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Seasonal snow cover evolution in the Nationalparks Austria since 1961

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Abstract

We analyse past snow cover changes and trends (seasonal mean snow depth SD, seasonal snow cover duration SCD) within the six Nationalparks Austria over the period 1961 to 2017 using a spatially distributed numerical snow model calibrated with homogenized long-term point measurements and satellite data and driven with newly available gridded meteorological data based on point observations. Results show a marked and significant SCD decrease (-5 to -7 days per decade) over the whole investigated period in all analyzed parks, whereas past SD changes are only significant negative in half of the parks. There is no strong elevation dependency of the calculated SCD trends although numbers start to become less negative above 1000 to 1500 m a.s.l. Negative SCD trends are even visible up to 2500 m a.s.l. For most of the shorter time (sub-) periods in the investigated period trends become non-significant as natural inter-annual to decadal variability of the snow cover dominates. Positive significant snow cover trends are not visible in any park within the investigated period.

Keywords

snow cover, cryosphere, snow depth, snow cover duration, warming climate, climate change

Introduction

Observed changes of the natural seasonal snow cover in Austria are characterized by high inter-annual to decadal and regional variability (NACHTNEBEL et al. 2014) which indicates a high sensitivity to atmospheric and climatic conditions and thus climate change. In Austria, temporal changes of the seasonal snow cover have widespread implications i.e. for society and economy (e.g. winter tourism), hydrology (temporal storage of water, evapotranspiration, soil moisture) and ecology (influence on the vegetation cycle and on plant species). For the six national parks in Austria ('Nationalparks Austria' (NPA)) these impacts are mainly restricted to hydrological and ecological impacts, although changes in the winter landscape may also have effects on park tourism and thus economy. Many studies about past snow cover variability and changes exist for Switzerland (e.g. BENISTON 1997; KLEIN 2016; LATERNSER & SCHNEEBELI 2003; MARTY 2008; MARTY et al. 2017) but less for Austria (e.g. HANTEL et al. 2000; SCHÖNER et al. 2009; MARKE et al. 2015). The most recent analysis of the snow cover evolution in Austria was conducted within the ACRP -funded project SNOWPAT (SCHÖNER et al. 2013; MARKE et al. 2015; 2016). A majority of these studies report a decrease of the snow depth since the mid-1980s for stations in lower elevations. MARTY et al. (2017) recently found a region independent reduction of snow water equivalent in the Swiss Alps driven by increasing temperatures and a coincident weak reduction of precipitation.
All of these studies make use of local station recordings and do not present an area-wide, spatiotemporal assessment of snow cover changes. Currently, MARKE et al. (in prep) and OLEFS et al. (in prep) are preparing first area-wide assessments of past snow cover changes in Austria using spatially distributed numerical snow models. In this study, we extract and analyze the results of the study of OLEFS et al. (in prep.) for the areas of the NPA.

Methods

A climate version of the operational SNOWGRID model (OLEFS et al. 2013) is used to derive daily grids of snow depth and snow water equivalent at a spatial resolution of 1x1 km for whole of Austria since the year 1961. This is done using recently created gridded datasets of air temperature, precipitation (HIEBL & FREI 2016; 2017) and snow sublimation (adapted from HASLINGER & BARTSCH 2016) at same temporal and spatial resolution that take into account the high variability of these variables in complex terrain. The model accounts for the shortwave radiation balance (PELLICCIOTTI et al. 2005) and uses a simple 2-layer scheme, considering settling, the heat and liquid water content of the snow cover and the energy added by rain as well as a simple scheme for lateral snow redistribution (FREY & HOLZMANN 2015). In a next step, so called snow indicators (e.g. snow cover duration, max. 72-H snow amounts) are derived that allow a climatic characterization of the snow cover to finally calculate area-wide changes and long-term trends. Calibration and validation of the model results are realized using homogenized long-term time-series of total snow depth and new snow amounts, recent operational snow depth measurements using laser sensors, winter glacier mass balance measurements, cumulative runoff data and satellite products (MODIS fractional snow cover). The selected snow indicators mean seasonal snow depth (SD) and snow cover duration (SCD) for the months November to April (NDJFMA) are extracted from the raster dataset for the NPA. SCD indicates the number of days with snow depth >= 1cm. The extraction is done using shapefiles of the national park borders (average of all pixels inside the respective park; Shapefiles are provided by the Umweltbundesamt GmbH - data.umweltbundesamt.at) and investigated with respect to past changes and trends (Mann-Kendall test (MANN 1945; KENDALL 1975)).

