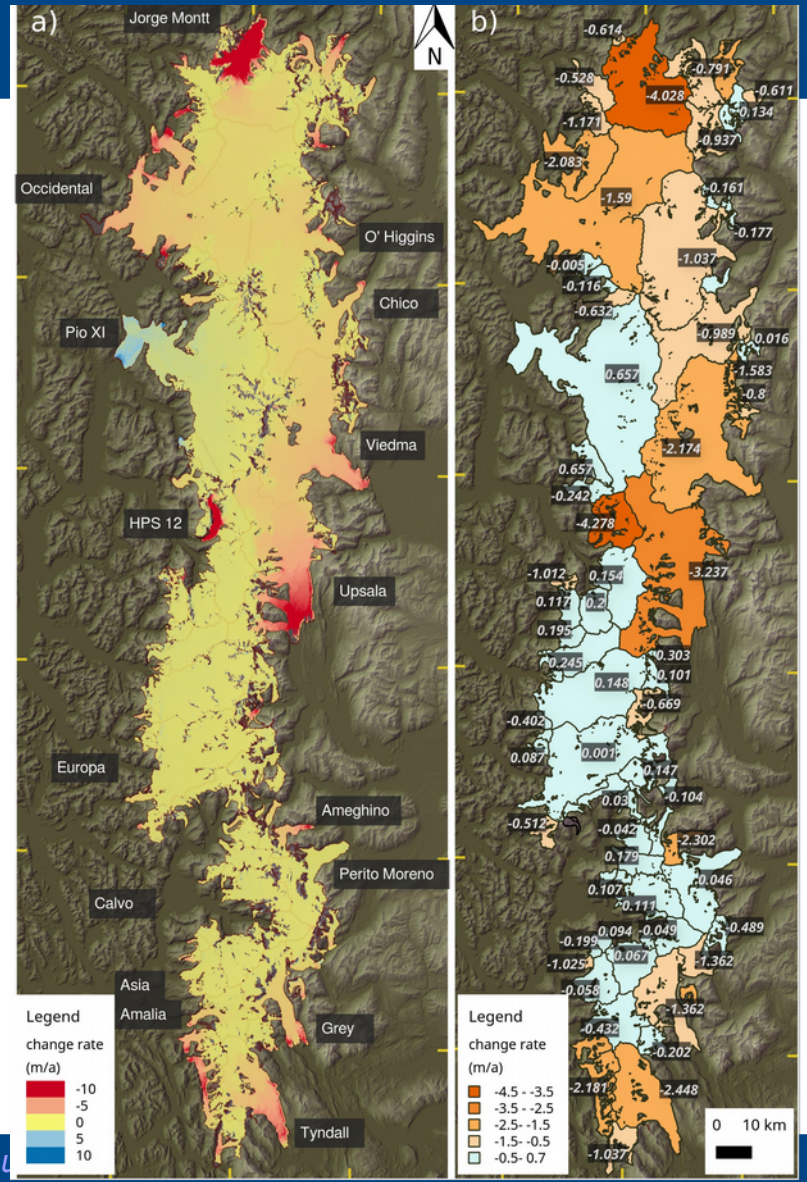
In 1970 the Ancash earthquake induced an ice avalanche whipping out the towns of Yungay and Ranrahirca. A volume of 80 million m³ of water, mud, rocks and snow was estimated.


http://www.ce.utexas.edu/

Conclusion & Outlook

With current satellite mission we have fantastic possibilities to determine various variables (not only ECVs!), however, we need:

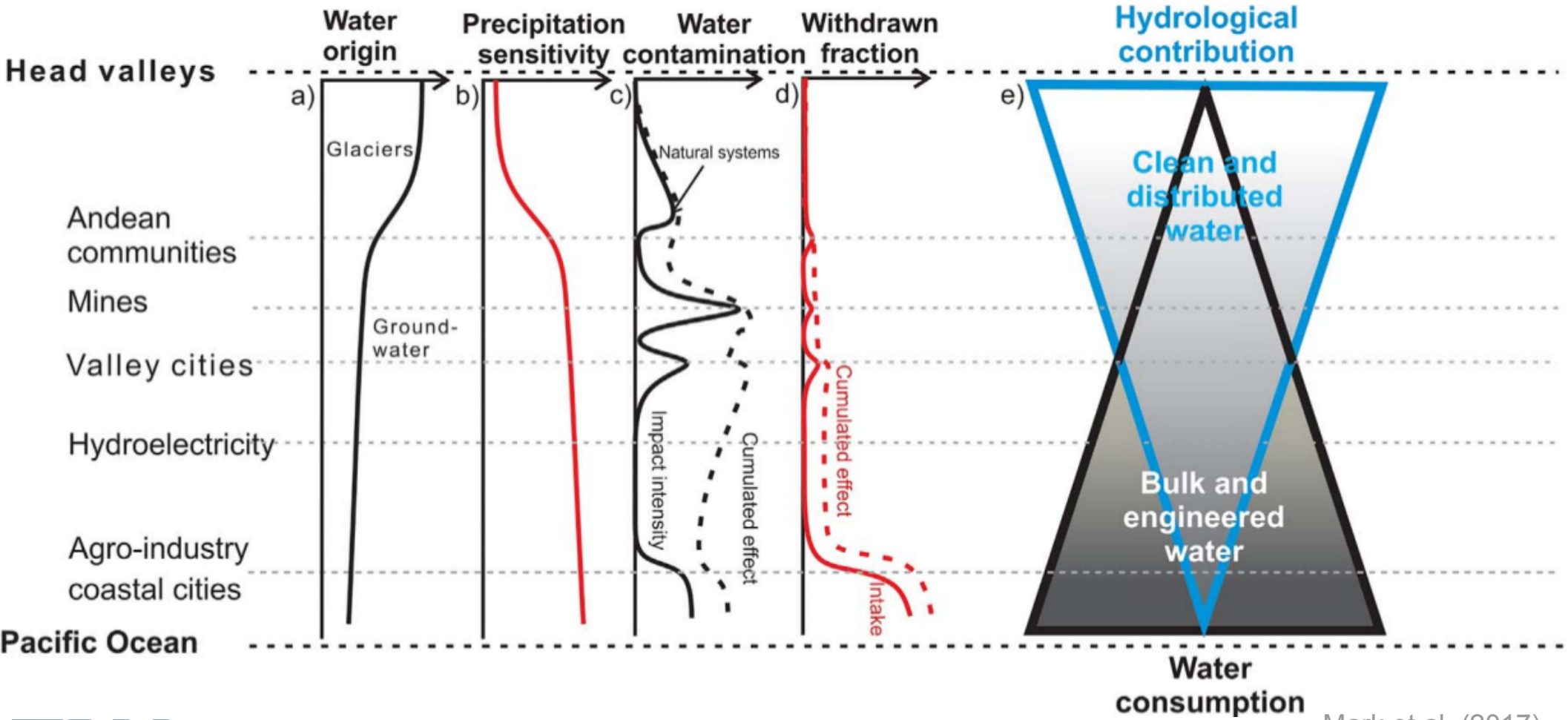
- global, reliable and glacier specific mass change estimates
- regular assessments of glacier status
- multi-mission approaches
- missions that can continue current measurements (Cryosat FO, TanDEM-L, TanDEM-X FO, ASTER FO)
- to be prepared for big data
- a common methodology for error assessment
- links to climatological and hydrological studies
  => hydrological scenarios
- more remote sensing integration into ice dynamic modelling and ice thickness reconstruction
  => ice volume and scenarios
- socio-economic and political links
  => awareness and mitigation
- fast, cost-free and continuous access to archives



