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Estimating snow conditions in Finland in the late 21st century using the SNOWPACK model with regional climate scenario data as input

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ABSTRACT. An assessment of possible snow changes in a changing climate for Finland is presented. The snowpack structure model SNOWPACK (developed at the Swiss Federal Institute for Snow and Avalanche Research) was used for calculating snow conditions at six different locations in Finland for the decades 1980–89 and 2080–89. Regional climate model (RCAO) data from the Rossby Centre, Sweden, were used as input to the SNOWPACK model. Ten years from the RCAO control run and scenario run were chosen, and the snow conditions for different snow zones were calculated for these winters. The snow-cover depth and duration decreased at all locations in the scenario run cases, and the snow-cover quality also changed between the control and scenario runs: grains were bigger, snow was warmer and denser, and the fraction of faceted snow decreased while the fraction of icy or melting snow increased, even in mid-winter. Finally, the variability between different global climate predictions was analyzed. Significant differences were found between different climate-model outputs. The inter-model variability is comparable to the interannual variability of a single model. The qualitative conclusions from the scenario run do not critically depend on the climate-model variability.

1. INTRODUCTION

As concentrations of carbon dioxide and other atmospheric greenhouse gases continue to increase, the global mean temperature is expected to rise (Houghton and others, 2001). The warming will likely be accompanied by changes in other aspects of climate, such as precipitation and cloudiness. Although climate-change projections are still associated with large quantitative uncertainty, the consequences of climate change for natural and human systems need to be studied.

The snow cover has large effects on global and local climate, the hydrological cycle and ecology. Snow-cover duration, snow depth and snowpack structure all depend on the prevailing weather conditions. The amount of snow and snow-cover duration are expected to decrease in the future.

To obtain estimates of the future snow winters, estimates of the future winter climate are first needed. Different global atmosphere–ocean general circulation models (GCMs) show encouraging agreement on the direction of climate changes (in particular on an overall increase in temperature and high-latitude precipitation), but the variation between models is significant (Houghton and others, 2001; Räisänen 2001). In addition, the regional details of climate are difficult to model with GCMs having a grid size of several hundred kilometres. Regional climate models (RCMs) are run with higher (e.g. 50 km) horizontal resolution than GCMs. This enables a more detailed and potentially more realistic description of local climates, partly because the effects of smaller-scale topography and water bodies like the Baltic Sea can be taken into account much better than in GCMs. However, such high-resolution models can only be run in a limited domain and they require GCM boundary data that describe climate evolution outside their own area.

In this paper, possible future snow conditions are studied using meteorological data simulated by the Rossby Centre coupled atmosphere–ocean (RCAO) regional climate model (Räisänen and others, 2003). This model has been run using boundary data from two state-of-the-art GCMs (HadAM3H and ECHAM4/OPYC3), and, for each of these, two scenarios of future greenhouse-gas and aerosol emissions (Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2 and B2) have been used. It is hoped that the four climate-change scenarios obtained in this way will give some indication of the certainties and uncertainties associated with future snow properties.

The RCAO simulations are used to drive the Swiss snowpack structure model SNOWPACK, which calculates snowpack structure evolution during the winter with meteorological conditions as input. Climate models also give estimates on snow-cover formation, melt and snow water equivalent, but snow models included in GCMs and RCMs are very rough. In particular, they give no information on snowpack structure. Many of the ecologically, climatically and hydrologically important effects of snow cover are due to the combined properties of single snow layers.

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In this paper, snow-cover scenario calculations are presented for the decade 2080–89 in Finland. Climate-change scenarios for that decade are more stable than for the next few decades, because the signal is stronger and therefore easier to discern from natural variability (Räisänen, 2001). The results for this future period are compared with simulated conditions for the years 1980–89. The two decades chosen were selected from the 30 year RCAO control (1961–90) and scenario runs (2071–2100) as the ones in which the simulated winter climate conditions in Finland are, as a whole, closest to the respective 30 year means. Most of the world's snow zones can be found in Finland, such that trends shown here may also be representative for other parts of the world.

