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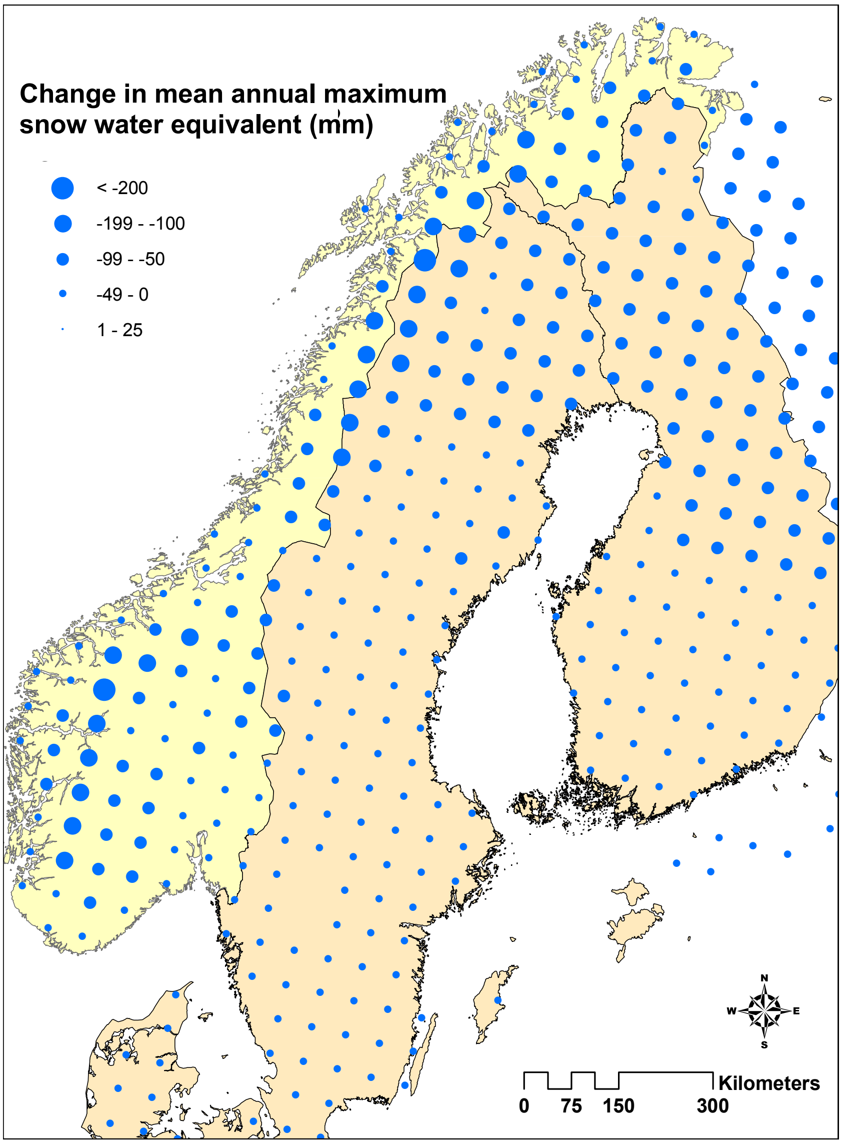
Comparison of snow water equivalent estimated by the HIRHAM and the HBV (GWB) models:

- current conditions (1961-1990) and scenarios for the future (2071-2100)

Dagrun Vikhamar-Schuler and Eirik J. Førland



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Abstract

The snow water equivalent estimated by the regional climate model HIRHAM was compared to the snow water equivalent estimated by the spatially distributed water balance model HBV (GWB) in Norway. The analysis compares the snow water equivalent for present climate (1961-1990) and for future scenarios (2071-2100). The derived variable “mean number of days per year with snow cover” was also compared. The results show that different representation of topography and precipitation modelling in the HIRHAM and the HBV models lead to deviations in the estimated snow water equivalents. Below 200 m a.s.l. both models provide most similar results. With increasing altitude, the estimated snow water equivalent values from the two models deviate increasingly, and the HBV model estimates much higher values than the HIRHAM model. These differences are also caused by the effects of the very different spatial resolution used in the two models. Since the scale of the HBV model is 1 km grid cells while the scale of the HIRHAM model is about 55 km grid cells, local topographical effects are better described in the HBV model. The results show a potential for improving the snow water equivalent calculations in both models. However, which model that computes snow water equivalent values closest to observations has not been analysed in this study. Comparisons to observations will be a topic for future work.

Keywords

Snow water equivalent, HBV, GWB, HIRHAM, climate change, Norway

Responsible signature

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1 Introduction

Snow is an important part of the terrestrial water balance and the energy balance at the boundary between the land surface and the atmosphere. Snow processes are therefore important parts of both water balance models that solve the water balance, and regional climate models that essentially solve the vertical energy balance. The regional climate models and hydrological models have different focus, which makes it a challenge to directly compare common output variables such as snow water equivalent. The models operate on different spatial and temporal scales, and they account differently for the sub-grid variability.

The aim of this report is to compare the output variable snow water equivalent from the regional climate model HIRHAM, and the spatially distributed water balance model HBV. The comparison is made for present climate (1961-1990) and for future scenarios (2071-2100).

The report is divided into six Chapters. Chapter 2 gives an overview of the regional climate model and the water balance model, as well as the data set used in the analyses. Chapter 3 compares the modelled snow water equivalent from the regional climate model and the hydrological model, while Chapter 4 compares the two models by focusing on the snow season duration. Differences in modelling precipitation in the two models HIRHAM and HBV are discussed in Chapter 5. Summary and conclusions are provided in the end of the report.

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2 Dataset and methods

2.1 HIRHAM Model

The HIRHAM model is a regional climate model (Haugen and Iversen, 2005; Bjørge et al., 2000), which is based on the physics of the global climate model ECHAM4 (Roeckner et al., 1999) and the dynamics of the weather forecast model HIRLAM (High Resolution Limited Area Model). HIRHAM produces climate variables with approximately 55 km × 55 km spatial resolution. One of the output variables is snow water equivalent. This output variable is in focus in this report.

2.1.1 Snow algorithm

The HIRHAM model calculates the snow water equivalent over land and glacier areas from (DKRZ, 1993):

$$\frac{\delta}{\delta t} S_n = \frac{J_{Q_{S_n}} + P_{S_n} - M_{S_n}}{\rho_w}, \tag{1}$$

where: $J_{Q_{S_n}}$ is the evaporation rate per unit area over the snow pack, P_{S_n} is the snow fall rate per unit area, M_{S_n} is the snow melt rate per unit area and ρ_w is the density of water.

2.2 Spatially distributed HBV Model

The HBV model is a water-balance model (hydrological model) developed by Bergström (1976) and Sælthun (1996). A spatially distributed version of the HBV model, also called GWB model (Gridded Water Balance), is later developed by Beldring et al. (2002, 2003). The model gives quantitative estimates of hydrological processes in Nordic environments. The water balance is calculated in each grid cell (1 km × 1 km). The land cover within each grid cell is described with a maximum of four land-cover elements: two vegetation types, glacier area and lake area. The vegetation types are selected among five defined types: (i) areas above the tree line with extremely sparse vegetation, mostly lichens, mosses and grass; (ii) areas above the tree line with grass, heather, shrubs or dwarfed trees; (iii) areas below the tree line with subalpine forests; (iv) lowland areas with coniferous or deciduous forests; and (v) non-forested areas below the tree line. The spatially distributed HBV model contains submodules for snow accumulation, snow melt, glacier mass balance, interception storage, soil moisture storage, evapotranspiration, ground water storage, lake evaporation and runoff response.

The HBV model is run using daily time steps. Therefore, daily values for precipitation and temperature are necessary model input. Usually, temperature and precipitation are estimated for each grid cell using inverse distance weighting of the three nearest precipitation stations and the two nearest temperature stations. The output from the model are daily values of water balance elements such as evaporation, runoff, glacier mass balance and snow water equivalent. Only the output variable snow water equivalent is studied in this report. The results presented from the HBV model are extracted from a study which is described in Vikhamar-Schuler et al. (2006) and Roald et al. (2006). In the rest of this report the spatially distributed HBV model (GWB model) is referred to as the HBV model.

2.2.1 Snow algorithm

Snow accumulation and snow melt are both modeled on sub-grid scale. Snow accumulates when precipitation falls at temperatures lower than a threshold temperature (TX). Otherwise, precipitation falls as rain. Snow is accumulated by assuming a lognormal distribution of snow for each grid cell, where the coefficient of variation (CV) is a function of land-cover type. When CV equals zero the snow is evenly distributed, while the distribution becomes more skewed as CV increases. In doing so, differences in even and uneven snow distribution in mountain areas, forests and lowland areas are taken into account.

Snow melt is modelled using a temperature-index approach (degree-day model):

$$\begin{aligned} M &= CX(T - TS) \quad forT > TS \\ M &= 0 \quad forT < TS, \end{aligned} \tag{2}$$

where the melt factor (CX) determines the amount of snow melt (M) when the temperature (T) exceeds a specified threshold (TS).

2.2.2 Parameter values

Model parameters are determined through a calibration procedure. The calibration procedure rests on the hypothesis that model elements with identical landscape characteristics have similar hydrological behaviour, and should consequently be assigned the same parameter values. Therefore, the model is calibrated with the restriction that the same parameter values are used for all computational elements of the model that fall into the same class for land surface properties (Beldring et al., 2003).

The set of parameter values applied when running the HBV model for the entire country are shown in Table 1. Only parameters applied in the snow algorithm are included.

	TX (°C)	TS (°C)	CX (mm/°C/day)	CV
Mountainous areas with sparse vegetation	1.0	0.0	3.38	0.5
Mountainous areas with abundant vegetation	1.0	0.0	2.56	0.5
Mountainous areas, forested	1.0	0.0	3.84	0.4
Forests, lowlands	1.0	0.0	2.49	0.3
Agricultural areas	1.0	0.0	2.87	0.3

Table 1: *Parameter values applied for the snow algorithm in the HBV model.*

2.3 Climate scenarios

Global climate scenarios of temperature and precipitation are produced from Atmospheric-Ocean General Circulation Models (AOGCMs). The AOGCMs are run using different emission scenarios. In our analysis two AOGCMs have been used (Table 2): 1. The ECHAM4/OPYC3 model from the Max Planck Institute for Meteorology in Germany (Roeckner et al., 1999) and; 2. The HadAm3 from the Hadley

Centre for Climate Prediction and Research in United Kingdom (Gordon et al., 2000). Both models are run with the emission scenario B2 (Cubasch et al., 2001), for control periods and scenario periods as specified in Table 2. The B2 scenario was selected because it resembles the A1b scenario which will be included in the next IPCC report. Up to 2100 the B2 scenario gives approximately 2.5°C increase in the global temperature. The spatial resolution of the forcing data from the two AOGCMs is approximately 300 km × 300 km and the temporal resolution is 6 hours.

Dataset	Climate model	Emission scenario	Control period	Scenario period
A	HadAm3	B2	1961-1990	2071-2100
B	ECHAM4/OPYC3	B2	1961-1990	2071-2100

Table 2: *The dataset consists of temperature, precipitation and snow water equivalent produced from two global climate models for a control period and a scenario period, run with the B2 emission scenario. In this report the climate model HadAm3 is referred to as the Hadley model, and the ECHAM4/OPYC3 is referred to as the Echam model.*

2.4 Comparison of snow water equivalent from the HIRHAM and the HBV models

2.4.1 Data processing

When comparing the output variable snow water equivalent from the two models HIRHAM and HBV one should keep in mind that the projected daily temperature and precipitation data from HIRHAM has been further processed before running the HBV model.

The temperature and precipitation data resulting from the HIRHAM model are spatially too coarse for being used as input to the HBV model. An additional adjustment to local stations was necessary. The methods applied for the local adjustment are described in Engen-Skaugen et al. (2002) and Engen-Skaugen (2004).

The adjustment accounts for e.g. differences in station altitude and HIRHAM grid point altitude and the overestimation of precipitation from the HIRHAM model on days without precipitation (Frei et al., 2003). In general, the climate simulations include natural variations of the climate. The simulations for the control period are therefore not directly comparable to station observations on a day-by-day basis. However, the statistical properties of the simulated temperature and precipitation should be similar to those of the observed temperature and precipitation. The local adjustment methods try to maintain these statistical properties (e.g. monthly mean and variance of daily values). Using inverse distance weighting, these adjusted station values were then applied for generating daily precipitation and temperature grids (1 km × 1 km) (see Section 2.2).

2.4.2 Spatial resolution

The output variable snow water equivalent from the two models HIRHAM and HBV have very different spatial resolution. HIRHAM provides daily snow water equivalent values for grid cells of 55 km × 55 km spatial resolution, while the spatial resolution of the snow water equivalent values from the HBV model is 1 km × 1 km.

Because of the differences in spatial resolution, the topography is better represented in the HBV model than in the HIRHAM model. The coarse spatial resolution of the HIRHAM model leads to a much more averaged representation of the topography (Figure 1). The highest location in the HIRHAM terrain model is 1281 m a.s.l., while the highest location in the HBV terrain model is 2256 m a.s.l.

In all of the presented analyses, comparison of snow water equivalent values are made by extracting the 1 km × 1 km grid cell that is located at the center point of the 55 km × 55 km grid cell. An example is shown in Figure 2 where the topography in the HIRHAM and the HBV models is compared. One should note that this is a first approach for comparing the two models. In the case of very smooth topgraphy within the 55 km × 55 km grid cell, the extracted 1 km × 1 km HBV grid cell is more representative for the entire HIRHAM grid cell than for the case of very rough topography. In a future study it would be interesting to study e.g. an average of all 1 km × 1 km HBV grid cells located inside a 55 km × 55 km HIRHAM grid cell.

