Large scatter and multidecadal fluctuations in the 20th century mass loss of 30 Alpine glaciers

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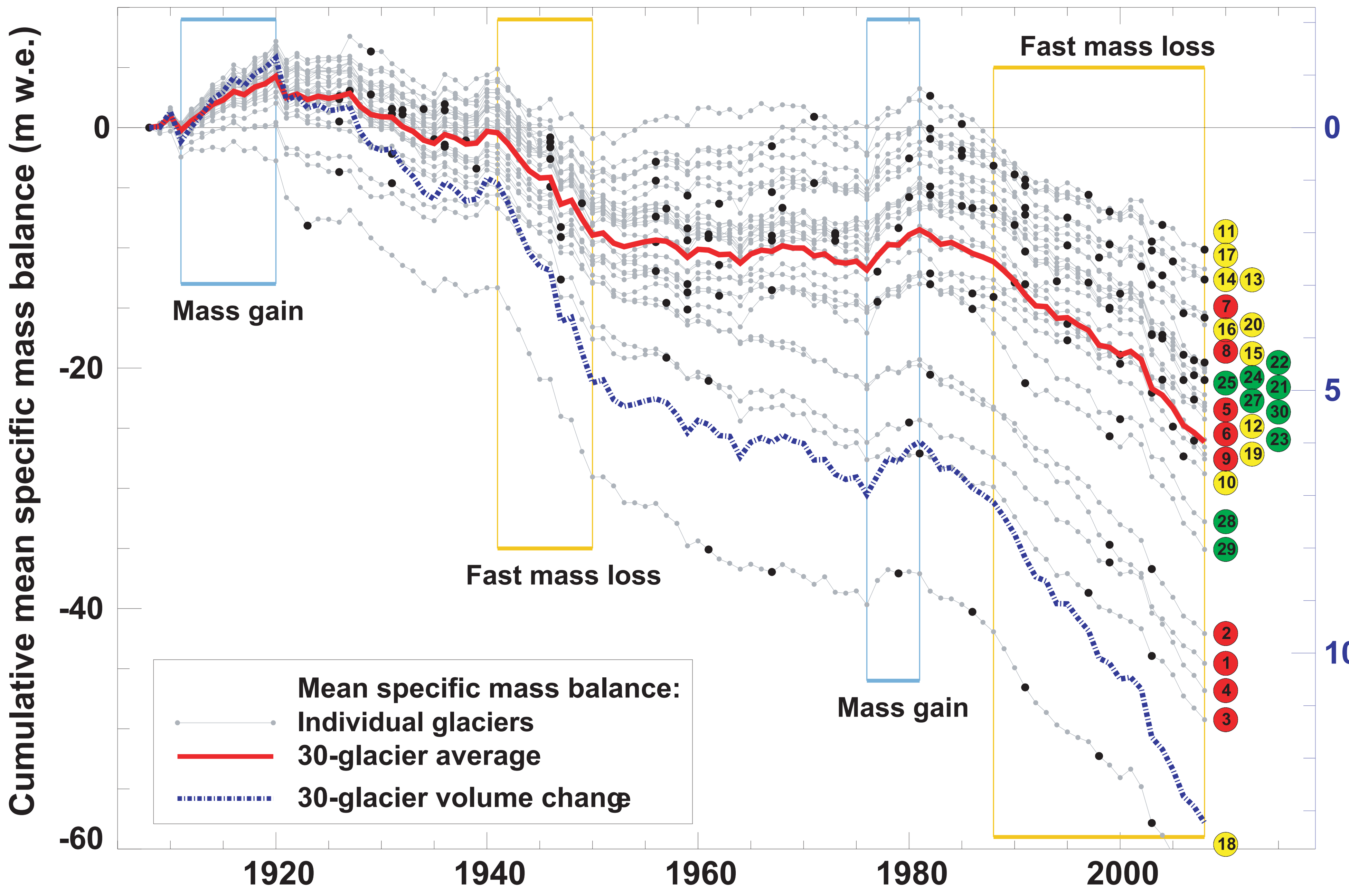

Fig. 2: Cumulative mean specific mass balance of 30 Swiss glaciers and their total cumulative volume change in the 20th century. Series for the individual glaciers are shown in grey; black dots indicate the dates of DEMs. The solid red line represents the arithmetic average. Numbered symbols at the right-hand side indicate glacier size (color), name (Fig. 1b) and location (Fig. 1a). The dash-dotted blue line (right-hand side axis) shows the cumulative total volume change of the 30 glaciers. Two short periods with mass gain and two periods with fast mass loss are marked.