2. SNOWPACK MODEL

SNOWPACK is a one-dimensional snowpack structure model, which has been developed at the Swiss Federal Institute for Snow and Avalanche Research (SLF) for avalanche warning purposes. SNOWPACK is a predictive model that uses Lagrangian finite elements to solve for heat and mass transfer, stresses and strains within the snowpack. The model calculates snow-cover evolution during the winter (e.g. stratification, density, crystal structure, water equivalent and runoff). The model is physically based: energy balance, mass balance, phase changes, water and water-vapour movement and wind transportation are included, and most of the calculations are based on snow microstructure (crystal size and form, bond size, number of bonds per crystal).

As input the model requires air temperature, air humidity, wind velocity, wind direction, shortwave and longwave radiation and snow depth or precipitation. Surface and ground temperatures can be estimated. Ideal time resolution for the input data is 30 min, but even 6 hour resolution can be used.

A complete description of the model can be found in Bartelt and Lehning (2002) and Lehning and others, (2002a, b). Examples of model validation studies are Lundy and others (2001), Etchevers and others (2002) and Fierz and others (2004).

3. ROSSBY CENTRE REGIONAL CLIMATE SCENARIOS

The Rossby Centre regional climate model RCAO (Räisänen and others, 2003) was run at 49 km horizontal resolution in an area covering Europe and the eastern North Atlantic Ocean. Two series of three 30 year RCAO simulations were made, one with boundary data from the Hadley Centre for Climate Prediction and Research (U.K.) HadAM3H GCM (Gordon and others, 2000), and the other with boundary data from the Max Planck Institute for Meteorology (Germany) ECHAM4/OPYC3 GCM (Roeckner and others, 1999). For each driving GCM, a control run representing the period 1961–90 and two scenario runs representing the period 2071–2100 were made. The latter two were based on the IPCC SRES A2 and B2 emission scenarios, respectively, the A2 scenario assuming larger greenhouse gas emissions than B2 (Nakićenović and others, 2000). In the following, the HadAM3H-driven simulations are referred to as RCAO-H, and the ECHAM4/OPYC3-driven simulations as RCAO-E.

Fig. 1. Snow zonation in Finland and locations for SNOWPACK simulations.

The RCAO control-run climates and the simulated climate changes for 1961–90 to 2071–2100 are documented in Räisänen and others (2003). Briefly, the RCAO-H and RCAO-E control climates are of similar quality, both giving a reasonable simulation of climate in northern Europe. Compared with the observed conditions in 1961–90, however, the winters are slightly too mild in Finland, especially in the north. Precipitation is larger than observed, especially in winter and spring, but biases in the measurement of (especially) solid precipitation complicate the interpretation. The global mean warming from 1961–90 to 2071–2100 varies in the driving GCMs from 2.3°C in the HadAM3H B2 scenario to 3.4°C in the ECHAM4/OPYC3 A2 scenario. These values are in the mid-range of the recent IPCC estimates (Houghton and others, 2001).

To drive the SNOWPACK model, single (but as far as possible, representative) decades of the RCAO control (1980–89) and scenario simulations (2080–89) were selected. The scenario periods are characterized by much warmer conditions than the control simulations, in particular during the winter half-year. The average simulated warming in Finland from the 1980s to the 2080s during the November–March period is from 3.7°C in the RCAO-H B2 scenario to 5.1°C in the RCAO-H A2 scenario. A considerable increase in November–March precipitation (from 18% to 49%) also occurs in all four scenario simulations.

The SNOWPACK model was driven with 6 hourly RCAO output, using at each of the selected study locations data from the nearest RCAO gridbox.

4. SITES AND MODEL VALIDATION

Snowpack structure during the winter has been mapped at six locations in Finland for the years 2000–02. The SNOWPACK model has been validated in these same locations. Agreement scores (Fierz and others, 2004) between observed and modelled snowpack crystal structure varied between 0.7 and 0.95 during winter 2000/01, even when using 6 hour time resolution (Grönholm, 2003).