SRTM – TanDEM-X elevation & mass changes Southern Patagonian Icefields, 2000-2015/16 (Malz et al. 2018)

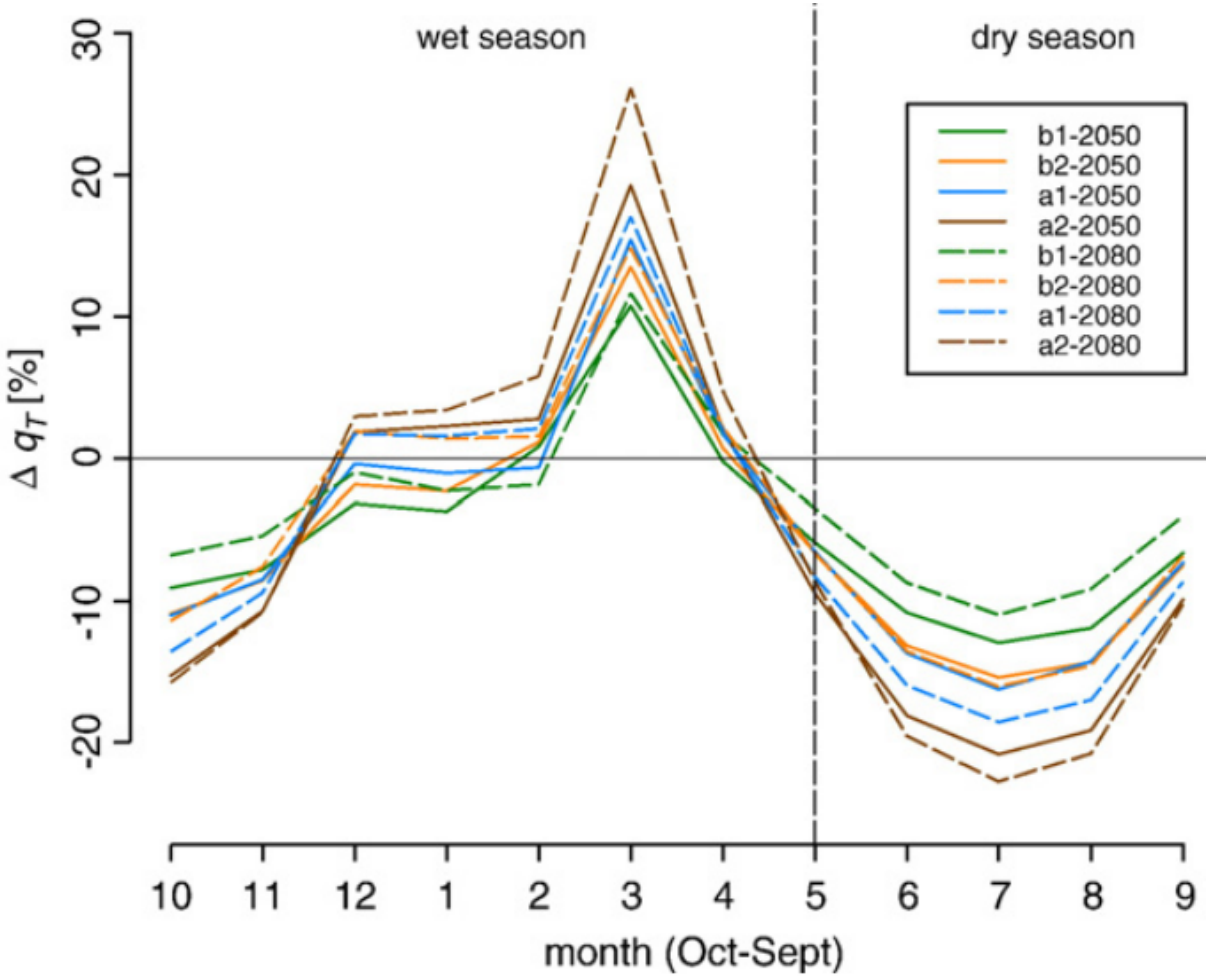

Thanks for attending and listening

Hydrological impacts in the Tropical Andes

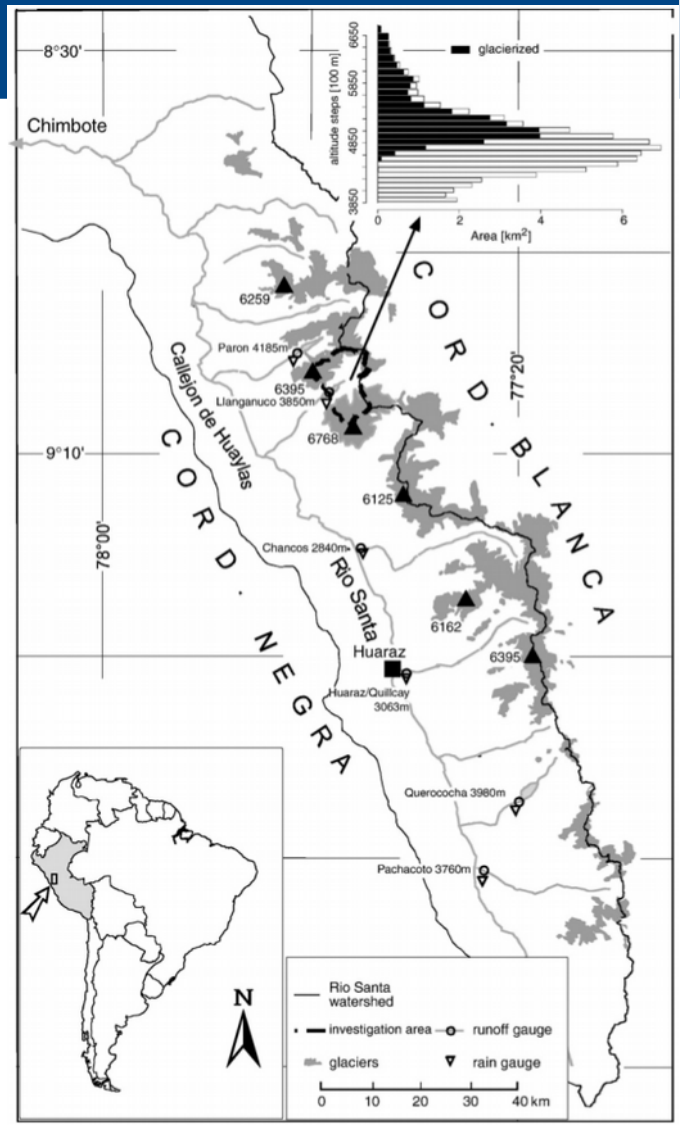


