A statistical mass-balance model for reconstruction of LIA ice mass for glaciers in the European Alps

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ABSTRACT. Stepwise linear regression models were calibrated against the measured mass balance of glaciers in the Austrian Alps for the prediction of specific annual net balance and summer balance from climatological and topographical input data. For estimation of winter mass balance, a simple ratio between the amount of winter precipitation and the measured winter balance was used. A ratio with a mean value of 2.0 and a standard deviation of 0.44 was derived from the sample of measured winter balances. Climate input data were taken from the HISTALP database which offers a homogenized data source that is outstanding in terms of its spatial and temporal coverage. Data from the Austrian glacier inventory were used as topographical input data. From the group of possible predictors summer air temperature, winter precipitation, summer snow precipitation and continentality (as defined from seasonal temperature variation) were selected as climatological driving forces in addition to lowest glacier elevation and area-weighted mean glacier elevation as topographical driving forces. Summer temperature explains 60% of the variance of summer mass balance and 39% of the variance of annual mass balance. Additional factors increase the explained variance by 22% for summer and 31% for annual net balance. The calibrated mass-balance model was used to reconstruct the mass balance of Hintereisferner and Vernagtferner back to 1800. Whereas the model performs well for Hintereisferner, it fails for some sub-periods for Vernagtferner due to the complicated flow dynamics of the glacier.

INTRODUCTION

The mass balances of glaciers directly reflect climate on both local and larger spatial scales. Many factors contribute to local climate and consequently to the mass balance of an individual glacier. Some of them are of a very local nature. Such local variable driving factors can result in adjacent glaciers with remarkably different glacier behaviour (not only length changes but also mass balance), as in the well-known example of Hintereisferner and Kesselwandferner in the Alps (Kuhn and others, 1985). A model which describes the mass balance of a glacier in general is therefore difficult to derive. Nevertheless the large efforts for such a model are balanced by the added value to climate research. Beside the interpretation of glacier-geomorphologic features in terms of climate (if combined with an ice-flow model) and resulting paleoclimate reconstructions, a climate–mass-balance model can be used for physical plausibility studies of paleoclimate data. Finally, the mass balance of a glacier, which results from the interaction of various climate elements, is also a highly sensitive measure of climate change.

Many studies have investigated the relationship between climate and glacier behaviour in the Alps and elsewhere. For example, Oerlemans and others (1998) and Reichert and others (2001) used a combined mass-balance and ice-flow model to estimate changes of glacier length and validated the model against observed glacier length records. In turn, Oerlemans (2005) used measured glacier length records worldwide and a simplified version of a combined mass-balance and ice-flow model to reconstruct annual global temperatures back to 1600 and compared it to other temperature proxy reconstructions. Besides physically based models, different types of statistical models have been used for investigation of climate–glacier relationships (see the review by Reynaud and Dobrovolski, 1998). This group of models includes degree-day approaches (e.g. Hoinkes and Steinacker, 1975; Braithwaite, 1981; Laumann and Reeh, 1993), simpler linear regression methods using monthly/seasonal/annual data of air temperature and precipitation (e.g. Kuhn and others, 1997) as well as neural network approaches (e.g. Steiner and others, 2005). Another promising approach consists in distributed (e.g. geographical information system (GIS)-based) mass-balance modelling for entire mountain chains (e.g. Machguth and others 2006). Although models based on physical laws should be the first choice for modelling the mass balances of glaciers, this group of models is limited if applied to long-term reconstructions. One major limitation for the application of physically based models comes from the lack of multiple meteorological input data, which is quite often overcome by parameterization (and consequently non-physical laws).

The European Alps represent a unique example in terms of climate information of the past from both direct (e.g. instrumental measurements) and indirect (proxy data) sources. Systematic instrumental measurements are available back to about 1750. They therefore cover the final part of the Little Ice Age (LIA) period, which is known to be systematically cooler by about 2°C compared to present-day climate. Moreover, in contrast to other regions elsewhere, three-dimensional evaluations of the lower troposphere of the Alps are possible from long-term instrumental series, using both lowland and high-elevation stations back to the early 19th century (Auer and others, 1998; Böhm and others, 1998). Applying long-term instrumental data, however, without any data processing is not useful. Many investigators showed that the potential of instrumental climate data can only be exploited if the data are subject to careful homogenization and quality control (e.g. Auer and others, 2006).