Due to their unique surface characteristics and their function as hydrological reservoirs, glaciers play an important role for water and energy budgets in many alpine areas. Regional climate models (RCMs) are an important tool in the analysis of the corresponding water and energy cycles and for the prediction of future changes in the individual components. In contrast to general circulation models (GCMs) the model domain of an RCM does not cover the entire globe but is typically restricted to some hundred to some thousand kilometres in x- and y-direction. This allows for the long-term simulation of regional climatic processes with a high horizontal resolution at comparatively low computational costs (current resolutions range from about 10 to 50 km). At the lateral domain boundaries, RCMs are driven by the output of a GCM or by global re-analysis products.

In mountainous terrain high resolution is especially important to resolve small-scale atmospheric processes, for instance those affected by orography or by details of the land surface. In many alpine areas the latter includes the presence of glaciers. However, mountain glaciers are only represented in an extremely simplified way—or even totally neglected—in state-of-the-art RCMs. Their size is usually far smaller than grid box resolution and only the largest glaciers are treated as fixed surface boundary conditions with runoff generation on glaciated surfaces being highly simplified. The simulation of a possible feedback of changes in ice cover extent to the atmosphere and of the influence of enhanced glacier melt on runoff conditions is therefore not possible.

To overcome these deficiencies and to represent processes related to mountain glaciers in an appropriate way, a glacier parameterization on the subgrid level has been developed and implemented into the RCM REMO (Jacob, 2001). The new scheme is embedded in the land surface model of the RCM and replaces the static glacier mask used previously. It bi-directionally couples the atmospheric model component to glaciated surfaces and allows for an explicit simulation of glacier mass and energy balance in each RCM grid box. Given the size of typical RCM domains, the new parameterization must be applicable on the scale of entire mountain ranges (e.g., the European Alps) and, hence, should only require a minimum amount of glacier-specific input data. At the same time it should be based on physical principles in order to ensure its predictive capability and its validity under future climatic conditions. Following these requirements a rather simplistic approach has been chosen in which the total ice mass within a climate model grid box is represented by a two-layer ice body covering a certain fraction of the total grid box area (see Figure, upper panel). Surface fluxes are derived separately for glaciated and non-glaciated parts. The glaciated fraction of an individual grid box is adjusting dynamically depending on accumulation and ablation conditions. Surface runoff and drainage originating from the glacier fraction are

Upper panel: Simplified treatment of glacier surfaces in REMO’s land surface model based on a dynamic tile approach. Example for a grid box covered by non-glaciated land (45%), glacier ice (15%), water (30%) and sea ice (10%).

Lower panel: Mean specific mass balance for the entire European Alps for the period 1958 to 2003 as simulated by REMO and as compiled by Dyurgerov & Meier (2005) and Frauenfelder et al. (2005).
added to total grid box runoff which finally closes the grid box water balance. The subgrid variability of precipitation and of global radiation within each RCM grid box is explicitly accounted for. In order to assess the effect of changing ice volumes on river discharge in glaciated catchments, a hydrological routing scheme is coupled to REMO in an offline mode.

The new parameterization scheme has been developed and validated in the area of the European Alps applying a horizontal RCM resolution of approximately 18 km x 18 km. The illustration shows a comparison between the simulated alpine-wide glacier mass balances for the period 1958-2003 (REMO) with recent estimates by Dyurgerov & Meier (2005) and Frauenfelder et al. (2005), both based on mean values of measured mass balances at individual glaciers. In a number of years, the simulated values almost match the observation-based estimates and the observed inter-annual variability of glacier mass balance is, in general, very well reproduced by the model. The strong glacier mass loss towards the end of the century is, however, clearly underestimated. We believe that this deficiency is mainly related to a) an overestimation of precipitation in the 1970s and 1980s as simulated by the atmospheric component of the RCM and b) the simplifying assumption of a uniform glacier surface in each REMO grid box which is either totally snow-free or totally covered by a snow layer. The simulated glacier area loss in the Alps between 1958 and 2003 is 23.6 % which is less than estimates based on glacier inventory data (about 30 %).

A further interesting point from the climate modelling perspective is to investigate the influence of glaciers on the regional climate (the full feedback loop is closed as the new parameterization scheme is coupled in a two-way mode to the RCM). In the chosen model setup the effect of the new subgrid parameterization on atmospheric parameters is generally restricted to the lower troposphere and to glaciated grid boxes. A full description of the new parameterization scheme as well as more details on model results can be found in Kotlarski (2007).

References:

News from Glaciers-online
"Glaciers-online" has recently added a new section to their website which may provide useful information for educational purposes. This new page shows imagery of Arctic islands with brief descriptions focusing on glaciology and other aspects of the natural history of the Canadian Arctic, Greenland, and Svalbard.
<www.glaciers-online.net/arctic-islands/>.

The site's Alpine glacier section has been developed further to include more images. For instance, repeat photography of the Stegletscher and the Triftgletscher that illustrates their dramatic recession over the last five years.
<www.glaciers-online.net/glaciers/alps/>.

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