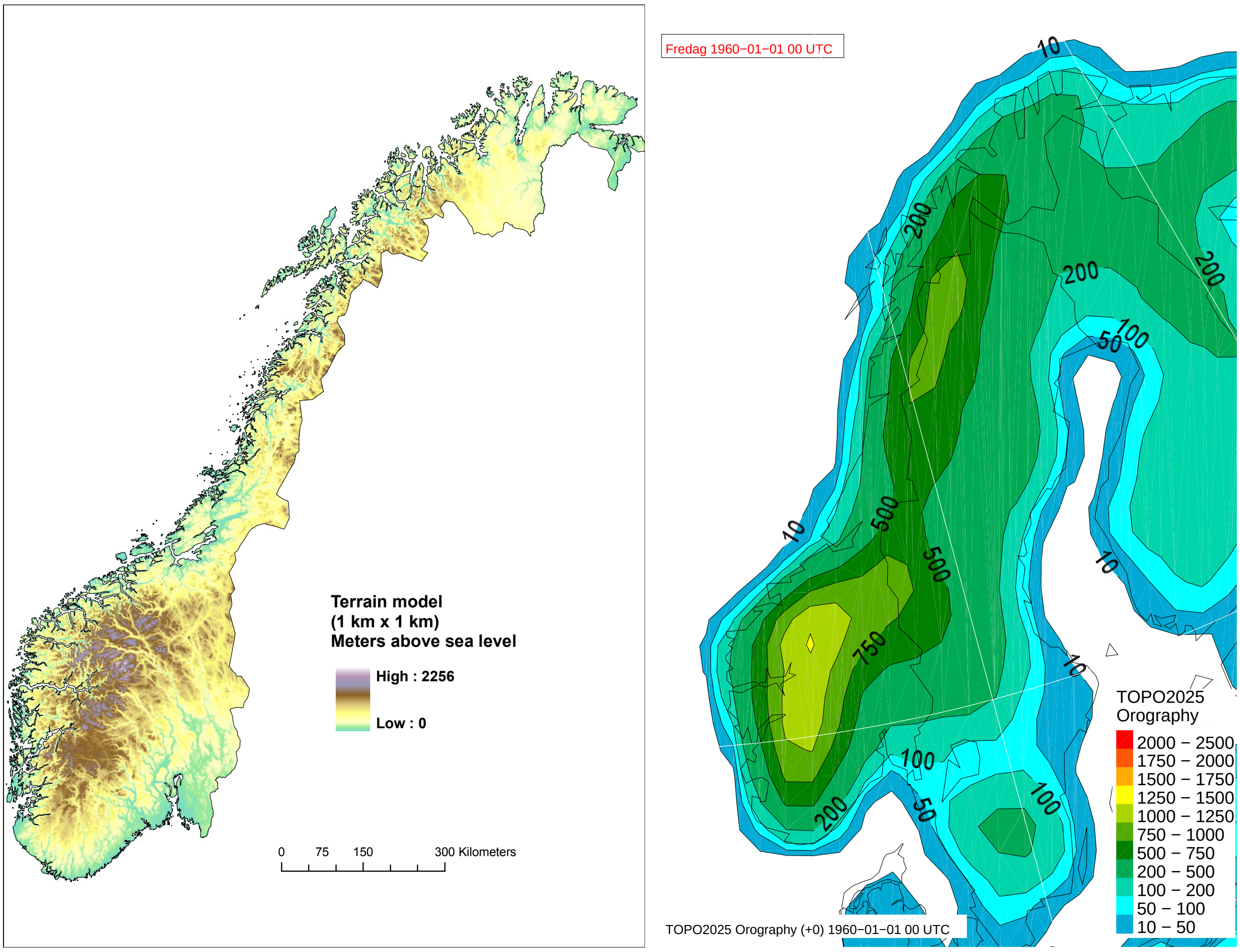

Figure 1: *Terrain model used to represent the topography in a) the HBV model (1 km × 1 km grid cells), and b) the HIRHAM model (55 km × 55 km grid cells).*

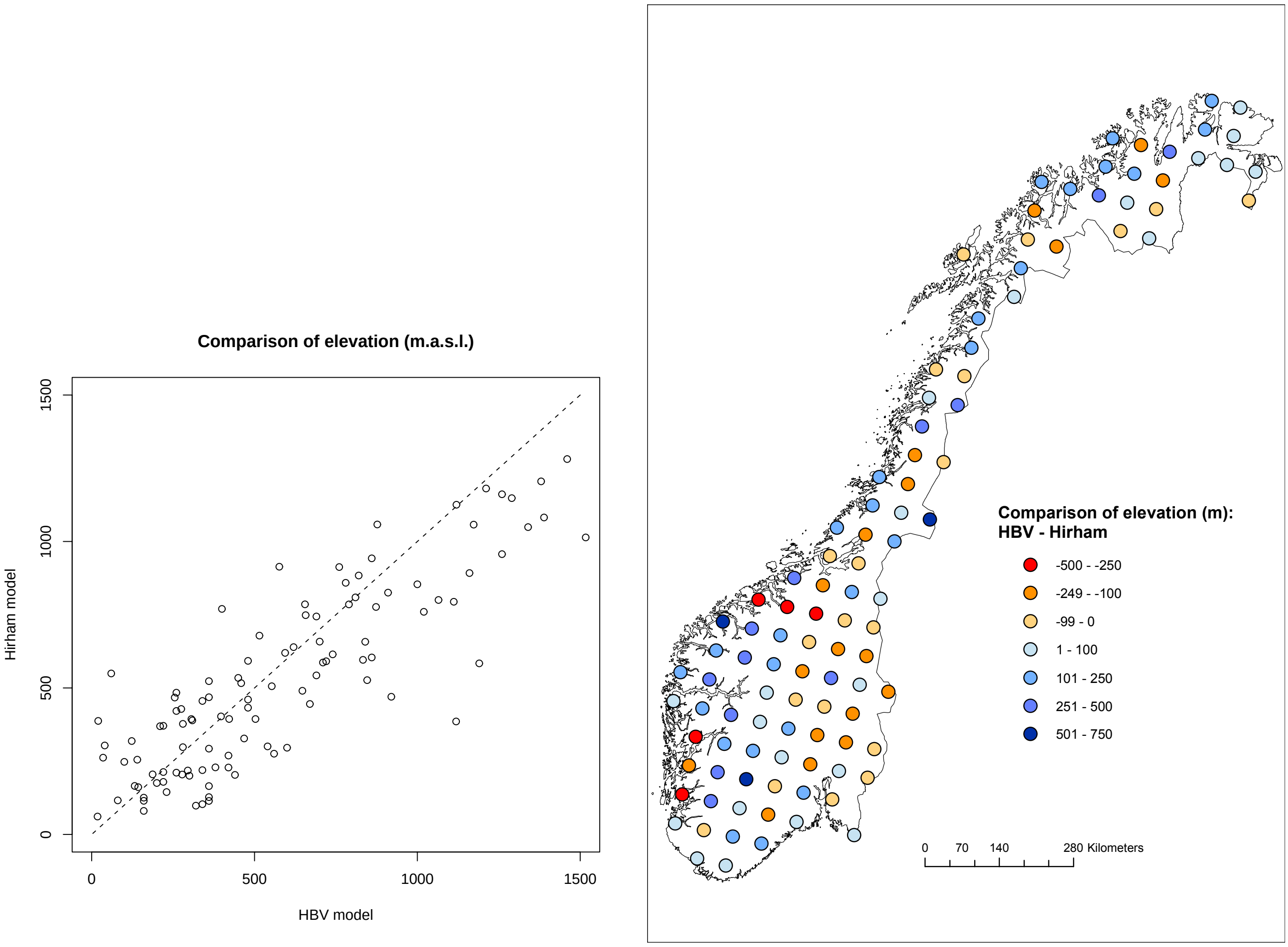

Figure 2: *Comparison of elevation used in the HIRHAM model and the HBV model. a) Scatter plot: The points show the elevation in the HIRHAM 55 km × 55 km grid cell, and the elevation of the 1 km × 1 km grid cell located at the center point of the HIRHAM grid cell. The dashed line is a 1:1 line. b) Map showing differences in elevation: HBV height - HIRHAM height.*

3 Mean annual maximum snow water equivalent

3.1 Current climate (1961-1990)

Maps of mean annual maximum snow water equivalent (mm) calculated for the control period of both the dynamically downscaled Hadley and Echam AOGCMs (dataset A and B), are presented for:

- the HIRHAM model (Figures 3a,b) and
- the HBV model (Figures 4a,b).

The maps resulting from running the HIRHAM model show points which represent 55 km × 55 km grid cells. The maps resulting from running the HBV model show grid cells which cover 1 km × 1 km. This is valid for all the maps in the report.

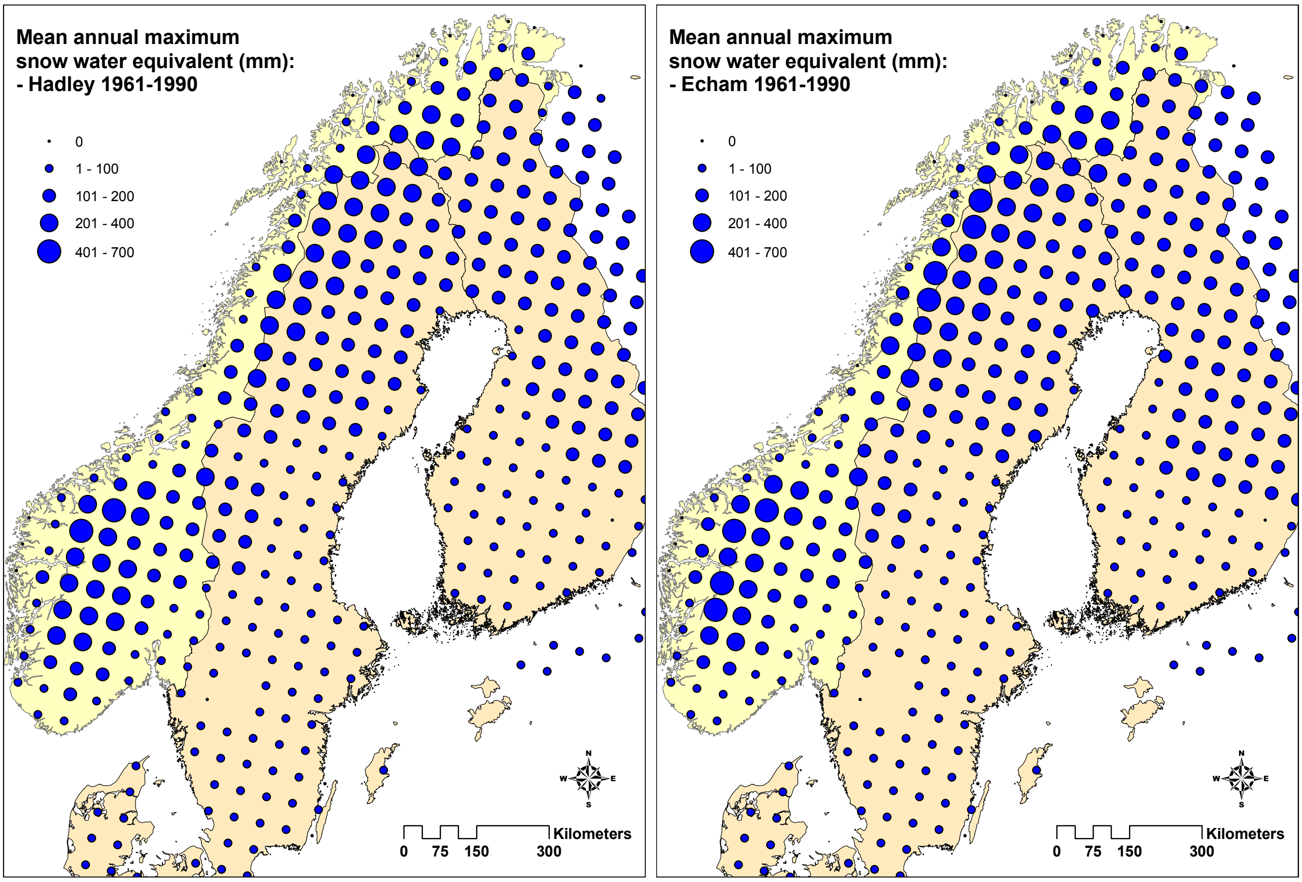

Figure 3: *Mean annual maximum snow water equivalent (mm) derived from the HIRHAM model, for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam.*

A comparison of the results from the HIRHAM and the HBV models are shown in Figures 5a and b. These scatter-plots show that the areas located below 200 m a.s.l. get snow water equivalent values in the same order of magnitude regardless the model. However, with increasing altitude there is an increasing deviation of estimated snow water equivalent between the two models. The largest deviations between the two models are observed at locations above 1000 m a.s.l., where the HBV model give much higher snow water equivalent values than the HIRHAM model. This occurs for both the Hadley and the Echam AOGCMs.

The geographic distribution of these deviations is presented in a map (Figures 6a,b). These maps are calculated by subtracting the value of the 55 km × 55 km HIRHAM grid cell from the value in the 1 km × 1 km HBV grid cell located in the mid-location of the 55 km × 55 km HIRHAM grid cell: $diff_{ctrl} = swe_{HBV,ctrl} - swe_{HIRHAM,ctrl}$, where swe is the snow water equivalent and $ctrl$ refers to the control period.

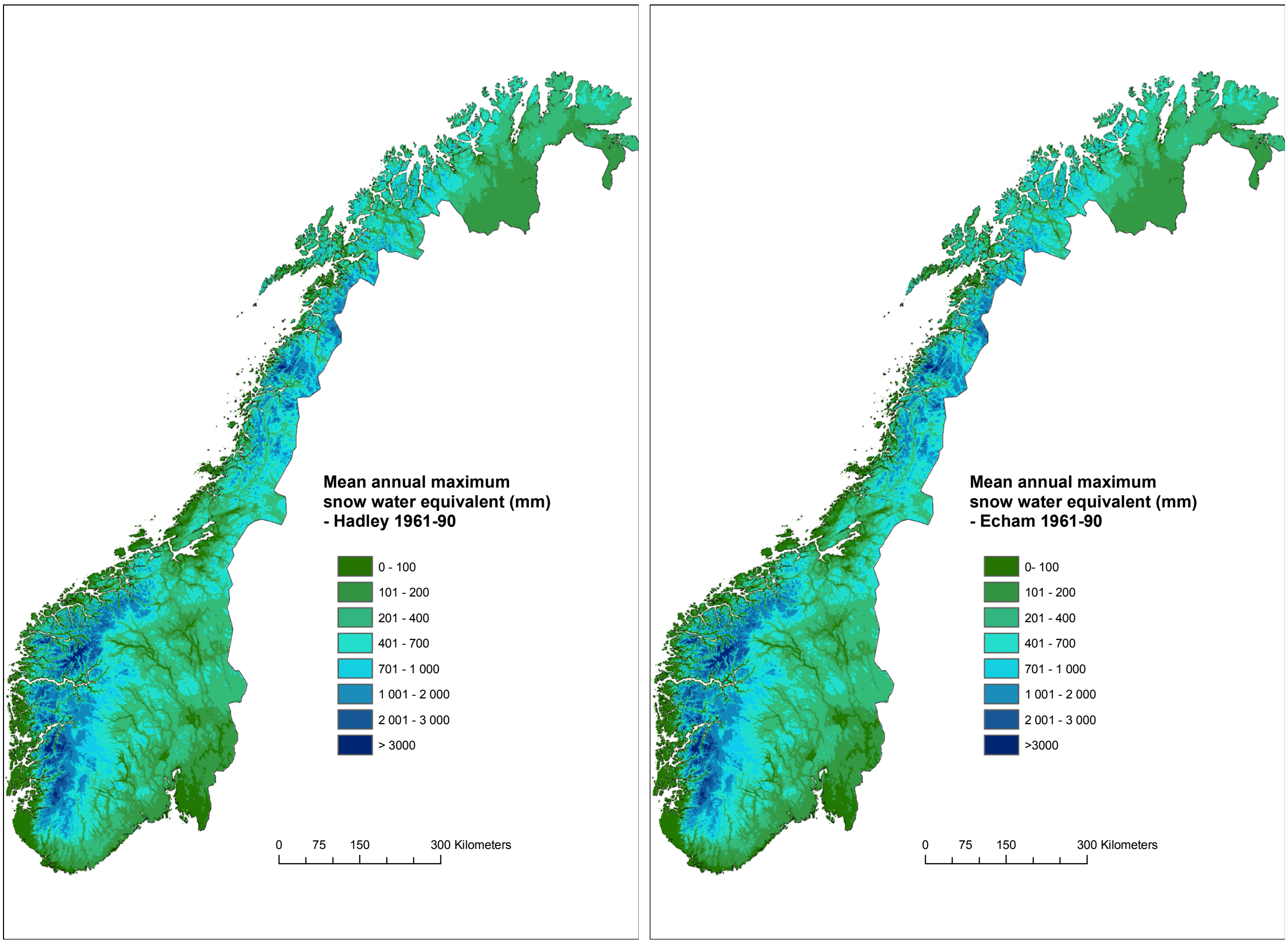

Figure 4: *Mean annual maximum snow water equivalent (mm) derived from the HBV model, for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam.*