Is the rate of Alpine glacier mass loss linked to the Atlantic Multidecadal Oscillation (AMO)?

Introduction

The ongoing retreat of mountain glaciers strongly impacts on the hydrological cycle, might cause economic losses in alpine regions and is expected to dominate eustatic sea level rise over the next century. Long-term time series of glacier mass balance represent a key to projecting future glacier changes and understanding the glacier-climate linkage, in particular glacier response to large-scale climatic forcings. However, mass balance is only measured on some selected glaciers, and the typical length of the records is a few decades (Kaser et al., 2006).

We present thirty new time series of glacier surface mass balance, accumulation and melt over the past 100 years in the Swiss Alps (Fig. 1). The data set includes different glacier sizes, exposures and regions, and thus constitutes the first long-term mass balance time series being representative on a mountain range scale.

20th century Alpine glacier mass loss

All glaciers show considerable mass loss, but rates differ strongly between individual glaciers (Fig. 2). 100-year cumulative mass balance varies between −11 m water equivalent (w.e.) (Allalin) and −65 m w.e. (Gries), with an arithmetic average of −26 m w.e. These strong differences in the response of glacier mass balance to changes in climate forcing are attributed to an interaction of several complex processes. Large and flat glaciers tend to have more negative mass balance due to their long reaction time. Positive and negative albedo feed-back mechanisms, as well as changing winter precipitation, variable on smaller spatial scales than air temperatures, might also explain some of the differences.

Mass loss is particularly rapid in the 1940s and late 1980s to present, while short periods of mass gain occurred in the 1910s and late 1970s (Fig. 2). This indicates that glacier mass loss over the 20th century was not linear, but exhibits important long-term variations (Fig. 3a to 3c).

Relation to large-scale forcing

We find variations in the rate of glacier mass loss in the Swiss Alps with a period of 65 years, which are significantly anticorrelated to the Atlantic Multidecadal Oscillation (AMO) index. Positive AMO leads to pronounced mass loss, during periods of negative AMO Swiss glaciers showed slow mass loss or slight gain. The AMO refers to the anomaly in the sea surface temperature in the North Atlantic (Fig. 3d) and showed persistent oscillations with a period of 60-100 years over the last centuries (e.g. Gray et al., 2004). North Atlantic variability had a recognizable impact on glaciers in the European Alps for at least 250 years (Fig. 4). The AMO is related to the thermohaline ocean circulation, which is projected to weaken over the next decades (Knight et al., 2005). During the next decades, this might result in a deceleration of rate of glacier mass loss compared to the last years.

