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A Subgrid Glacier Parameterisation for Use in Regional Climate Modelling

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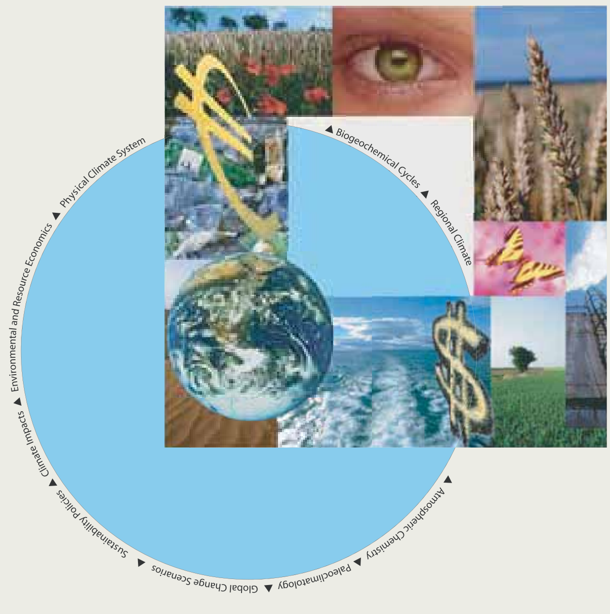

Summary

Due to their unique surface characteristics and their function as hydrological reservoirs glaciers can be considered as an interacting component of the climate system. In alpine areas they often play a major role in determining regional water and energy budgets. 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. However, glaciers are only represented in an extremely simplified way (or even totally neglected) in state-of-the-art climate models. Their size is usually beyond grid box resolution and only the largest glaciers are treated as fixed surface boundary conditions with runoff generation on glaciated surfaces being simplified to a very high degree. The direct prediction of changes in glacier mass balance and glacier extent as a response to changing climatic conditions is therefore not possible. As a consequence, the feedback of changes in ice cover to the atmosphere and the influence of enhanced glacier melt (as generally expected for the next decades) on runoff conditions cannot be assessed.

To overcome these deficiencies and to represent glaciers in an appropriate way, a subgrid glacier parameterisation has been developed and implemented into the RCM REMO. The new scheme partly replaces the static glacier mask used so far and includes the explicit simulation of glacier mass and energy balance. The total ice mass within a climate model grid box is represented by a two-layer ice cuboid covering a certain fraction of the total grid box area. Surface fluxes are derived separately for glaciated and non-glaciated parts. The subgrid variability of snowfall and of global radiation within a climate model grid box is explicitly accounted for by simple redistribution concepts. The glaciated fraction of an individual grid box is adjusting dynamically depending on accumulation and ablation conditions and following simple volume-area relationships. Surface runoff and drainage originating from the glacier fraction are added to the total grid box runoff thereby closing the grid box water balance. In order to assess the effect of changing ice volumes on river discharge the routing scheme HD (Hydrological Discharge) is coupled to REMO in an offline mode. Several simulations with the new model system $\text{REMO}_{\texttt{glacier}}$ have been carried out for the period 1958-2003 for the European Alps, driven by the ERA40 re-analysis and the operational analysis of the ECMWF at the lateral boundaries. In all experiments a standard horizontal resolution of $^1/_6{}^\circ$ (approx. 18 x 18 km^2) has been used.

The temporal evolution and the general magnitude of the simulated glacier mass balance are in good accordance with observations, especially during the first half of the investigated period. However, the strong mass loss of Alpine glaciers towards the end of the 20$^{\text{th}}$ century is systematically underestimated by $\text{REMO}_{\texttt{glacier}}$. This is especially true for grid boxes along the northern slopes of the main Alpine ridge which experience a net gain of ice-covered area and ice volume. Probably, these shortcomings are associated with a strong positive bias of the simulated wintertime precipitation compared to observational datasets and with the assumption of a uniformly distributed snow layer on top of the grid box glacier cuboids. Depending on the chosen method for translating glacier mass changes into changes of the ice-covered area (volume-area relationship), the simulated total glaciated area in the Alps considerably decreases from 1958 to 2003 by -17.1 to -23.6% (ice volume: -15.5 to -16.7%).

Concerning the influence of glaciers on the regional climate, the effect of the new subgrid parameterisation on atmospheric parameters is generally restricted to the lower troposphere and to glaciated grid boxes themselves as well as their direct vicinity. The large scale flow conditions are not affected significantly in the chosen model setup. In glaciated grid cells the incorporation of the glacier scheme into REMO causes a lowering of the near surface air temperature by several degrees Celsius and a less intense local recycling of water by reducing both precipitation and evapotranspiration. These effects are most pronounced in summer and autumn. Also the influence of the new parameterisation scheme on surface hydrology is mainly restricted to strongly glaciated areas in high-altitude regions of the Alps. Here, glacial meltwater can play an important role especially in late summer and early autumn by contributing a considerable fraction (more than 20%) to the total amount of grid box runoff and river discharge.

The simulated glacier mass balance and the corresponding changes of the ice-covered area strongly depend on the chosen value for a number of model parameters. Especially the adequate description of the subgrid variability of snow accumulation, global radiation (slope and shading effects) and air temperature is of high importance. The latter is so far not accounted for in the standard parameterisation scheme. Generally, the results obtained indicate that it is possible to approximately reproduce observed regional glacier mass balances within an RCM based on extremely simple concepts of glacier-climate interaction. However, it has also been shown that realistic results can only be achieved if the subgrid variability of atmospheric parameters within a climate model grid box is explicitly accounted for.