Global Glacier Changes: The state of knowledge after IPCC AR5

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The new WGI IPCC report (AR5)





Headline Statements from the Summary for Policymakers *

Observed Changes in the Climate System

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.





Cryosphere in IPCC AR5: Authors & Results

Observations: Cryosphere

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Glaciers

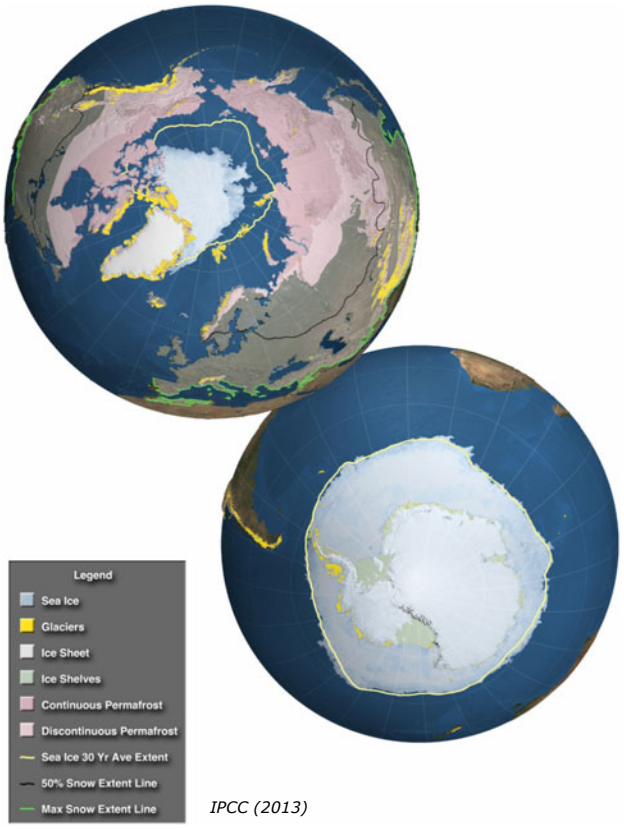
Since AR4, almost all glaciers worldwide have continued to shrink as revealed by the time series of measured changes in glacier length, area, volume and mass (*very high confidence*). Measurements of glacier change have increased substantially in number since AR4. Most of the new data sets, along with a globally complete glacier inventory, have been derived from satellite remote sensing. {4.3.1, 4.3.3, Figures 4.9, 4.10, 4.11}

Between 2003 and 2009, most of the ice lost was from glaciers in Alaska, the Canadian Arctic, the periphery of the Greenland ice sheet, the Southern Andes and the Asian Mountains (*very high confidence*). Together these regions account for more than 80% of the total ice loss. {4.3.3, Figure 4.11, Table 4.4}

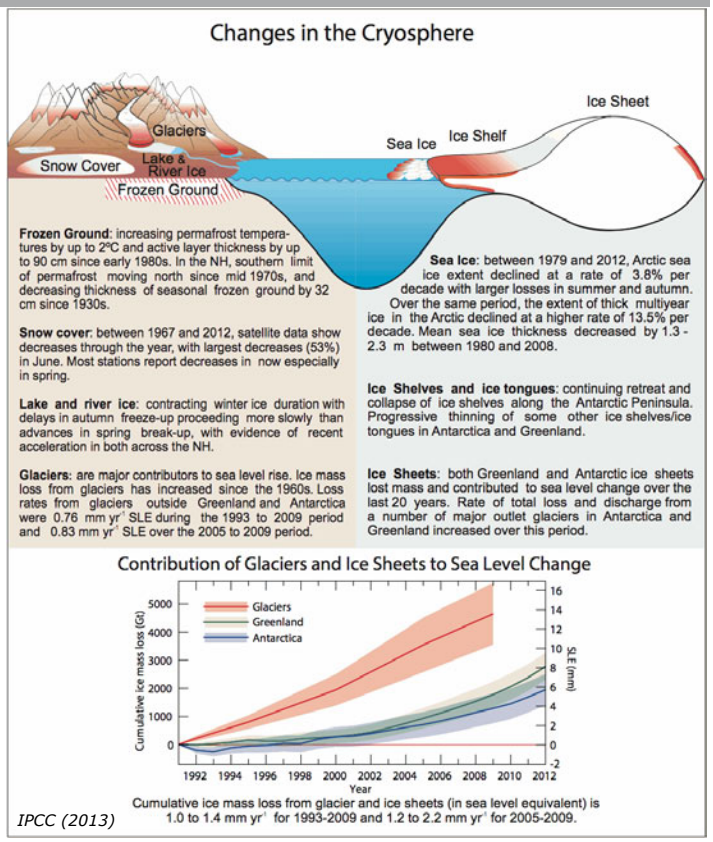
Total mass loss from all glaciers in the world, excluding those on the periphery of the ice sheets, was *very likely* 226 ± 135 Gt yr^{-1} (sea level equivalent, 0.62 ± 0.37 mm yr^{-1}) in the period 1971–2009, 275 ± 135 Gt yr^{-1} (0.76 ± 0.37 mm yr^{-1}) in the period 1993–2009, and 301 ± 135 Gt yr^{-1} (0.83 ± 0.37 mm yr^{-1}) between 2005 and 2009. {4.3.3, Figure 4.12, Table 4.5}

Current glacier extents are out of balance with current climatic conditions, indicating that glaciers will continue to shrink in the future even without further temperature increase (*high confidence*). {4.3.3}

IPCC AR5: The global cryosphere



IPCC (2013)



IPCC (2013)

Each glacier is individual



Different methods are used to determine changes

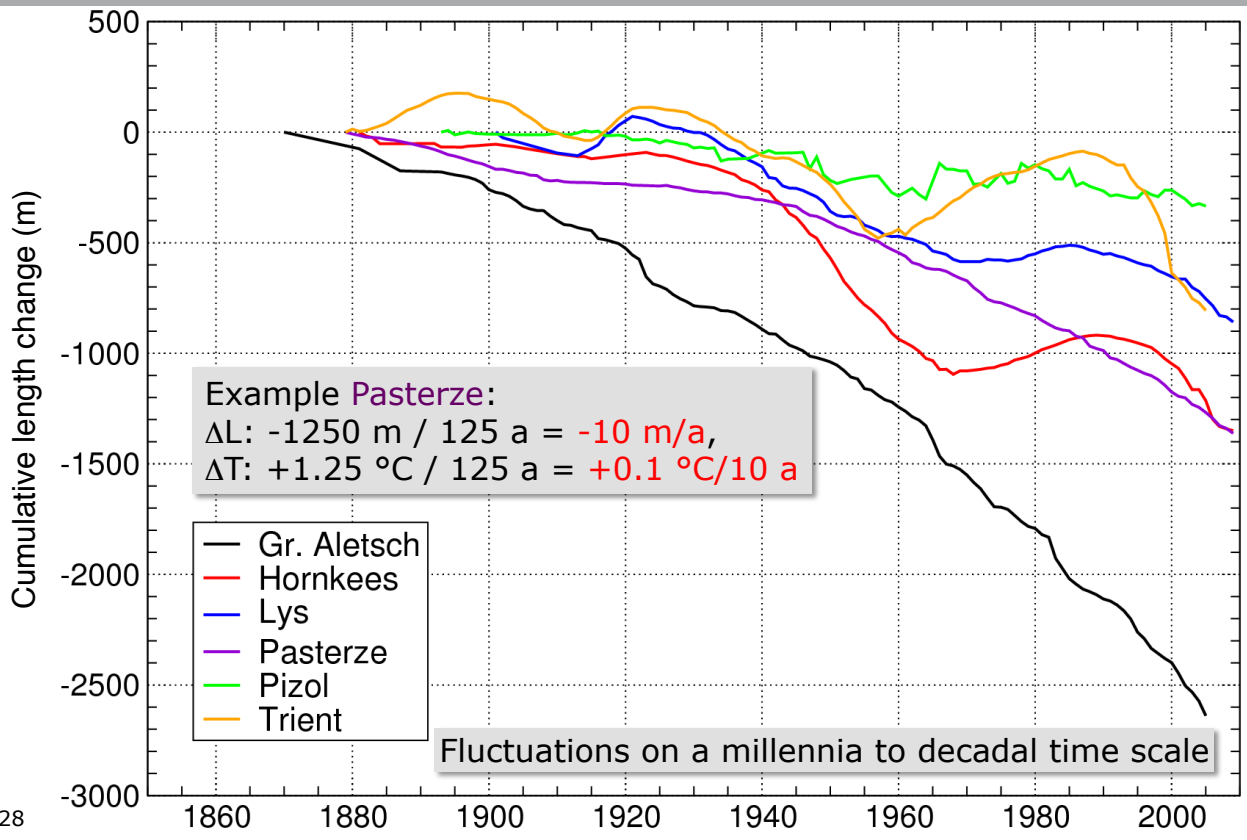
Parameter	Method	Technique	Typical accuracy	Number of Glaciers	Repeat Interval	Earliest Data
Length change	Various	Reconstruction	10 m	Dozens	Decadal – centuries	Holocene
	Field	*In situ* measurement	1 m	Hundreds	Annual	19th century
	Remote Sensing	Photogrammetric survey	Two image pixels (depending on resolution)	Hundreds	Aannual	20th century
Area change	Maps	Cartographic	5% of the area	Hundreds	Decadal	19th century
	Remote sensing	Image processing	5% of the area	Thousands	Sub-decadal	20th century
Volume change	Remote sensing	Laser and radar profiling	0.1 m	Hundreds	Annual	21st century
	Remote sensing	DEM differencing	0.5 m	Thousands	Decadal	20th century
Mass change	Field	Direct mass balance measurement	0.2 m	>450 annually	Seasonal	20th century
	Remote sensing	Gravimetry (GRACE)	dependent on the region	Global	Seasonal	21st century

