ALPINE GLACIERS AS A CLIMATE PROXY AND AS A PROMINENT CLIMATE IMPACT

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Fluctuations of glaciers and ice caps in cold mountain areas have been systematically observed for more than a century in various parts of the world (Forel 1895) and are considered to be highly reliable indications of worldwide warming trends. Mountain glaciers and ice caps are, therefore, key variables for early-detection strategies in global climate-related observations. Advanced monitoring strategies integrate detailed observations of mass and energy balance at selected reference glaciers with more widely distributed determinations of changes in area, volume and length; repeated compilation of glacier inventories enables global representativity to be reached (Haeberli et al. 2000, 2002).

Long-term *mass balance* (Fig. 1) measurements provide direct (undelayed) signals of climate change and constitute the basis for developing coupled energy-balance/flow models for sensitivity studies. These investigations explore complex feed-back effects (albedo, surface altitude, dynamic response) and can be used in conjunction with coupled ocean-atmosphere general circulation models (model validation, hydrological impacts at regional and global scales, etc.; cf. Beniston et al. 1997). They combine direct glaciological and geodetic/photogrammetric methods in order to determine changes in volume/mass of entire glaciers (repeated mapping) with high spatio-temporal resolution (annual measurements at stakes and pits). Laser altimetry combined a kinematic Global Positioning System (GPS) are applied for monitoring thickness and volume changes of very large glaciers which are the main meltwater contributors to ongoing sea-level rise (Ahrendt et al. 2002).

Change in *glacier length* (Fig. 2) is a strongly enhanced and easily measured but indirect, filtered and delayed signal of climate change (Oerlemans 2001). It represents an intuitively understood and most easily observed phenomenon to illustrate the reality and impacts of climate change. Work on glacier recession has considerable potential to support or qualify the instrumental record of temperature change and to cast further light on regional or worldwide temperature changes before the instrumental era. Studies of past fluctuations in glacier length are particularly useful for the reconstruction of historical and holocene climate variability (Haeberli and Holzhauser 2003).

Modern *Glacier inventories* (Fig. 3) are compiled by using a combination of remote sensing and GIS technologies (Kääb et al. 2002, Paul et al. 2002). Surveys take place at time intervals of a few decades – the characteristic dynamic response time of medium-sized mountain glaciers. Length and area changes can be measured for a great number of ice bodies. Area changes mainly enter calculations of glacier contributions to sea-level rise and of regional hydrological impacts (cf. Meier and Bahr 1996). In contrast, cumulative length changes not only influence landscape evolution and natural hazards (especially from ice- and moraine-dammed lakes) but can also be converted to average mass balance over decadal time intervals and, thus, help to establish the representativity of the few direct mass balance observations (Haeberli and Hoelzle 1995, Hoelzle et al. 2003).

The global retreat of mountain glaciers during the 20th century is striking. Trends in long time series of cumulative glacier-length and volume changes represent convincing evidence of fast climatic change at a global scale. Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has documented such changes as evidence of the existence of global warming, independent of the various surface temperature datasets. Characteristic average rates of glacier thinning are a few decimeters per year for temperate glaciers in humid climates and centimeters to a decimeter per year for glaciers in continental climates with firn areas below melting temperature. The total retreat of glacier termini is commonly measured in kilometers for larger glaciers and in hundreds of meters for small ones. The apparent homogeneity of the signal at the secular time scale, however, contrasts with great variability at local/regional scales and over shorter time periods of years to decades. Intermittent periods of mass gain and glacier readvance during the second half of the 20th century have been reported from various mountain chains, especially in areas of abundant precipitation, such as southern Alaska, Norway and New Zealand.

Work for ALP-IMP on glaciers in the Greater Alpine Region will focus on mass balances as directly measured for a few decades on a number of glaciers and as reconstructed for longer time periods from past length variations. (Fig.4 and Fig. 5)

