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Climate Change Effects on the Alpine Snow Cover

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Summary

In this paper a stochastic weather generator is applied to provide long time series of consistent synthetical future climate data from measured historical records. The stochastic weather generator is applied to weekly episodes of a hourly meteorological dataset from a network of climate stations in the high alpine area of the Berchtesgaden National Park (Germany). The generated future climate scenario includes a temperature increase of 1.5 °C until 2050, and a corresponding up-to-10 % shift of precipitation from summer to the winter months. Then the energy balance snow cover model AMUNDSEN (Alpine Multiscale Numerical Distributed Simulation Engine) is applied using the generated future climate data time series to simulate the respective seasonal evolution of the snow cover in the National Park area. AMUNDSEN includes physical descriptions of specific alpine snow processes such as the complex interaction of topography and radiation, snow slides or canopy-snow interception and sublimation. The results reveal and spatial effects of the changing climatic conditions on the seasonal duration of the snow cover.

Keywords

Climate change, mountain snow cover, stochastic weather generator

Methods

We apply the ***A****lpine* ***MU****ltiscale* ***N****umerical* ***D****istributed* ***S****imulation* ***EN****gine* AMUNDSEN (Strasser 2008) for a reference period and a future scenario period to investigate the effect of a changing climate on the snow cover period duration in the area of the Berchtesgaden National Park (Germany, fig. 1). To drive the model, continuous recordings from an automatic network of meteorological stations are utilized (table 1); the latter also serve as data base for generating a future data series accounting for a changing climate by applying a stochastic weather generator. AMUNDSEN includes several interpolation routines for scattered meteorological measurements, rapid computation of topographic parameters from a digital elevation model, sophisticated simulation of short- and longwave radiative fluxes including consideration of shadows and cloudiness, parameterization of snow albedo, modelling of snow- or icemelt, modelling of forest snow processes and of gravitational snow slides, and a built-in stochastic weather generator to produce synthetic future meteorological data for climate change scenario simulations (Strasser & Mauser 2006). The latter produces data with the same temporal resolution as the input data, i.e. as is required by the snow model, and does not alter the physical relations between the meteorological parameters. Basic assumption of the method is that a climate storyline can be divided into time periods which are characterized by a certain temperature and precipitation, and these two variables are not independent from each other:

$$\overline{P} = f\left(\overline{T}\right)$$

with $\overline{P}$ being the mean precipitation of a certain time period, $\overline{T}$ its mean temperature and f their functional dependency. In our application the periods are weeks (fig. 2).

A typical annual course of the meteorological variables is constructed by computing mean temperature and total precipitation for the periods using all years of the measured historical dataset. This mean annual climate course is used to construct the future data period by period: first, the according temperature is modified with a random variation and the given trend. Then a corresponding precipitation is derived, considering the T/P relation and again a random variation. As a result, the week to construct is defined by a certain temperature and precipitation. In a last step, the period from the historical periods with the most similar T and P is selected applying the nearest neighbour criterion. Measured data of this period is then added to the future time series to be constructed. This procedure is repeated for all 52 weeks of the year, and all years of the future time series. For this study, the weather generator was applied to produce time series of hourly air temperature, precipitation, global radiation, relative humidity, and wind speed for the period 1 August 2006 to 31 July 2050, assuming a temperature increase and a shift of precipitation from the summer season into the winter: a linearly increasing amount of mean weekly precipitation, up to a maximum difference of 10 % in 2050, is subtracted from the selection measure of all weeks between May and September and added to it for all weeks between November and April. Consequently, the weather generator selects weeks with more observed precipitation in winter, and weeks with less observed precipitation in summer to build up the scenario dataset.

Results

As one first indicator for the effect of a changing climate on the simulated snow cover, the mean future seasonal snow cover duration is analyzed. For this purpose, the obtained continuous hourly climate datasets for the reference period 1998–2006 and the scenario period 2042–2050 have been used to compute averages for the annual duration of the snow cover (e.g., number of days with snow on the ground). The results are spatially distributed and covering the entire area of the National Park.

