Recent and Future Glacier Changes in the European Alps

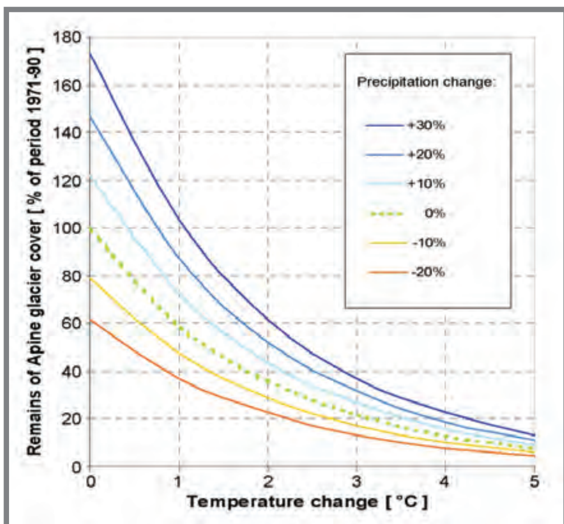
Frank Paul (fpaul@geo.unizh.ch), Michael Zemp, Martin Hoelzle, Wilfried Haeberli

Department of Geography, University of Zurich, Switzerland

European alpine glaciers lost about 35% of their total area from 1850 until the 1970s, and almost 50% by 2000 (Zemp *et al.*, 2006). With respect to the 1970s area, there was little change until 1985 (-1%) and a strong decrease (-20%) until the year 2000 (Paul *et al.*, 2004). This rapid decline in glacier area has been confirmed by analysis of more recent satellite data (Paul *et al.*, 2007a). This study compared Landsat TM and ASTER imagery from 2003/04 with the earlier data sets and found similar patterns of massive glacier retreat and thinning throughout the entire Alps. Thereby, the thinning was only derived indirectly by recognizing increasing areas with rock outcrops, separation of glacier tongues and disintegrating/collapsing glacier bodies, but is confirmed by direct mass balance measurements as well (Zemp *et al.*, 2005). At several locations pro-glacial lakes have been formed which are partly still growing.

The currently observed rapid changes are most likely a response to the sudden increase in Alpine temperature of about 1°C in the 1980s, which has shifted the equilibrium line altitude (ELA) by about 150 m upwards. From the application of simple GIS-based models (Paul *et al.*, 2007b; Zemp *et al.*, 2006) it could be shown that this ELA shift would reduce the overall glacier area by about 40%. About a half of this area has already disappeared and the remaining 20% is expected to disappear until 2020, even without a further temperature increase. Additionally, several positive feedbacks might have enhanced the decay, for example a gradual albedo lowering in hot and dry summers, increased turbulent heat fluxes from now ice free terrain, and surface lowering instead of a dynamic retreat towards higher elevations. Extreme events like the summer of 2003 melted most of the final firn reserves on many glaciers, which are now prone to an even faster melt (Paul *et al.*, 2007a; Zemp *et al.*, 2005).

If temperatures will increase even further (without a substantial increase in precipitation), the future of most glaciers in the Alps is doubtful. An increase of only 2°C would shift the ELA 300 m further upwards and could finally reduce the 1980s glacier area by about 80%, a result that has been obtained from both modelling approaches (Paul *et al.*, 2007b; Zemp *et al.*, 2006). Of course, due to a different ice thickness some glaciers will change their size more slowly, but the change will occur nevertheless.



Above: Modelled Alpine ice cover (climatic accumulation area) according to an increase in summer air temperature of +1 to +5°C and changes in annual precipitation. The total of 100% refers to the ice cover of the period 1971-1990.

References

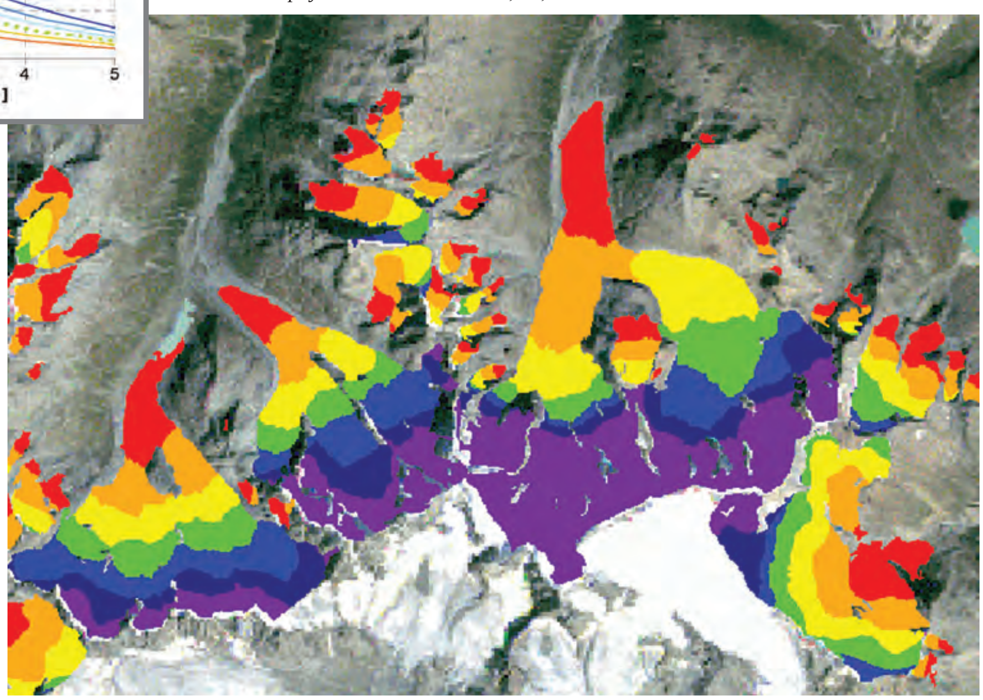
Paul, F., Kääb, A., Maisch, M., Kellenberger, T. W. and Haeberli, W. 2004: Rapid disintegration of Alpine glaciers observed with satellite data. *Geophysical Research Letters*, 31, L21402.

Paul, F., Kääb, A. and Haeberli, W. 2007a: Recent glacier changes in the Alps observed from satellite: Consequences for future monitoring strategies. *Global and Planetary Change*, 56 (1/2), 111-122.

Paul, F. Maisch, M., Rothenbühler, C., Hoelzle, M. and Haeberli, W. 2007b: Calculation and visualisation of future glacier extent in the Swiss Alps by means of hypsographic modelling. *Global and Planetary Change*, 55 (4), 343-357.

Zemp, M., Frauenfelder, R., Haeberli, W. and Hoelzle, M. 2005: Worldwide glacier mass balance measurements: general trends and first results of the extraordinary year 2003 in Central Europe. *Data of Glaciological Studies [Materialy glyatsiologicheskih issledovanii]*, 99, Moscow, Russia: 3-12.

Zemp, M., Haeberli, W., Hoelzle, M. and Paul, F. 2006: Alpine glaciers to disappear within decades? *Geophysical Research Letters*, 33, L13504.



On the right: Glacier extent for a part of the Bernina Group in the year 1973 (all colours) and modelled extent for six shifts of the ELA_0 (in 100 m steps) using an AAR_0 of 0.6. For each upward step of the ELA_0 the respective coloured glacier area will disappear (red: +100, orange: +200, etc). In the background is a Landsat TM satellite image from Sep. 1999, also showing glaciers in Italy which are not considered for the modelling. North is at top; image size is 15 km by 10.5 km; the used DEM is from swisstopo.