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Table 1. Means and standard deviations for some snow winter characteristics at different locations as observed; present-day conditions in simulated RCAO-H control-run winters 1980–89 and future conditions in simulated RCAO-H A2 scenario-run winters 2080–89

	1960–89, observed		*1980–89, modelled*		*Change*		*2080–89, modelled*	
	Mean	*Std dev.*	*Mean*	*Std dev.*	*To observed*	*To modelled*	*Mean*	*Std dev.*
Santala:								
Formation (date)	2 January	30	26 November	13	*−15*	*+22*	18 December	20
Melt (date)	25 March	35	9 April	14	*−3*	*−17*	22 March	15
Max. (date)	16 March	10–20	16 February	34	*−32*	*−3*	12 February	25
Max. WE (mm)	100	30–40	19	7	*−77*	*+4*	23	11
Max. depth (cm)	23	5	9	3	*−13*	*+1*	10	3
Hyytiälä:								
Formation (date)	3 December	25	31 October	9	*−5*	*+28*	28 November	13
Melt (date)	17 April	20	26 April	10	*−10*	*−19*	7 April	13
Max. (date)	26 March	10–20	25 March	15	*−33*	*−34*	21 February	27
Max. WE (mm)	120	30–40	104	31	*−43*	*−27*	77	35
Max. depth (cm)	55	10	36	8	*−28*	*−9*	27	9
Lammi:								
Formation (date)	3 December	25	7 November	13	*−4*	*+22*	29 November	15
Melt (date)	17 April	20	20 April	10	*−16*	*−19*	1 April	16
Max. (date)	26 March	10–20	15 March	23	*−49*	*−41*	5 February	34
Max. WE (mm)	120	30–40	81	34	*−75*	*−36*	45	18
Max. depth (cm)	42	10	29	9	*−25*	*−12*	17	5
Mekrijärvi:								
Formation (date)	18 November	15	27 October	11	*+1*	*+23*	19 November	10
Melt (date)	2 May	10	27 April	13	*−18*	*−13*	14 April	10
Max. (date)	1 April	10–20	26 March	19	*−25*	*−18*	7 March	15
Max. WE (mm)	180	30–40	117	28	*−82*	*−19*	98	37
Max. depth (cm)	63	10	40	7	*−30*	*−7*	33	10
Oulanka:								
Formation (date)	29 October	15	26 October	18	*+10*	*+13*	8 November	12
Melt (date)	17 May	5	5 May	11	*−27*	*−15*	20 April	10
Max. (date)	16 April	10–20	24 March	32	*−20*	*+2*	27 March	18
Max. WE (mm)	200	30–40	140	40	*−80*	*−20*	120	41
Max. depth (cm)	68	10	48	12	*−28*	*−8*	40	11

Notes: In the middle columns, mean differences between "future" and "present-day" cases are given for all of the characteristics. Snow-cover duration observations are from 1960/61 to 1989/90 (Finnish Meteorological Institute, 1991; Solantie, 1996) and water equivalent (WE) observations from 1952 to 1984 (Perälä and Reuna, 1990).

These locations, situated in different snow zones (zones by Sturm and others (1995) and Oksanen (1999)), are marked in Figure 1. The simulations described below were performed for five of these locations. Santala is located in the ephemeral snow zone, Lammi in the thin maritime zone, Mekrijärvi in the maritime zone, Hyytiälä in the transition zone and Oulanka in the taiga zone.

5. METHOD

Ten-year time series of RCAO data were taken for each location for the years 1980–89 and 2080–89. Input data include air temperature (0°C) relative humidity, wind speed ($m\,s^{-1}$) and direction (°), precipitation (mm), shortwave radiation and longwave radiation ($W\,m^{-2}$) with 6 hour time resolution. For most of the locations, only the RCAO-H control and A2 data were used. For the Hyytiälä simulations, the other four RCAO runs (RCAO-H B2 and RCAO-E control, A2 and B2) were also included to have a sensitivity range for the results. The SNOWPACK model uses the temperature between snow and soil as the lower Dirichlet boundary condition. This temperature has been set to 0°C.

The snow-cover evolution has been calculated during ten selected winters using the SNOWPACK model. The following aspects of the model results were studied:

- dates of snow-cover formation and snowmelting
- date of maximum water equivalent
- maximum of water equivalent and snow depth.

For 15 March (the average date for present-day maximum snow depth) in addition the following quantities were analyzed:

- bulk density, temperature and grain-size
- fraction of icy or melting snow
- fraction of new or rounded-grain snow
- fraction of faceted grain or depth-hoar snow.