The map of the mean annual differences in the duration of the snow-covered period between 2042–2050 under scenario conditions and the reference period 1998–2006 is characterized by a complex pattern. The following structures can be detected: (i) a general decrease in the duration of the snow-covered period in the valley regions from NE towards SW, (ii) a separation of the forested areas (substantial decrease in the number of snow days) from non-forested areas (moderate decrease in the number of snow days), (iii) the maximum reduction of the period of snow coverage in the snow slide deposition zones, and (iv) a moderate increase in the number of snow days in areas where snow is entrained and gravitationally transported by means of the snow slides model.

On the plateau of the Untersberg in the very North of the domain, the warming and increased precipitation in winter compensate for each other, whereas on the plateau of the Reiter Alm (in the same elevation), the change equals approximately −14 days (non-forested areas) to −18 days (forested areas). The yellow-reddish coloring for the valleys corresponds to −10 days, approximately.

In the forested areas, the reduction of the snow-covered period, amounts to values around 20 days. The sublimation of previously intercepted snow in the canopy is an efficient process remarkably reducing the duration of the period of snow coverage beneath the canopy. This process is strongly dependent on radiation input, and therefore considerably more efficient during the changed climate. A maximum reduction of the snow-covered period (35 days) can be detected in the snow slide deposition zones. Here, the effect of additional winter precipitation is compensated most efficiently by the higher temperature, additional increase of global radiation (+7.6 W m^{-2}), and reduced relative humidity (−1.9 %) during summer, all supporting a more efficient melting process.

Finally, the duration of the snow-covered period is moderately increased in the steep zones of entrainment and gravitational transport of snow. Whereas in other regions the mass balance of the snow cover is controlled by precipitation input and the energy balance in the transport zones it is mainly forced by precipitation input and consecutive gravitational removal of snow. As a consequence, snow is efficiently removed after each snowfall event, and the remaining snow layer quickly becomes thin enough to completely melt out the next time the energy balance becomes positive, even in mid winter. The absolute number of snow days in the transport zones is considerably smalier than in non-transport zones of the same elevation, clearly visible at the mountain ridges. Consequently, an increase in winter precipitation (mostly snowfall at these elevations) results in more days with snow coverage.

For the distributed patterns of snow cover duration it can be concluded from the simulations, that a general warming will lead to shorter snow-covered period, the effect being most pronounced in forested areas. On steep rock faces, snow might remain longer due to the more frequent precipitation events (with precipitation still falling as snow). If precipitation increases in winter, the increased air temperatures will be compensated for to a certain extent, and again the forested areas react most sensitive to the change.

The snow cover duration in the snow slide accumulation zones seems to depend more on the melt energy supply rather than on accumulation amount.

Conclusions

Applying the stochastic weather generator a future climate change scenario was constructed and used for a prognostic model run to estimate the potential seasonal evolution of the mountain snow cover under changed climatic conditions. For an assumed moderate trend towards higher temperatures and a shift of precipitation from summer to winter, the results show a rapid but spatially very differentiated decline of snow cover duration. Overall it becomes evident that although the increased winter precipitation still predominantly falls as snow, the additional accumulation of the snowpack is compensated for by the higher temperatures.

References

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STRASSER U. & MAUSER W. (2006): Using a stochastic climate generator for simulating global warming effects on the water resources in a mountain basin, Geophysical Research Abstracts, Abstracts of the European Geosciences Union General Assembly 2006, Vienna, Austria.