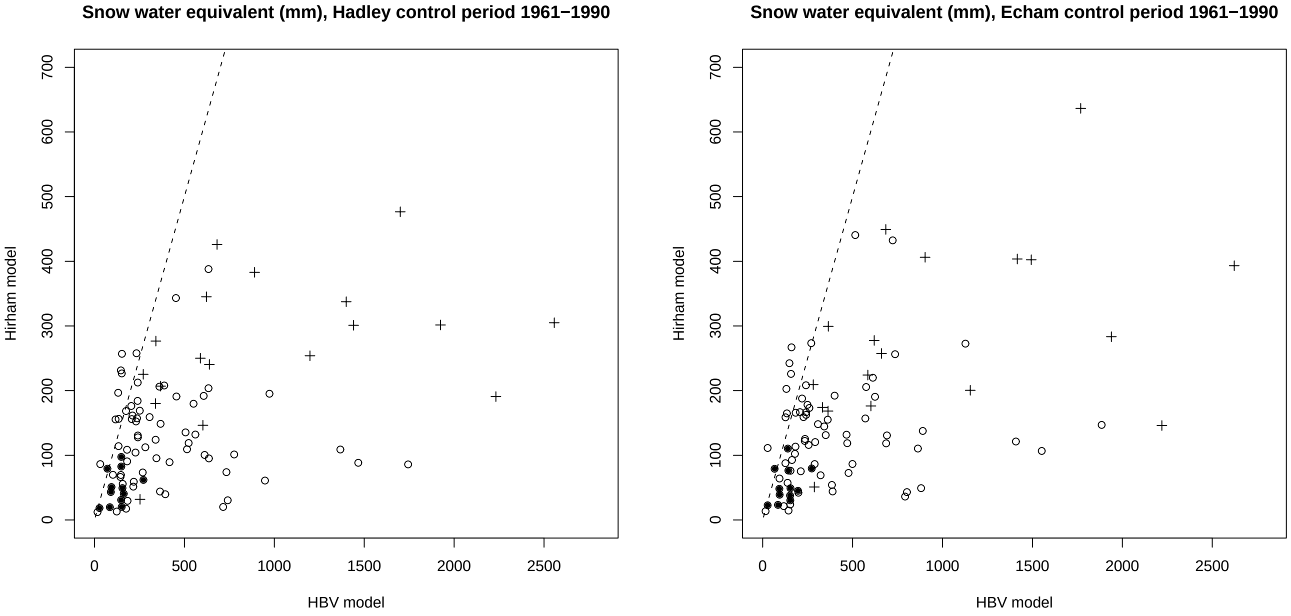

Figure 5: *Scatter plot of mean annual maximum snow water equivalent (mm) comparing the HBV model and the HIRHAM model, for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

The maps (Figures 6a,b) show that:

- The smallest deviations are generally found in eastern parts of South Norway as well as at and around Finnmarksvidda in Northern Norway. These areas typically have a smooth topography and/or are located in the lowlands.
- The largest deviations are found in inner regions of South-West Norway and in Nordland. In these regions the HBV model produced much higher snow water equivalent values than the HIRHAM model. Typically, these areas have rough topography and receive much precipitation. Differences in modelled snow water equivalent values might be related to differences in modelled precipitation (see Chapter 5) and modelled topography (see Section 2.4.2).

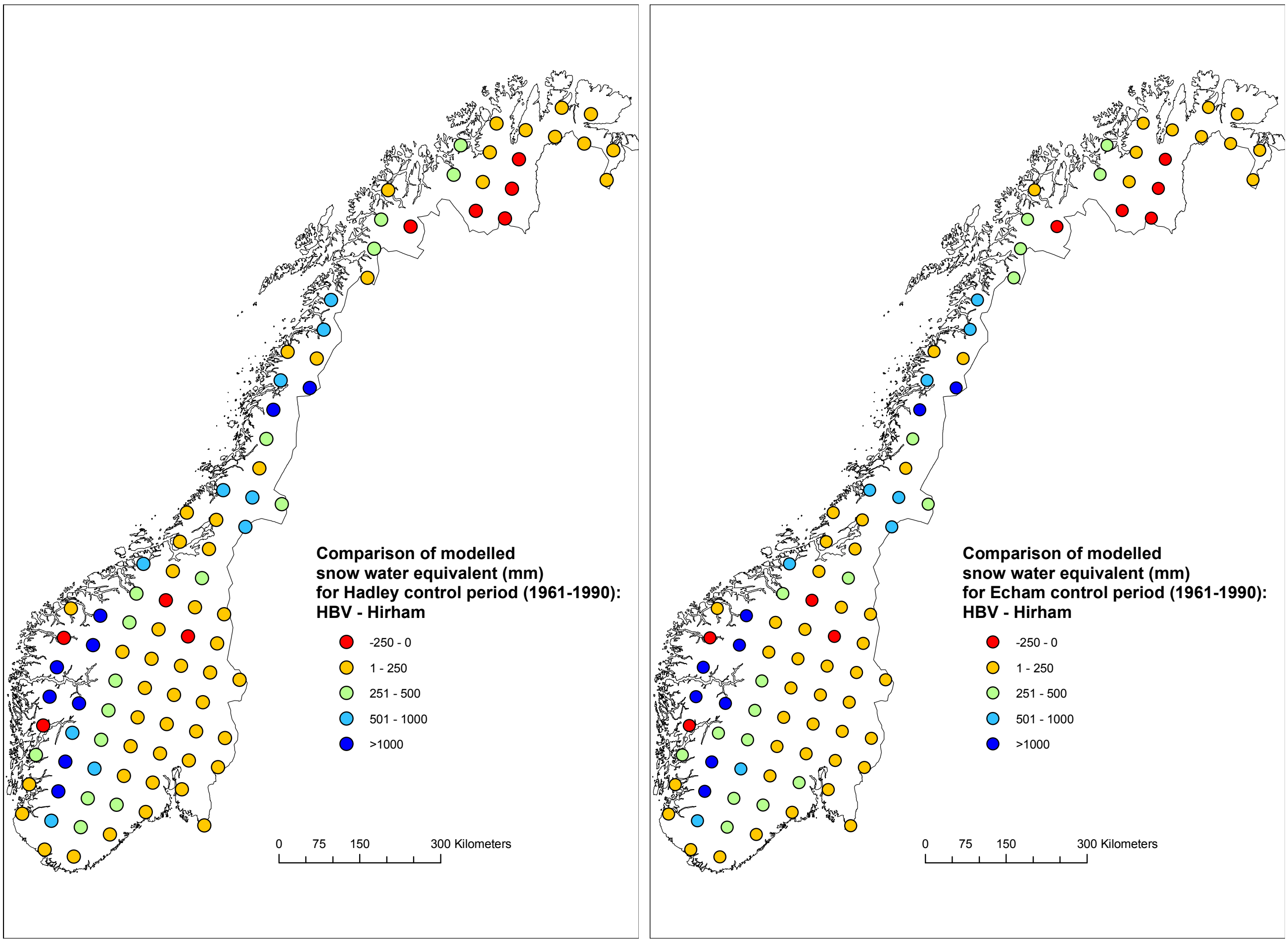

Figure 6: *Comparison of modelled mean annual maximum snow water equivalent (mm) for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam.*

3.2 Future climate (2071-2100)

Maps of mean annual maximum snow water equivalent (mm) calculated for the scenario period of the Hadley and Echam AOGCMs (dataset A and B), are presented for:

- the HIRHAM model (Figures 7a,b) and
- the HBV model (Figures 8a,b).

The projections of snow water equivalent for a future climate resulting from these two models are compared in the same way as for the control period (see Section 3.1). Scatter-plots comparing the estimated snow water equivalent values resulting from the HBV model and the HIRHAM model are presented in Figures 9a and b. Maps showing the geographic distribution of the differences in modelled snow water equivalent between the two models are shown in Figures 10a,b. The maps are computed in the following way: $diff_{scen} = swe_{HBV,scen} - swe_{HIRHAM,scen}$, where swe is the snow water equivalent and $scen$ refers to the scenario period.

The comparison shows that the HBV model still estimates considerably higher values of the snow water equivalent than the HIRHAM model. Similar to the control period, the differences between the estimations of the HBV model and the HIRHAM model increases with increasing altitude. For locations above 1000 m a.s.l. the HBV model projects up to ten times higher values than the HIRHAM model.

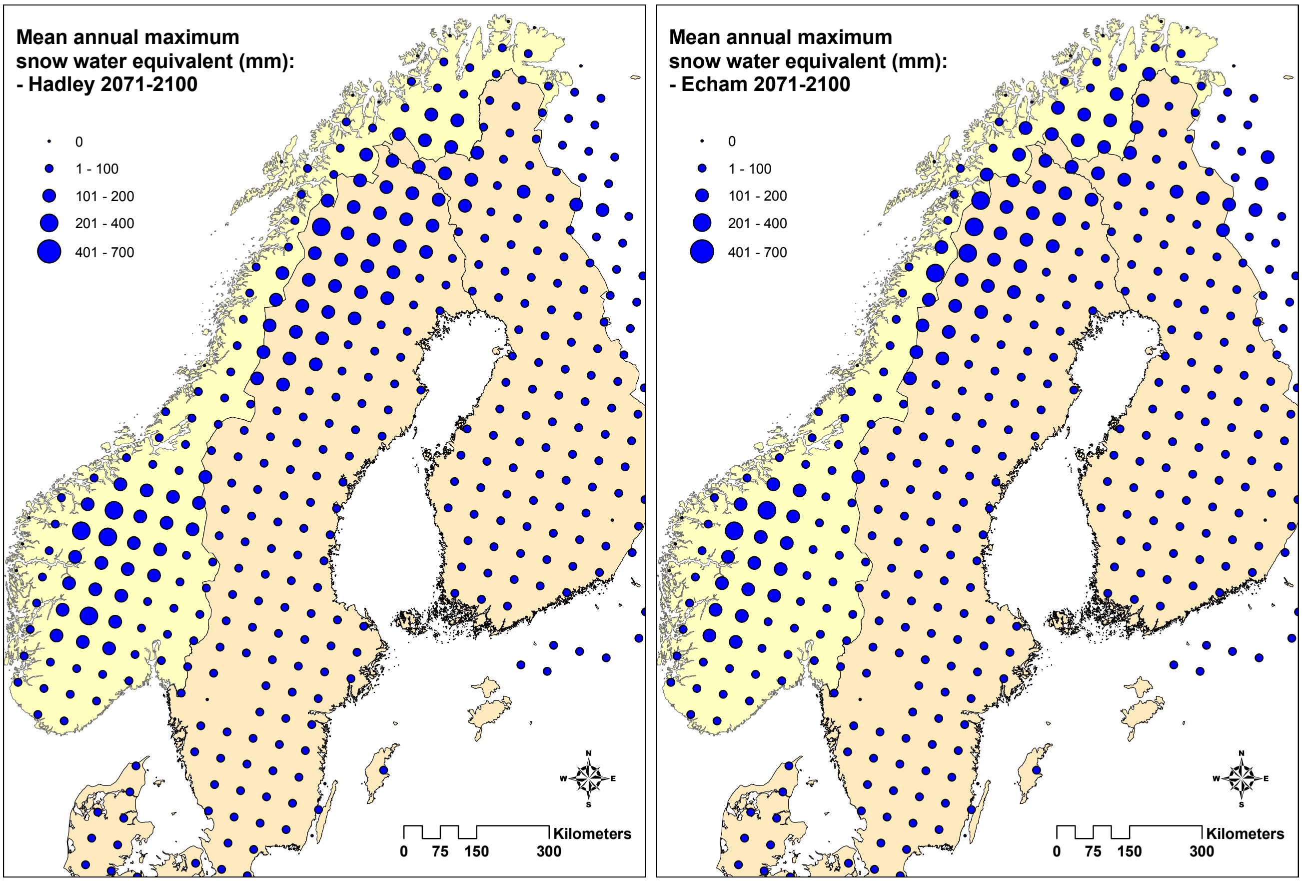

Figure 7: *Mean annual maximum snow water equivalent (mm) derived from the HIRHAM model, for the scenario period 2071-2100, with the B2 emission scenario. a) Climate model: Hadley, b) Climate model: Echam.*

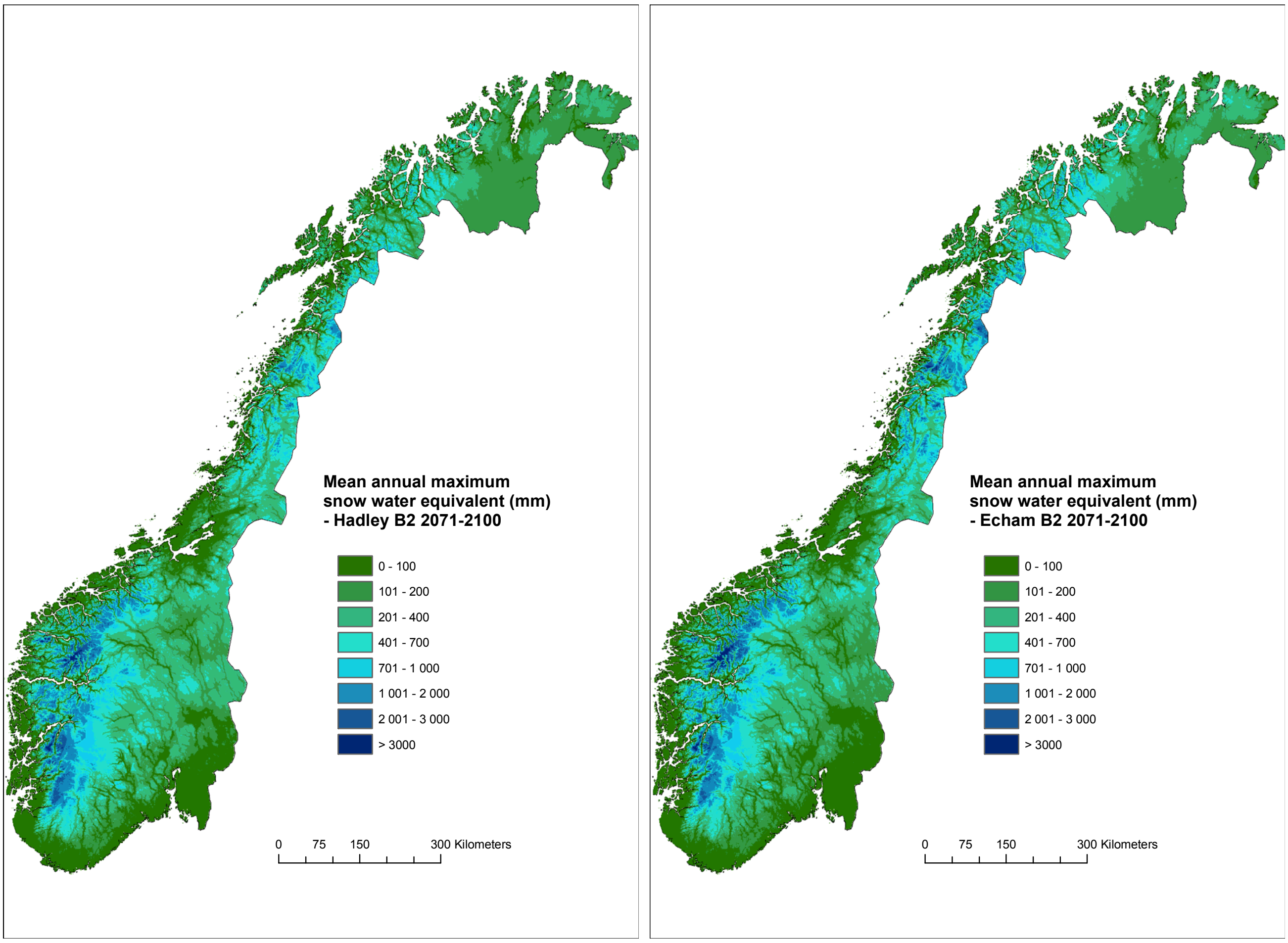

Figure 8: *Mean annual maximum snow water equivalent (mm) derived from the HBV model, for the scenario period 2071-2100, with the B2 emission scenario. a) Climate model: Hadley, b) Climate model: Echam.*