Results

The results of the model validation against point measurements (69 homogenized long-term point measurements: squared correlation coefficient of 0.69; Bias = 0.03 m) and satellite data (>600 scenes; skill score = 0.76) indicate a very good model performance over Austria.

During the climate normal period (1981-2010), SD and SCD in the analyzed NPA (see Fig. 1) are in the range of 1 to 128 cm and 33 to 174 days, respectively. As Tab.1 suggests, significant decreasing SCD trends (-5 to -7 days per decade) are calculated in all six parks for the period 1961-2017, for SD this is only found in the Salzburg part of the Hohe Tauern, the Kalkalpen park and very small (but significant) trends in the Donau-Auen park. Fig. 2 shows the average temporal evolution of SCD in all six parks for the period 1961 to 2017. Fig. 3 depicts the results of a running-trend analysis of SCD in all six parks based on the time-series shown in Fig. 2 (trends are not analyzed for periods < 20 years) and indicates that significant decreasing SCD trends over the last 50 to 55 years are found in all parks whereas they are only visible in the Gesäuse and Kalkalpen Park at shorter time-scales within the period 1961-2017. A marked SCD decrease since the year 2005 that is striking in Fig. 2 is still to recent in time to be analyzed in terms of possible trends (minimum 20 year window). Above around 1500 m a.s.l. negative SD and SCD trends over the whole period become gradually less negative with elevation in most of the relevant parks (Hohe Tauern, Kalkalpen), in Gesäuse park this already starts at 1000 m a.s.l.. Below these altitude limits there is practically no elevation dependency of the calculated trends. The Kalkalpen park is the only one with largest decreasing trends in mid elevations (1100 to 1500 m a.s.l.). Trends are still negative in 2500 m a.s.l. in the Hohe Tauern park. Above this altitude model uncertainty largely increases due to wind effects (lateral snow redistribution). In general, there are no positive significant snow cover trends in any park within the investigated period.