Figures

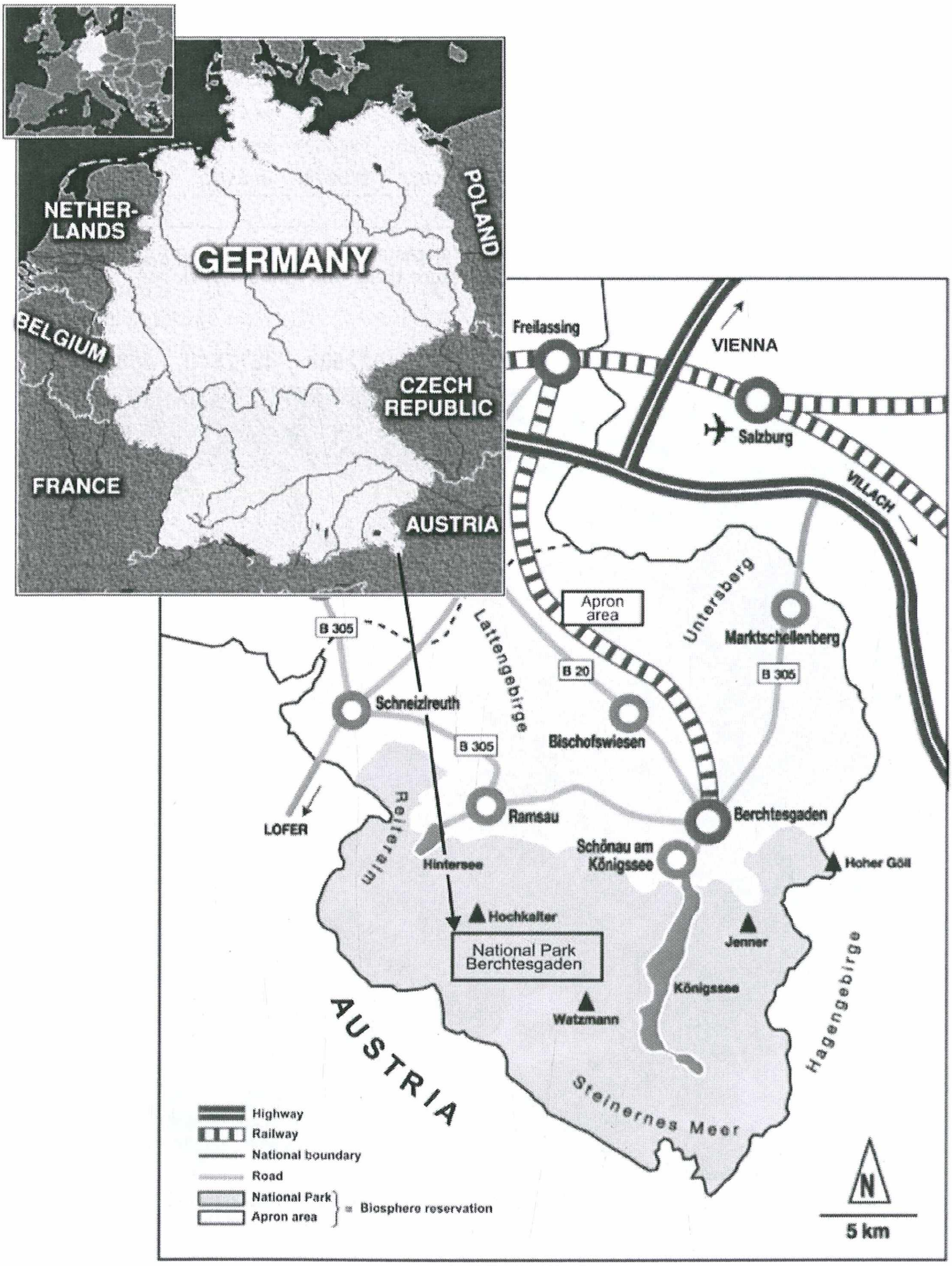

Figure 1: Location of the Berchtesgaden National Park (Germany).