Averages and standard deviations were calculated for both decades for all of the listed quantities, and the results of the control and scenario runs were compared.

6. RESULTS USING "PRESENT-DAY" RCAO DATA

To allow a comparison between observed and modelled present-day snow winter characteristics, both long-term

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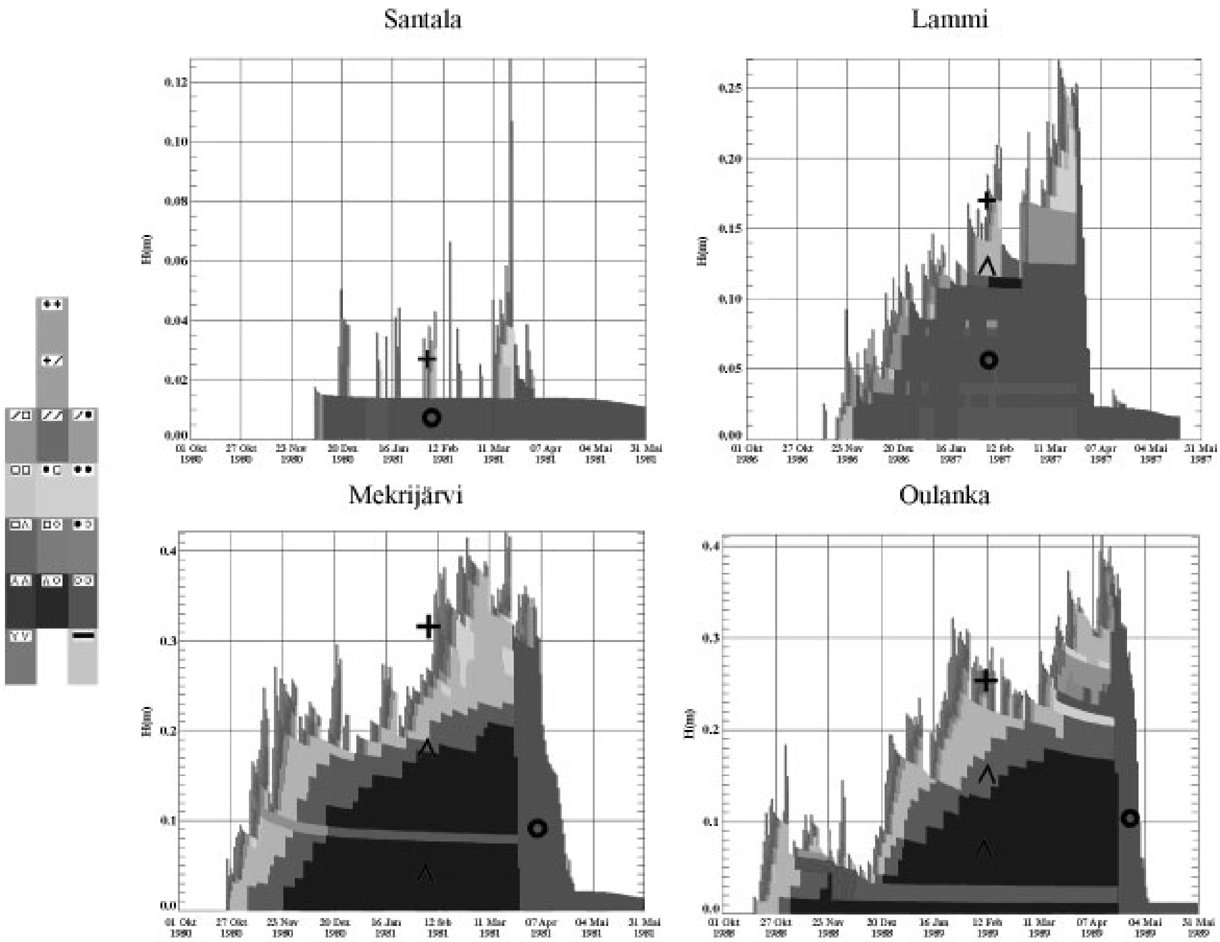

Fig. 2. Examples of typical snow winter crystal-structure evolution in study locations using RCAO-H control runs (compares to the present-day situation). Code with standard snow-crystal classification symbols (Colbeck and others, 1990) is on the far left.

observed and modelled present-day (RCAO-H control run) snow winter characteristics are shown in Table 1. Dates for snow-cover formation, snowmelt and maximum snow depth, as well as maximum snow water equivalent and snow depth, are presented for different locations.