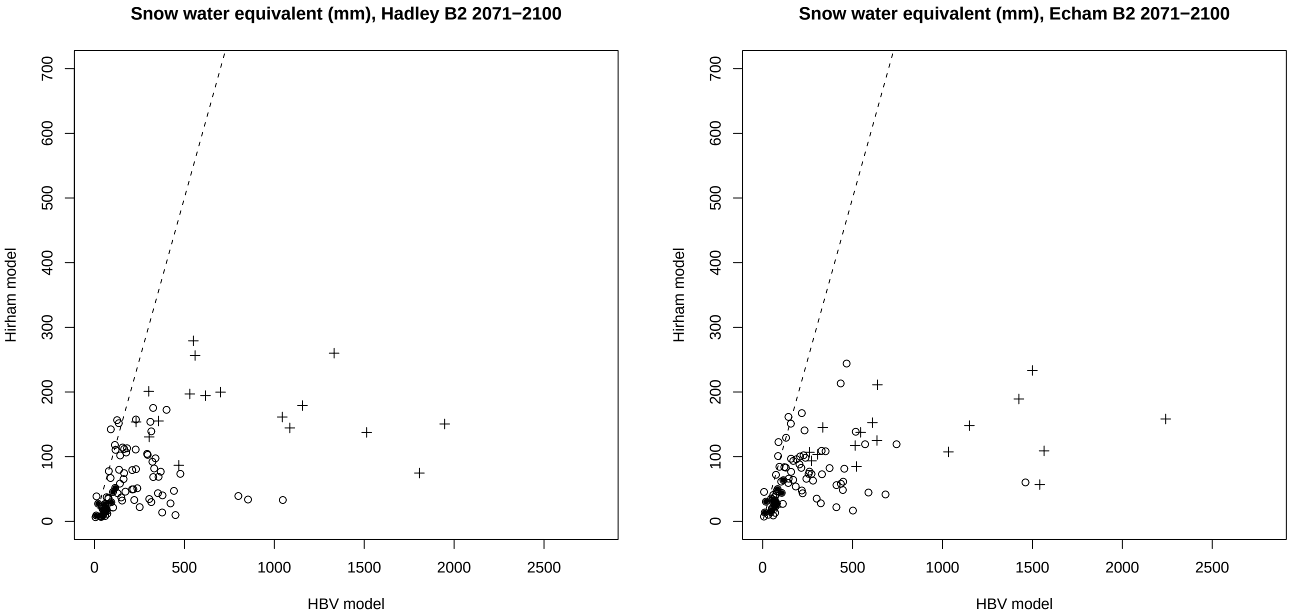

Figure 9: *Scatter plot of mean annual maximum snow water equivalent (mm) comparing the HBV model and the HIRHAM model, for the scenario period 2071-2100, with the B2 emission scenario. a) Climate model: Hadley, b) Climate model: Echam. Dashed line is a 1:1 line. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

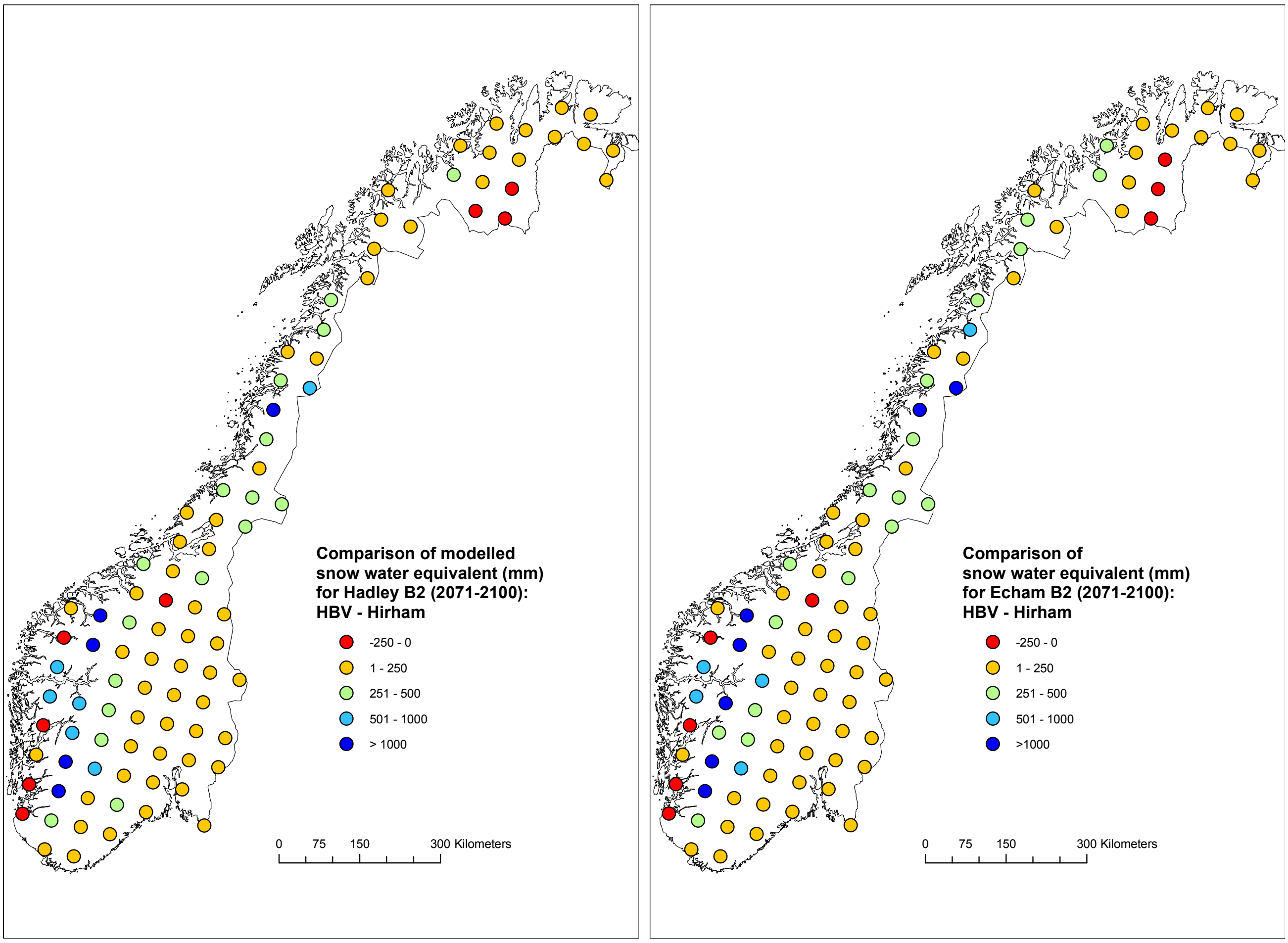

Figure 10: *Comparison of modelled mean annual maximum snow water equivalent (mm) for the scenario period 2071-2100, with the B2 emission scenario. a) Climate model: Hadley, b) Climate model: Echam.*

3.3 Changes from current (1961-1990) to future climate (2071-2100)

3.3.1 Absolute changes

Maps of absolute changes (mm) in mean annual maximum snow water equivalent from the control period to the scenario period for the Hadley and Echam AOGCMs (datasets A and B), are presented for:

- the HIRHAM model (Figures 11a,b) and
- the HBV model (Figures 12a,b).

The maps in the Figures 11a,b are computed in the following way: $change_{abs,HIRHAM} = swe_{HIRHAM,scen} - swe_{HIRHAM,ctrl}$, where swe is the snow water equivalent, $scen$ and $ctrl$ refer to the scenario and the control period, respectively, and abs is absolute change. The maps in Figures 12a,b are similarily computed, but for the HBV model: $change_{abs,HBV} = swe_{HBV,scen} - swe_{HBV,ctrl}$.

Generally, both the HIRHAM and the HBV models project reduced amounts of snow in Norway from the period 1961-1990 to the period 2071-2100. Only the HBV model has some minor areas with increased amounts of snow. Both models project largest decrease in snow water equivalent (mm) at the inner parts of West-Norway. These areas normally have large maximum snow water equivalents (see Figures 3 and 4).

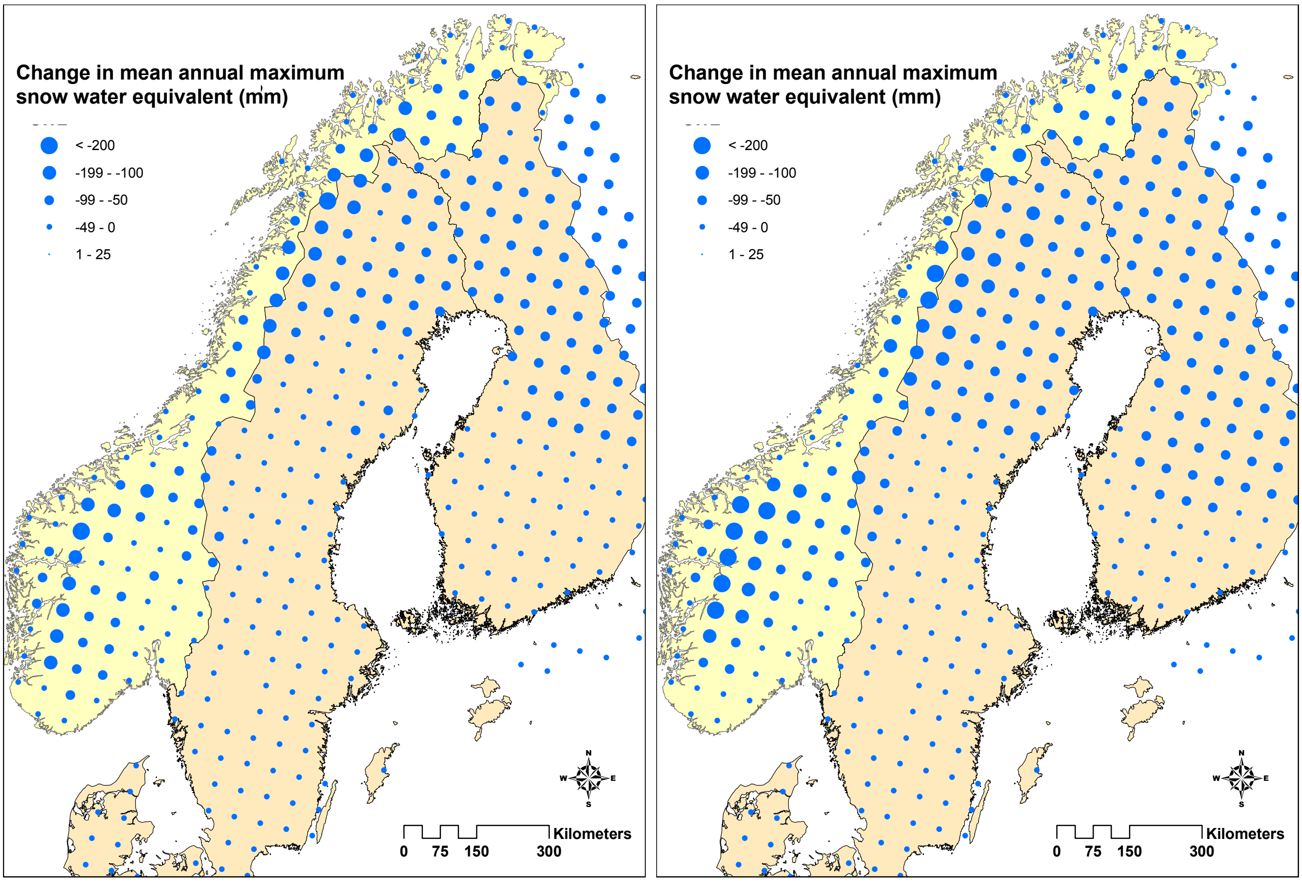

Figure 11: *Change in mean annual maximum snow water equivalent (mm) derived from the HIRHAM model. Calculated difference between the scenario period (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam.*

A comparison of the two models is shown in Figure 13a and b. The scatter-plots show that the HBV model and the HIRHAM model project changes in the same order of magnitude for areas located below 200 m a.s.l. For areas above 200 m a.s.l. the HBV model often project much larger reductions in snow amounts than the HIRHAM model.

In Figure 14a,b the differences in projected absolute changes for the two models are illustrated geographically. These maps are computed in the following way: $change_{abs,HBV} - change_{abs,HIRHAM}$.

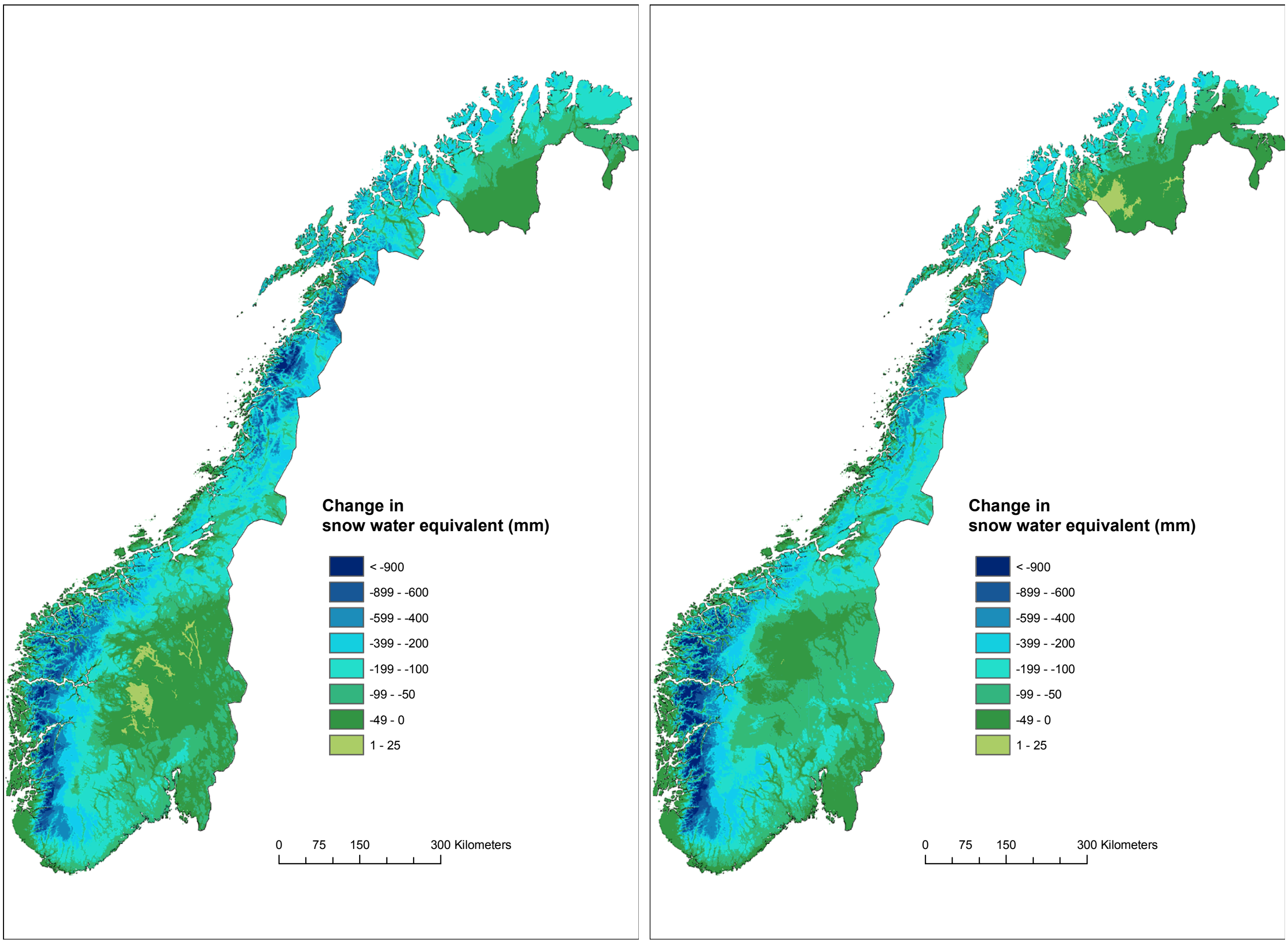

Figure 12: *Change in mean annual maximum snow water equivalent (mm) derived from the HBV model. Calculated difference between the scenario period (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam.*