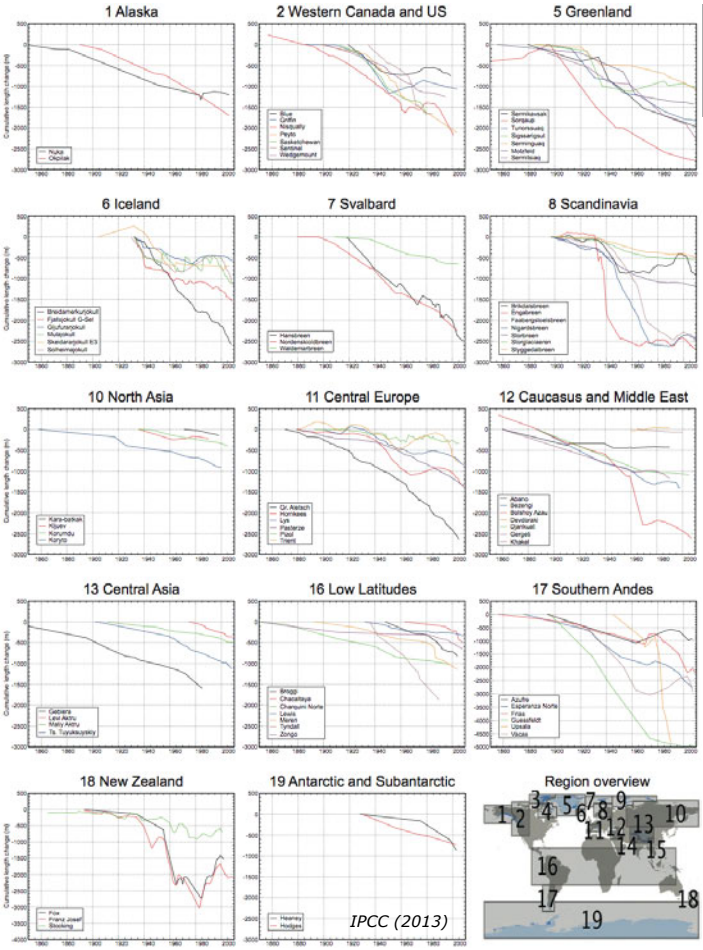
IPCC (2013)

Key research questions for AR5

- **Compilation of a globally complete glacier inventory**
  - **glacier area and volume, spatial extrapolation, future development**
- **Overall contribution to global slr (in-situ, dDEMs, altimetry)?**
- **Separating the local glaciers on Greenland from the ice sheet**
- **What is going on in High-Mountain Asia?**

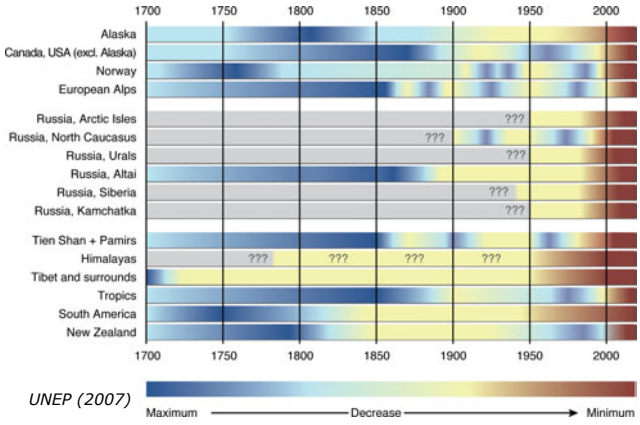
Cumulative length changes (Alps)





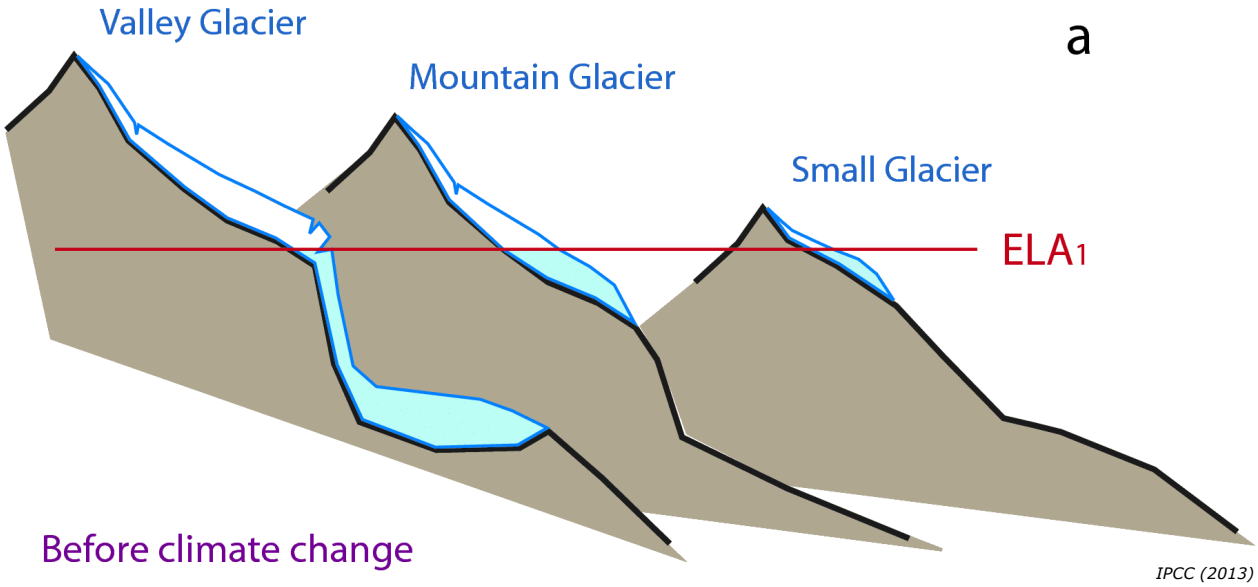
Global length changes

- Largely globally homogenous retreat at the millennia time scale (km range)
- Intermittent phases of re-advance in several regions at decadal time scale
- Some glaciers exhibit special conditions (calving, surging, debris)
- Quantitative values not to be averaged only possible for general trends
- Signal comes from mountain glaciers



