Glaciology – what we (don't) know

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Topics

- Glaciers today
- Concepts and field measurements
- Understanding the past and forecasting into the Future

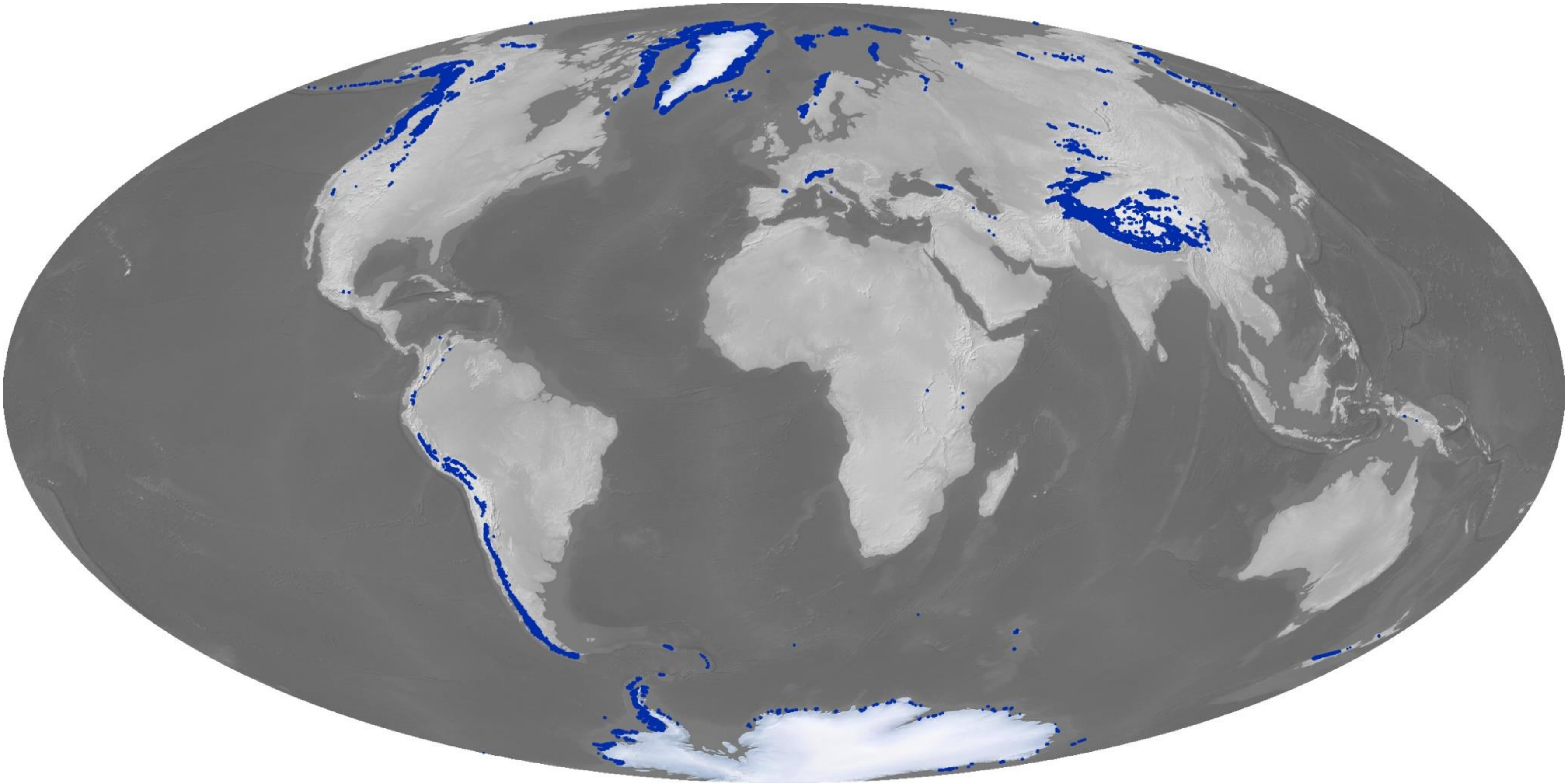
Glaciers Globally

Total Area:

RGI:	734 933 km^2
WGI:	747 688 km^2

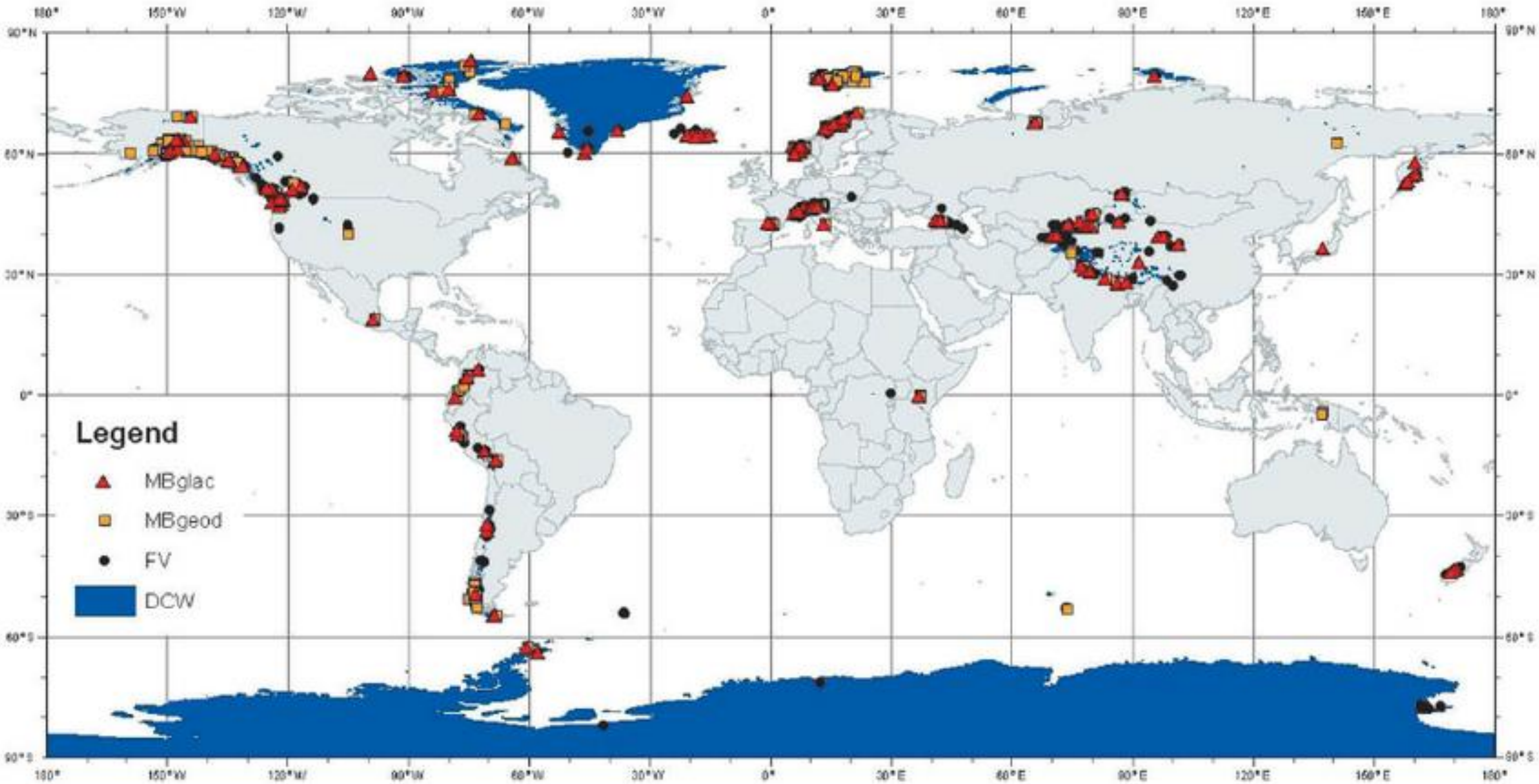
Volume (SLE, m):