Mark et al. (2017)

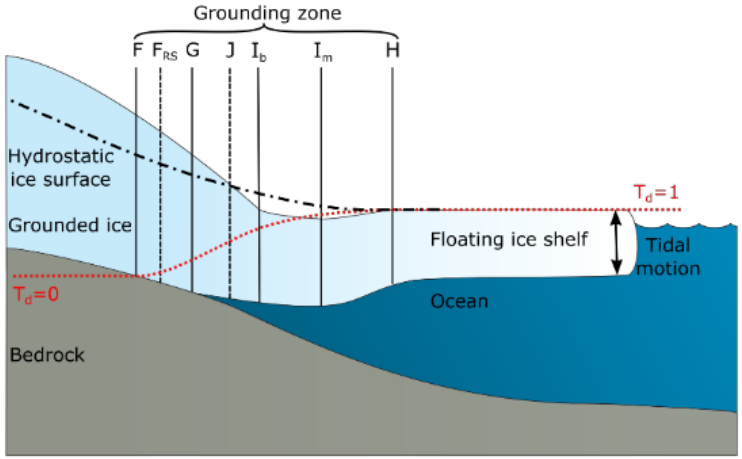
Seasonal runoff change (Santa river, Peru)



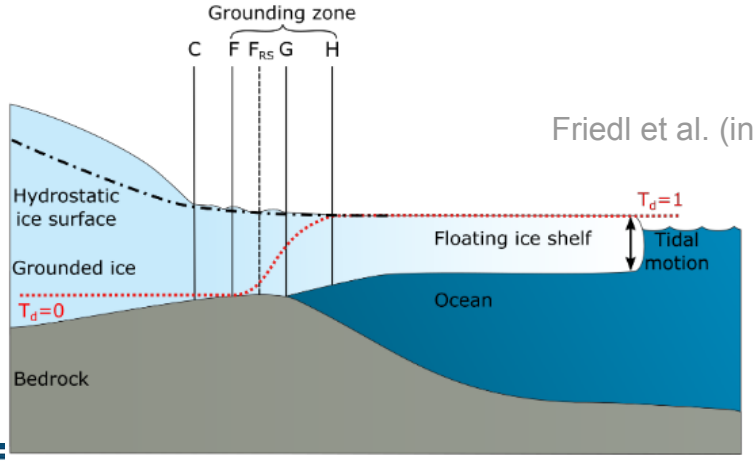
Juen et al. (2007)



Grounding line mapping with remote sensing

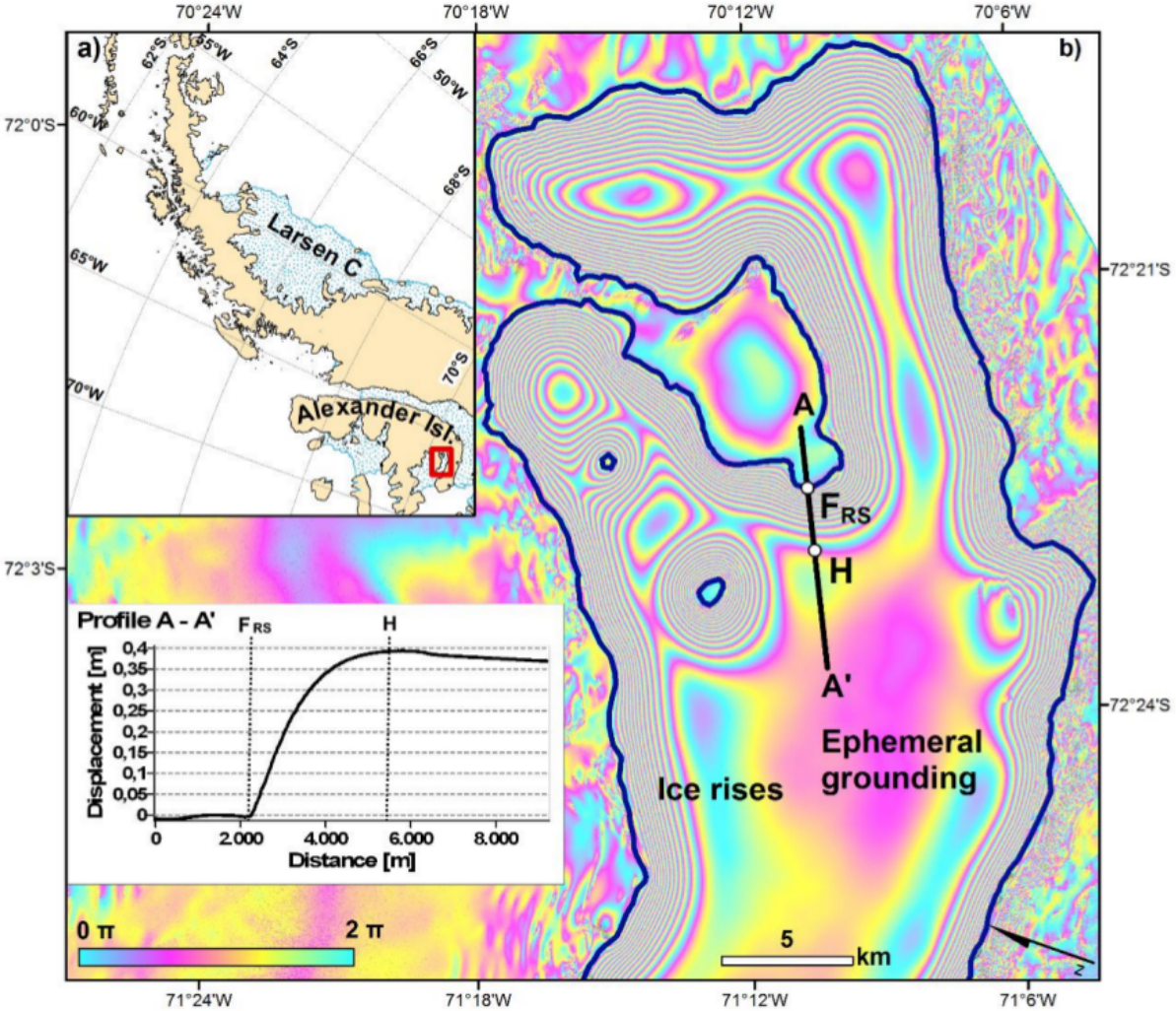


(a)