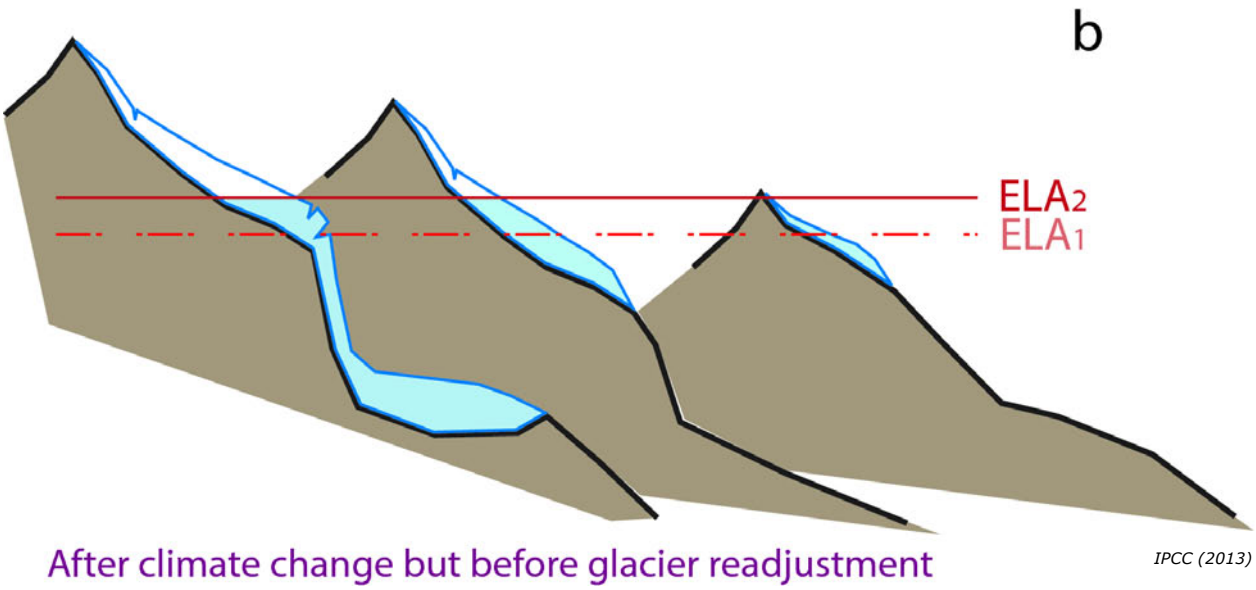
UNEP (2007)

How do glacier react to climate change?



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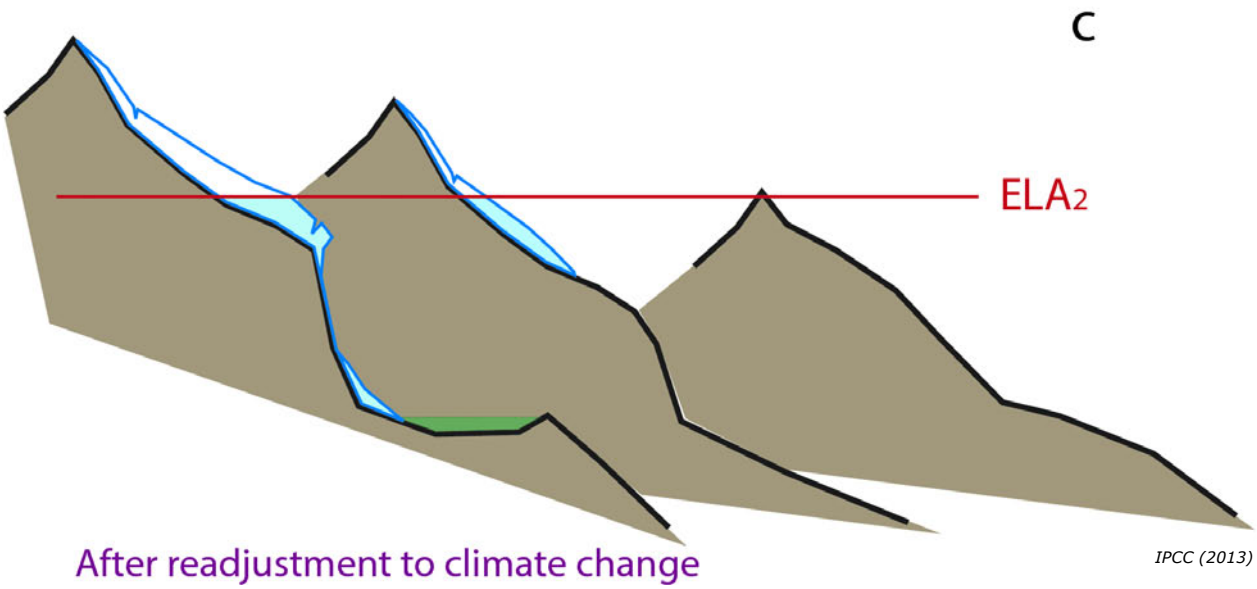
How do glacier react to climate change?



After climate change but before glacier readjustment

IPCC (2013)

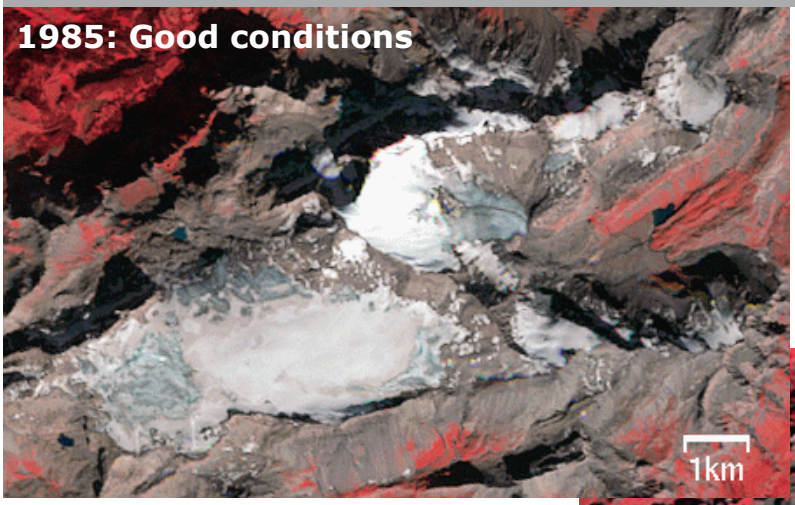
How do glacier react to climate change?

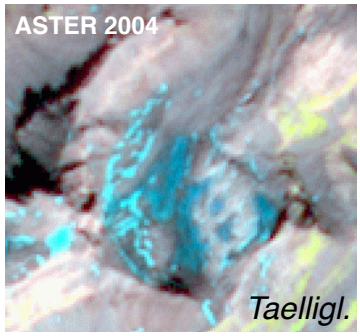


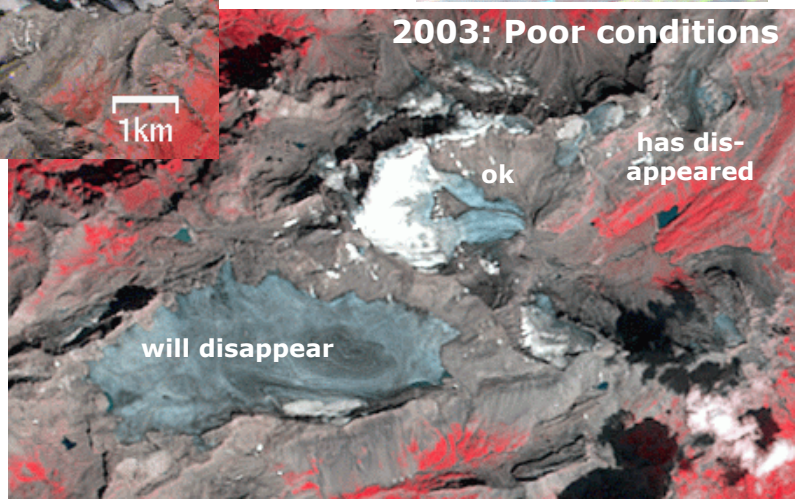
After readjustment to climate change

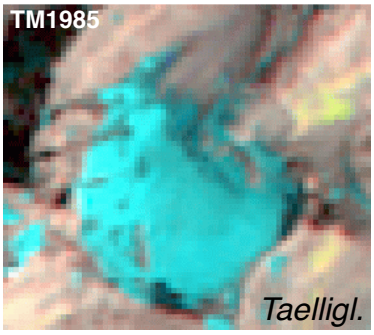
IPCC (2013)

How does this look like in reality?