In all cases, model simulations show too shallow snow covers with too low water equivalents, in unstable ephemeral conditions as low as one-fifth of the observed mean water equivalent. This is probably due to the slightly too warm winter air temperatures and too high, possibly liquid, precipitation in the RCAO control runs. Also in some locations snow-cover formation is too early in the modelled case, and so is the date for the maximum water equivalent. In most cases, the "shape" and time evolution of the snow cover is realistic. Agreement between observed and modelled mean states seems to be better in the north, where snow conditions are more stable and winter melting periods and liquid precipitation events are fewer. The results suggest that the snow cover in the south is much more susceptible to warming trends. The smaller errors in the climate control-run simulation from the south have a larger impact on the snow cover than the larger errors in the north. The uncertainties and large spatial variance in snow-cover observations have also to be taken into account when interpreting these results.

In Figure 2, examples of the snowpack crystal-structure evolution for typical snow winters for different locations are shown based on RCAO-H control-run calculations. At all locations, the most representative winter development, i.e. the closest to the climatological mean, is shown. Snow cover-formation and melt in different snow zones, as well as different snowpack structure evolution, are clearly seen in this figure.

7. RESULTS USING SCANARIO DATA

In Table 1, values for the period 2080–89 (RCAO-H A2 scenario run) are also given, as well as changes between present-day observations and the scenario run, and the control run and the scenario run. In Table 2, the respective snowpack structure characteristics for 15 March are analyzed.

From the simulations, a clear trend is visible: around 2090, snowpack formation occurs later (13–18 days) than at present, while melting occurs earlier (13–19 days). The date of the maximum water equivalent is also earlier than at present. Maximum water equivalents and snow depths decrease by approximately one-fifth compared to present-day mean values, although with some variation between sites. A noteworthy exception is Santala, where, due to higher winter precipitation, slightly higher maximum snow depth and maximum water equivalent are observed.

Changes are homogeneous except for the ephemeral snow zone. The results confirm the earlier observation, based on the control run, that the snow cover in the south of the country will undergo more severe changes. Assuming that the future-climate simulation has a systematic error

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Table 2. Means and standard deviations for some snowpack structure characteristics at 15 March at different locations in simulation winters 1980–89 and 2080–89

	"1980" Mean	"1980" Std dev.	Change	"2080" Mean	"2080" Std dev.
Santala:					
Depth (cm)	3	2	*0*	3	4
WE (mm)	9	5	*+1*	10	10
Density (kg m^{-2})	395	149	*−23*	372	150
Temp. (°C)	−0.3	0.6	*+0.3*	0	0
Size (mm)	2	1.3	*0*	2	0.9
Hoar (%)	25	35	*−22*	3	11
Rounded (%)	22	23	*−12*	10	29
Ice (%)	53	39	*+34*	87	30
Hyytiälä:					
Depth (cm)	29	9	*−11*	18	12
WE (mm)	87	29	*−28*	59	41
Density (kg m^{-2})	300	25	*+35*	335	44
Temp. (°C)	−1.7	1.6	*+1.1*	−0.6	0.9
Size (mm)	1.2	0.3	*+0.2*	1.4	0.5
Hoar (%)	66	29	*−48*	18	27
Rounded (%)	13	14	*−2*	11	17
Ice (%)	21	23	*+50*	71	31
Lammi:					
Depth (cm)	23	8	*−15*	8	8
WE (mm)	67	23	*−42*	25	25
Density (kg m^{-2})	297	30	*+60*	357	159
Temp. (°C)	−1.5	1.5	*+1*	−0.5	1.2
Size (mm)	1.2	0.3	*+0.7*	1.9	0.9
Hoar (%)	52	39	*−45*	7	12
Rounded (%)	15	17	*−5*	10	16
Ice (%)	33	37	*+50*	83	24
Mekrijärvi:					
Depth (cm)	33	7	*−7*	26	11
WE (mm)	97	19	*−13*	84	41
Density (kg m^{-2})	298	21	*+19*	317	39
Temp. (°C)	−2.1	2	*+1.1*	−1	1.6
Size (mm)	1.3	0.2	*−0.1*	1.2	0.3
Hoar (%)	78	24	*−33*	45	33
Rounded (%)	10	8	*+2*	12	16
Ice (%)	12	23	*+31*	43	30
Oulanka:					
Depth (cm)	40	14	*−7*	33	11
WE (mm)	118	43	*−16*	102	39
Density (kg m^{-2})	291	9	*+18*	309	29
Temp. (°C)	−2.5	0.9	*+1.3*	−1.2	1
Size (mm)	1.3	0.1	*−0.2*	1.1	0.2
Hoar (%)	95	5	*−29*	66	31
Rounded (%)	5	5	*+7*	12	5
Ice (%)	0	0	*+22*	22	31