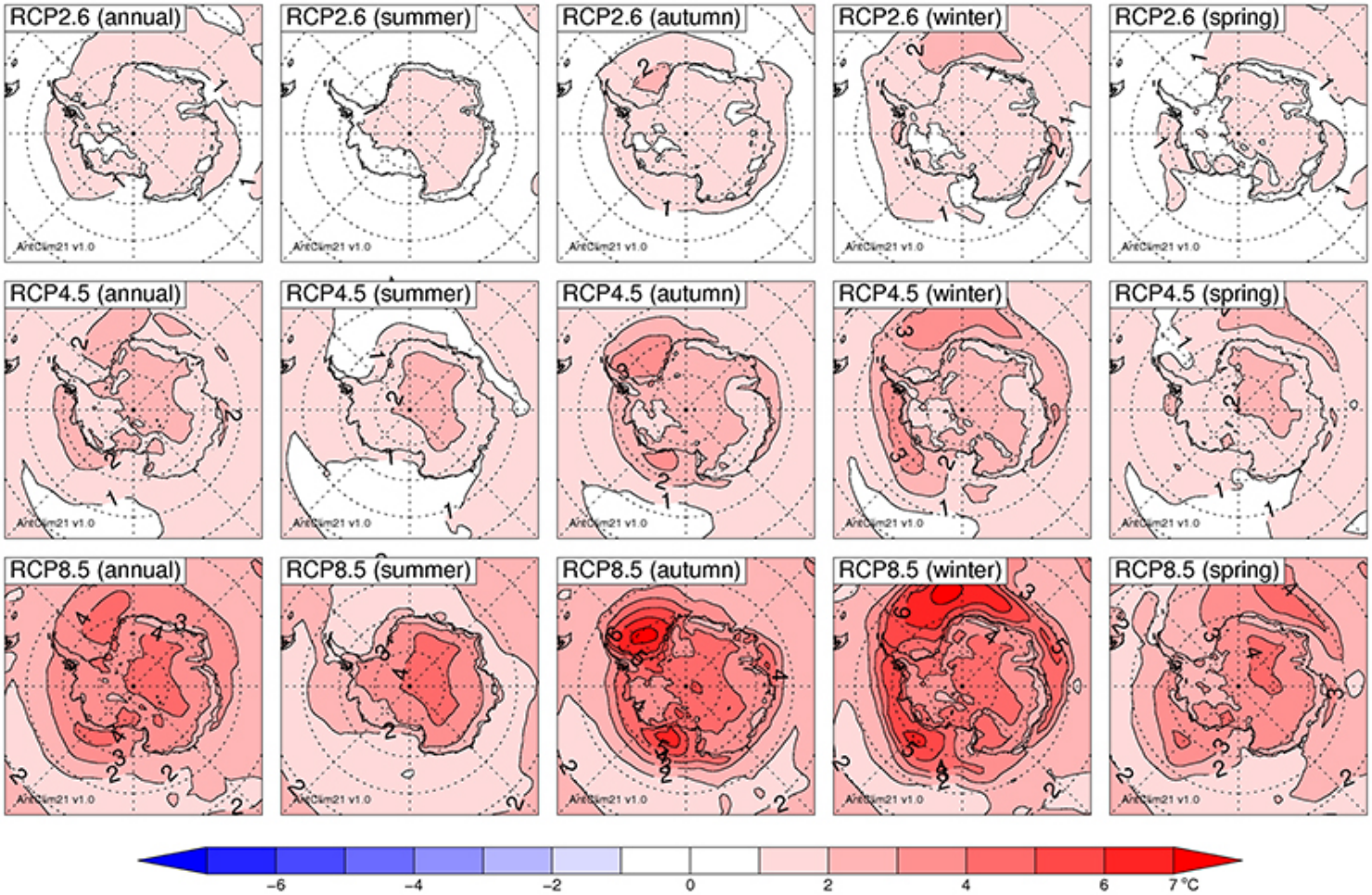
(b)

Friedl et al. (in prep.)