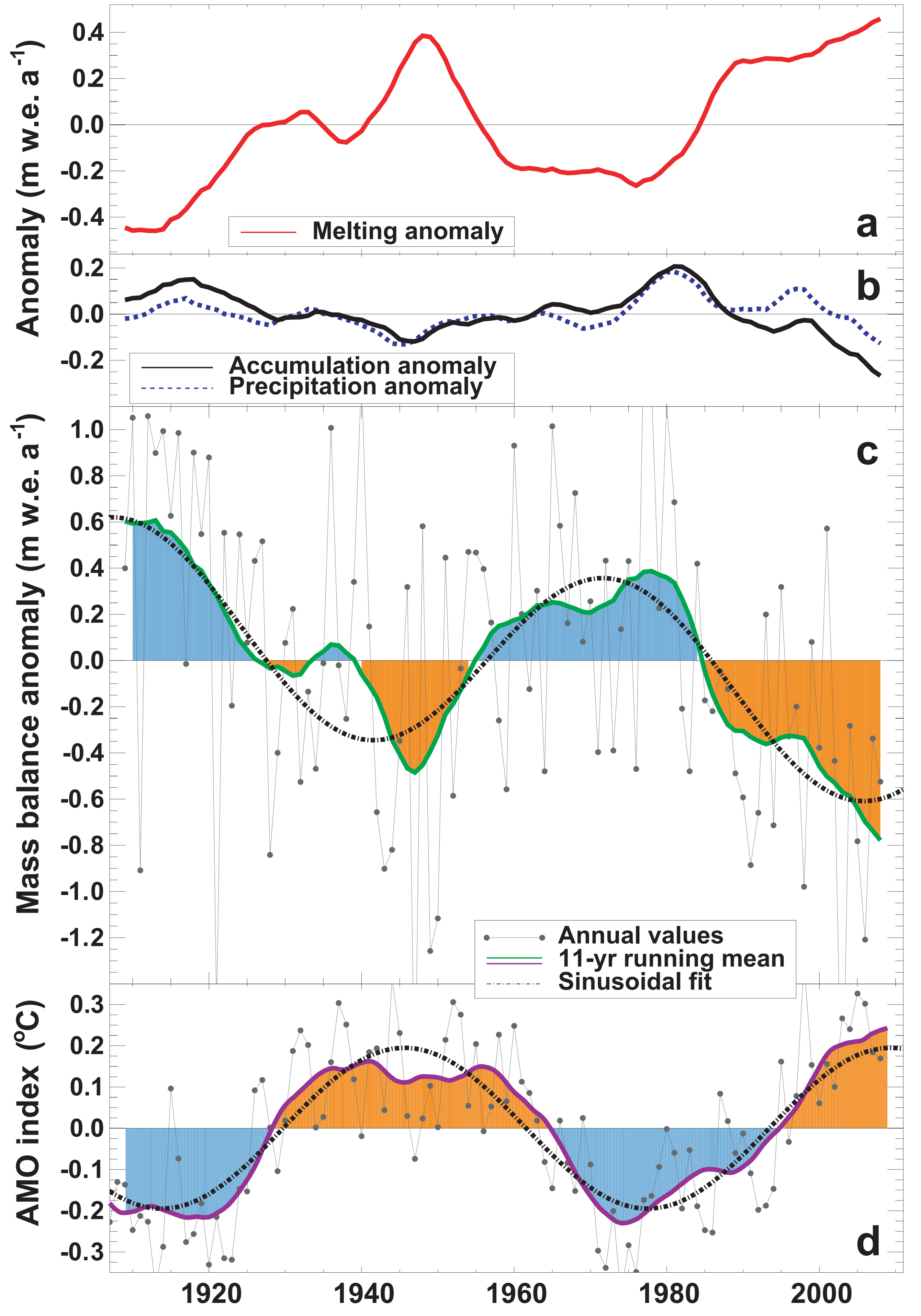

Fig. 3: (a) 11-year running mean of the annual glacier melt anomaly averaged over the 30 glaciers, and (b) annual accumulation and precipitation anomaly (deviations from the 1908-2008 average). (c) Annual mass balance anomaly. A sinusoid superimposed on a linear trend is shown. (d) Atlantic Multidecadal Oscillation index (Enfield et al., 2001).