Notes: Only RCAO-H control runs and A2 scenario runs were used here. In the middle column, the mean difference between "future" and "present-day" cases is given for all of the characteristics.

comparable to that of the present-day scenario, the magnitude of the changes in snow characteristics is given by the comparison between the modelled present-day and modelled future case. Therefore, comparison between observed present-day and modelled future snowpack structure is not interpreted. Also, our limited number of point observations appears to be a small data basis for representing present-day snowpack structure conditions in Finland. However, there is no a priori knowledge that the assumption of non-changing systematic error is justified.

Analyzing the results for 15 March, the same decreasing trend can be seen in snow depth and water equivalent at all locations except Santala. The following changes are also seen in most cases: an increase in snow bulk temperature towards the melting point, which reflects higher air temperatures; and an increase in density and in grain-size, which can be explained by more frequent melt–freeze cycles in the snowpack. The most pronounced changes can be seen in the fractions of differently metamorphosed snow. There is a large increase in melt forms and melt–freeze crusts by several tens of per cent. These forms increased mainly at the expense of faceted crystals, with a smaller decrease observed for rounded crystals.

In Figure 3, typical examples of snow winter crystal-structure evolution in different locations in the 2080s are shown, using RCAO-H A2 data. Also here, different winters were chosen at different locations to find as close a match as possible to mean conditions during the 10-winter time slice at each location.

The differences between different snow zones are seen here, as in Figure 2. When comparing Figures 2 and 3, changes in snow depth, snow-cover formation and melt, and snowpack structure can be seen between the two decades analyzed.

Table 3. Mean air temperatures and mean daily precipitation for November–March period in Hyytiälä for different RCAO control and scenario runs

	Temperature OBS	Temperature RCAO-H	Temperature RCAO-E	Precipitation OBS	Precipitation RCAO-H	Precipitation RCAO-E
	°C	°C	°C	mm d^{-1}	mm d^{-1}	mm d^{-1}
CTRL	−5.94	−5.6	−5.5	1.59	2.01	1.99
A2		−1.0	−0.2		2.42	2.87
B2		−1.7	−1.0		2.38	2.75
A2-CTRL		4.6	5.2		20%	44%
B2-CTRL		3.8	4.5		19%	38%

Notes: Observations are from 1960/61 to 1989/90 (Finnish Meteorological Institute, 1991).

8. COMPARISON BETWEEN DIFFERENT RCAO SCENARIOS

In Table 3, mean air temperature as well as mean daily precipitation for the November–March period in Hyytiälä during the studied decades are given for RCAO-H and RCAO-E control runs. These results are compared to the long-term observations from Hyytiälä between 1960/61 and 1989/90. Both RCAO runs give slightly too high mean temperatures and daily precipitations.

In Table 3, different RCAO scenario runs are also compared. As expected, changes in B2 runs are smaller than in A2 runs when compared to the control-run situation. Also increases in temperature and in precipitation are greater in the RCAO-E cases than in the RCAO-H cases. The increase in precipitation is remarkably high for the RCAO case, mostly due to the increase in liquid precipitation.