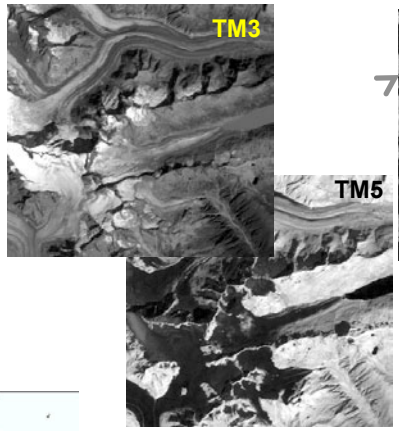


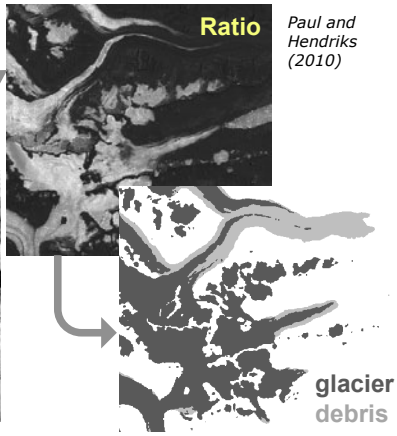


13/28

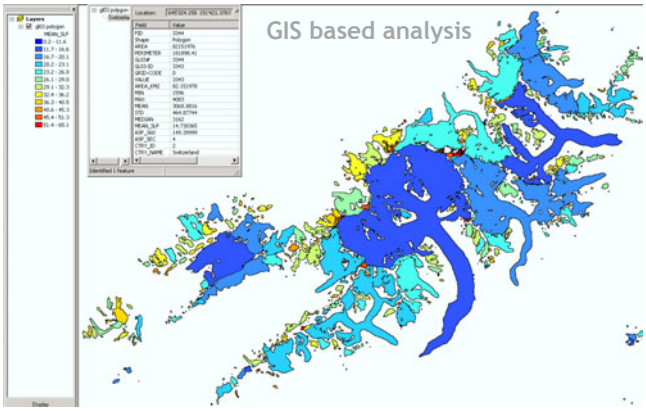
Creating a glacier inventory

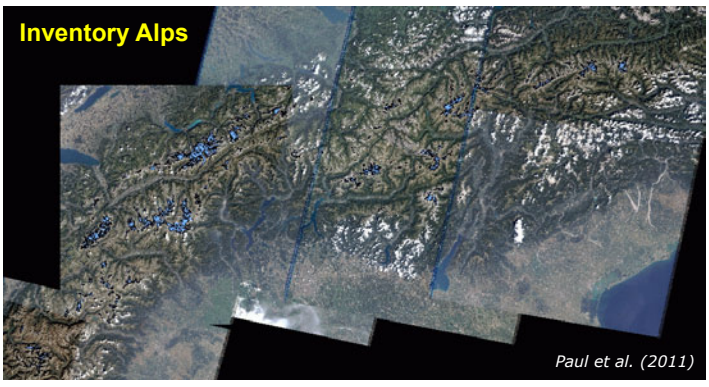






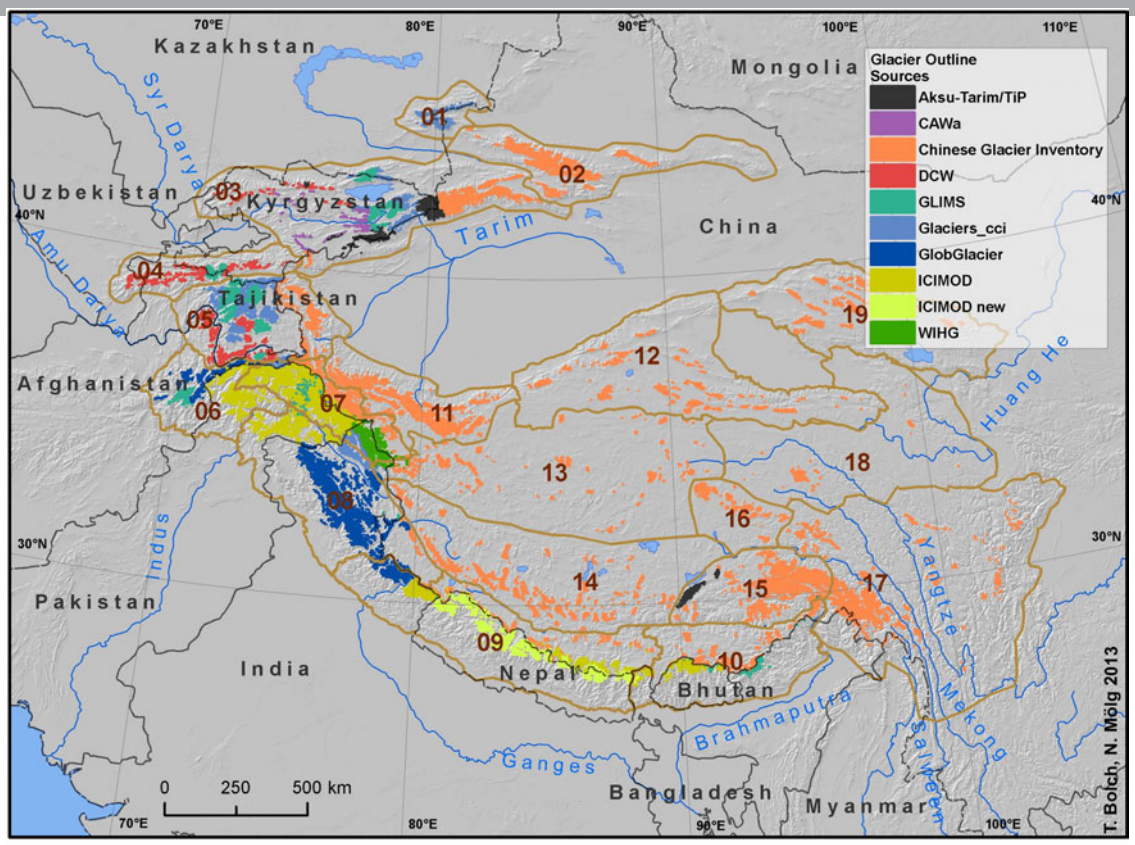
Paul and Hendriks (2010)





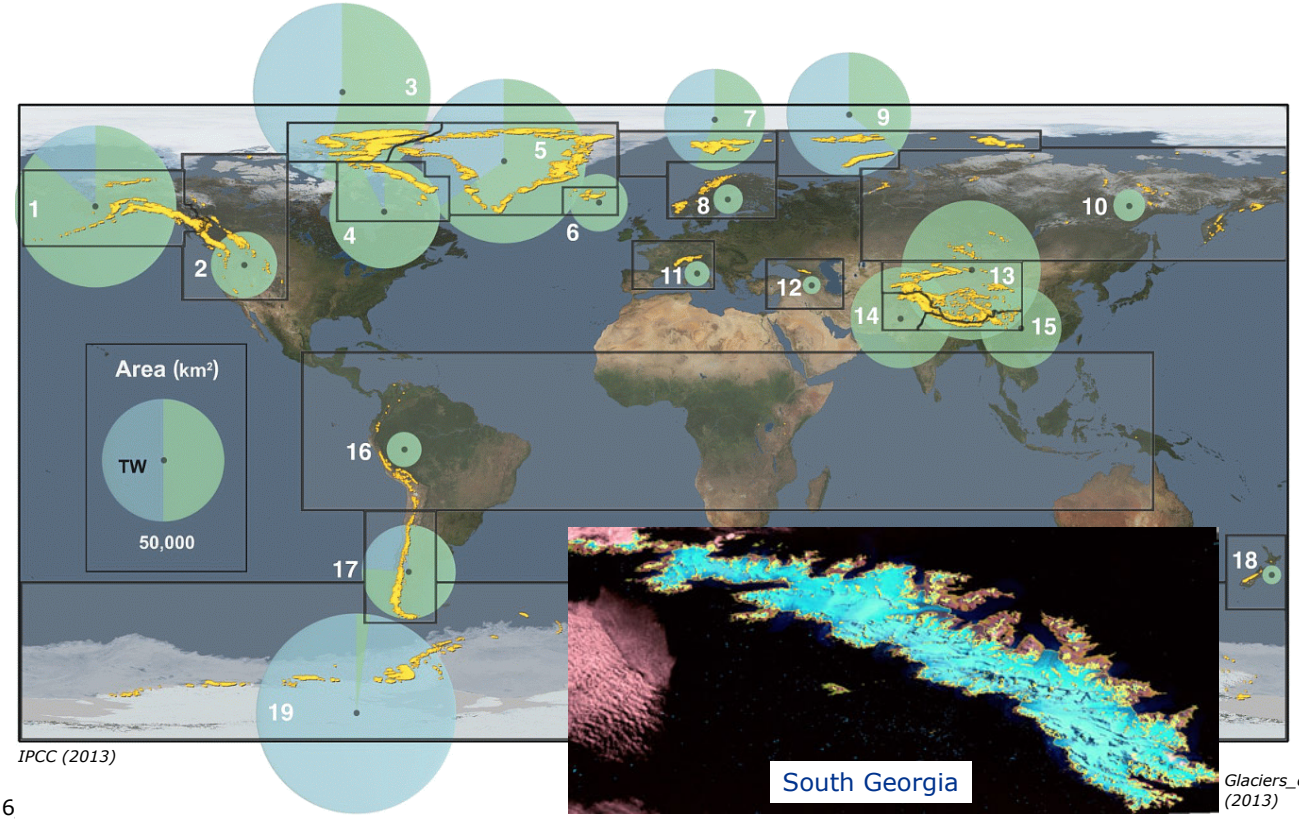
14/28

The RGI is a merged product: Example HMA



Glaciers_cci (2013)