Radic & Hock, 2010:	0.60 +/- 0.07
Huss & Farinotti, 2012:	0.43 +/- 0.06
Grinsted, 2013:	0.35 +/- 0.07



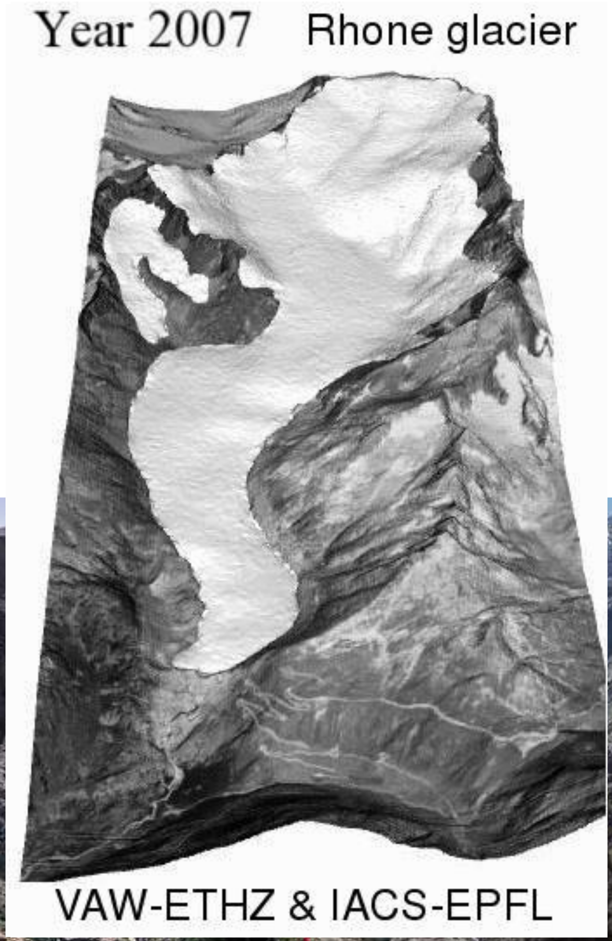
R. Simmon, NASA; based on RGI4 (2013)

Measurements



Zemp et al., (2013) in *Global Land Ice Measurements from Space*, Springer

From Observations to Models



Grindelwaldgletscher (top) and Triftgletscher (bottom); Source: www.gletscherarchiv.de

Mass Balance Time Series

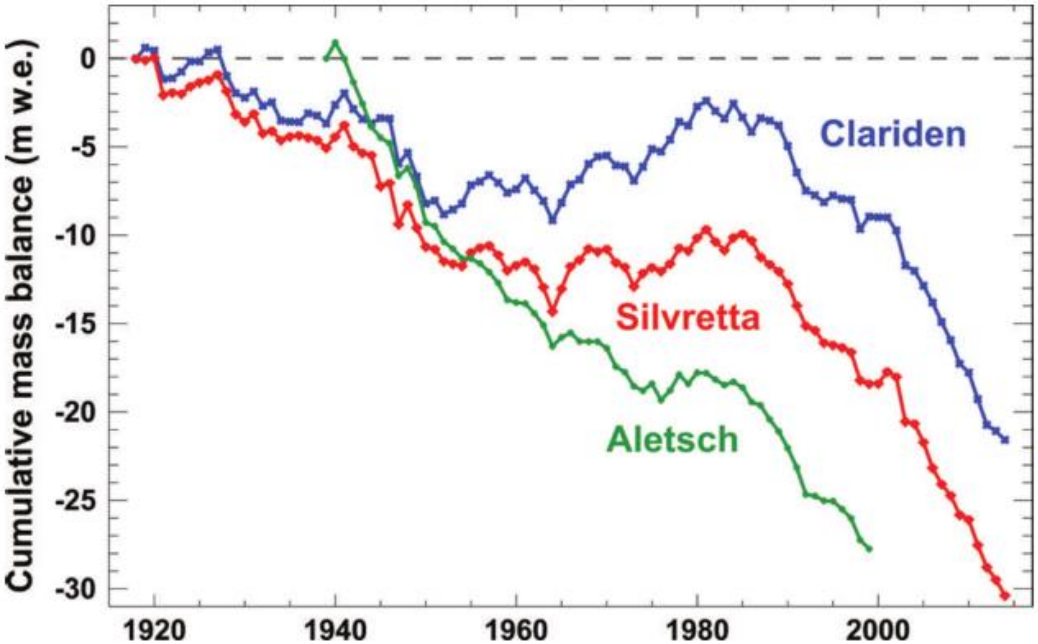


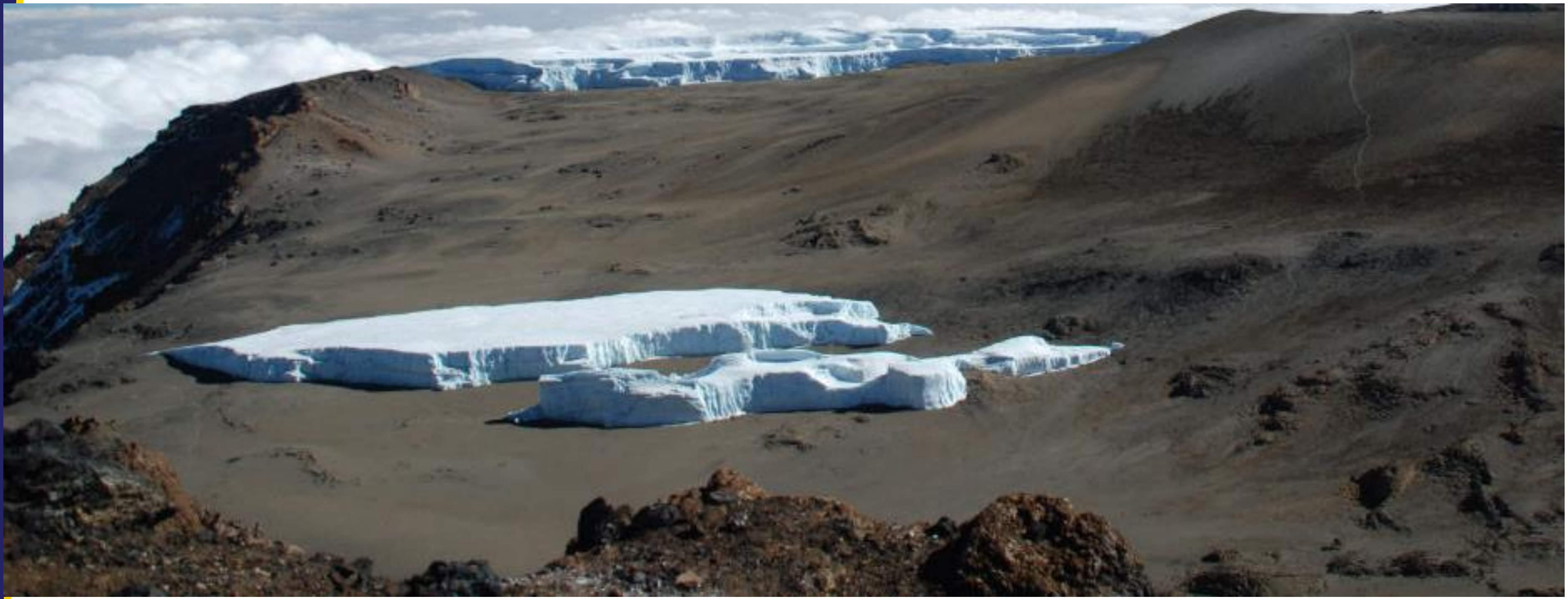
Fig. 4. Cumulative mass balance for Clariden and Silvretta (1918–2014) and Aletsch (1939–1999).