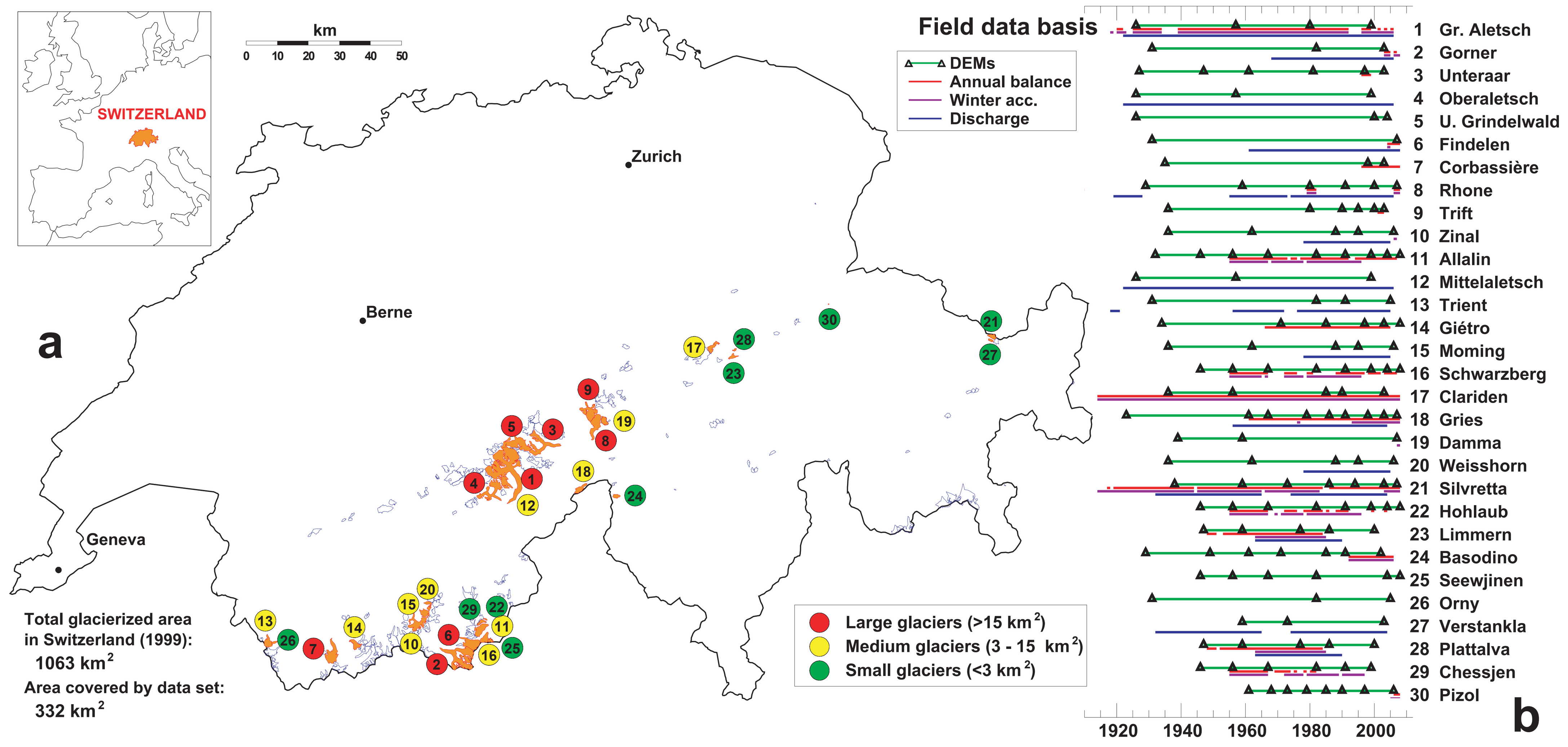

Fig. 1: (a) Overview map. Investigated glaciers (orange) are numbered according to their size which is indicated by the color of the dots. (b) Periods covered with field data displayed by bars: (i) ice volume changes (dates of DEMs shown with triangles), (ii) point annual balance, (iii) winter accumulation, and (iv) discharge.

Methods

The results are based on a comprehensive set of field data and modelling. For each glacier, up to 10 high-accuracy digital elevation models (DEMs) covering the last 100 years were established providing ice volume changes in subdecadal to semicentennial periods (Bauder et al., 2007). In addition, almost 10'000 direct observations of annual mass balance and winter accumulation, as well as discharge records from proglacial streams are available (Fig. 1b). This data base was used to constrain a distributed mass balance model (Huss et al., 2008) driven by daily air temperature and precipitation for the period 1908-2008. The model provides distributed surface mass balance components in daily resolution for every glacier on a 25x25m grid. Mean specific mass balance is calculated over annually updated glacier surface areas.