The Randolph Glacier Inventory (RGI)



IPCC (2013)

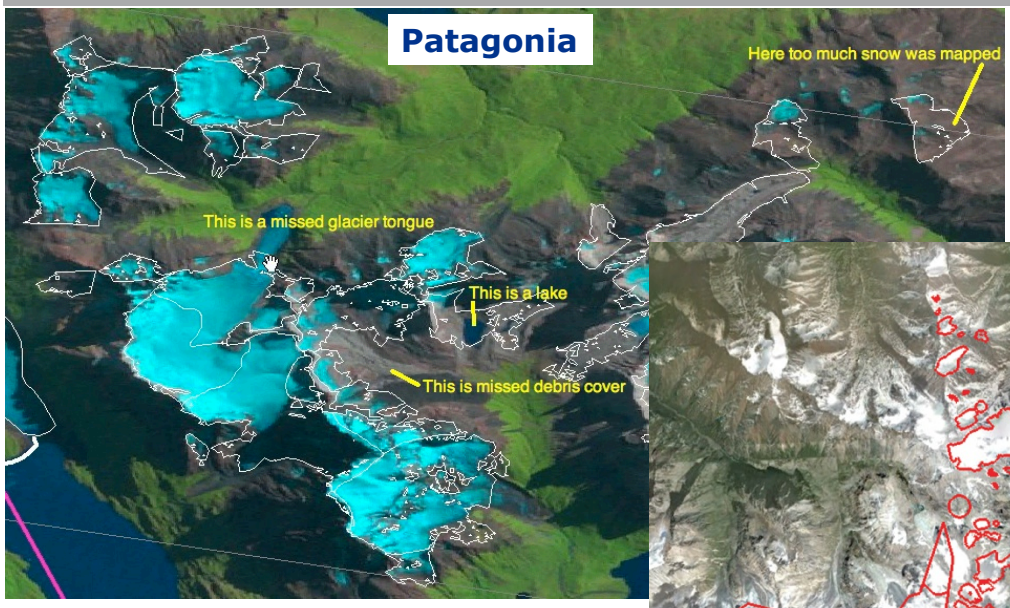
Glaciers_cci (2013)

The Randolph Glacier Inventory (RGI)

Region	Region Name	Number of Glaciers	Area (km²)	Percent of total area	Tidewater fraction (%)	Mass (minimum) (Gt)	Mass (maximum) (Gt)	Mean SLE (mm)
1	Alaska	23,112	89,267	12.3	13.7	16,168	28,021	54.7
2	Western Canada and USA	15,073	14,503.5	2.0	0	906	1148	2.8
3	Arctic Canada North	3318	103,990.2	14.3	46.5	22,366	37,555	84.2
4	Arctic Canada South	7342	40,600.7	5.6	7.3	5510	8845	19.4
5	Greenland	13,880	87,125.9	12.0	34.9	10,005	17,146	38.9
6	Iceland	290	10,988.6	1.5	0	2390	4640	9.8
7	Svalbard	1615	33.672.9	4.6	43.8	4821	8700	19.1
8	Scandinavia						290	0.6
9	Russian Arctic						21,315	41.2
10	North Asia[a]						247	0.5
11	Central Europe						125	0.3
12	Caucasus	1339	1125.6	0.2	0	61	72	0.2
13	Central Asia	30,200	64,497	8.9	0	4531	8591	16.7
14	South Asia (West)	22,822	33,862	4.7	0	2900	3444	9.1
15	South Asia (East)	14,006	21,803.2	3.0	0	1196	1623	3.9
16	Low Latitudes[a]	2601	2554.7	0.6	0	109	218	0.5
17	Southern Andes[a]	15,994	29,361.2	4.5	23.8	4241	6018	13.5
18	New Zealand	3012	1160.5	0.2	0	71	109	0.2
19	Antarctic and Sub-Antarctic	3274	13,2267.4	18.2	97.8	27,224	43,772	96.3
IPCC (2013)	Total	168,331	726,258.3		38.5	113,915	191,879	412.0

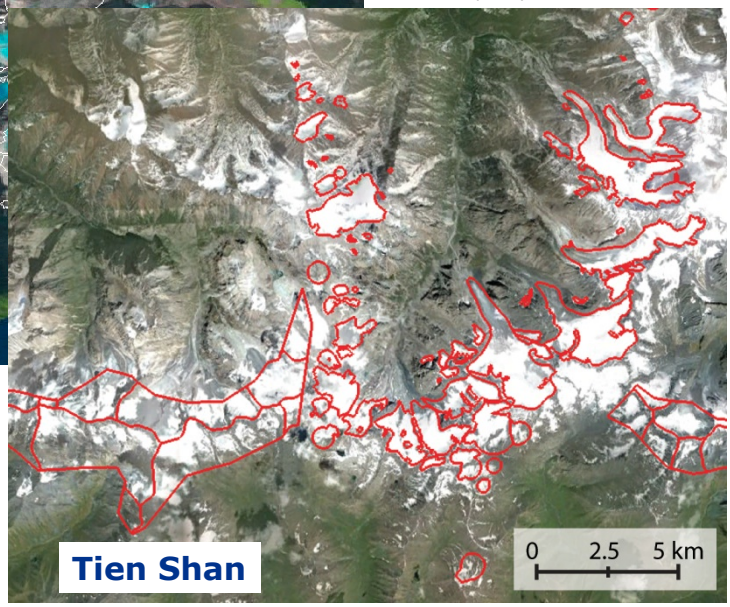
- **170,000 glaciers worldwide covering 730,000 km²**
- **Volume of about 170,000 km³ or 41 cm SLE**
- **Numbers will change through RGI updates**