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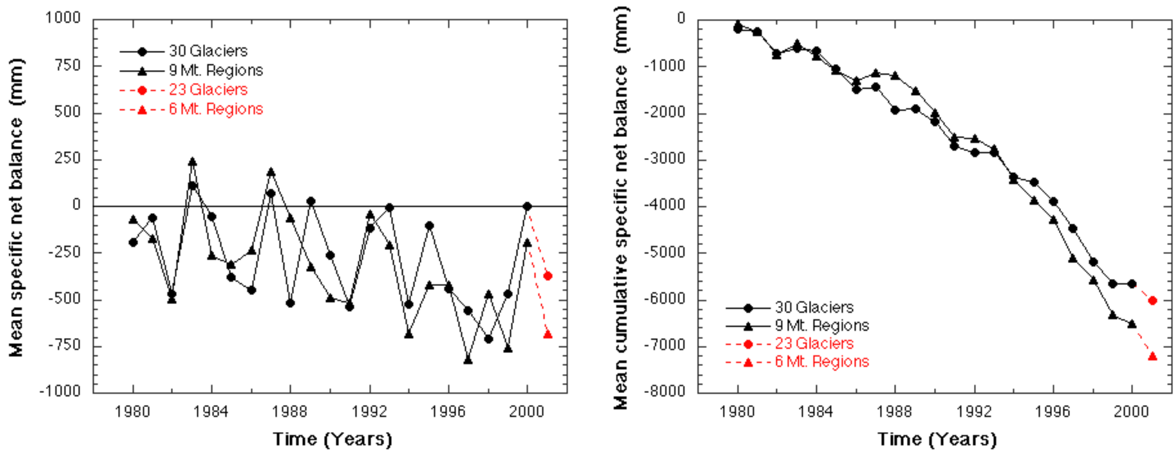

Figure 1: Recent glacier mass changes within major mountain systems

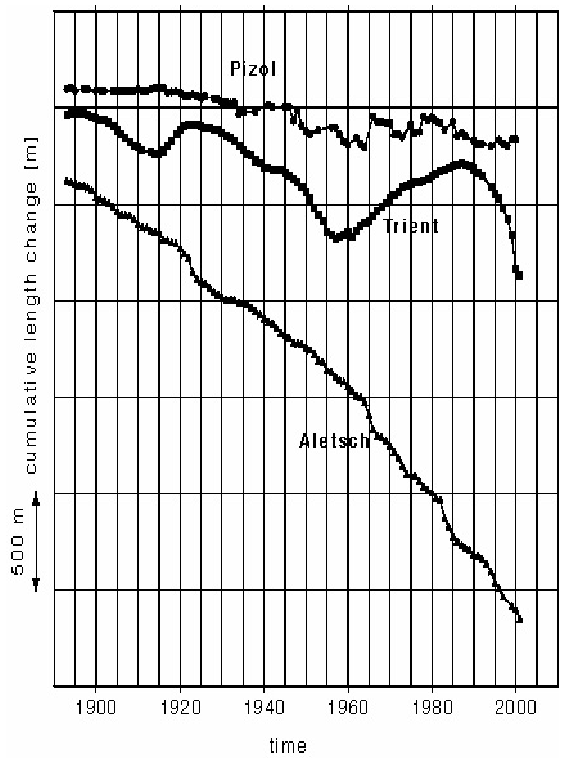

Figure 2: Dynamic reaction: glacier length change (advance/retreat)