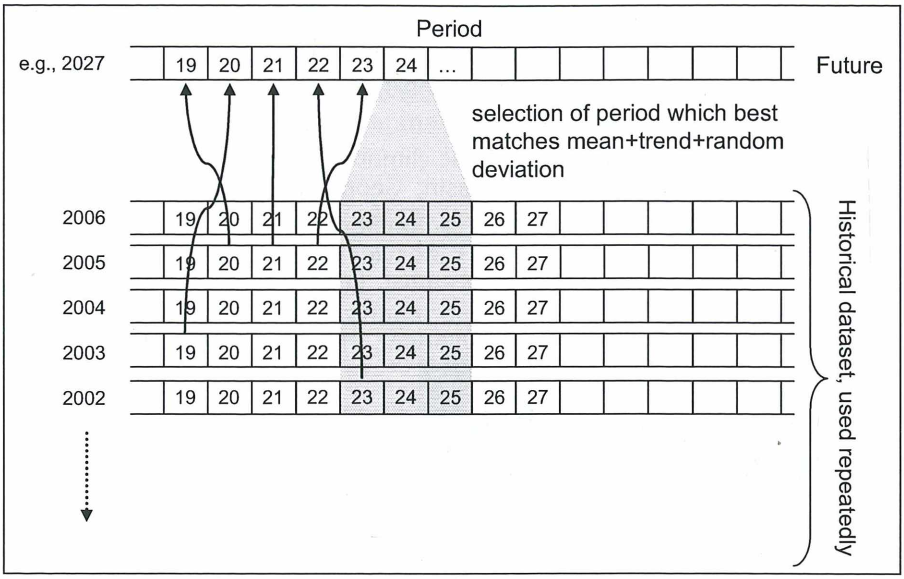

Figure 2: Principle of selecting periods of measured data to build up a future data time series with a certain temperature trend and random deviation.