Changes of glaciers & ice caps

CMIP5 predictions under different emission scenarios



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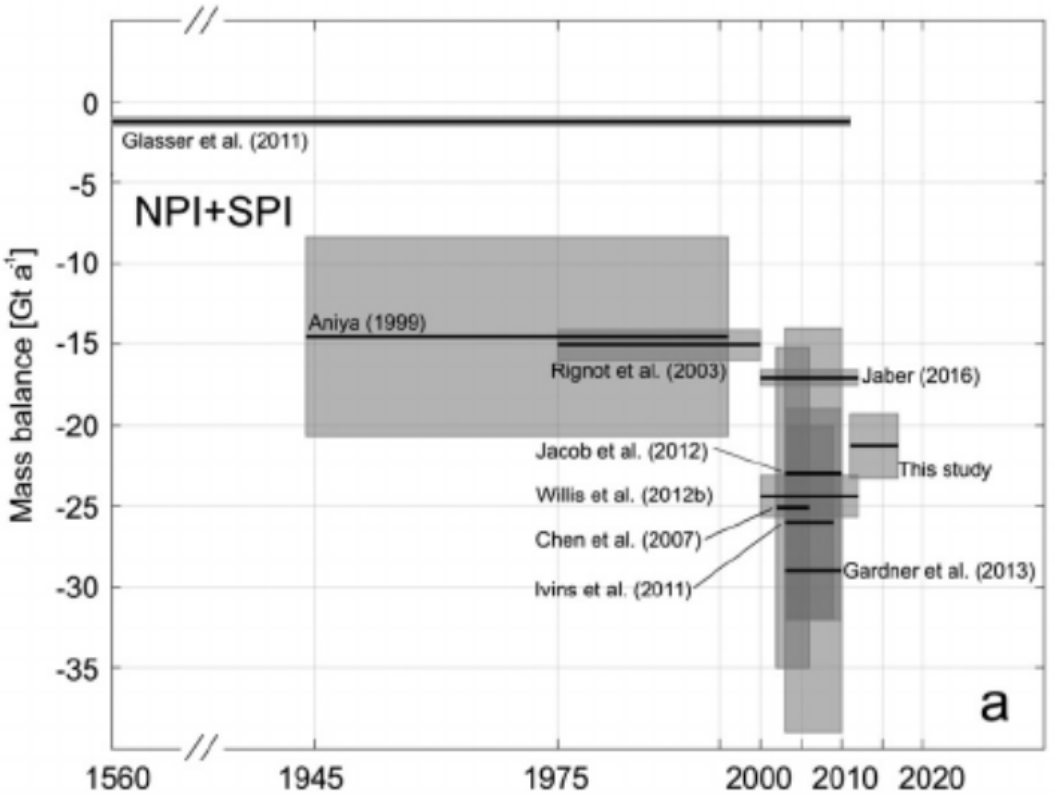
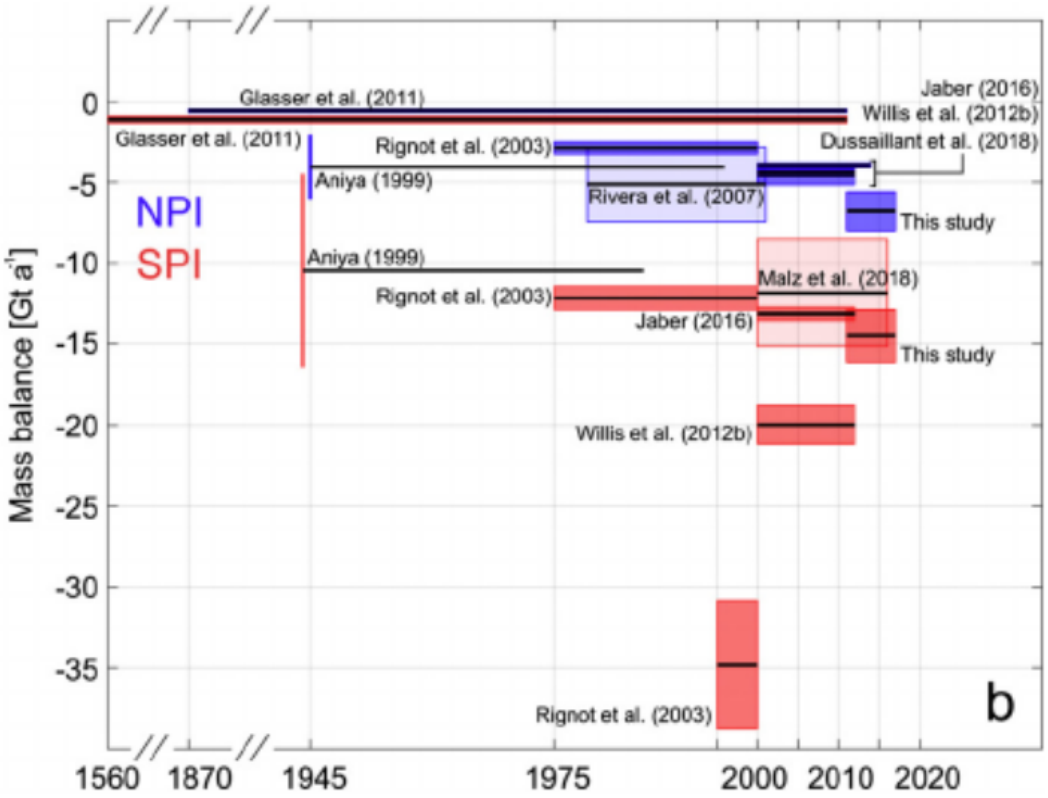
Mass change estimates of the Patagonian ice fields