Huss et al., 2015 JoG

Elephant Foot Glacier,
NE - Greenland

Baltoro Glacier,
Karakoram/Pakistan

Belvedere Glacier,
Val d’Aosta, Italian Alps

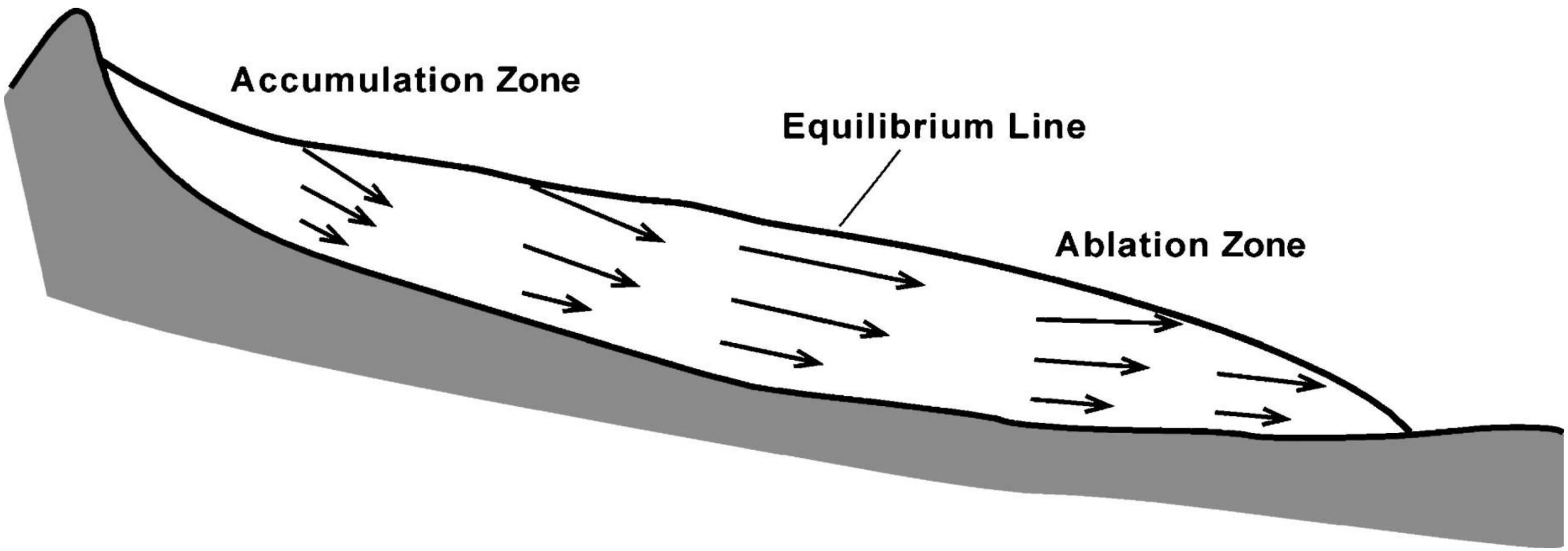


Furtwaengler Glacier,
Kibo/Kilimanjaro,
Tanzania

Theory

- Mass Balance
  - Field Measurements
  - Remote Sensing
- Energy Balance
  - Basic Principles
- Flow Dynamics

Mass Balance – Accumulation and Ablation



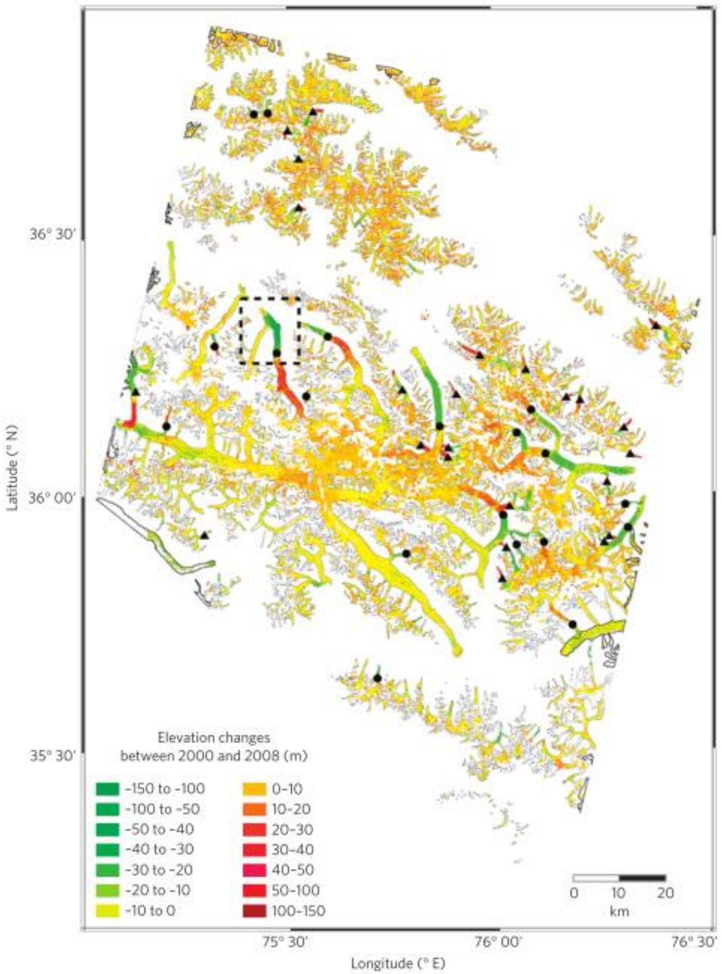
Cuffey and Patterson (2010)

- ELA – Equilibrium Line Altitude
- AAR – Accumulation Area Ratio (= A_{Acc} / A_{total})


Claridenfirn, Switzerland
G. Kappenberger

Claridenfirn, Switzerland
G. Kappenberger

Geodetic Mass Balance



Gardelle et al., NatGeo (2012)

Figure 2 | Map of glacier elevation changes between February 2000 and December 2008. Grey polygons correspond to the glacier outlines (thick black polygons correspond to edge glaciers that were excluded from the mass-balance computation). The total ice-covered area is 5,615 km^2. The black triangles represent glaciers in a surge phase; black circles represent glaciers in a post-surge or quiescent phase. The dashed black box defines the area shown in Supplementary Fig. S1. 41% of elevation changes do not exceed ±5 m. Elevation differences off-glaciers are shown in Supplementary Fig. S4.