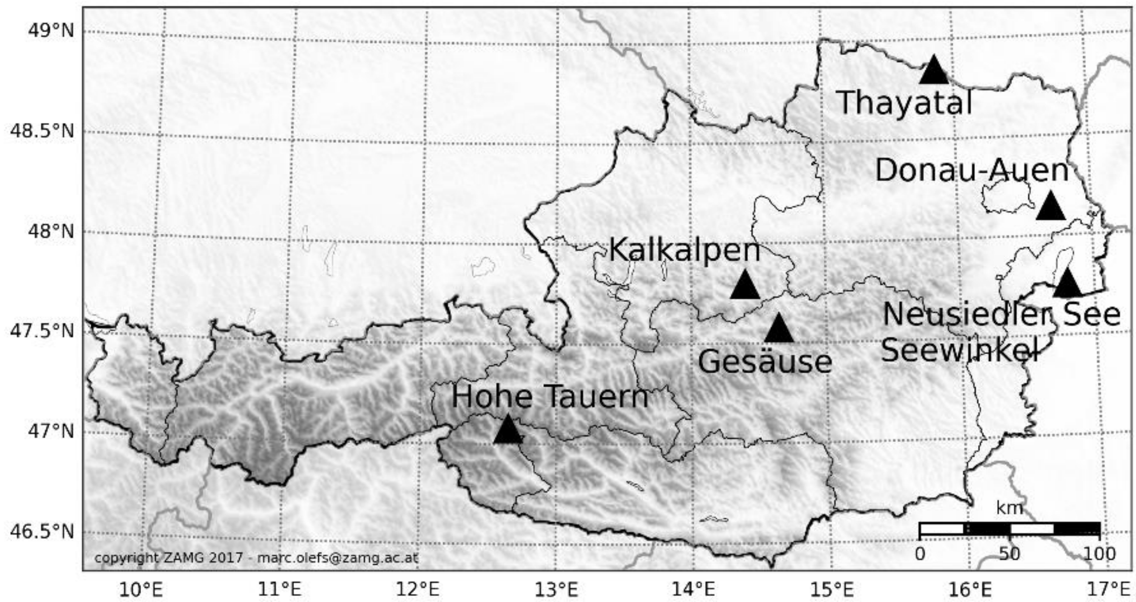

Figure 1: Topographic map with the six Nationalparks Austria (NPA) investigated in this study.

national park	SD cn [cm]	SCD cn [d]	SD Trend [cm/dec]	SCD Trend [d/dec]	MAE SD [cm]	MAE SCD [d]
Hohe Tauern KT/TI/SB	128	174	-4	-7**	8	19
Hohe Tauern KT	126	174	-3	-7**	8	19
Hohe Tauern TI	145	178	-3	-7*	8	19
Hohe Tauern SB	114	171	-5*	-7**	8	19
Gesäuse	52	145	-2	-6**	6	22
Kalkalpen	54	139	-4*	-7**	8	14
Thayatal	2	37	0.0	-5*	<1	7
Donau-Auen	2	37	-0.0*	-5*	1	7
Neusiedler See / Seewinkel	1	33	0.0	-5*	1	7

Table 1: Climatological snow cover characteristics and past changes calculated with the SNOWGRID-CL model for the Nationalparks Austria. SD = seasonal mean snow depth for the months November to April (NDJFMA) in cm, SCD = snow cover duration (NDJFMA) in days, Cn = climate normal period 1981-2010, Trends are given in units per decade (dec) for the period 1961 – 2017, significant trends are marked with one (95 % significance level) or two (99% significance level) asterisks, MAE = mean absolute error of the model compared to homogenized long-term measurement in the surroundings of the respective parks. For the Hohe Tauern park province specific analyses are performed (KT= Carinthia, SB = Salzburg, TI=Tirol).