Quality issues in some regions need to be solved



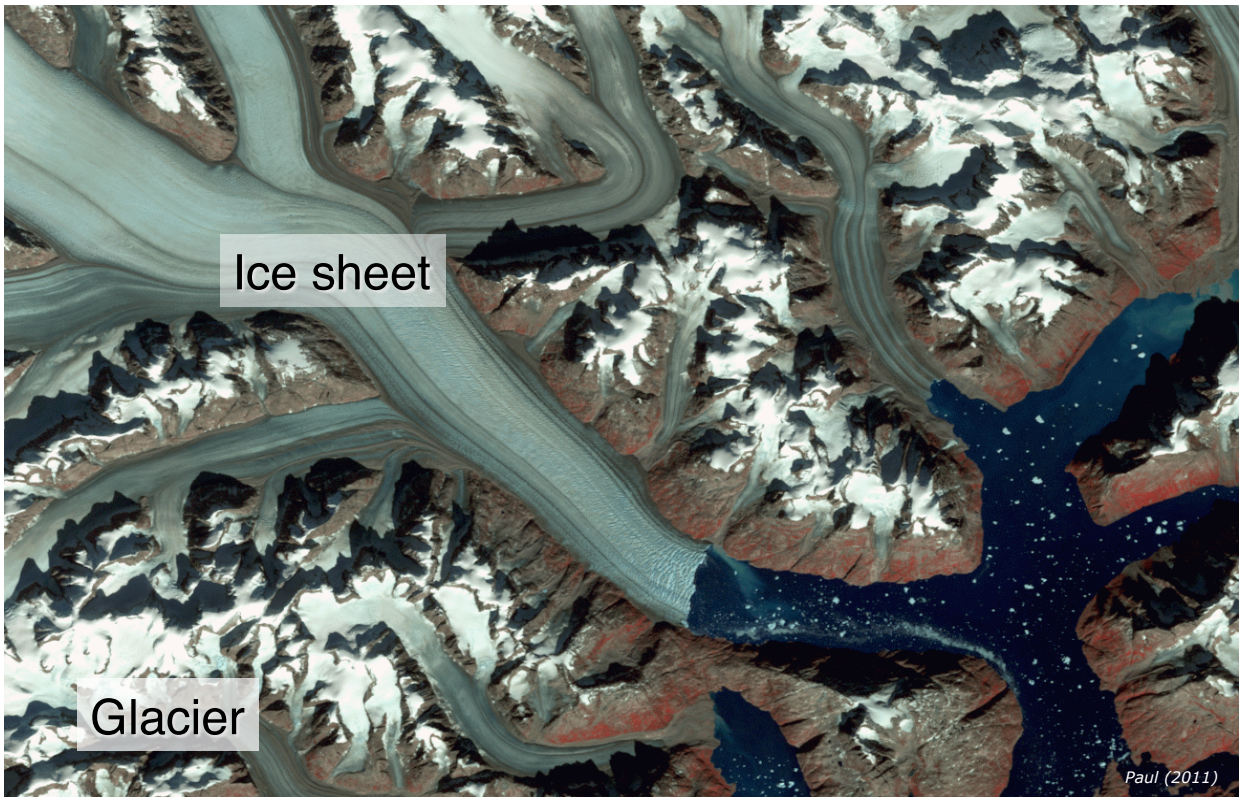
> reworked for RGI 3.0

Glaciers_cci (2013)



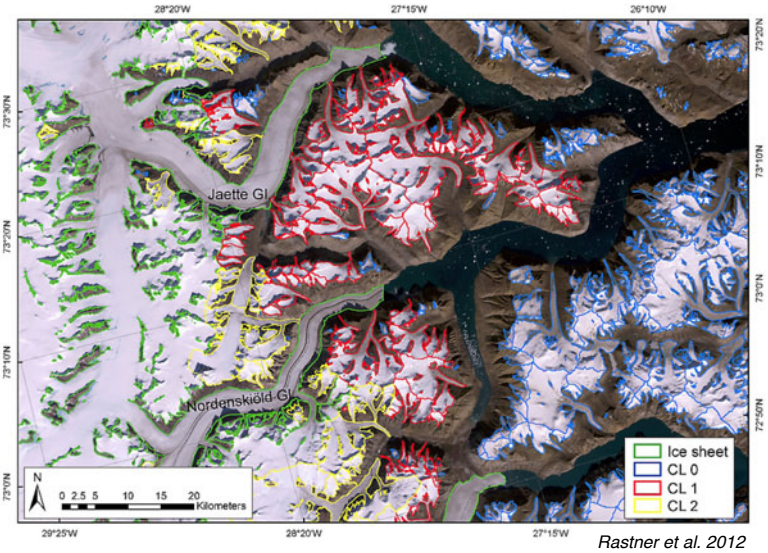
addressed in CCI <

Where is the boundary of the Greenland ice sheet?

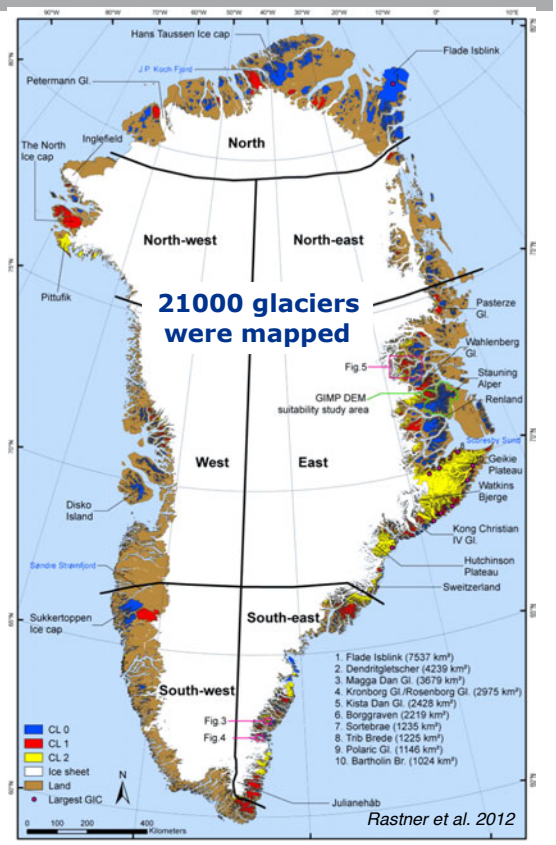


Greenland: separating the GIC from the GRIS

Three connectivity levels were assigned:
CL0: no connection, CL1: weak, CL2: strong