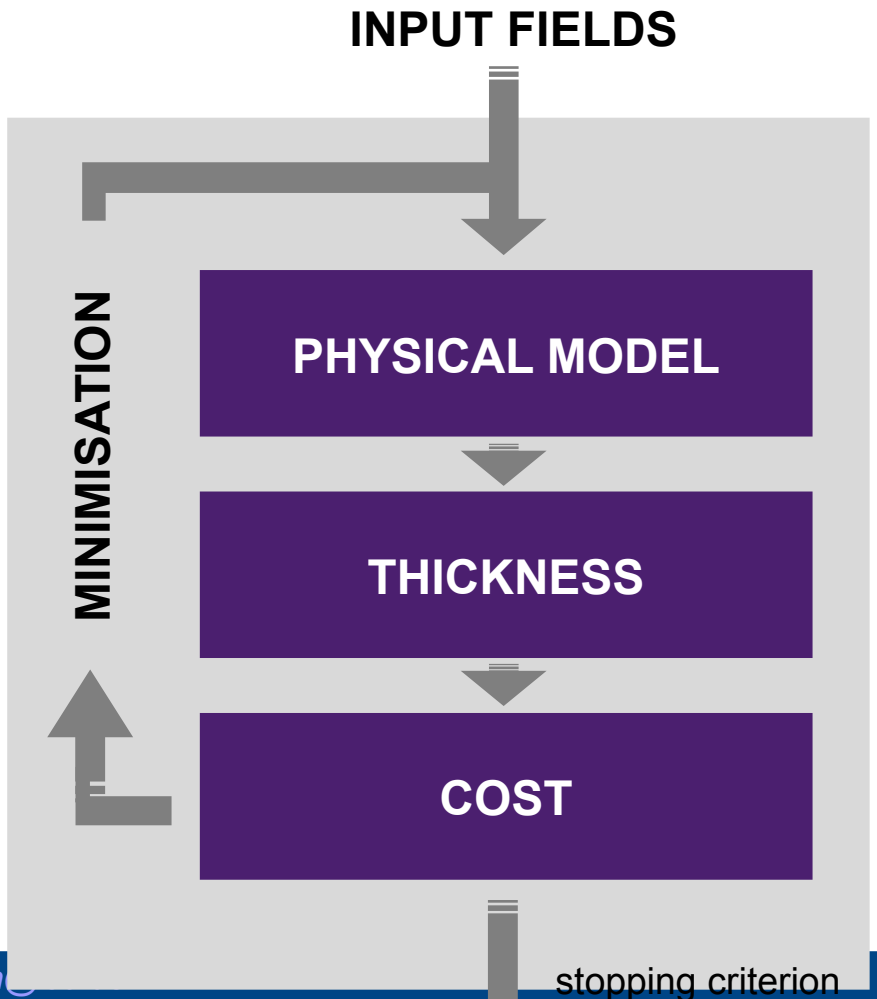




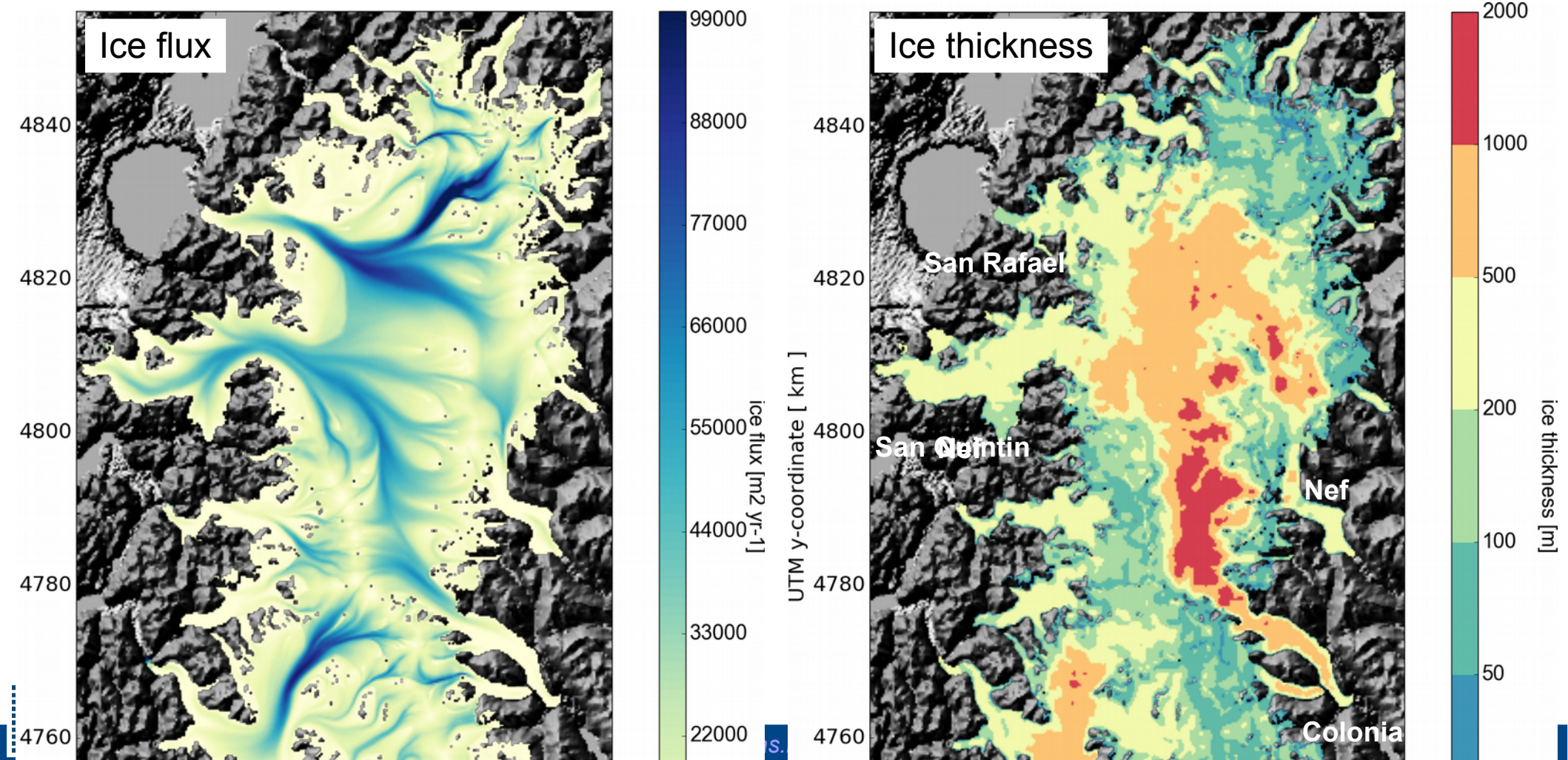
Foresta et al. (2018), RSE

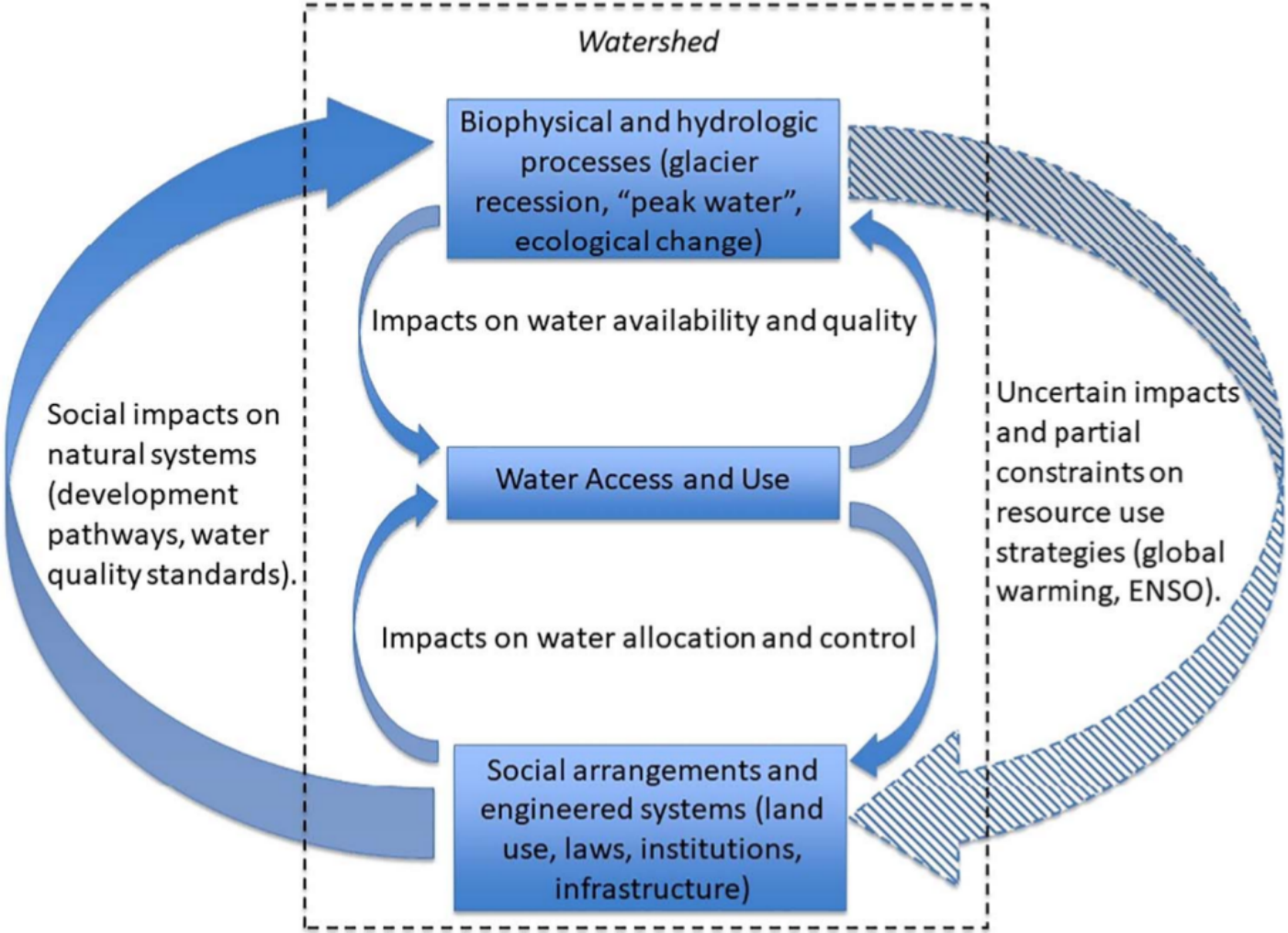
Ice thickness reconstruction

- 2D physically based bedrock map
- Input: DGM, outlines, SMB, dh/dt, measured thickness, surface velocity
- Based on mass conservation & solves for ice flux
- Cost functions for optimization
- Robust under different glacier geometries (ice cap, land- or marine-terminated glaciers, …)
- High degree of automation
- Provides uncertainty estimate
- Embedded in Elmer Ice ice flow model on FAU High Performance Computing Center

