Continental-scale glacier variations in Europe (Alps, Scandinavia) and their connection to climate: past – present – future

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The understanding of long-term, natural climate variability on different spatial and temporal scales is crucial to assess the recent climate change in a global to regional context. Since glaciers are considered as very important climate indicators, the understanding of past and present glacier variations is a key task for evaluating current climate change (*1*), and expected future glacier decrease due to warming has large socio-economic consequences and implications (e.g. water supply, hydropower, natural hazards, tourism etc.) (*2*). Historical and proxy-records have documented that there is a substantial asynchronous development in temperature, precipitation and glacial variations between European regions during the last few centuries. The causes of these temporal anomalies are yet poorly understood (*3*).

This project investigates the importance of regional/continental temperature and precipitation (*4*, *5*) as driving factor for glacier dynamics (retreats, advances). The role of the atmospheric circulation over the North Atlantic/European area for similar/different glacier development in central and northern Europe covering the last few centuries is addressed, using glacier length and mass balance reconstruction data from a transect through the Alps and Scandinavia. Existing distributed glacier mass balance and equilibrium line altitude (ELA) models are able to calculate glacier ablation and accumulation in the course of a year from climatological data and a digital elevation model within specified glacier geometries. Such spatial models are not only suitable for reconstructions, they also build a key strategy for future studies of glacier-climate relationships and they will be applied in this project within Scandinavia and the Alps (*6*). They have proved to be quite accurate for small catchments and to be able to reproduce the observed glacier down-wasting. Their potential for large-scale applications in combination with gridded climatologies or output from Regional Climate Models (RCMs) have a large potential. The project will be addressed by the following major tasks:

- Determination of glacier length fluctuations using (mainly) historical data (*7*) in the entire Alps during the last half millennium, and comparison with Scandinavian (especially western Norwegian) glacier dynamics.
- Reconstruction of glacier mass balances for the Alps and Scandinavia covering the last 500 years (high- and low-resolution) based on the reconstructed glacier length data and seasonally resolved temperature and precipitation data.

- Investigation of the sensitivity of Alpine and Scandinavian glaciers to variations in temperature and precipitation (i.e. what combination of seasonally resolved climate parameters determine glacier advances and retreats in central and northern Europe?).
- Large-scale atmospheric circulation patterns responsible for significant temperature and precipitation variability across Europe will be used to physically explain similarities/contrasting glacier developments in central and northern Europe at decadal time-scales throughout the Little Ice Age and the 20th century.
- Application of existing distributed mass balance and ELA models to estimate future glacier behaviour within the different mountain ranges of Scandinavia and the Alps.
- Study of changing perception of the glaciers in the Alps and Scandinavia for the last few centuries.
- Transforming of this knowledge for the public (public relations).

The long-term glacier length record for the Alps and Scandinavia will also be stored in the existing database of the Global Terrestrial Network on Glaciers (GTN-G) as part of the World Glacier Monitoring Service (WGMS). A statistical approach using non-linear models incl. neural networks (*8*) will be used to account for the spatial dimension of glacier fluctuations in Europe. The comparison between these two areas is very promising because of their different behaviour related to the North Atlantic Oscillation (NAO). Since there are some limitations in the application of statistical models relating glacier mass balance to climatological parameters, a complementary method by reconstruction of mass balances will be used: The glacier length reconstruction data serve as input for these mass balance reconstructions using a continuity approach combined with a GIS-based energy balance model and gridded climate data. Finally, the mass balances are extrapolated for the entire Alps and Scandinavia using a distributed energy balance model (*9*). This enables a synoptical analysis of European climate related to its significance for glacier fluctuations for the last half millennium.

The project integrates glacier fluctuations extensively with large-scale circulation and seasonally resolved climate patterns. It is expected to give a better understanding of the influence of the European climate dynamics on glaciers in the Alps and in Scandinavia during the last half millennium.

Key references:

1. J. Oerlemans, *Science* **308**, 675-677 (2005).
2. W. Haeberli *et al., Ann. Glaciol.* **46** (in press).
3. A. Nesje, S. O. Dahl, *Holocene* **13**, 139-145 (2003).
4. J. Luterbacher *et al.*, *Science* **303**, 1499-1503 (2004).
5. A. Pauling *et al., Clim. Dyn.* **26**, 387-405 (2006).
6. M. Zemp *et al.*, *Geophys. Res. Lett.* **33**, 10.1029/2006GL026319 (2006).
7. H. J. Zumbühl, *Die Schwankungen der Grindelwaldgletscher in den historischen Bild- und Schriftquellen des 12. bis 19. Jahrhunderts* (Birkhäuser Verlag, Basel, 1980).
8. D. Steiner *et al.*, *J. Glaciol.* **51**, 313-323 (2005).
9. H. Machguth *et al., Ann. Glaciol.* **43**, 335-343 (2006).