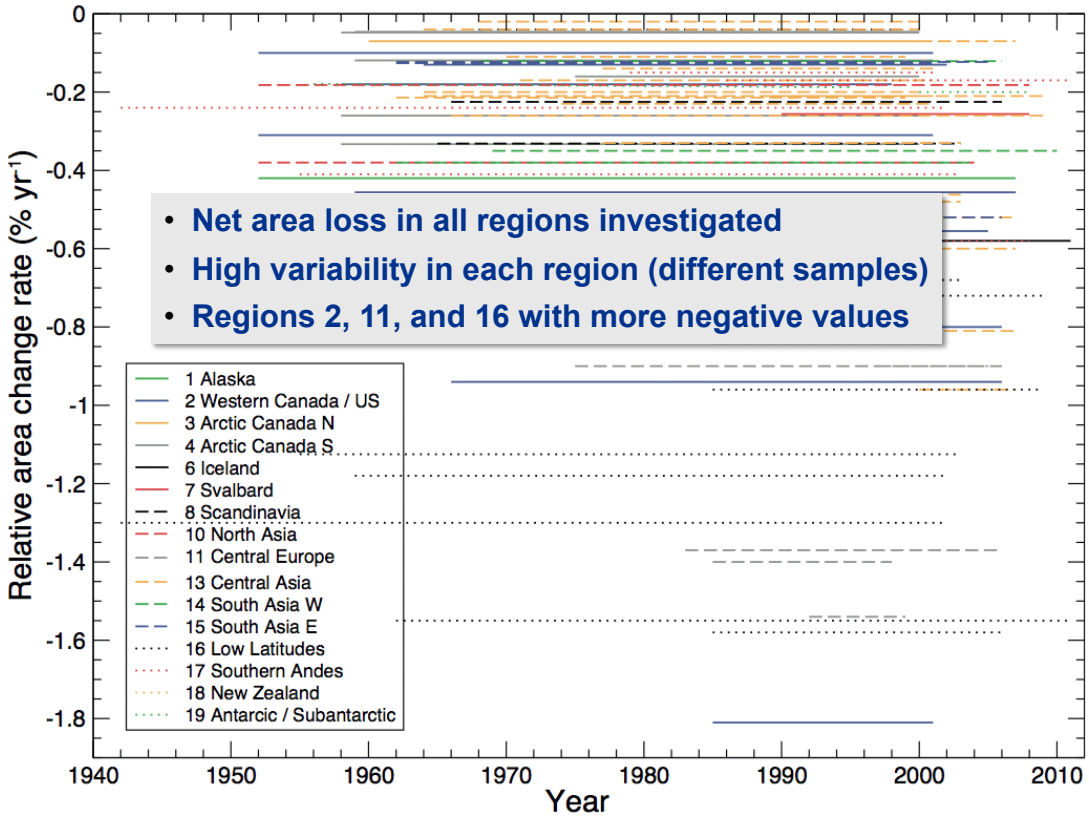
Rastner et al. 2012



Rastner et al. 2012

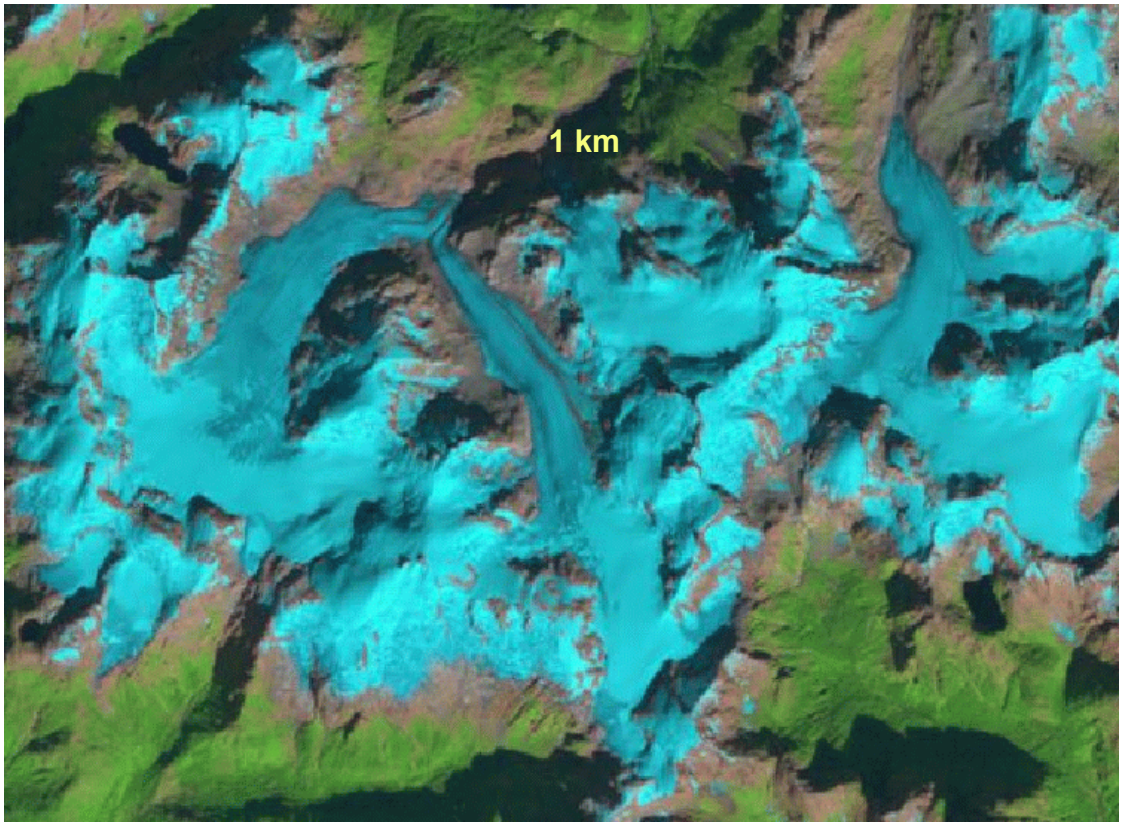
Area of local GIC is 50% larger than assumed

Mean glacier area change rates

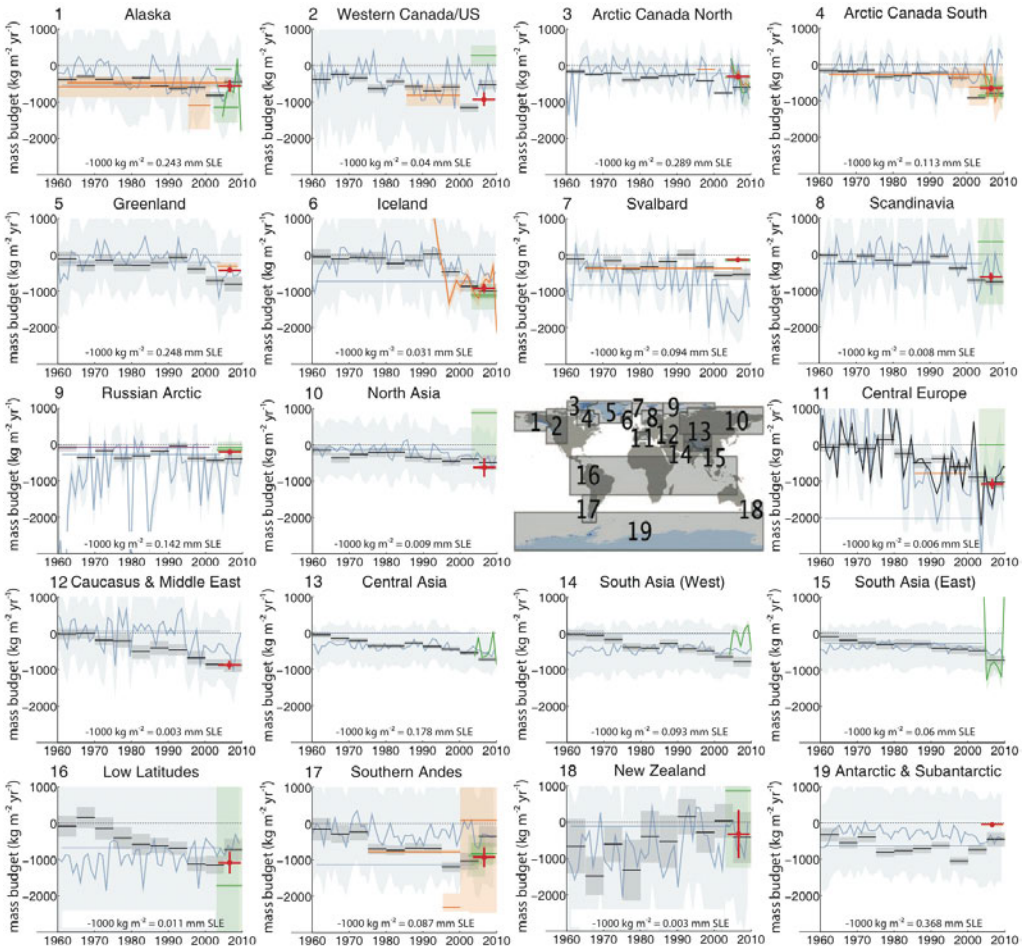


IPCC (2013)

Area changes in Patagonia: 1985-2000-2014



Glaciers_cci (2014)

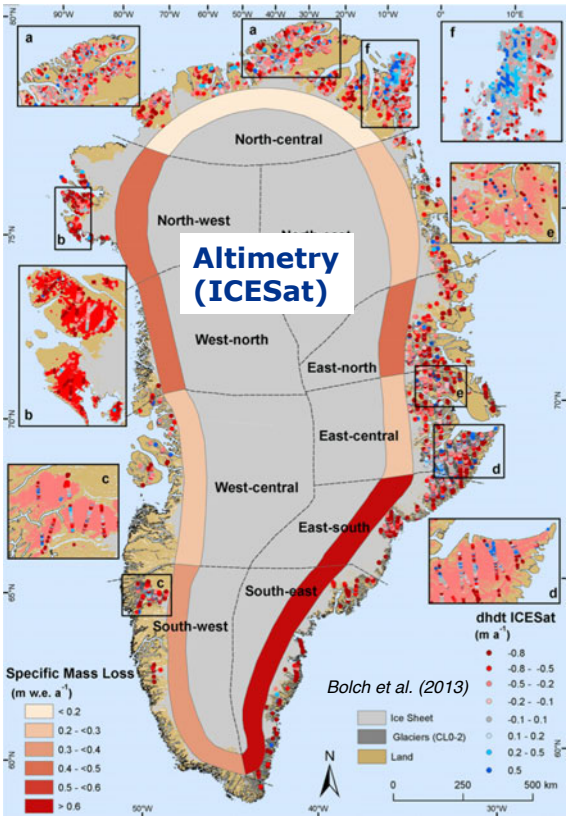


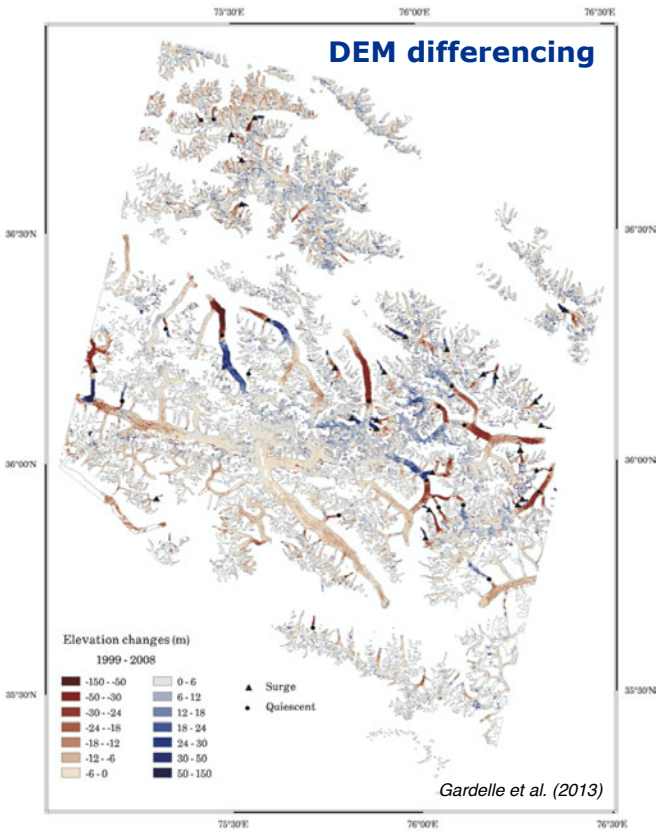
Mass changes

- Predominantly negative values
- Accelerated loss in the past decades
- High interannual variability in most regions (pentads)
- Different methods (field, ICESat, dDEM) mostly in good agreement