In Table 4, "present-day" snow winter characteristics in Hyytiälä as simulated with RCAO-H and RCAO-E control-run data are compared. Simulated winters are surprisingly similar between the two cases. Table 4 also compares the results for Hyytiälä in the 2080s between the four differ-

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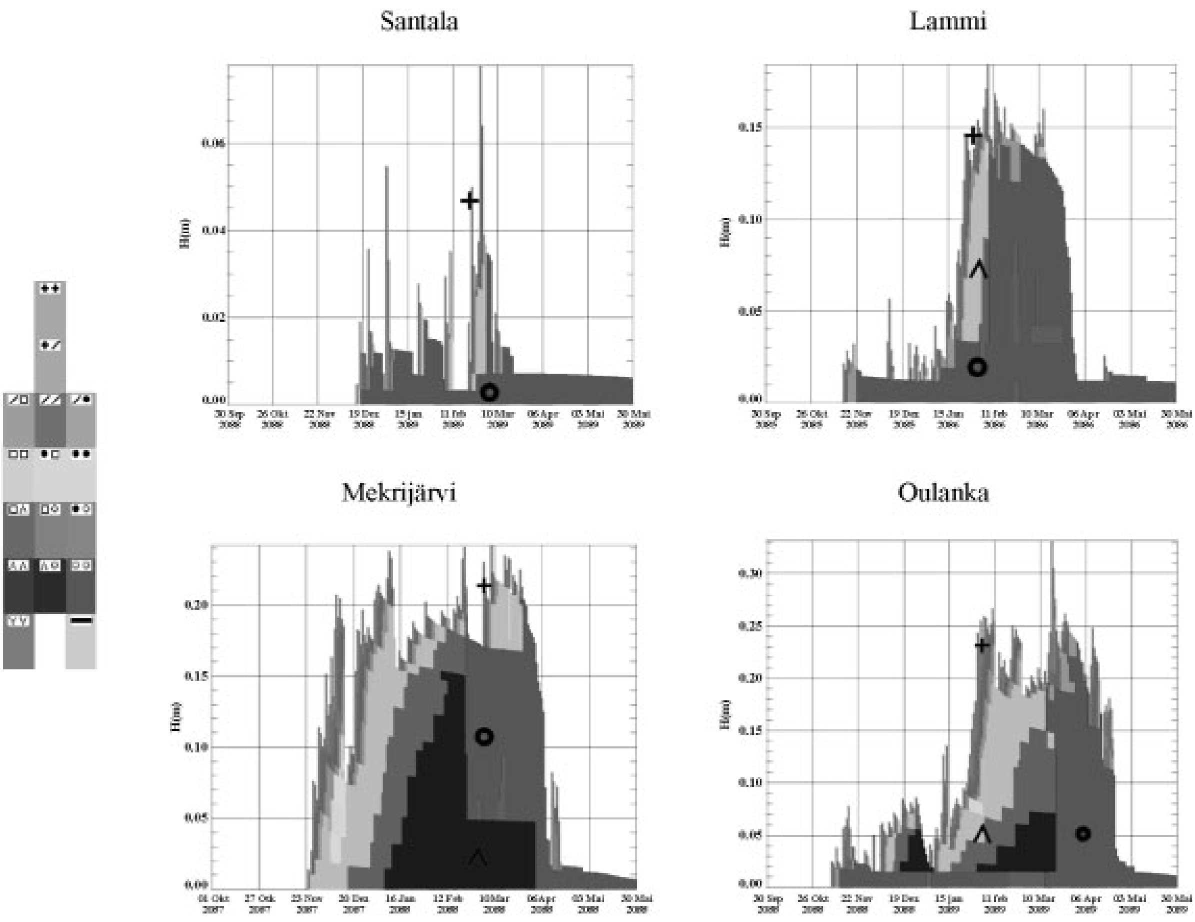

Fig. 3. Examples of typical snow winter crystal-structure evolution in study locations around 2080 using RCA-H A2 scenarios.

ent simulations (RCAO-H A2, RCAO-H B2, RCAO-E A2, RCAO-E B2). The simulations based on the RCAO-E results give shallower snow covers than those based on the RCAO-H results. The snowpacks are also denser and warmer, and they consist of larger snow grains. The fractions of icy/melting snow and faceted grain snow suggest warmer winters with more melt–freeze cycles than in the RCAO-H cases. Differences between the A2 and B2 scenarios are more pronounced for the RCAO-E than the RCAO-H results.