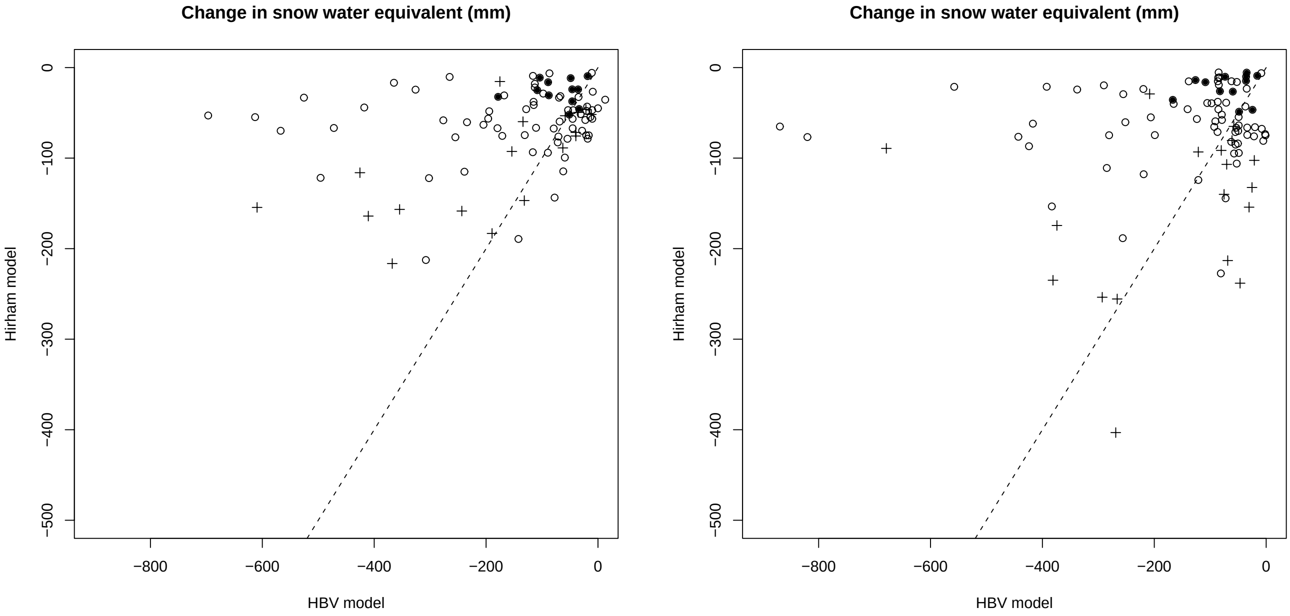

Figure 13: *Scatter plot of change in mean annual maximum snow water equivalent (mm) comparing the HBV model and the HIRHAM model. Calculated difference between the scenario period (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

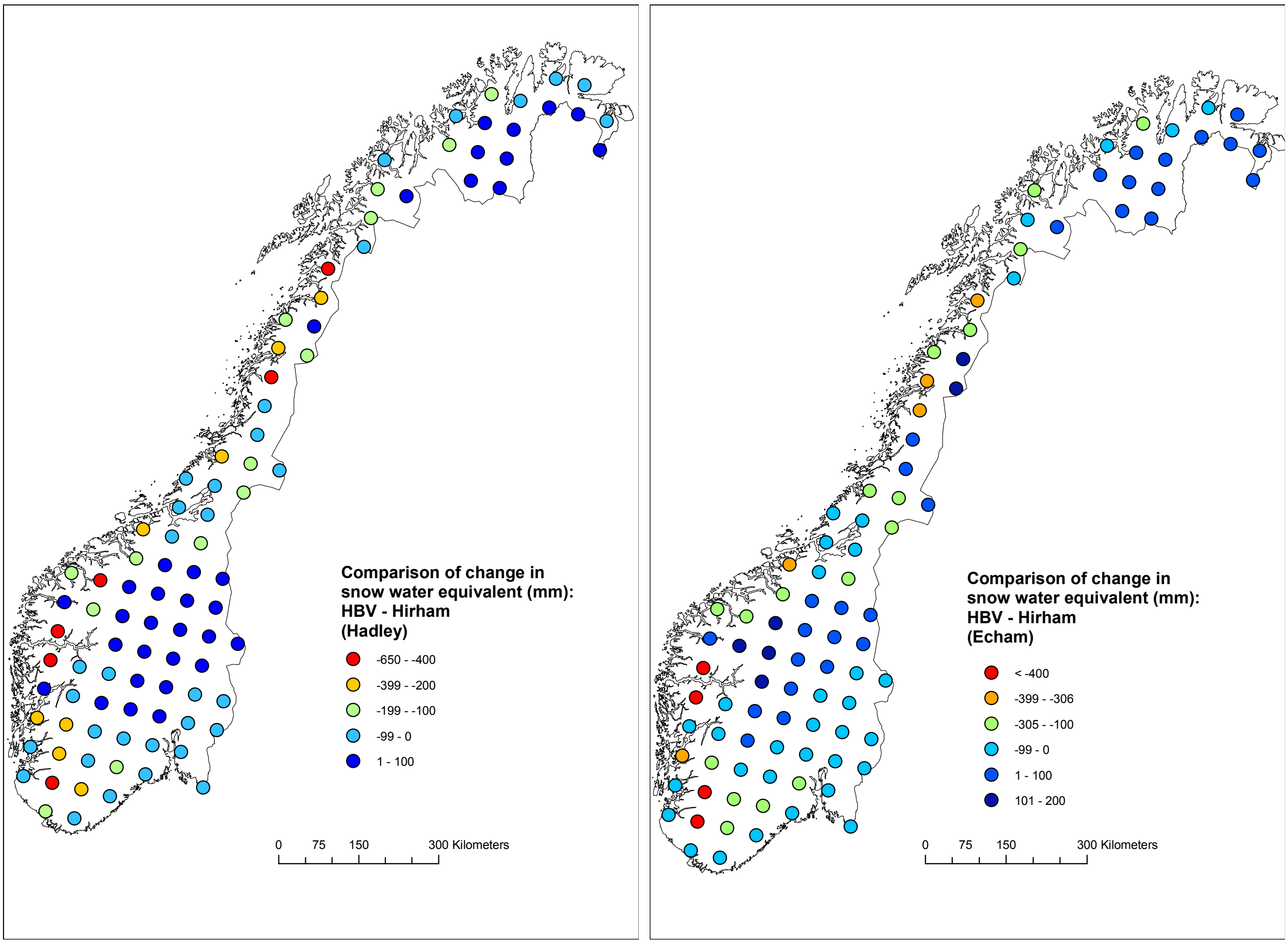

Figure 14: *Comparison of the HIRHAM and HBV models showing differences in absolute change in mean annual maximum snow water equivalent (mm). a) Climate model: Hadley, b) Climate model: Echam. The map is calculated based on the differences shown in Figure 13.*

Areas where the two models give most similar results are shown as blue circles (+/- 100 m snow water equivalent). Positive difference values (dark blue circles) are locations where the HBV model projects less reductions than the HIRHAM model. This occurs in mountainous areas in South Norway, as well as the Finmarksvidda region. Negative difference values (light blue, green, yellow and red circles) are locations where the HBV model projects larger reductions than the HIRHAM model. This occurs often in the lowlands and coastal areas. However, this is not a straight-forward systematic pattern.

3.3.2 Relative changes

Maps of relative changes (%) in mean annual maximum snow water equivalent from the control period to the scenario period for the Hadley and Echam AOGCMs (datasets A and B), are presented for:

- the HIRHAM model (Figures 15a,b) and
- the HBV model (Figures 16a,b).

The maps in Figures 15a,b are computed in the following way: $change_{HIRHAM,rel} = \frac{swe_{HIRHAM,scen} - swe_{HIRHAM,ctrl}}{swe_{HIRHAM,ctrl}} * 100[\%]$, where swe is the snow water equivalent, $scen$ and $ctrl$ refer to the scenario and the control period, respectively, and rel is relative change. The maps in Figures 16a,b are similarily computed, but for the HBV model: $change_{HBV,rel} = \frac{swe_{HBV,scen} - swe_{HBV,ctrl}}{swe_{HBV,ctrl}} * 100[\%]$.

A comparison of the two models showing projected relative changes (%) of snow water equivalent are presented in Figures 17a and b. There are indications that the HBV model projects smaller relative changes than the HIRHAM model in areas located above 1000 m a.s.l. For areas lower than 200 m a.s.l. the HBV model often projects larger relative changes than the HIRHAM model, specifically for the Echam climate scenarios. The Hadley climate scenarios do not show the same trend.

A geographic comparison of the differences in relative changes projected by the two models is shown in Figures 18a,b. The maps are computed in the following way: $change_{HBV,rel} - change_{HIRHAM,rel}$.

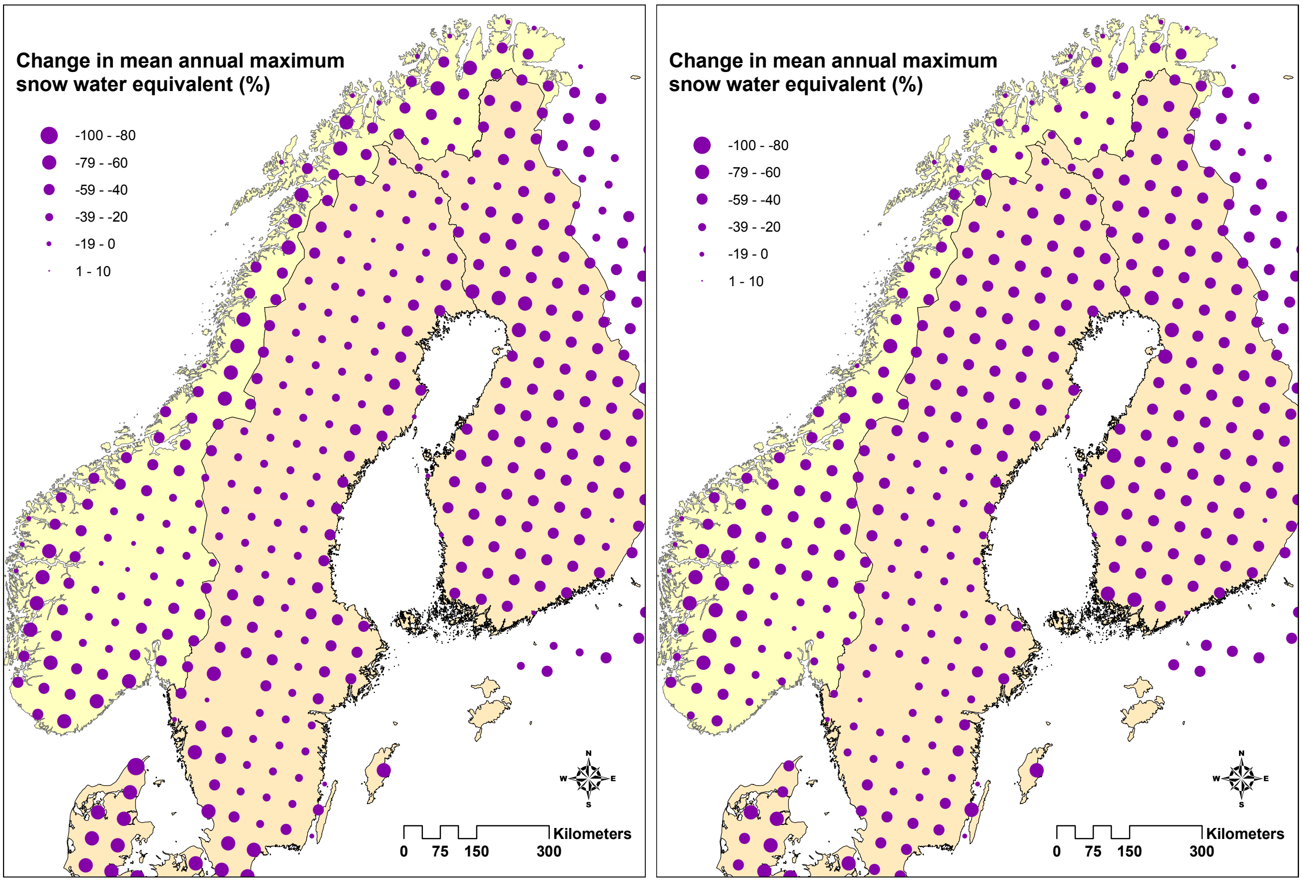

Figure 15: *Change in mean annual maximum snow water equivalent (%) derived from the HIRHAM model. Calculated relative change (%) from the control period (1961-1990) to the scenario period (2071-2100). a) Climate model: Hadley, b) Climate model: Echam.*