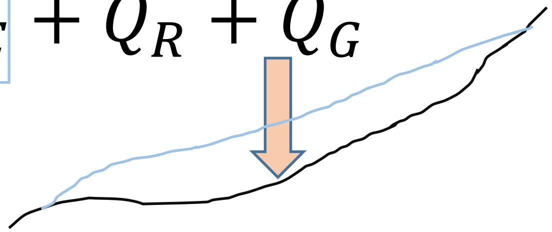
Energy Balance

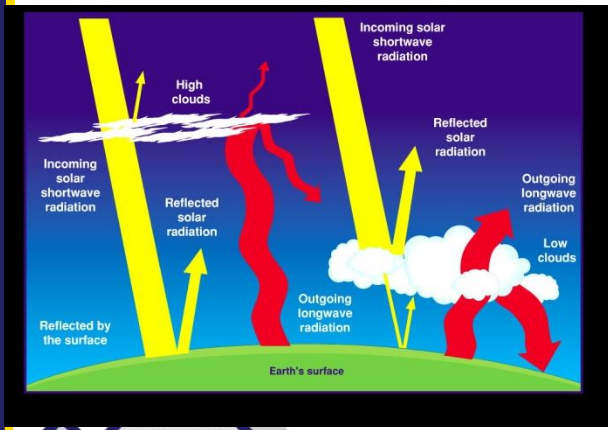
- … to melt ice we need Energy

$$h_{we}\,[m\,w.e.] = \frac{E\,[J]}{\rho_w\,[kg\,m^{-3}]\;L_f[J\,kg^{-1}]}$$

$$Q_M[W\,m^{-2}] = \frac{\delta E\,[J]}{\delta t\,[s]}$$

$$Q_M = \boxed{Q_{SW} + Q_{LW}} + \boxed{Q_H + Q_{LE}} + Q_R + Q_G$$



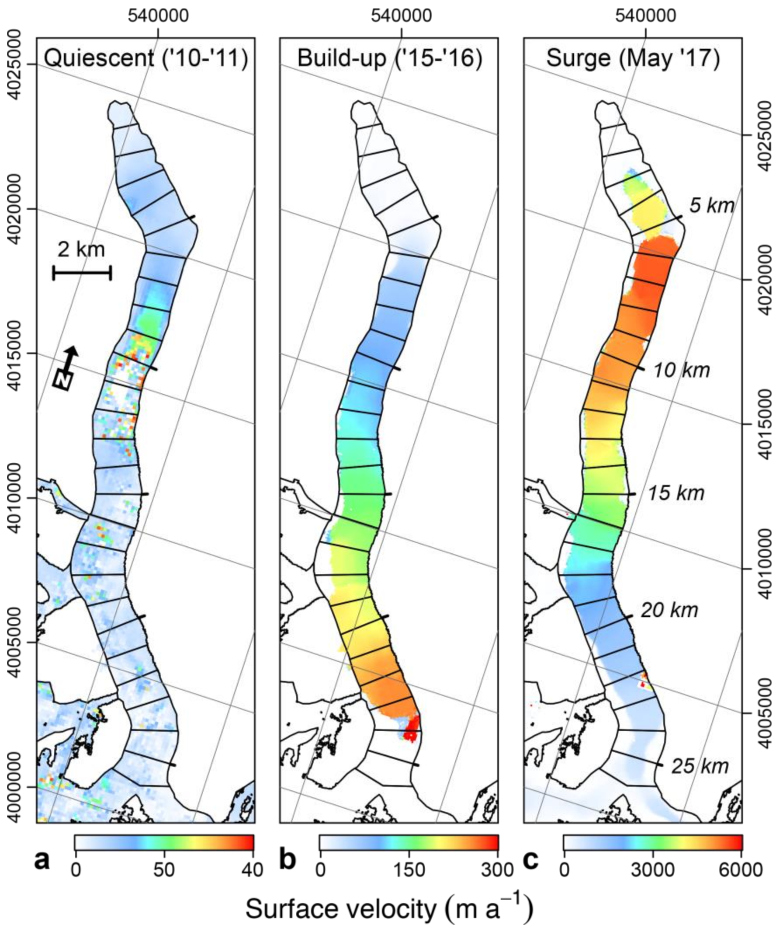


Radiative fluxes

Turbulent fluxes

Sensors on Glaciers

Glacier Flow



Steiner et al., 2018, Cryosphere

Physics of Glacier Movement

- Plastic deformation – water pressure
- Basal Slip – basal temperatures
  - Basal velocity
  - Shear Stress
  - Water Pressure and Volume at Bed
  - Bedrock Topography
  - Sediment Properties
- …. But we only see surface velocity and past evidence on bed rock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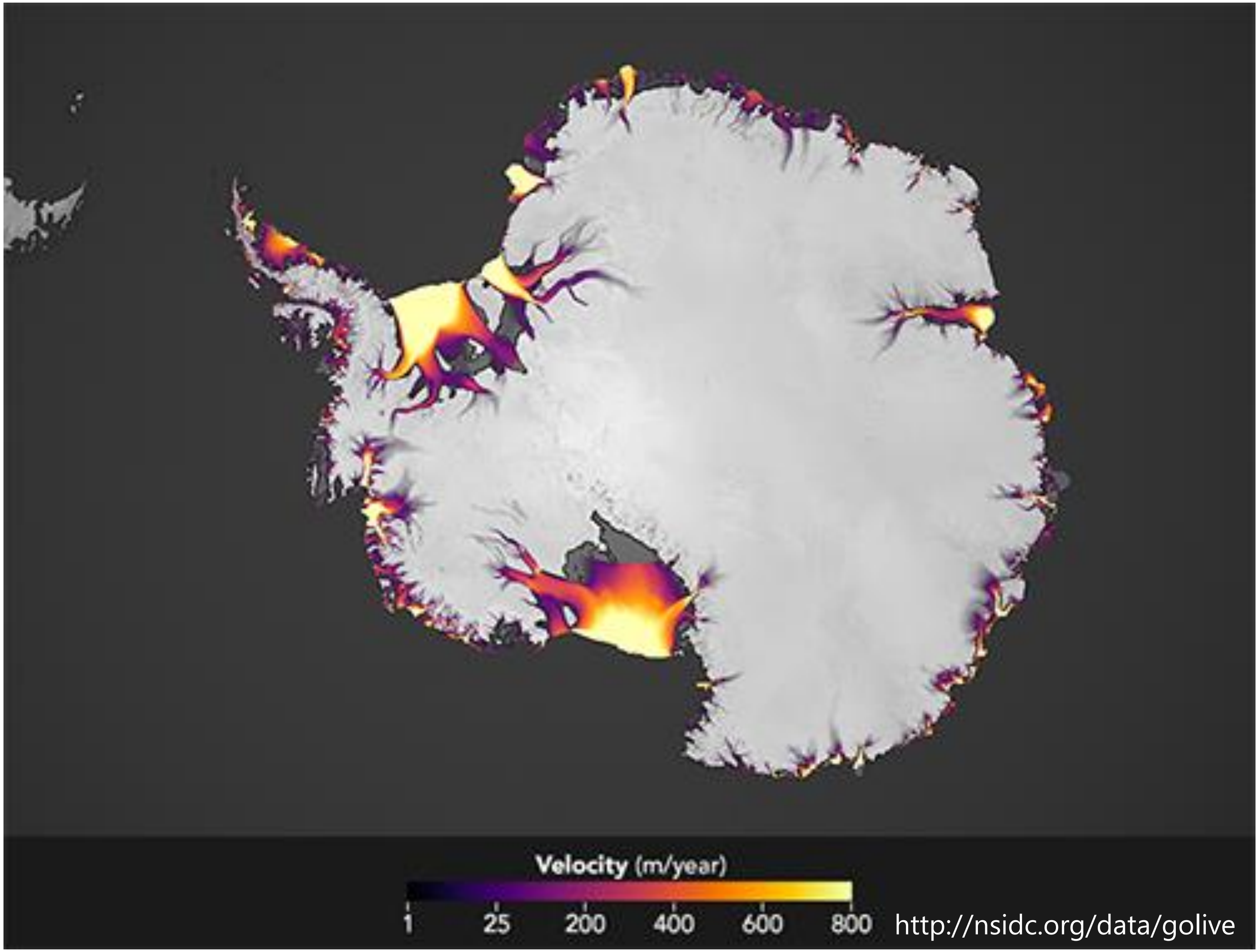
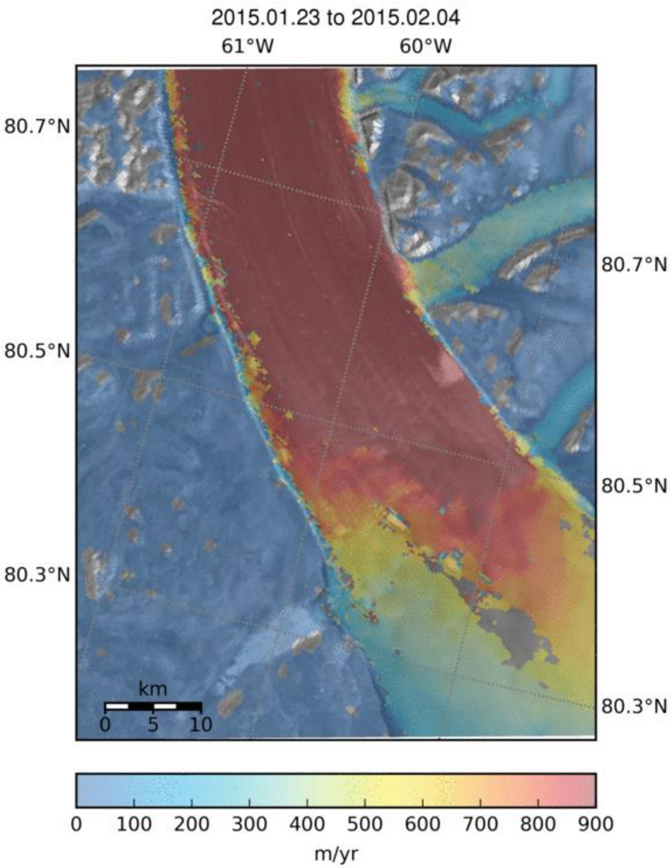
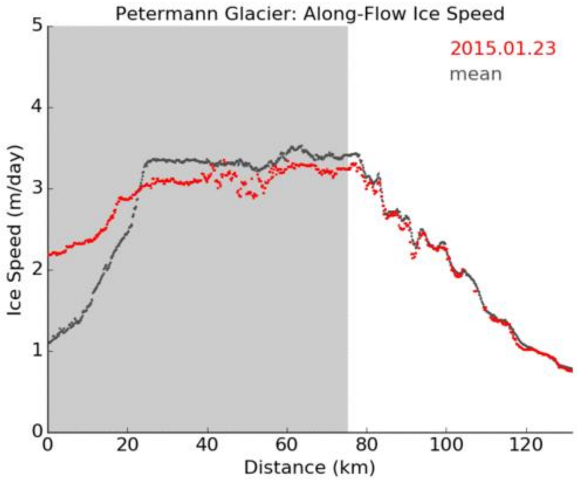
Velocity Fields – Coarse Resolution