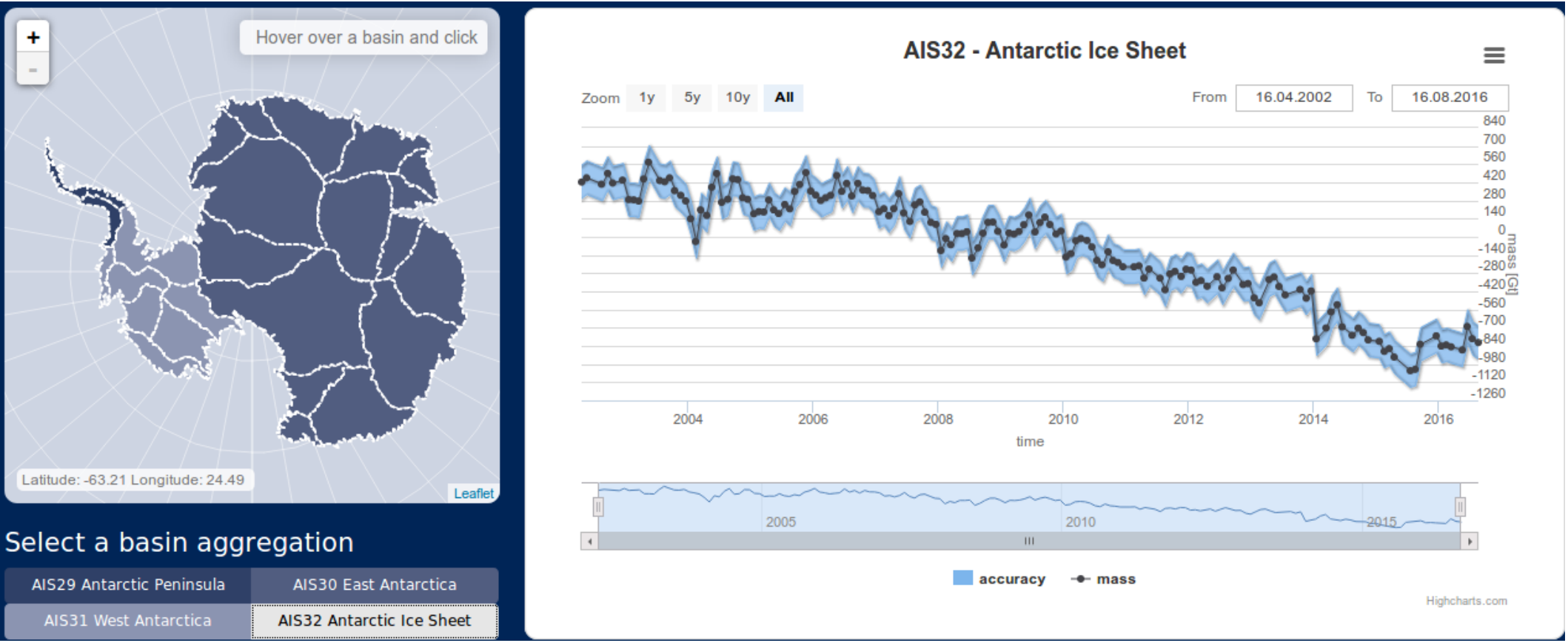


Ice thickness reconstruction – NPI



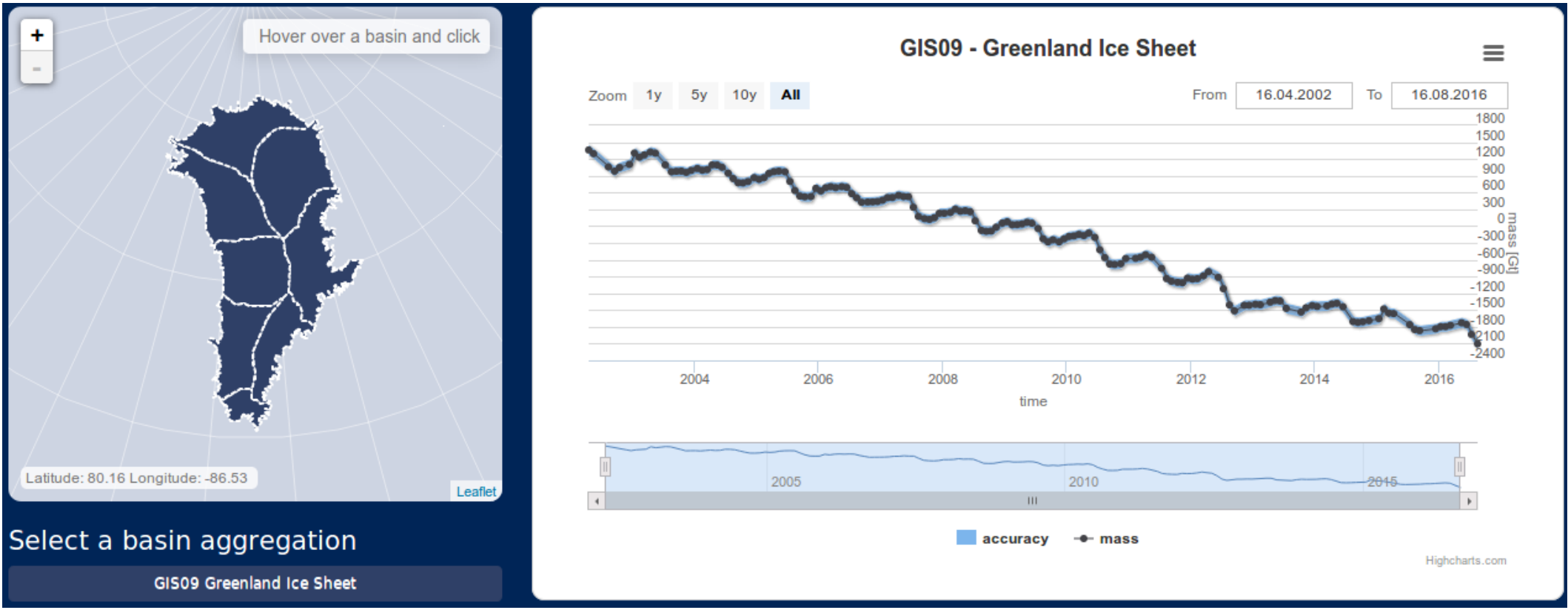

Watershed
Biophysical and hydrologic processes (glacier recession, "peak water", ecological change)
Impacts on water availability and quality
Water Access and Use
Impacts on water allocation and control
Social arrangements and engineered systems (land use, laws, institutions, infrastructure)
Social impacts on natural systems (development pathways, water quality standards).
Uncertain impacts and partial constraints on resource use strategies (global warming, ENSO).

Mass change of the Antarctic ice sheet from GRACE



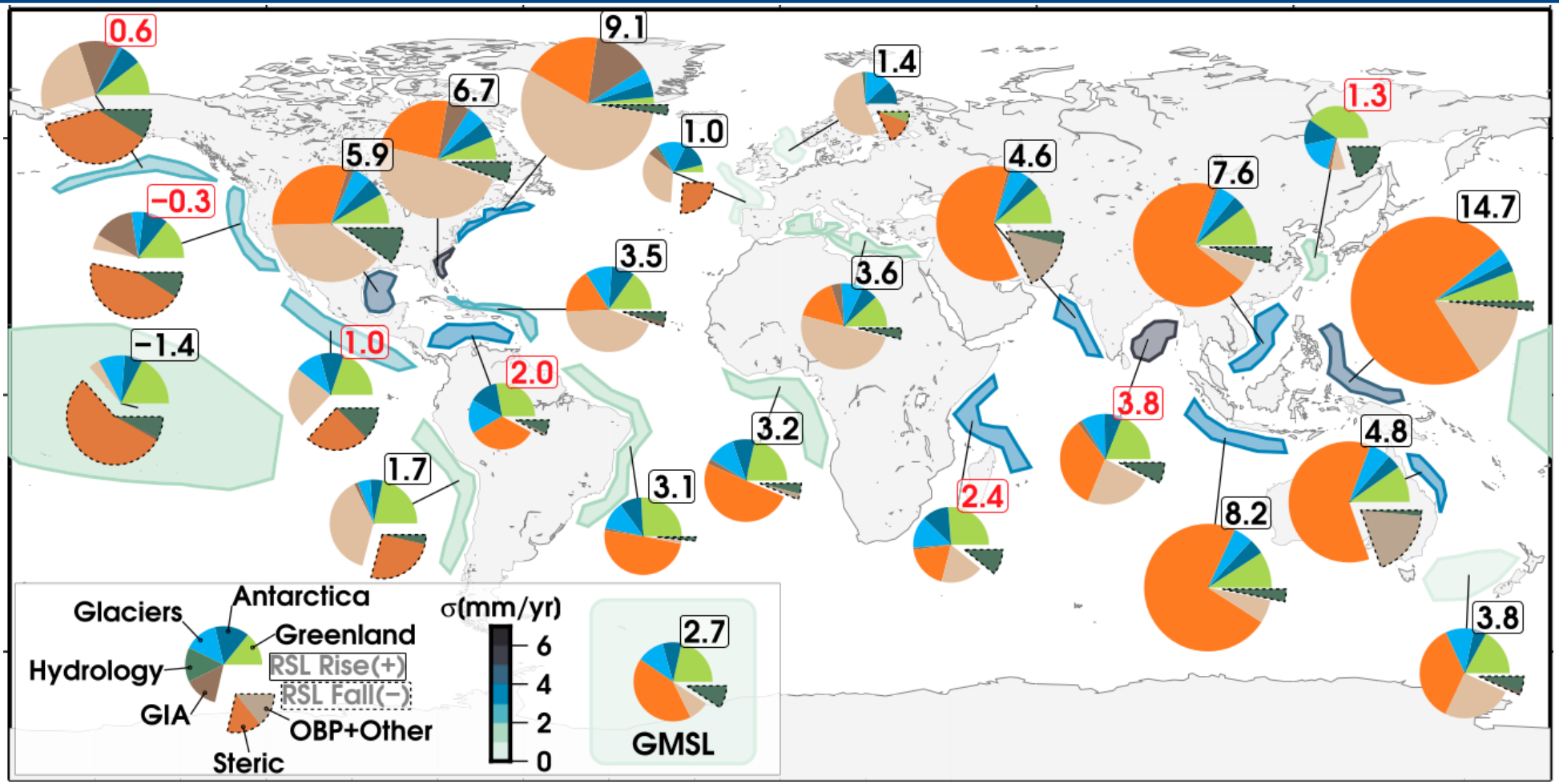
https://data1.geo.tu-dresden.de/ais_gmb/index.html

Mass change of the Greenland ice sheet from GRACE



https://data1.geo.tu-dresden.de/ais_gmb/index.html

Sea level finger prints (2003-2014)



Rietbröck et al. (2016), PNAS