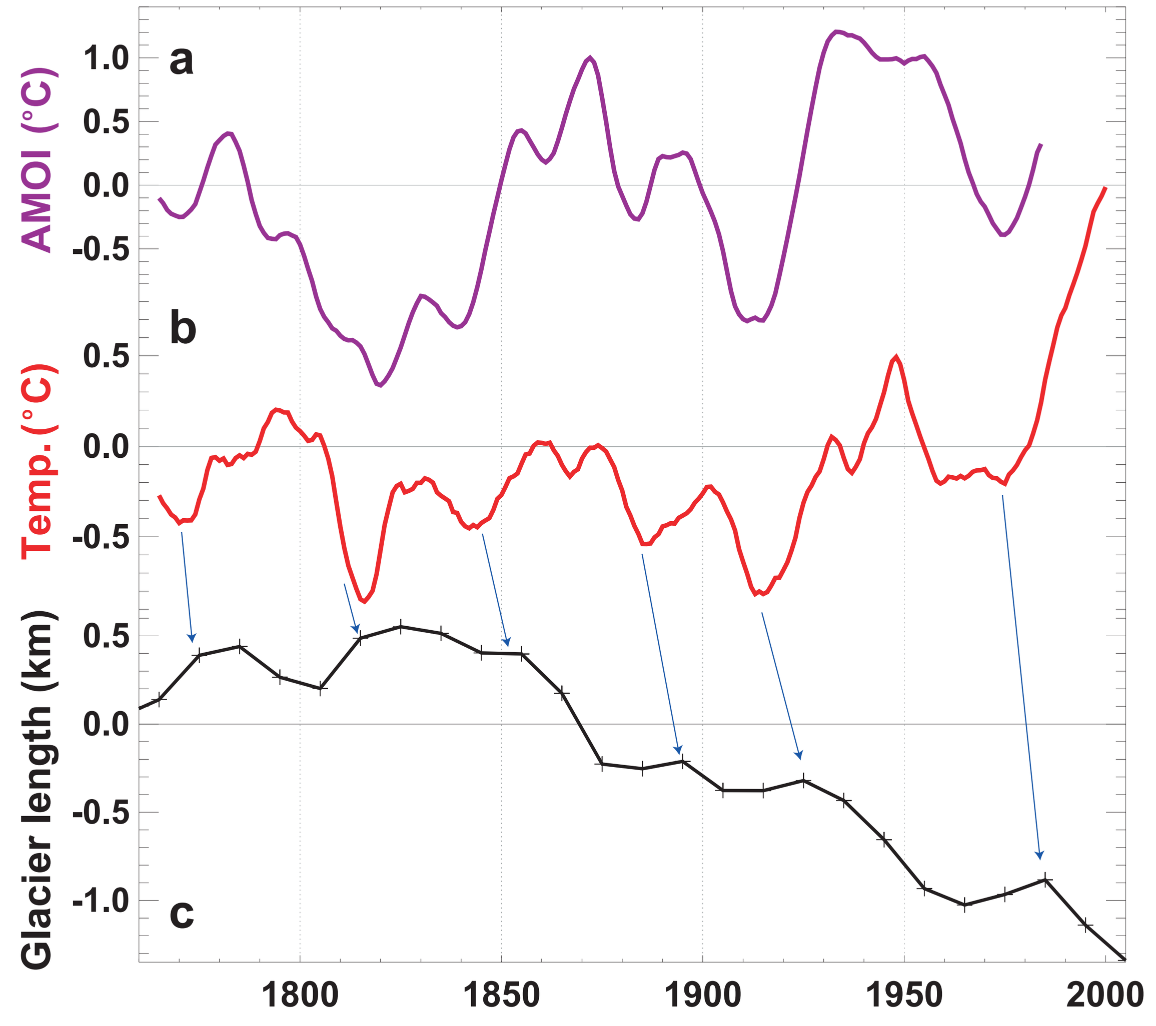

Fig. 4: (a) Reconstructed AMO index (Gray et al., 2004) and, (b) summer (JJA) air temperature from instrumental data in the Greater Alpine Region (Auer et al., 2007) (11-year low-pass filtered). (c) Observed length change of Unterer Grindelwaldgletscher (Holzhauser and Zumbühl, 1999); blue lines indicate phases of glacier advance in response to cooler temperatures.

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