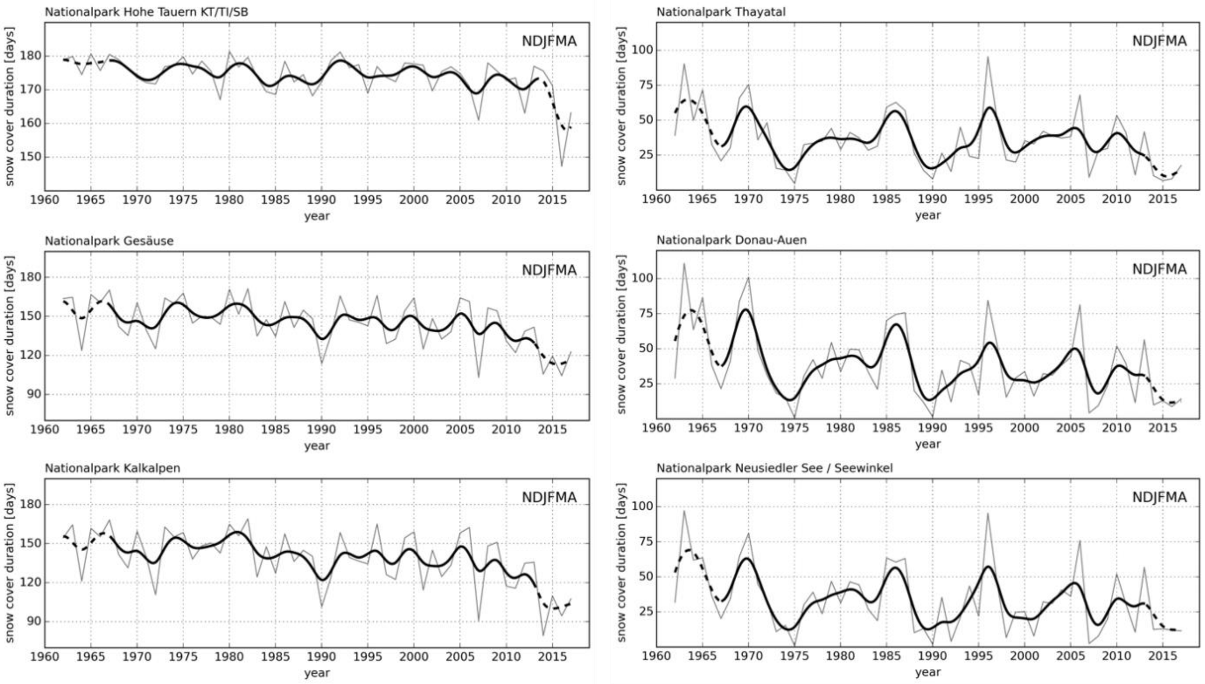

Figure 2: Calculated seasonal snow cover duration (NDJFMA) for the period 1961 – 2017 in the six Nationalparks Austria (annual values (thin line) and 11-year low-pass (gaussian) filtered values).

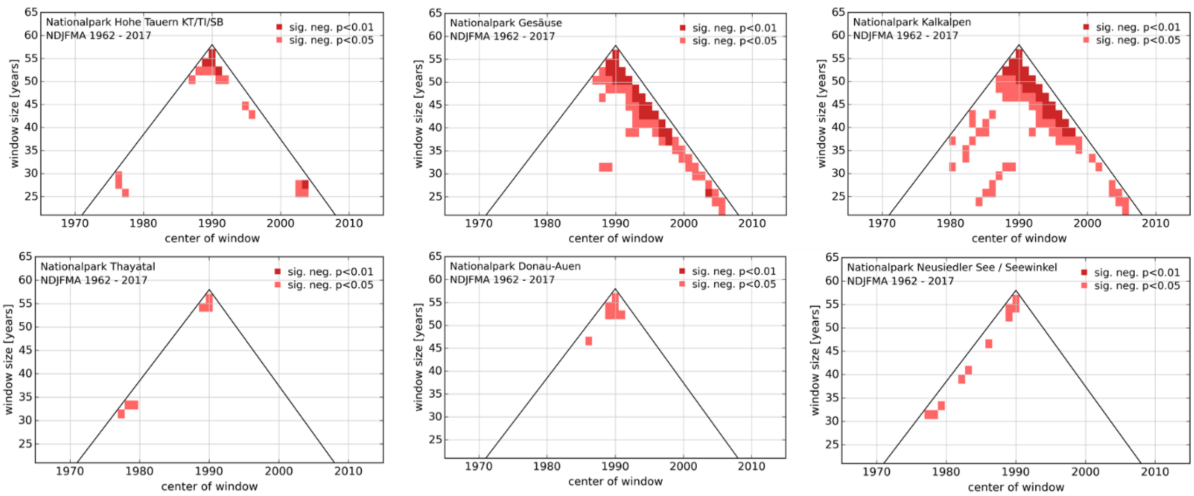

Figure 3: Running-trend analysis of seasonal snow cover duration (NDJFMA) for the period 1961-2017 in the six Nationalparks Austria. Blank areas in the triangles indicate no significant trends, light or dark red or grey (greyscale version) squares significant decreasing trends at the 95 or 99 % significance level, respectively.

Discussion

All results shown here are calculated using a spatially distributed numerical snow model driven with gridded meteorological data based on point observations. Both the numerical model and the gridded data introduce errors that propagate to the trend analyses. As mean absolute model errors for every park given in Tab.1 are all smaller than total SD and SCD changes over the entire period we have a very high confidence in the trend analysis results concerning the whole investigated period of 56 years. For shorter sub periods, we have high confidence in all results for periods > 30 years. For shorter sub periods, model errors often dominate and there is a large natural inter-annual to decadal variability of the snow cover.

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