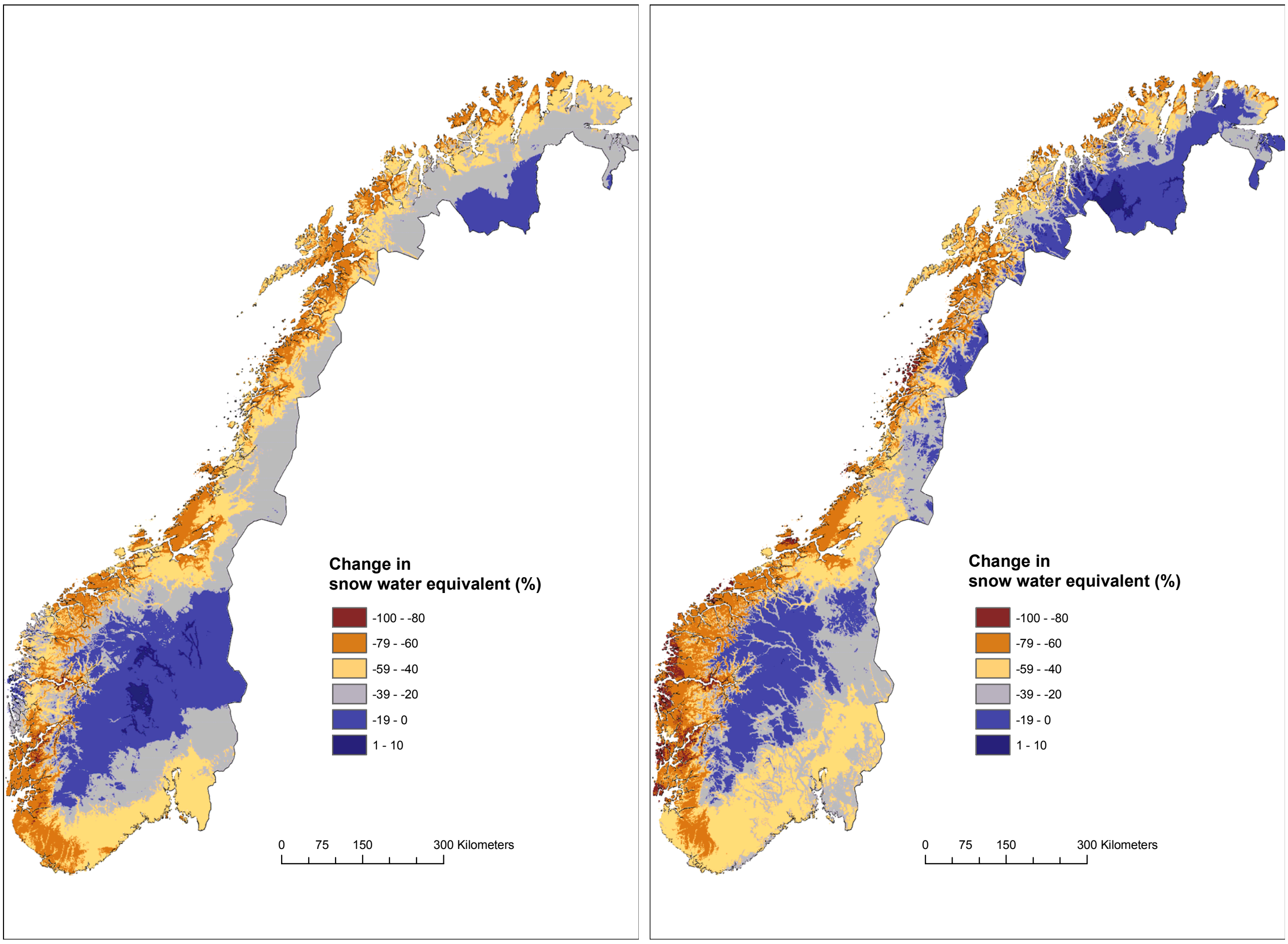

Figure 16: *Change in mean annual maximum snow water equivalent (%) derived from the HBV model. Calculated relative change (%) between the scenario period (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam.*

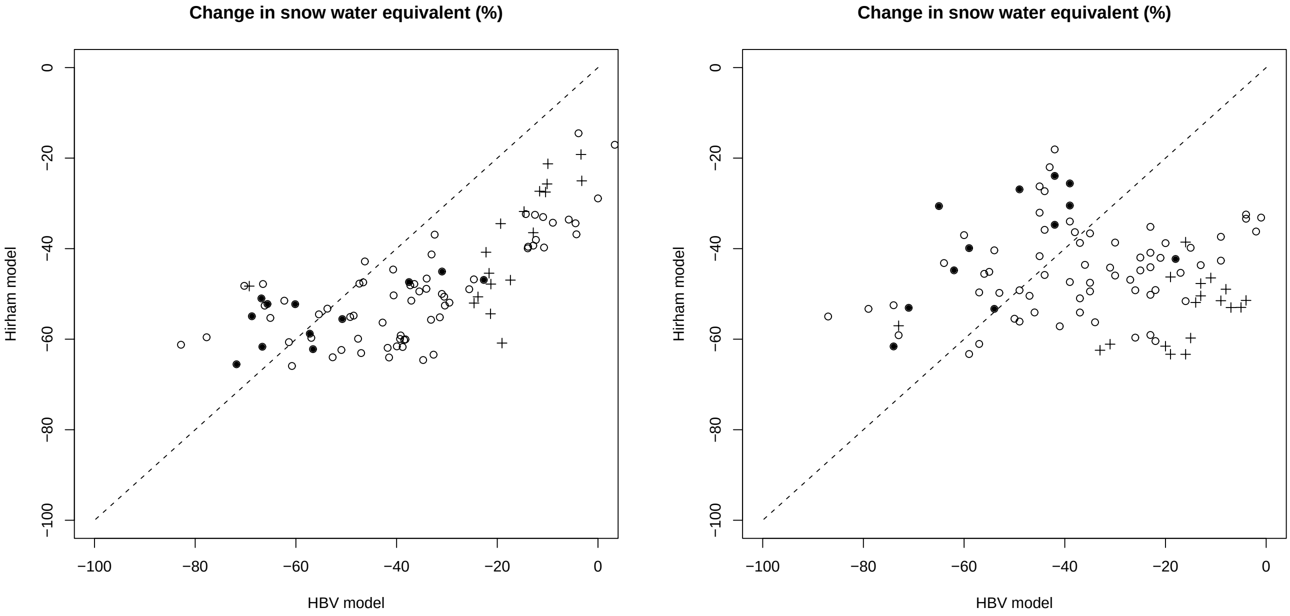

Figure 17: *Scatter plot of relative change in mean annual maximum snow water equivalent (%) comparing the HBV model and the HIRHAM model. Calculated relative change from the control period (1961-1990) to the scenario period (2071-2100). a) Climate model: Hadley, b) Climate model: Echam. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

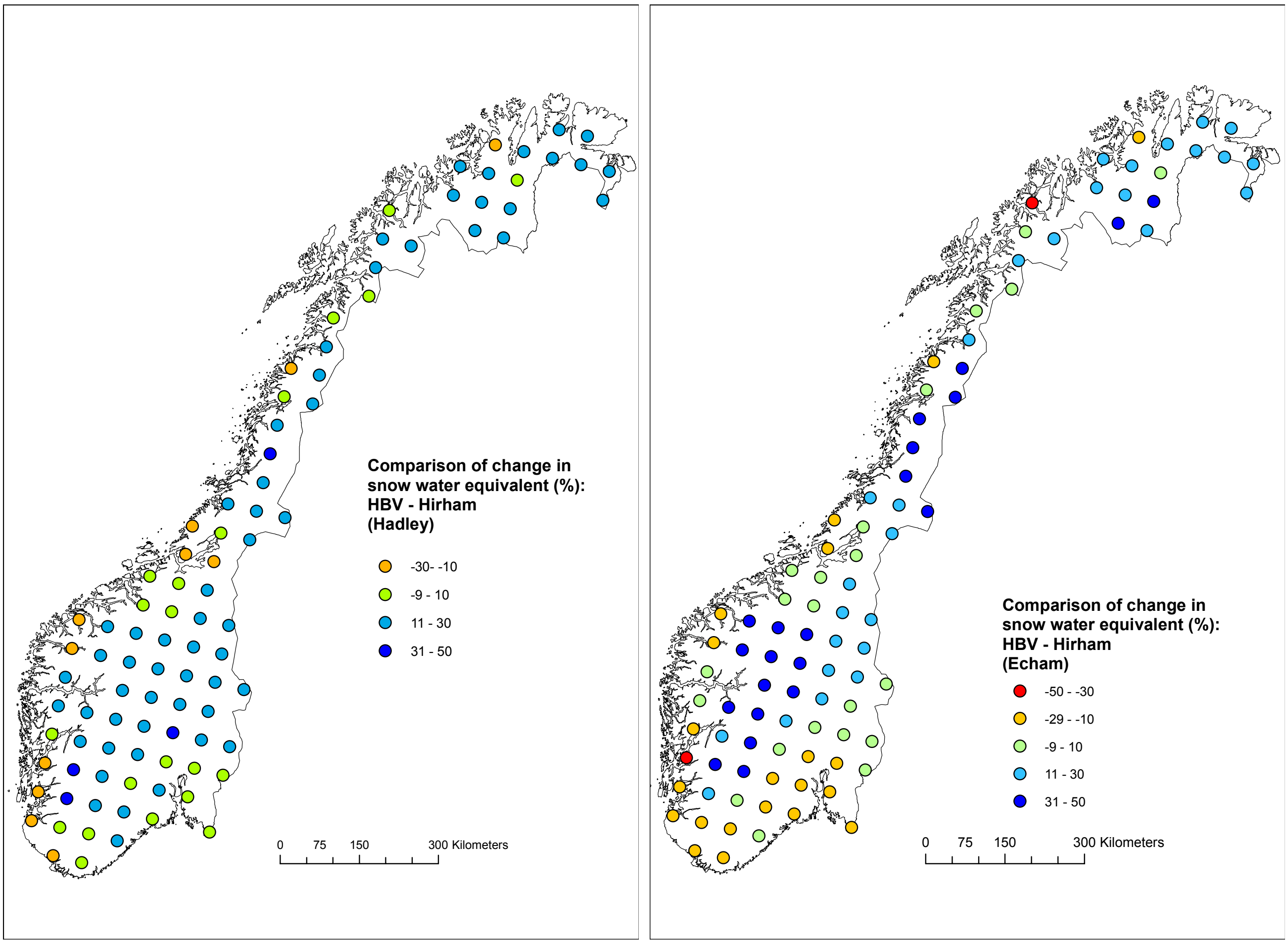

Figure 18: *Comparison of the HIRHAM and HBV model showing differences in relative changes in mean annual maximum snow water equivalent (%). a) Climate model: Hadley, b) Climate model: Echam. The map is calculated based on the differences shown in Figure 17.*

4 Mean number of days per year with snow cover

In this Section we compare the HBV and the HIRHAM models by studying the derived variable: mean number of days per year with snow-covered ground.

For the HBV model, we counted the days with more than 50% of the ground covered by snow. This variable is extracted from the results reported in Vikhamar-Schuler et al. (2006). For the HIRHAM model, we counted the days with more than 0 mm snow water equivalent. This difference in the way of counting days with snow will influence the comparison of the two models.

We choose to present the results for only one climate model (Hadley with the B2 scenario), since this variable is not a direct output from the two models. In this report we give priority to the direct output variables such as snow water equivalent and precipitation (Sections 3 and 5).

4.1 Current (1961-1990) and future (2071-2100) climate

We present the mean number of days per year with snow-covered ground for the HIRHAM model in Figures 19a and b. The variable is calculated for the control period (1961-1990) representing the current climate and for a future climate in the period 2071-2100. A similar figure is presented for the HBV model (see Figures 20a and b).

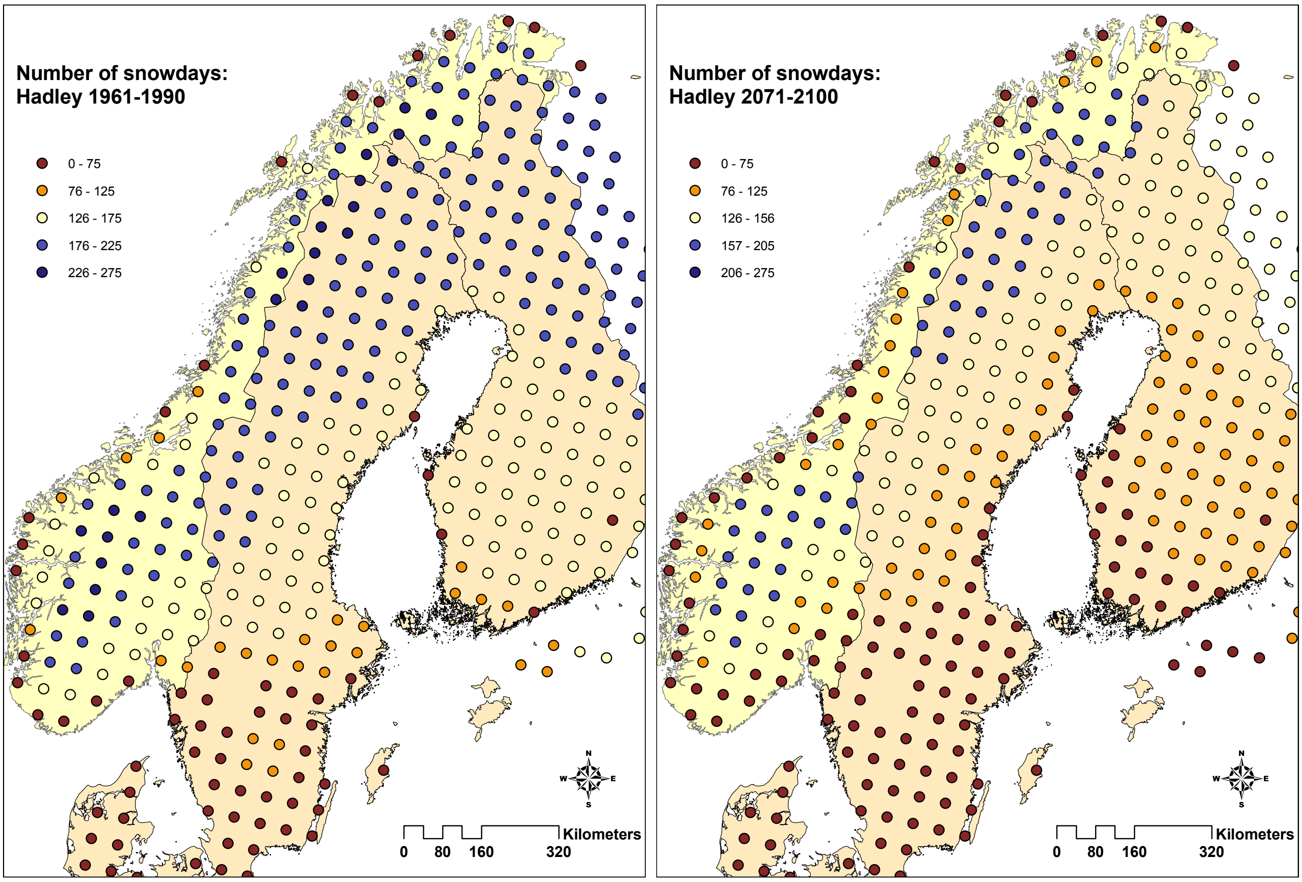

Figure 19: *Mean number of days with snow derived from the HIRHAM model for the Hadley climate model: a) the control period 1961-1990, b) the period 2071-2100 with the B2 emission scenario.*