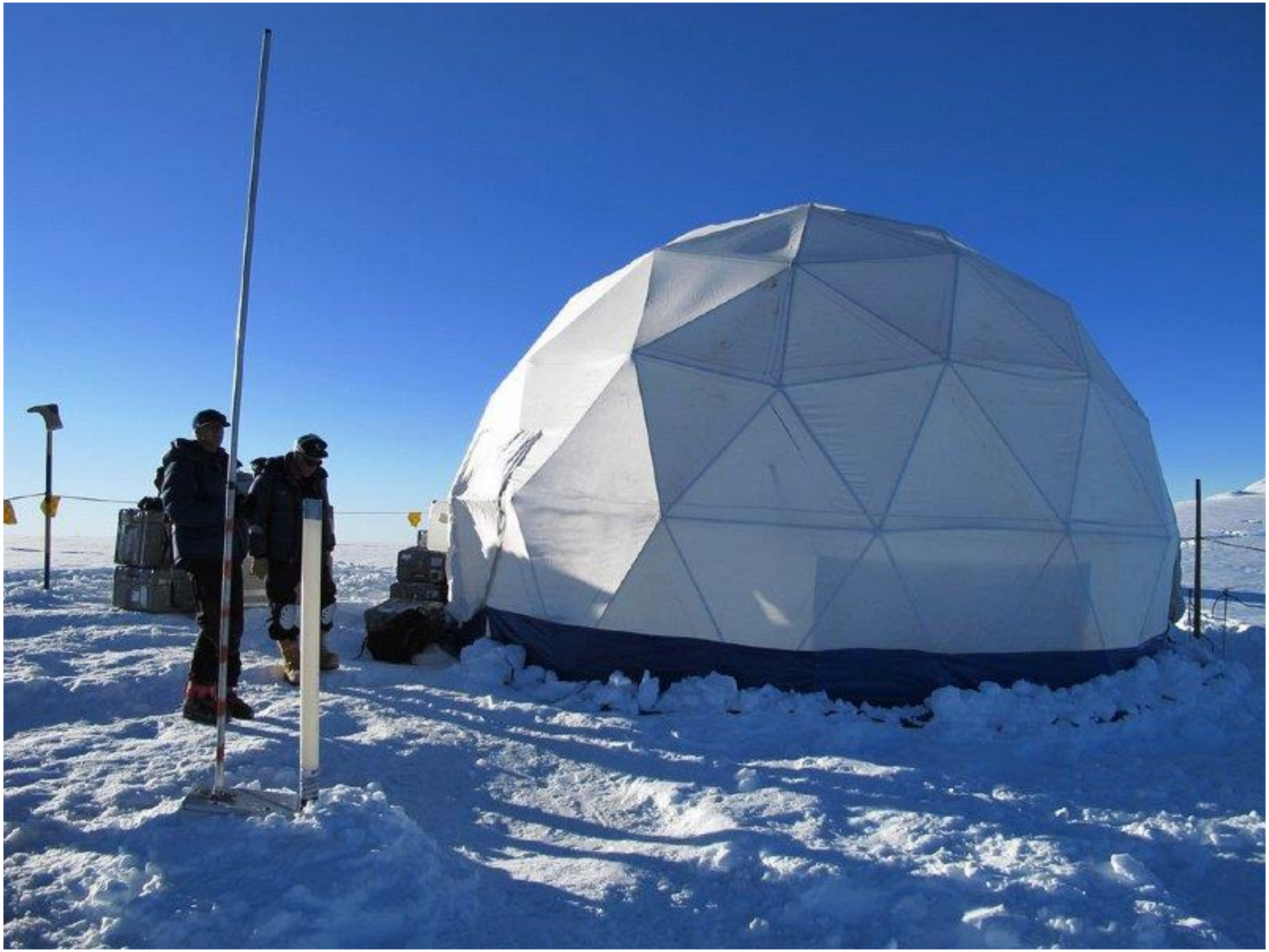
Velocity Fields – High Resolution





Sentinel Satellites (ESA)

Inside the Glacier ...



