GEOPHYSICAL RESEARCH LETTERS, VOL. 33, LXXXXX, doi:10.1029/2006GL026319, 2006

Alpine glaciers to disappear within decades?

Michael Zemp,[1] Wilfried Haeberli,[1] Martin Hoelzle,[1] and Frank Paul[1]

Received 21 March 2006; revised 11 May 2006; accepted 22 May 2006; published XX Month 2006.

[1] Past, present and potential future glacier cover in the entire European Alps has been assessed from an integrated approach, combining in-situ measurements, remote sensing techniques and numerical modeling for equilibrium line altitudes. Alpine glaciers lost 35% of their total area from 1850 until the 1970s, and almost 50% by 2000. Total glacier volume around 1850 is estimated at some 200 km^3 and is now close to one-third of this value. From the model experiment, we show that a 3°C warming of summer air temperature would reduce the currently existing Alpine glacier cover by some 80%, or up to 10% of the glacier extent of 1850. In the event of a 5°C temperature increase, the Alps would become almost completely ice-free. Annual precipitation changes of ±20% would modify such estimated percentages of remaining ice by a factor of less than two. **Citation:** Zemp, M., W. Haeberli, M. Hoelzle, and F. Paul (2006), Alpine glaciers to disappear within decades?, *Geophys. Res. Lett.*, *33*, LXXXXX, doi:10.1029/2006GL026319.

1. Introduction

[2] Impacts on cold mountain ranges from ongoing climate change are especially pronounced in regions above the timberline where effects related to perennial surface ice reflect increasing atmosphere/earth energy fluxes with extraordinary clarity [*Royal Swedish Academy of Sciences*, 2002]. Many mountain ranges have lost a significant proportion of their glacierization during the past 150 years with strong acceleration occurring in the past two decades [e.g., *Haeberli et al.*, 2005a, 2005b]. The shrinking of mountain glaciers is indeed the most obvious indication in nature of fast if not accelerating climate change on a worldwide scale. The predicted global temperature increase [*Intergovernmental Panel on Climate Change (IPCC)*, 2001] is likely to induce dramatic scenarios of future glacier developments including complete deglaciation of entire mountain ranges. Such future scenarios of glacier vanishing have thus far not been assessed quantitatively from spatial climatologies on an Alpine-wide scale, but are likely to affect landscape appearance, slope stability, the water cycle, sediment loads in rivers and natural hazards far beyond the range of historical and Holocene variability [*Watson and Haeberli*, 2004; *Barnett et al.*, 2005].

[3] In this study we apply an integrated approach, combining in-situ measurements, remote sensing techniques and numerical modeling to the European Alps. These techniques allow to quantitatively assess past as well as potential evolutions of area and volume of a glacier ensemble within an entire mountain chain. Glacier cover in the entire European Alps has been computed for different climate-change scenarios using satellite-derived glacier changes and a digital terrain model (DTM) together with a distributed model for equilibrium line altitudes (ELA). We thereby demonstrate the possibility of fast glacier disappearance within the European Alps, as well as the potential of new technologies to use information from glacier monitoring in mountain regions for quantification of global climate-change scenarios (Figure S1[1]).

2. Glacier Fluctuations From 1850–2000

[4] Information on glacier fluctuations in the European Alps is available from earlier and recent glacier inventories [*Haeberli et al.*, 1989; *Maisch et al.*, 2000; *Kääb et al.*, 2002; *Paul et al.*, 2002] (Figure S2) together with data compilations on past glacier fluctuations [*Zemp et al.*, 2006a] (Figure S2) National glacier inventories in the 1970s yield a total glacier area of 2909 km^2 [*Haeberli et al.*, 1989]. During the mid-1970s, glacier mass balances were close to zero or slightly positive [*Patzelt*, 1985] (Figure S3), many shorter glacier tongues slightly re-advanced and, hence, most glaciers were probably quite close to equilibrium conditions. The fact that the time basis for the corresponding inventory data is not uniform (Austria 1969, France 1967–71, Germany 1975, Italy 1975–84 and Switzerland 1973, cf. *Zemp et al.* [2006a]), therefore, plays a minor role: the center point of the corresponding time interval is thus defined as 1975. Detailed reconstructions of glacier areas around AD 1850 – the maximum extent for most glaciers in the European Alps at the end of the Little Ice Age – are available for the Swiss [*Maisch et al.*, 2000] and Austrian Alps (unpublished). The latest glacier inventory data based on satellite images is again available for most of the Swiss Alps in 1998/99 [*Kääb et al.*, 2002; *Paul et al.*, 2002], hereafter attributed to the year 2000 for the sake of simplicity. The Alpine glacier area in 1850 and 2000 is extrapolated by applying relative area changes for individual glacier size classes from the Swiss Alps to the corresponding entire Alpine glacier sample from 1975 (Table S1). This extrapolation reveals an overall loss in Alpine glacier area of 35% from 1850 up until 1975 (−2.8% per decade) and almost 50% by 2000 (−3.3% per decade). The area reduction between 1975 and 2000 is about 22% (−8.8% per decade), mainly occurring after 1985 (i.e., −14.5% per decade) as glacier fluctuation measurements and satellite-derived data have clearly shown [*Paul et al.*, 2004; *Zemp et al.*, 2006a] (Figure S3). Disintegration and

[1]Glaciology and Geomorphodynamics Group, Department of Geography, University of Zurich, Zurich, Switzerland.

0094-8276/06/2006GL026319$05.00

[1]Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2006gl026319.