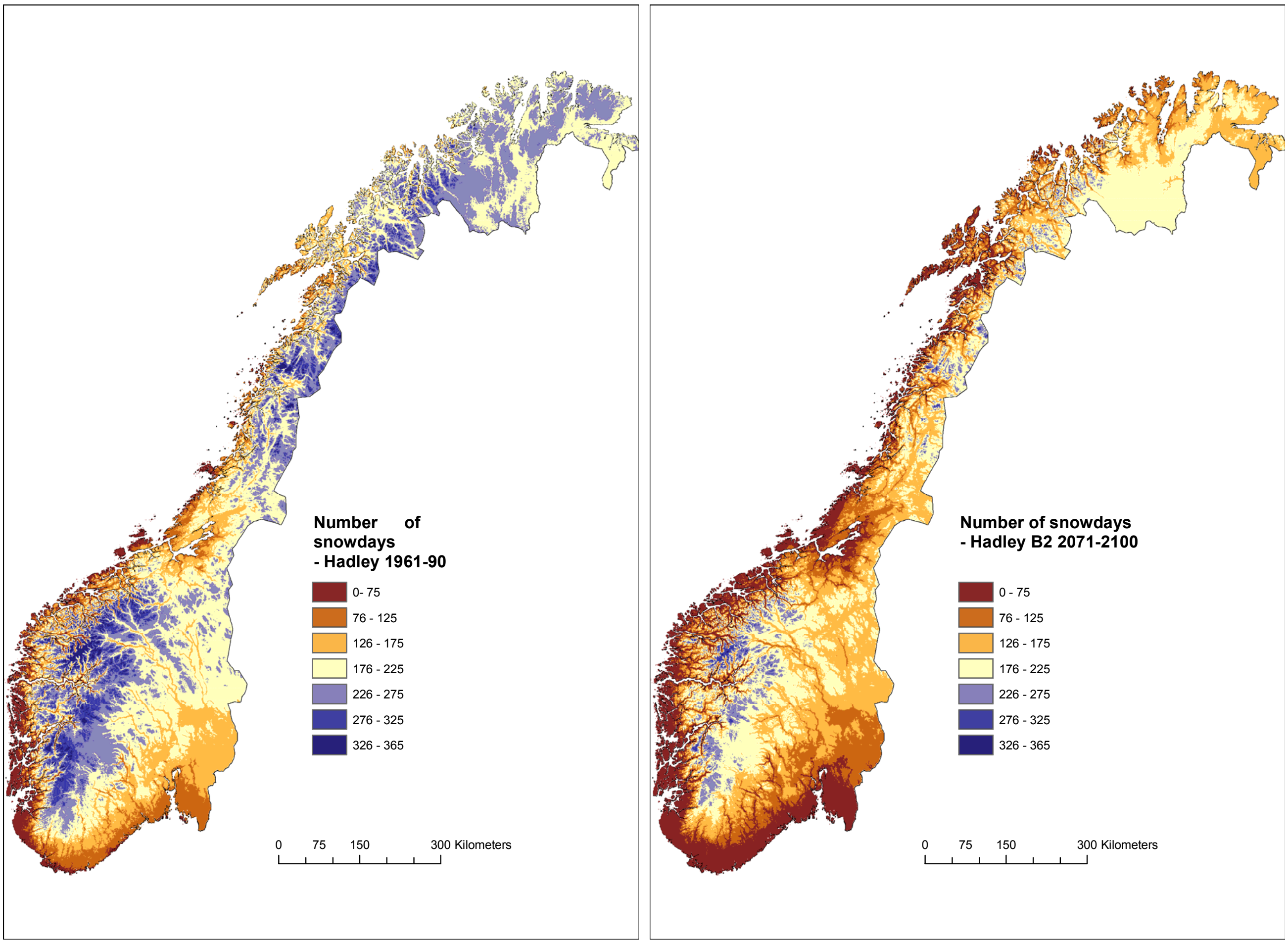

Figure 20: *Mean number of days with snow derived from the HBV model for the Hadley climate model: a) the control period 1961-1990, b) the period 2071-2100 with the B2 emission scenario.*

4.2 Changes from current (1961-1990) to future climate (2071-2100)

A comparison of changes in number of days per year with snow-covered ground for the HBV and the HIRHAM models is shown in Figure 21. Overall, there are major similarities between the two models:

- Both the HIRHAM and the HBV models project a shorter snow season duration in the entire country.
- Smallest change in snow season duration is projected in the high mountains of South Norway.
- Largest change in snow season duration is projected along the coast, and especially at the innermost parts of the coastal areas in West-Norway, Mid-Norway and North-Norway.

However, there are regional differences projected by the HBV and the HIRHAM models. Along the outermost parts of the coast in North-Norway, the HIRHAM model projects little or no change in number of days with snow cover. This is because the HIRHAM model already projects very few days with snow during the current climate (Figure 19a). The HBV model projects a reduction of more than 80 days in these areas. For the current climate the HBV model also projects quite many days with snow, often in the category 176-225 days. A similar pattern is also observed a few places at the outermost southern coastal parts of Norway.

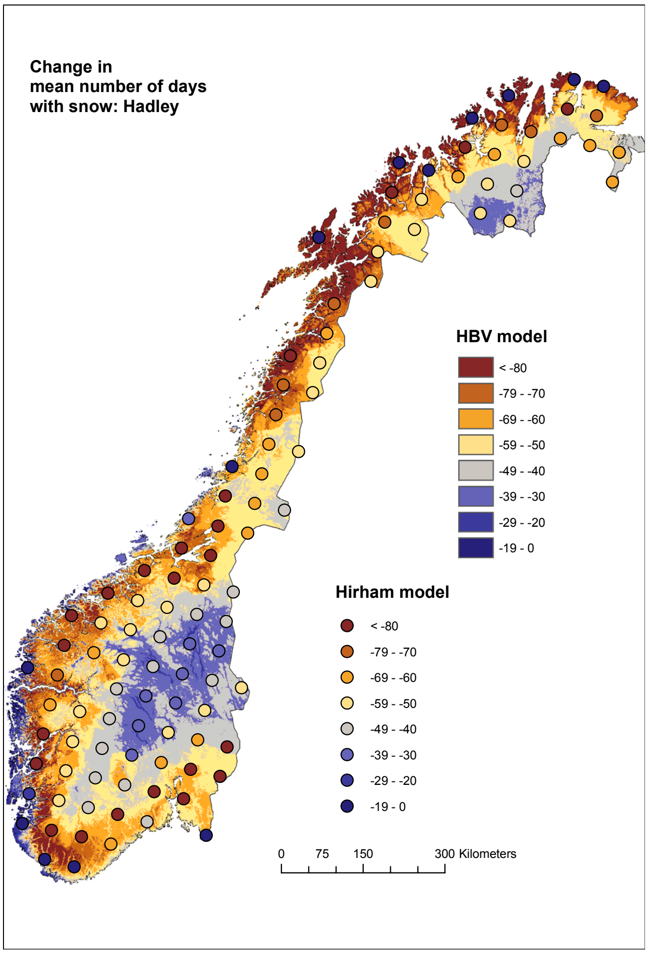

Figure 21: *Change in mean number of days with snow derived from both the HIRHAM and the HBV models for the Hadley AOGCM.*

5 Precipitation modelling in HIRHAM and HBV

In the previous Chapters we have seen that there are sometimes large differences in the modelled snow water equivalent values from the HIRHAM and the HBV models. Different representation of topography, different snow algorithm and precipitation modelling are potential sources for these differences. In this Chapter, we therefore compare precipitation modelling in the HIRHAM and HBV models.

The precipitation values from the HIRHAM model represent grid cells of 55 km × 55 km, while the precipitation values from the HBV model represent 1 km × 1 km. Comparison of precipitation values from the two models are carried out by extracting the 1 km × 1 km grid cell that is located at the center point of the 55 km × 55 km grid cell.

5.1 Current (1961-1990) and future (2071-2100) climate

Maps of mean precipitation (mm) during the winter months (December, January and February) and the spring months (March, April, May) calculated for the control period for both climate models, Hadley and Echam, are presented for:

- the HIRHAM model (Figures 22a,b and Figures 23a,b).
- the HBV model (Figures 24a,b).

Precipitation values from the HIRHAM and the HBV models are compared in the Figures 25, 26, 27 and 28. The comparison is performed for the results from the Hadley climate model. The scatter plots (Figures 25a,b and 26a,b) show that:

- For the winter months the two models provide quite similar precipitation values for areas located below 200 m a.s.l. In areas located above 1000 m a.s.l. the HBV model provide precipitation values much higher than the HIRHAM model, often up to twice as much precipitation. This pattern is similar for both control period and scenario period.
- For the spring months the HIRHAM model gives somewhat higher values than the HBV model for the lowermost located areas. However, the main difference between the two models is a larger span in precipitation values provided by the HBV model than the HIRHAM model.

A geographic illustration of the differences between the HBV and the HIRHAM model is shown in Figures 27 and 28. Blue points represent locations where the HBV model provide lower precipitation values than the HIRHAM model. This occurs typically in South-Eastern parts of Norway, but also in the innerparts of Finnmark. Yellow and red points represent locations where the HBV model provide higher precipitation values than the HIRHAM model. This occurs around the fjords and in the coastal areas of West-Norway as well as in the coastal parts of Nordland. This pattern occurs both during the winter- and the spring months.

A reason for getting higher precipitation values from the HBV model on the South-Eastern parts of Norway, and lower values than the HIRHAM model on the South-Western parts of Norway might be related to differences in the representation of the topography in the models. Different representation of terrain effects certainly affects the precipitation modelling. The topography is much better described in the HBV model than in the HIRHAM model (see Section 2.4.2). The topography is averaged in the HIRHAM model, such that the modelled elevation is lower than in reality in a mountainous region (e.g. in South-West Norway), while the modelled elevation is higher than in reality in lowlands (e.g. in South-East Norway). The HBV model uses a digital terrain model with 1 km × 1 km resolution, and therefore has a better local and regional representation of the topography.

Another reason for the HBV model giving higher precipitation values than the HIRHAM model might be related to the way precipitation is interpolated to the 1 km × 1 km grid cells. Precipitation in all grid cells are estimated by using inverse distance weighting of the three nearest precipitation stations. Additionally, a precipitation correction, which depends on the altitude of each grid cell, is applied by increasing the precipitation with 10% per 100 m below 1200 m a.s.l. and 5% per 100 m abowe 1200 m a.s.l. Very few precipitation stations are located in the high-mountains. In general, precipitation modelled for use with the HBV model is suspected to be overestimated in high-altitude regions.

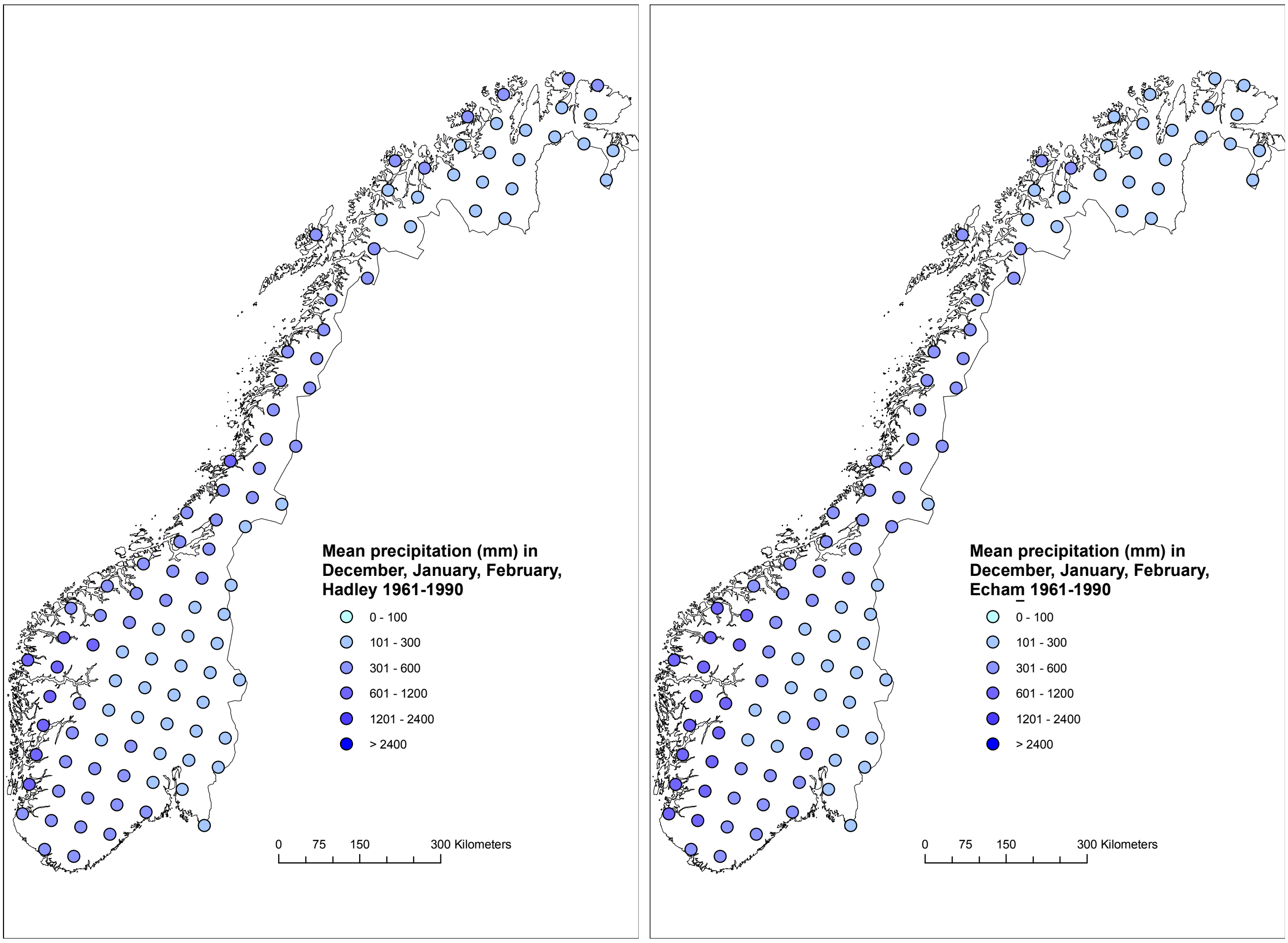

Figure 22: *Mean precipitation (mm) during December, January and February derived from the HIRHAM model, for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam.*

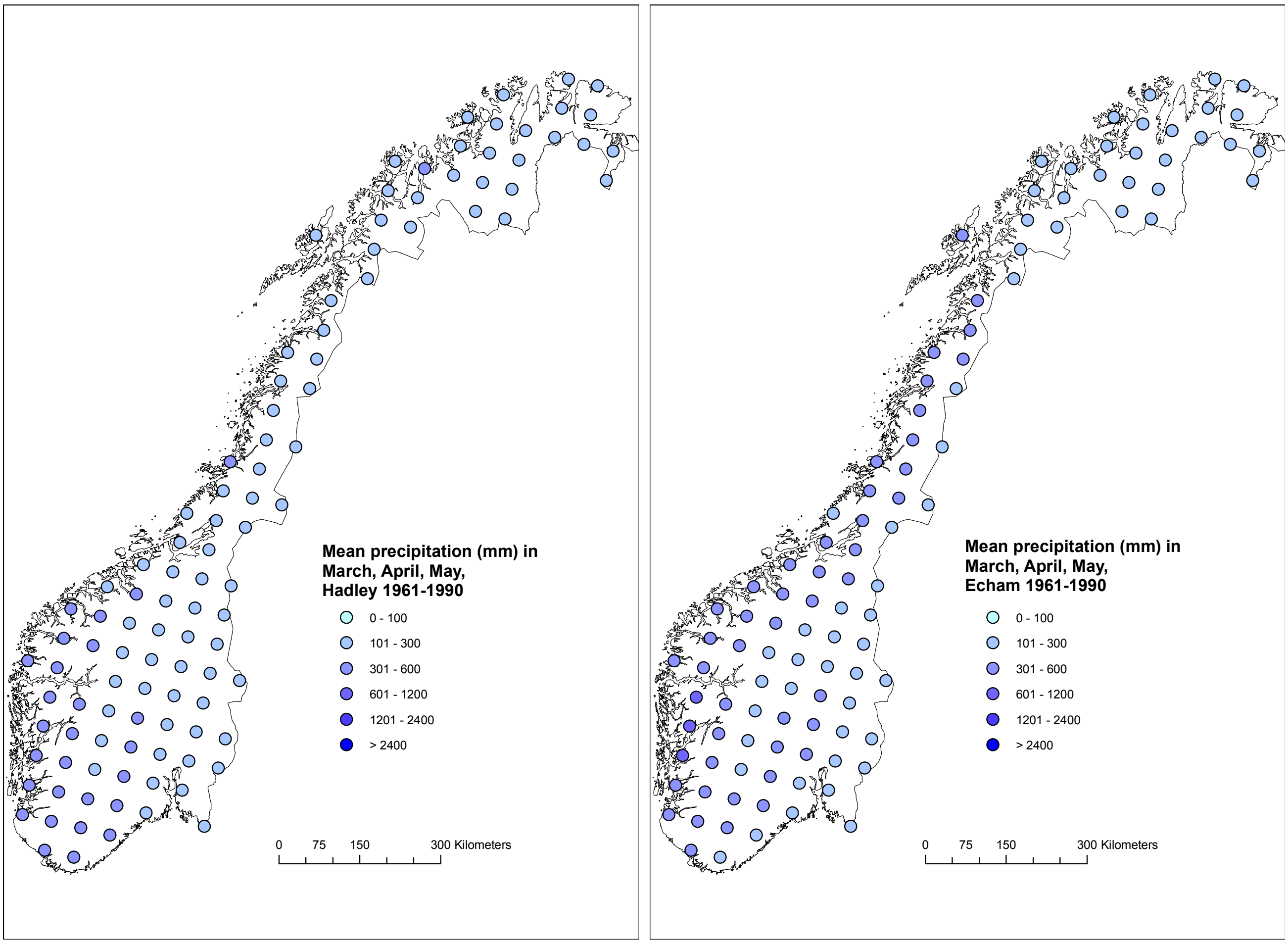

Figure 23: *Mean precipitation (mm) during March, April, May derived from the HIRHAM model, for the control period 1961-1990. a) Climate model: Hadley, b) Climate model: Echam.*