Ortles Project
European Alps

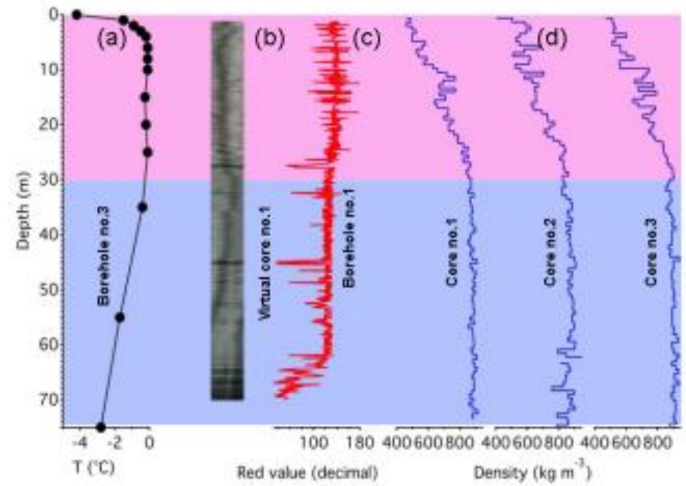
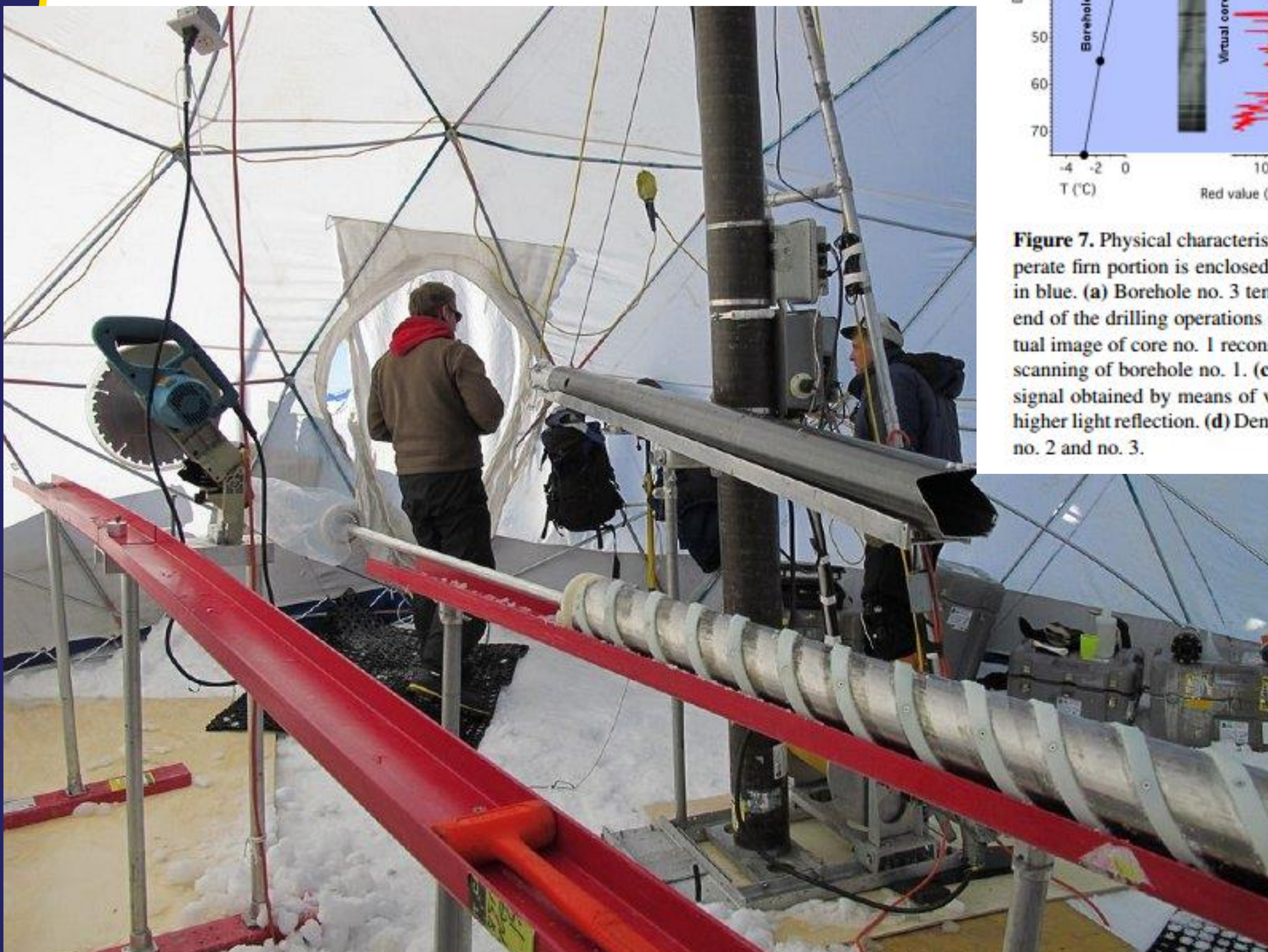
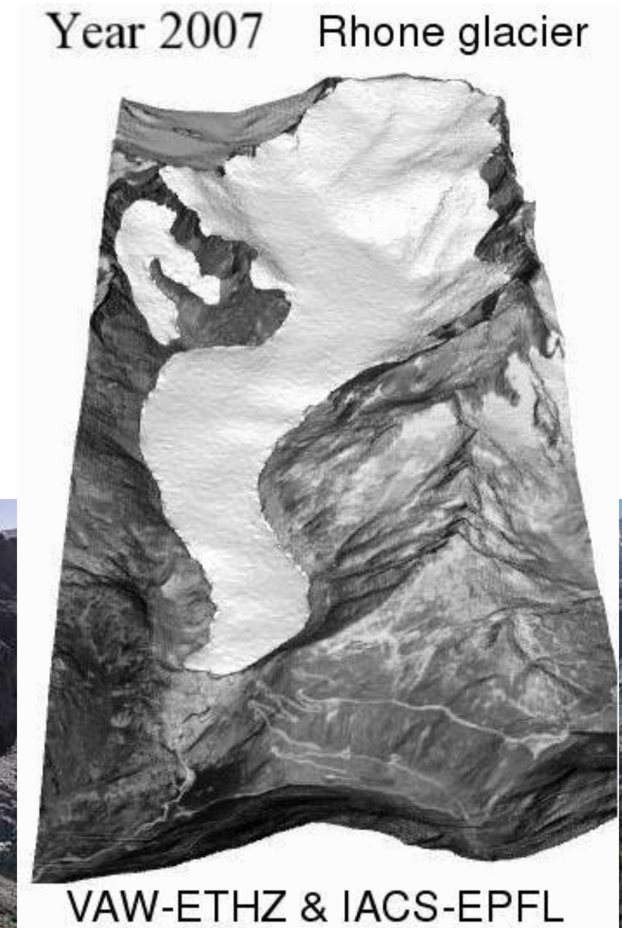


Figure 7. Physical characteristics of the Mt. Ortles cores. The temperate firn portion is enclosed in red shading, while the cold ice is in blue. **(a)** Borehole no. 3 temperatures recorded 43 days after the end of the drilling operations (from Gabrielli et al., 2012). **(b)** Virtual image of core no. 1 reconstructed from 360° Televiewer visual scanning of borehole no. 1. **(c)** Red component of the RGB digital signal obtained by means of visual scanning. High values indicate higher light reflection. **(d)** Densities of the Mt. Ortles ice cores no. 1, no. 2 and no. 3.