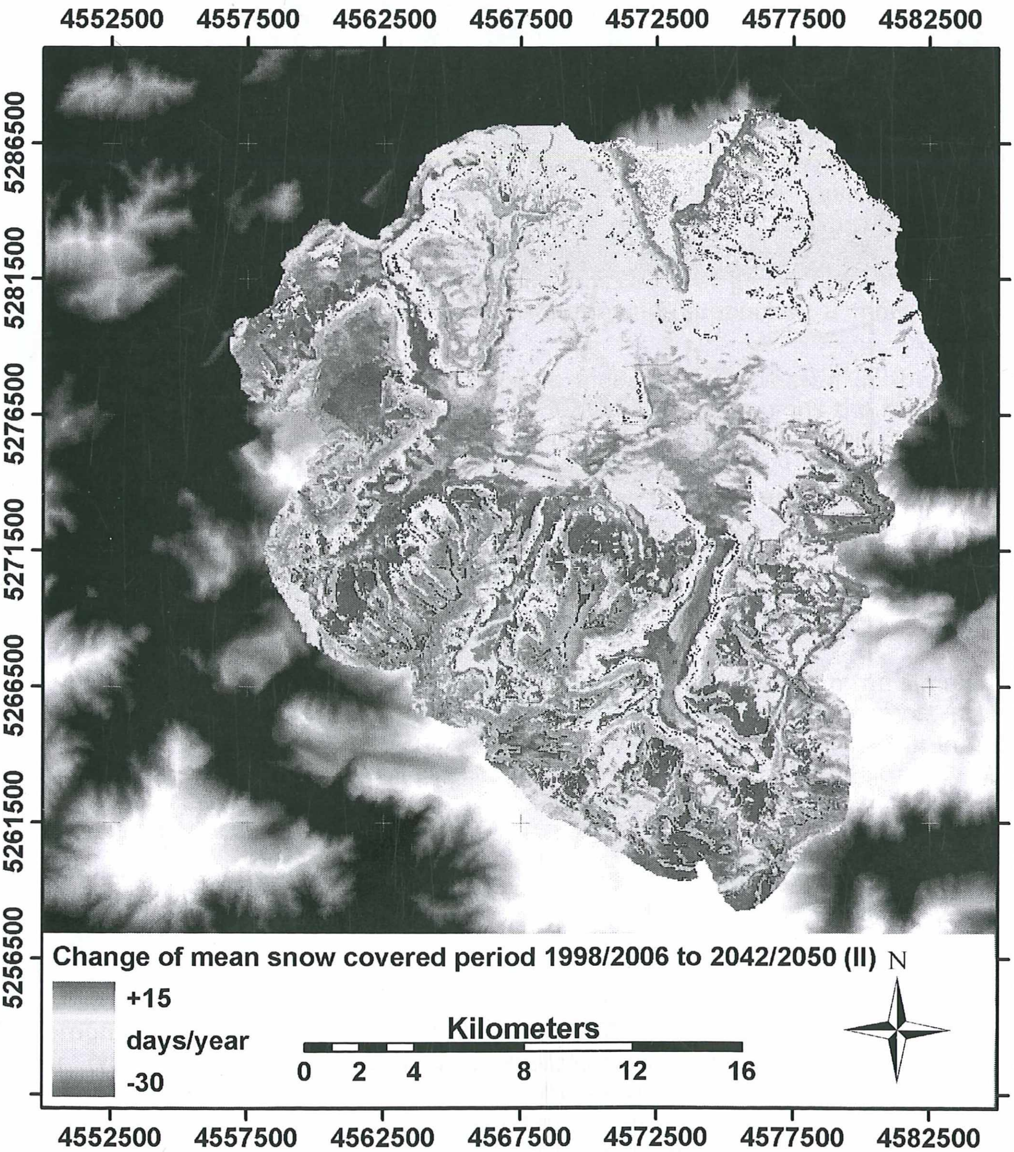

Figure 3: Mean annual difference in the duration of the snow-covered period between 2042–2050 under scenario conditions and the reference period 1998–2006.

Tables

Table 1: Meteorological stations and variables recorded in the Berchtesgaden National Park. The level of the temperature recordings is given with respect to the ground level.

Station	Elevation [a.s.l.]	Easting [m]	Northing [m]	Variables	Sampling rate
Reiter Alm I	1755 m	4560494	5279436	W, W_{max}, WD	10 min
Reiter Alm II	1670 m	4560835	5279235	T_a, T_s, T_{s20}, T_{s40}, T_{s60}, T_s, RH, H_s	10 min
Reiter Alm III	1615 m	4560950	5278982	T_a, RH, G, G_{ref}, P, H_s	10 min
Kühroint	1407 m	4572314	5270625	T_a, RH, G, G_{ref}, W, WD, P, H_s	10 min
Funtenseetauern	2445 m	4572939	5261755	T_a, RH, W, WD	10 min
Jenner I	1200 m	4576659	5272417	T_a, T_{s0}, T_{s20}, T_{s40}, T_s, RH, H_s	10 min
Jenner II	660 m	4575000	5273988	T_a, RH, P	10 min
Schönau	617 m	4573987	5275597	T_a, T_{a05}, RH, G, G_{dir}, SS, W, WD, P, p	10 min
Untersberg	1776 m	4575822	5287649	T_a, RH, W, W_{max}, WD, P	30 min

W	=	wind speed	T_s	=	snow temperature (at the surface)
W_{max}	=	maximum wind speed	RH	=	relative humidity
WD	=	wind direction	H_s	=	snow height
T_a	=	air temperature (2 m)	SS	=	sunshine duration
T_{a05}	=	air temperature (0.05 m)	G	=	global radiation
T_{s0}	=	snow temperature (0.0 m)	G_{dir}	=	direct radiation
T_{s20}	=	snow temperature (0.2 m)	G_{ref}	=	reflected radiation
T_{s40}	=	snow temperature (0.4 m)	P	=	precipitation
T_{s60}	=	snow temperature (0.6 m)	p	=	atmospheric pressure

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