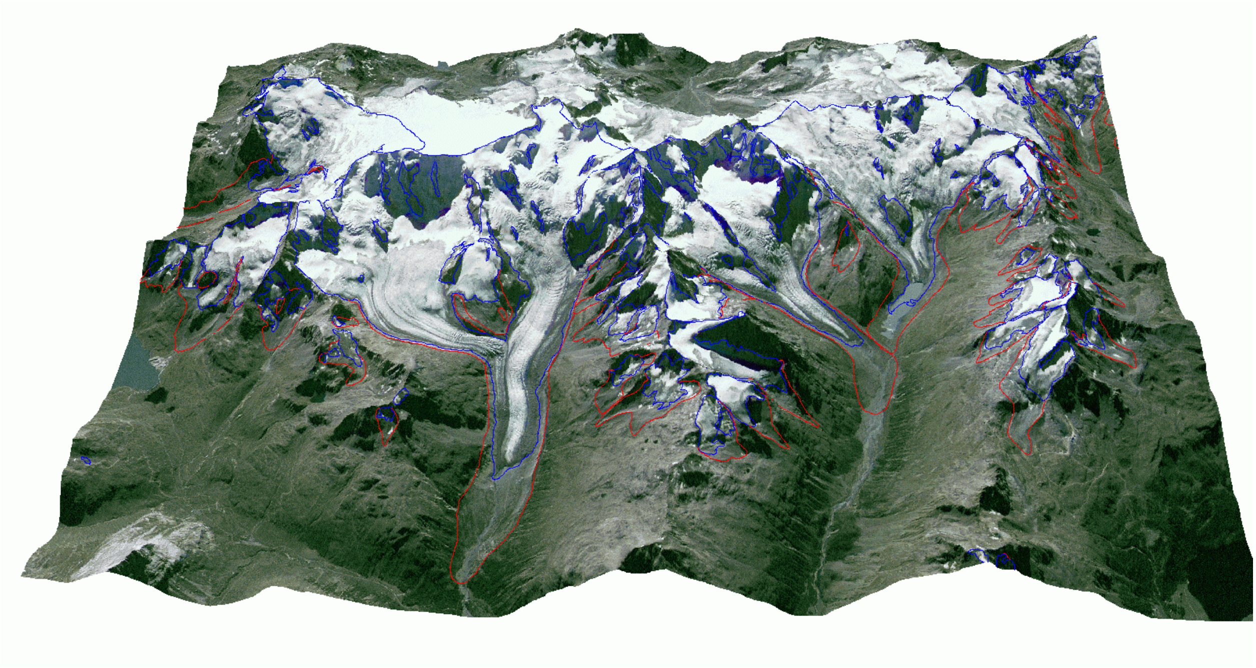

Figure 3: Repeated glacier inventories: Bernina group (Paul)

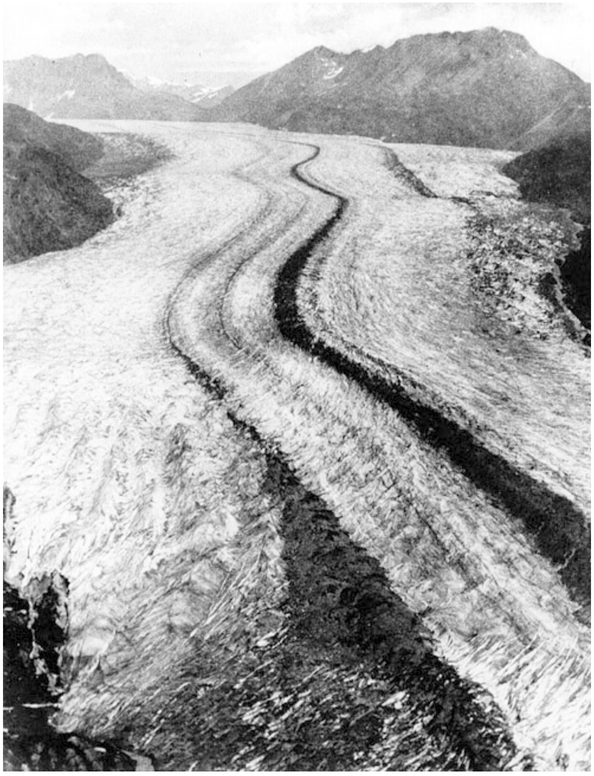

Figure 4: Aletsch historical length change: 1856, Martens and 2001, Holzhauser

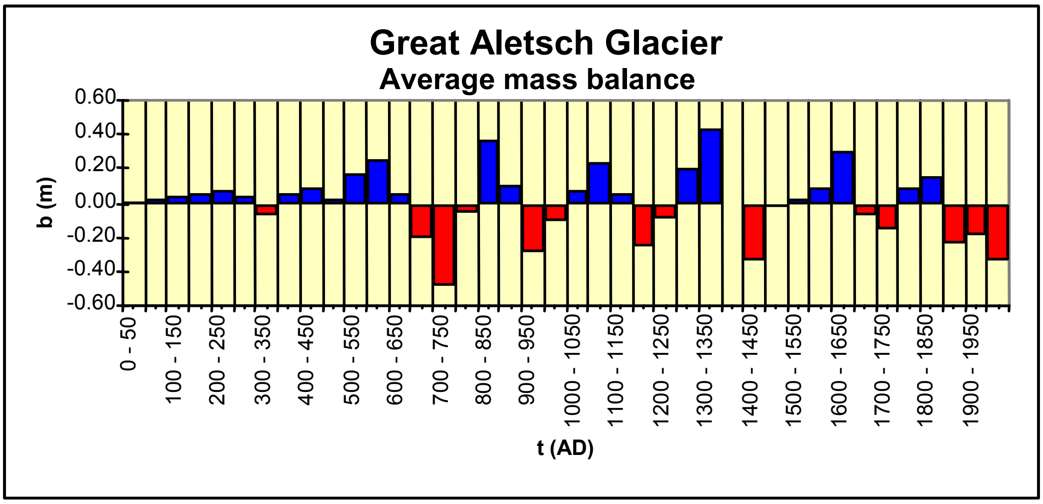

Figure 5: Aletsch reconstructed mean mass balance variation 0 to 2000 (AD)