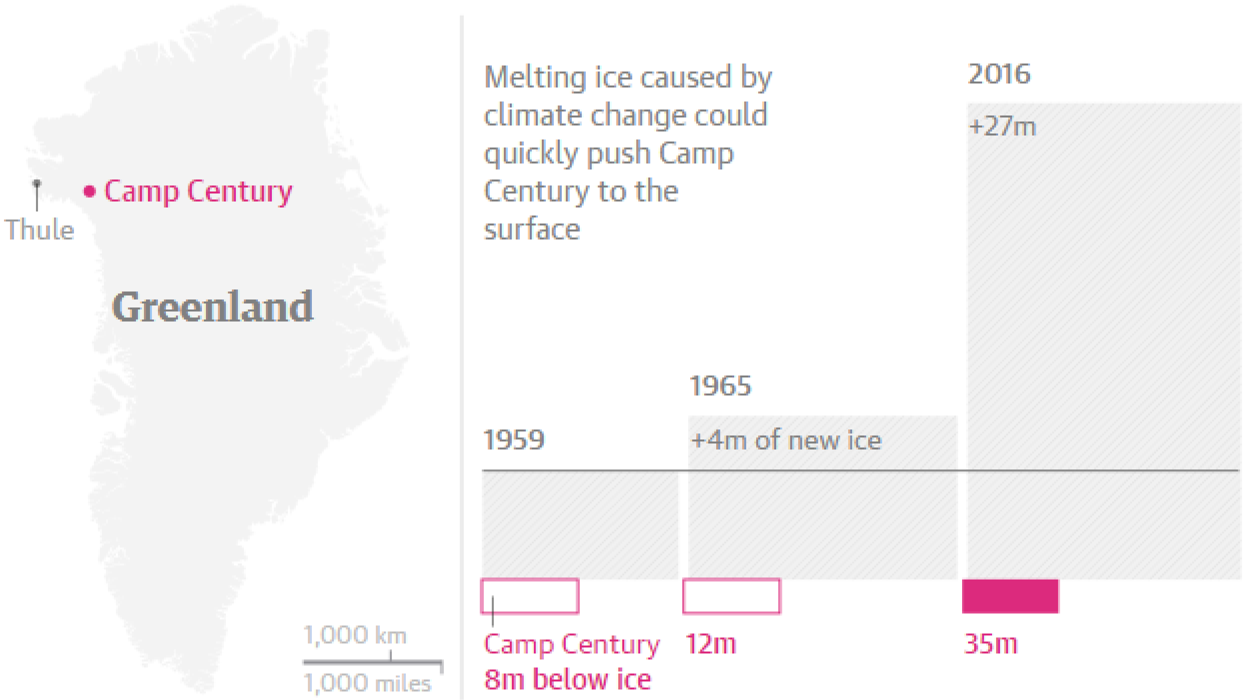


Past and future change



Grindelwaldgletscher (top) and Triftgletscher (bottom); Source: www.gletscherarchiv.de

Camp Century – Project IceWorm



Graphic: The Guardian, 27/09/2016

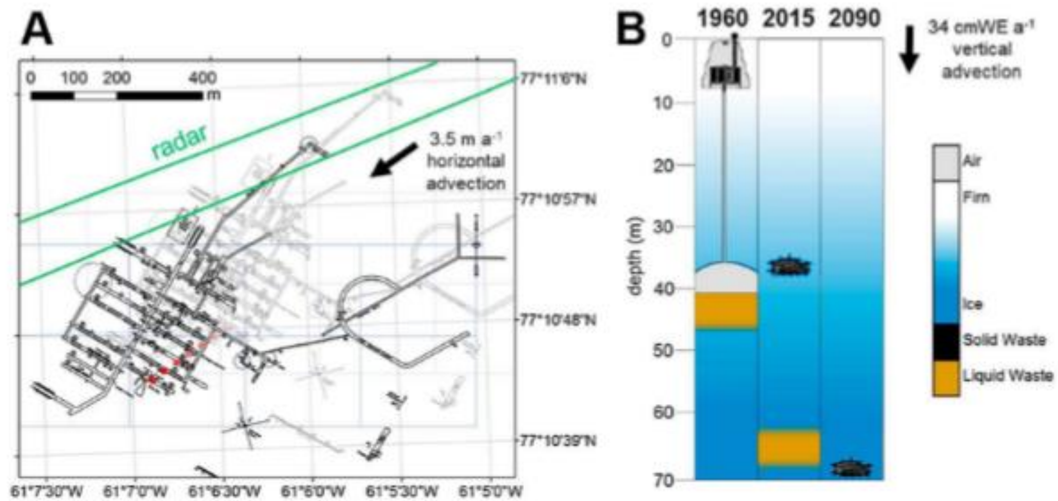


Figure 2. (a) Camp Century "as built" map georeferenced to 1960 (grey) and 2020 (black) locations [*Kovacs*, 1970], based on past surveys of the borehole location and horizontal advection associated with ice flow (Supplementary Methods). The red points denote decadal borehole location from 1960 to 2020. The green lines denote radar profiles shown in Figure 3. (b) Estimated Camp Century solid and refrozen liquid waste depths in 1960, 2015, and 2090, based on vertical advection rates (Figure S3). The horizontal extent of the liquid waste, while large relative to tunnel width, is small relative to camp width.

Colgan et al., 2016, GRL

Future Ice melt in a changing climate …

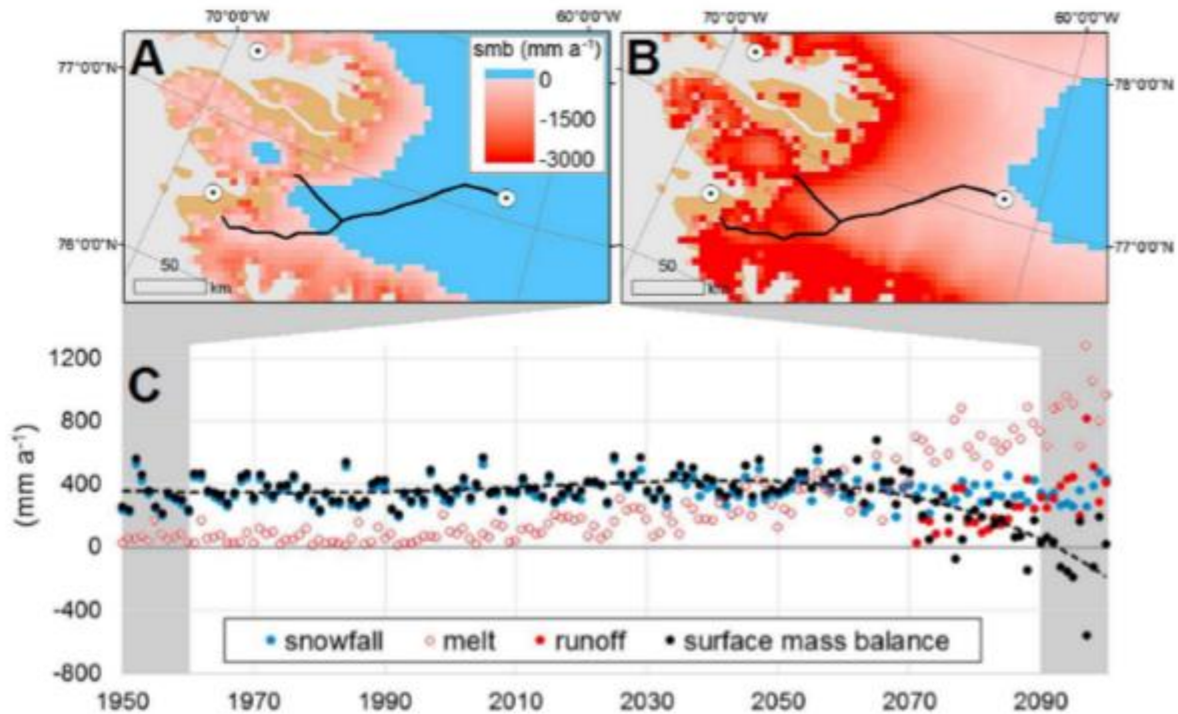


Figure 4. (a) Surface mass balance in Northwest Greenland during the 1950s (1950–1959) and (b) 2090s (2090–2099) as simulated by MAR v3.5 forced by CanESM2 under RCP8.5 [*Fettweis et al.*, 2013]. The color bars saturate at minimum and maximum values. The blue shading denotes the accumulation area where surface mass balance is positive. (c) Surface mass balance, and its components, at Camp Century during 1950–2100 as simulated by MARv3.5 and forced by CanESM2. The dashed line denotes polynomial trend. The NorESM1 simulation is shown in Figure S2.