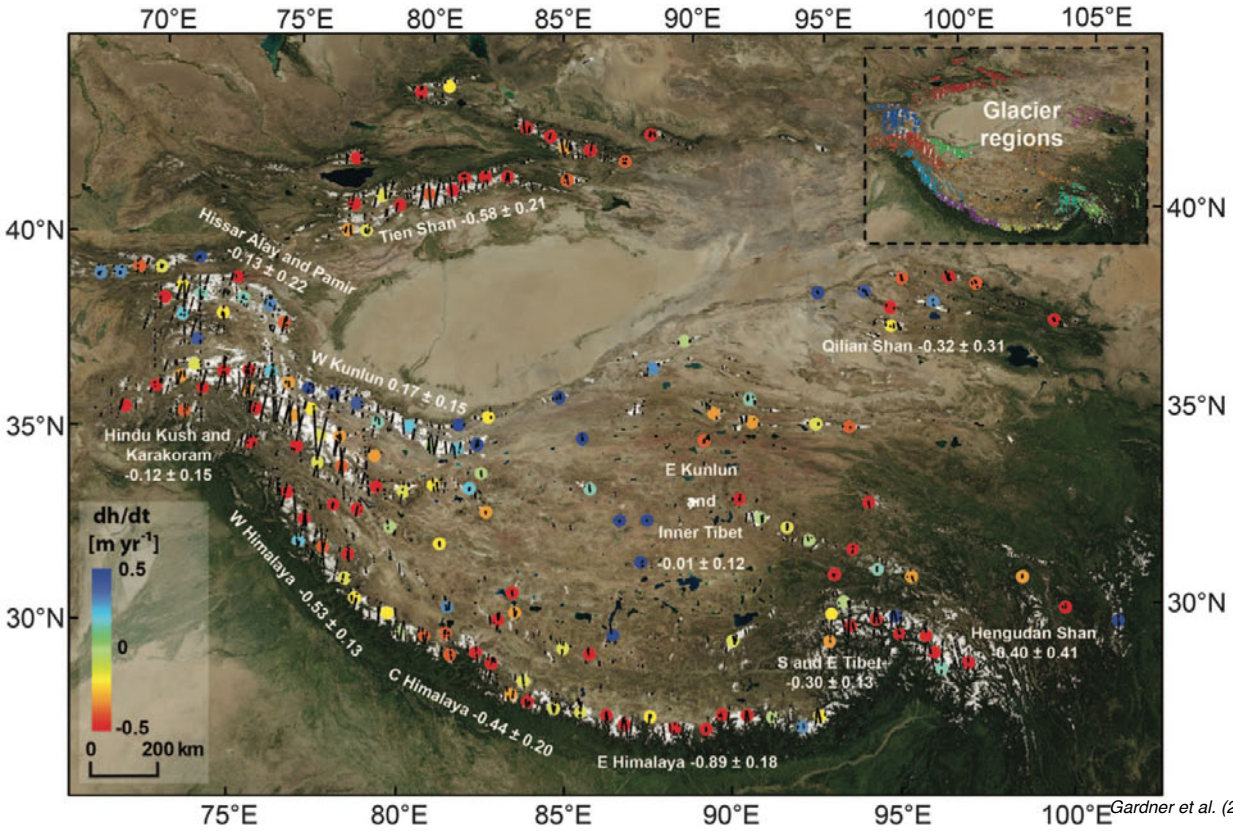
IPCC (2013)

Greenland: ICESat, Karakoram: DEM differencing





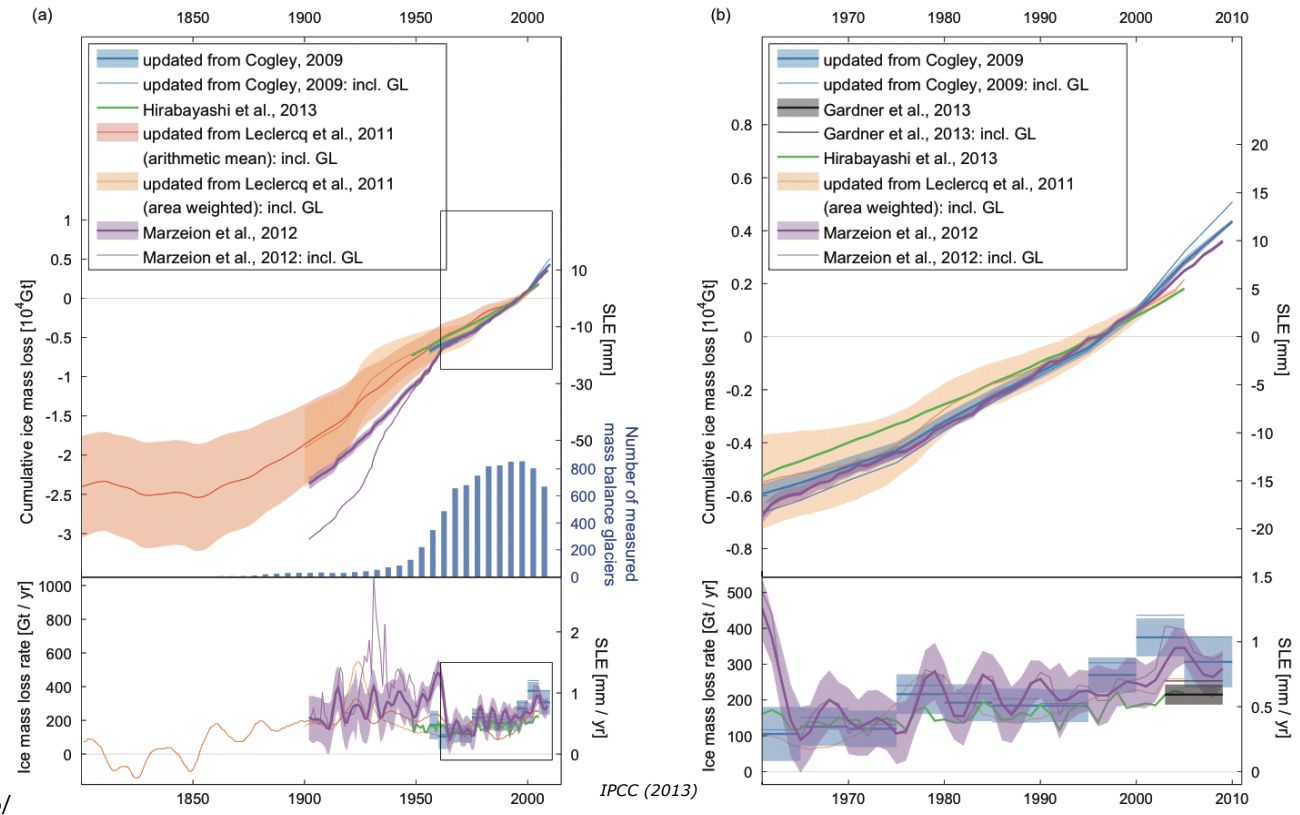
Elevation changes in High Mountain Asia



25/28

Gardner et al. (2013)

Contribution of glaciers to sea level change



IPCC (2013)

26/

Some key findings ...

- The RGI lists about 170,000 glaciers covering an area of 730,000 km^2 and a volume of 170,000 km^3 (41 cm SLE).
- The area of the glaciers on Greenland (CL0 and 1) is about 50% higher (total 90,000 km^2) then previously assumed
- They contribute c. 30 Gt/yr to the total loss of about 220 Gt/yr (2003-08), specific loss is as high as in the Alps (0.7 m/yr)
- All glaciers contribute about 1/3 to the observed SLR
- The spatial variability of elevation changes in High Mountain Asia is very high (regionalization required)
- Glaciers in the Karakoram with mass gain are often dynamically unstable (surge type)
- Glacier surface flow velocities have decreased globally
- Glaciers globally will continue to shrink in the future