9. DISCUSSION

The SNOWPACK mass balance has been shown to be accurate for high Alpine locations (Lehning and others, 2002a) as well as temperate climates (Etchevers and others, 2002), with a small bias towards underestimation of melt and overestimation of snow accumulation. Therefore, the observed discrepancy between data and control run in southern Finland is interpreted to be due to a bias in the me-

Table 4. "Present-day" and "future" snow winter characteristics in Hyytiälä as presented in RCAO-H and RCAO-E control runs and scenario runs RCAO-H A2 and B2, as well as RCAO-E and B2

	RCAO-H	*RCAO-E*	*RCAO-H A2*	*RCAO-H B2*	*RCAO-E A2*	*RCAO-E B2*
Formation	31 October	5 November	28 November	19 November	23 November	13 November
Melt	26 April	27 April	7 April	7 April	27 March	15 April
Max. date	25 March	10 March	21 February	25 February	25 January	6 February
Max. depth	36	35	27	24	18	21
Max. WE (mm)	104	102	77	69	45	55
15 March:						
Depth (cm)	29	27	18	14	5	9
WE (mm)	87	85	59	45	20	30
Density (kg m^{-2})	300	311	335	348	391	346
Temp. (°C)	−1.7	−2.6	−0.6	−0.9	0	−0.8
Size (mm)	1.2	1.3	1.4	1.5	2.9	1.4
Hoar (%)	66	64	18	39	0	17
Rounded (%)	13	10	11	10	16	15
Ice (%)	21	26	71	51	84	68

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teorological input data. But the control run already serves as a sensitivity case and demonstrates that the temperate snow covers in southern Finland might react more strongly on climate change than the more stable snow covers in the north.

The study presented shows qualitative trends and quantitative estimates for expected snow changes. The different scenarios calculated give a first assessment of variability. They show differences between different climate-model outputs. The simulations presented are not sufficient to calculate statistical trends and to separate interannual variability from the variability between the model scenarios. More model runs are needed at many locations with several GCM outputs and probably longer time series to make a statistical analysis.

This study concentrates on the mean state of the snowpack; the detailed interannual variations of snow conditions in the 2080s are, of course, unpredictable. If the climate changes as in the model scenario run, average snow conditions in different snow zones in Finland are expected to change.

An interesting result is the increase in the standard deviations for many of the studied quantities at many of the locations. This suggests that interannual variation of both snow winters and snowpack structure characteristics could be larger in the future. This could lead to more frequent extreme events in snow winters. Of course it must be reiterated that a 10 year sample is too small to make a statistical trend analysis.

It is important to understand that this study is based on modelling work. In this study the model has been compared with observed data, and some long-term observations are also presented to enable the reader to judge the uncertainties associated with the study. Our results are mainly based on a comparison between a control run for the present climate and scenario runs for the future. Therefore, model bias errors are avoided, if the bias does not change over time.

10. CONCLUSIONS

In a climate represented by the RCAO scenario runs, snow-cover thickness and duration are likely to decrease. Snow quality is also likely to change:

1. Snow will be denser and closer to the melting point even in mid-winter; grains will be larger
2. The fraction of depth hoar in the snowpack will decrease
3. The fraction of icy or wet snow in the snow cover will increase.

These changes will have certain effects on, for example, hydrology (winter runoff increases), building (snow loads on the roofs might increase even when the snow depth stays the same or decreases) and ecology. Many plants and animals, especially in the boreal and arctic zones, are adapted to the shelter of the snow against cold, dry winter conditions. They also need some faceted grain snow in order to move and nest in the snow. Some of these species may experience severe problems if snow winter characteristics change too quickly and "present-day" winters are too rare.

Even if the snow depths and water equivalents differ between, for example, maritime snow zones in Finland and in North America, it is probable that the directions of change in snow-season duration, amount of snow and snowpack structure will be similar to those presented in this study.

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