Colgan et al., 2016, GRL

… what about horizontal movement?

Glacier change and erratic boulders

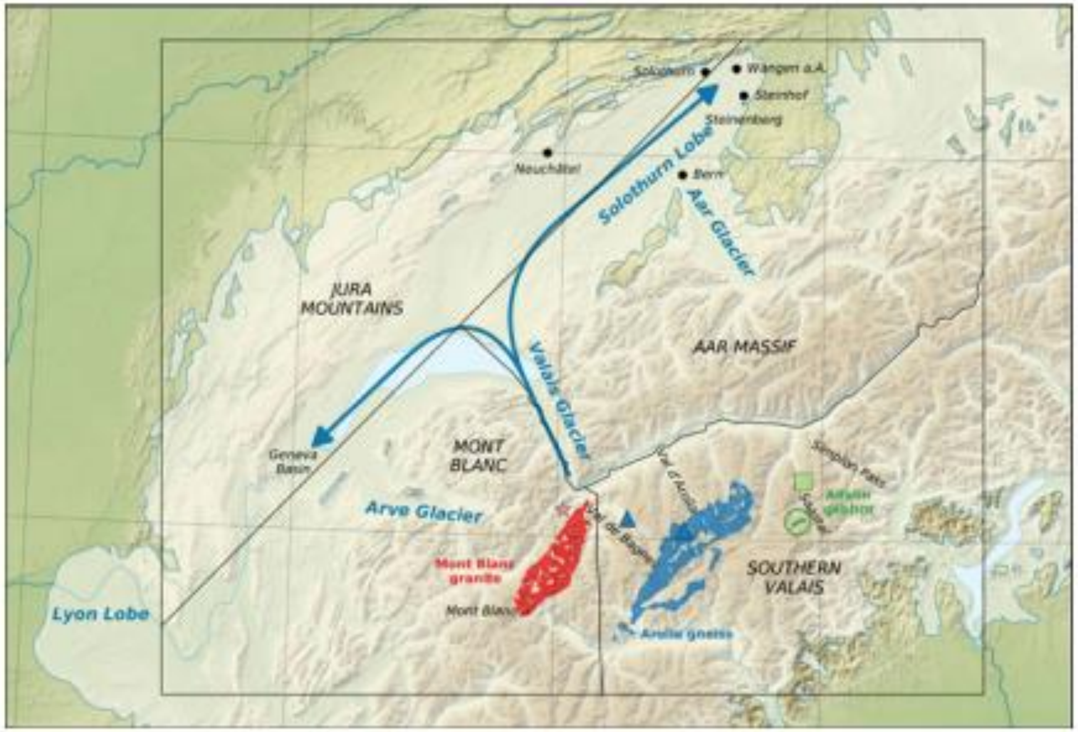
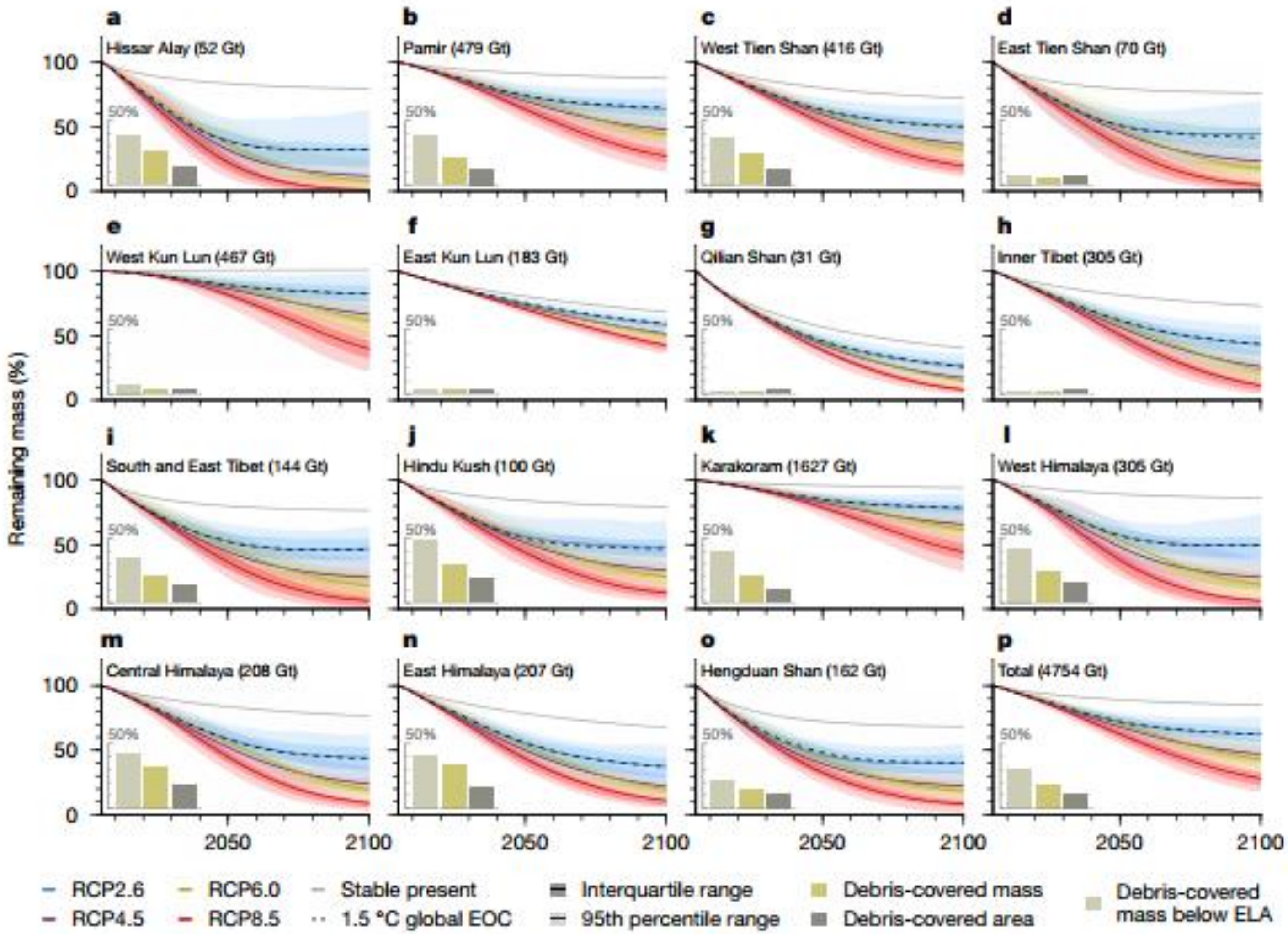


Fig. 1. Relief map of the north western alps showing the LGM extent of the alpine ice cap (blue line, after Ehlers and others, 2011). The arrows indicate the direction of the former ice flow from the Rhone Valley toward the Solothurn and Lyon lobes. The modelling domain (black rectangle) was divided into four precipitation zones: Mont Blanc, southern Valais, Jura Mountains and Aar Massif. Source regions of characteristic lithologies considered in this study (Mont Blanc granite, Arolla gneiss, and Allalin gabbro) are reproduced from (Swisstopo, 2005). Corresponding marker starting points used for modelling are shown by symbols ★, ▲ and ■. The background map consists of SRTM (Jarvis and others, 2008) and Natural Earth Data (Patterson and Kelso, 2015).

Jouvet et al., 2016, JoG

Future glacier volumes



Kraaijenbrink et al., 2017, Nature