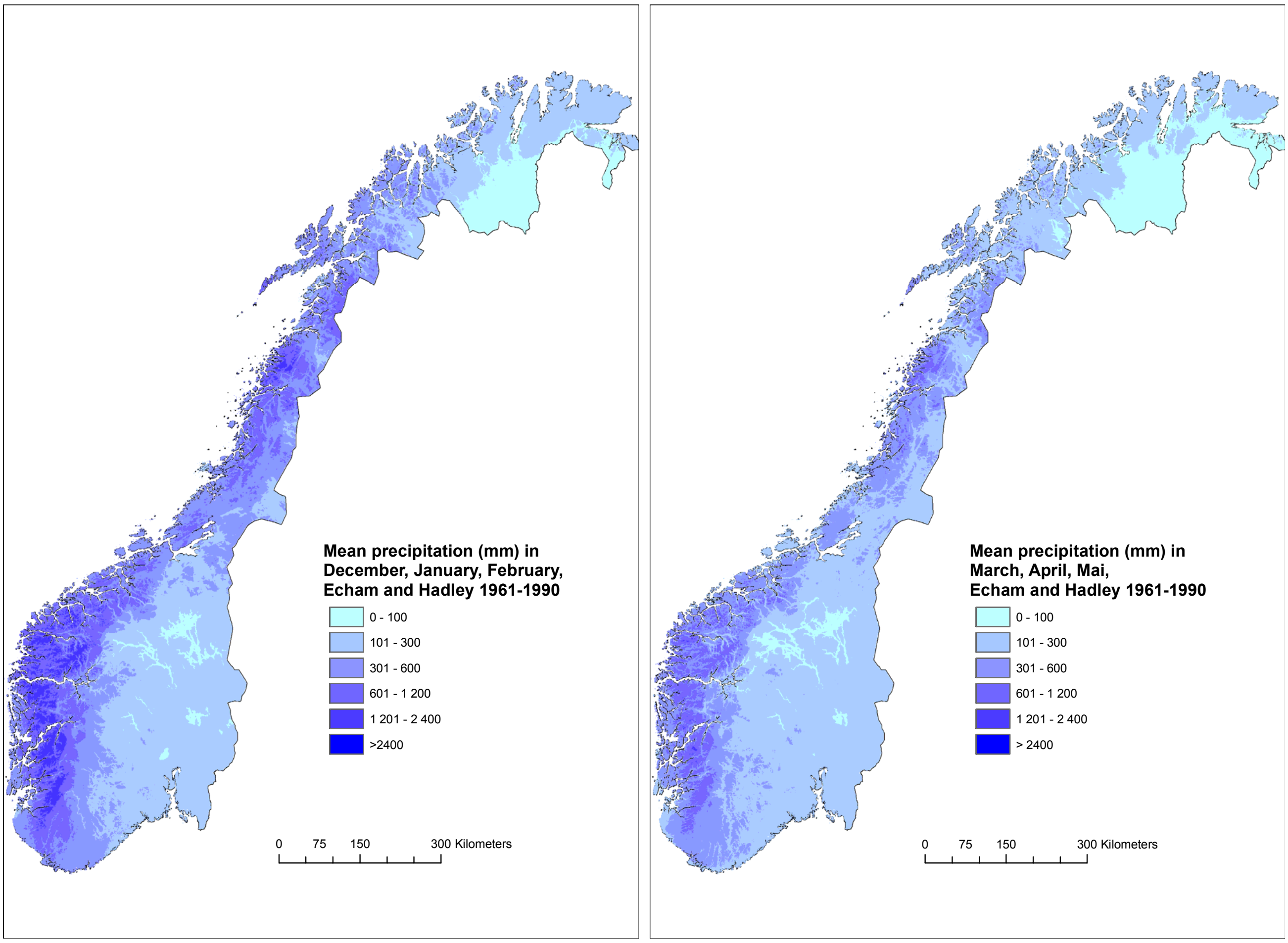

Figure 24: *Mean precipitation (mm) derived from the HBV model for the control period 1961-1990 during: a) December, January and February, and b) March, April and May. Due to local adjustment to stations, the map is the same for both the Hadley and the Echam climate models (Engen-Skaugen, 2004).*

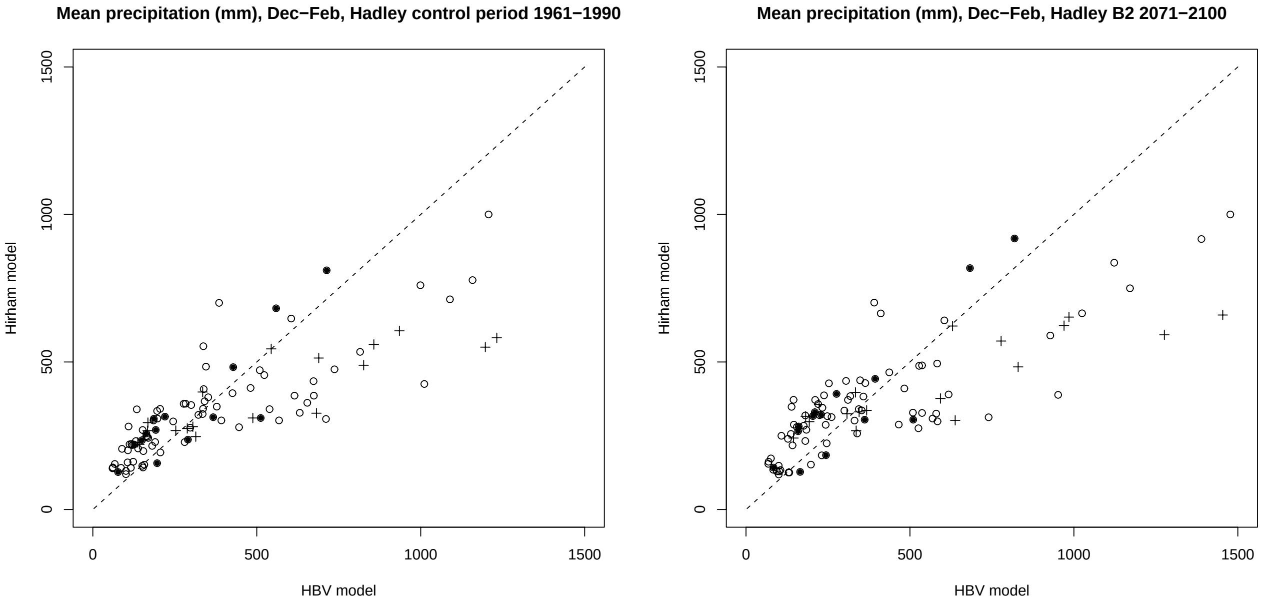

Figure 25: *Scatter plot of modelled mean precipitation (mm) during December, January and February comparing the HBV model and the HIRHAM model. a) The control period 1961-1990 and b) the scenario period 2071-2100. Only the Hadley climate model is shown. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

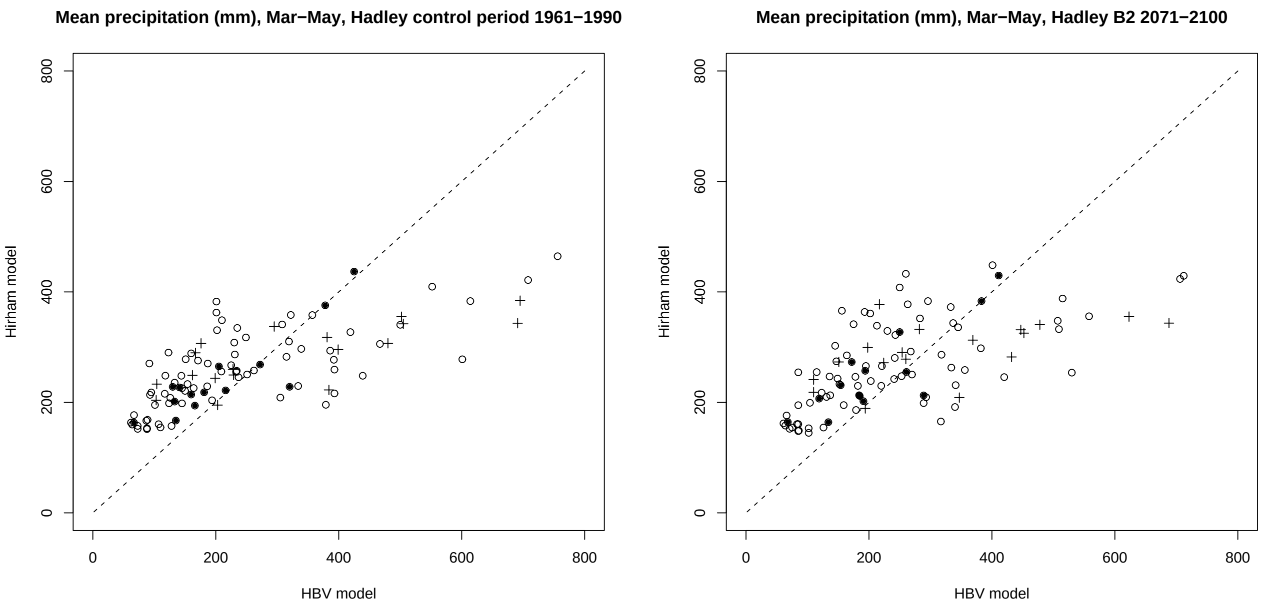

Figure 26: *Scatter plot of modelled mean precipitation (mm) during March, April, May comparing the HBV model and the HIRHAM model. a) The control period 1961-1990 and b) the scenario period 2071-2100. Only the Hadley climate model is shown. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

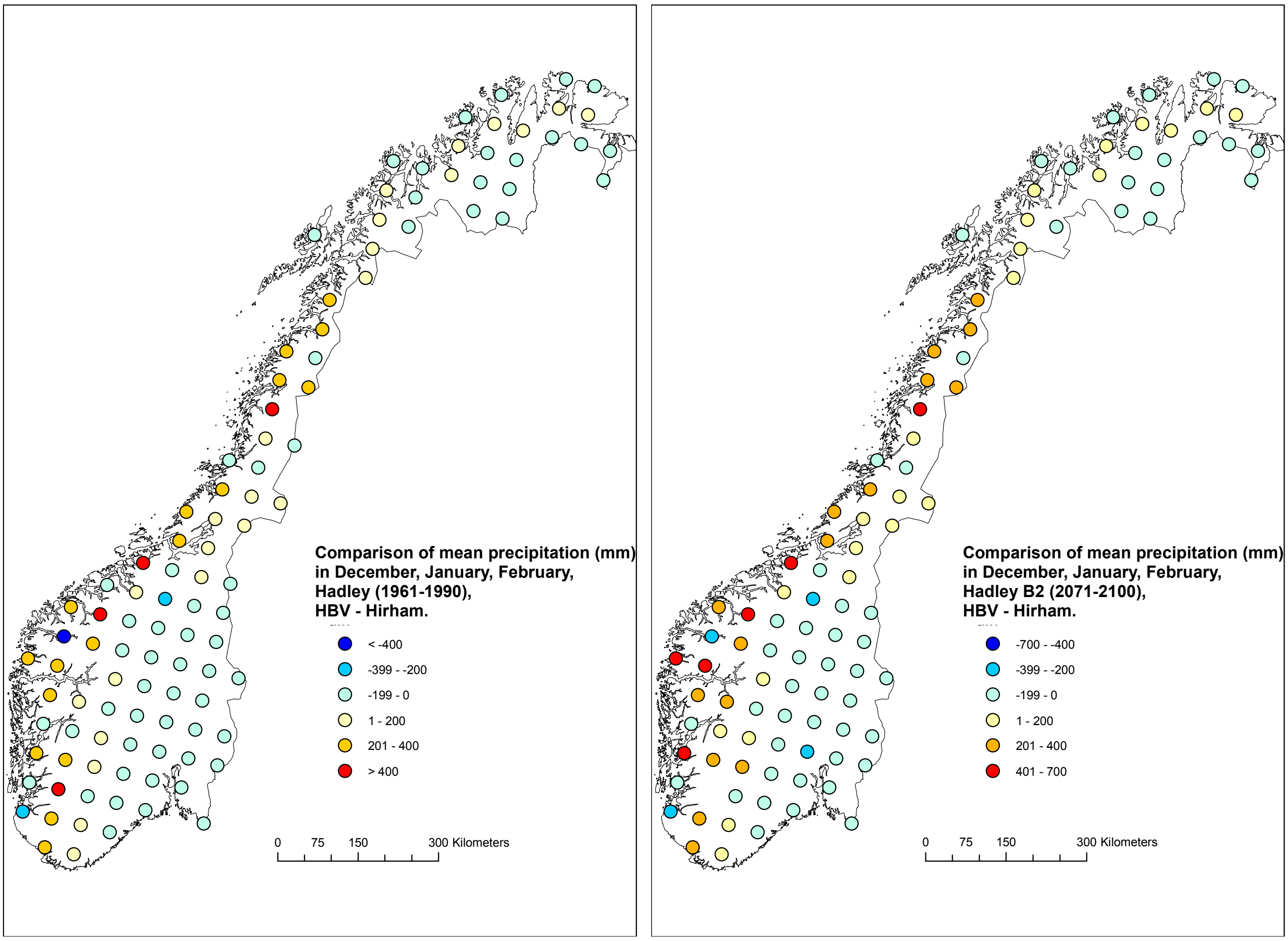

Figure 27: *Comparison of modelled mean precipitation (mm) during December, January and February for a) the control period 1961-1990 and b) the scenario period 2071-2100. The precipitation values are differences between the HBV model and the HIRHAM model. Only the Hadley climate model is shown.*

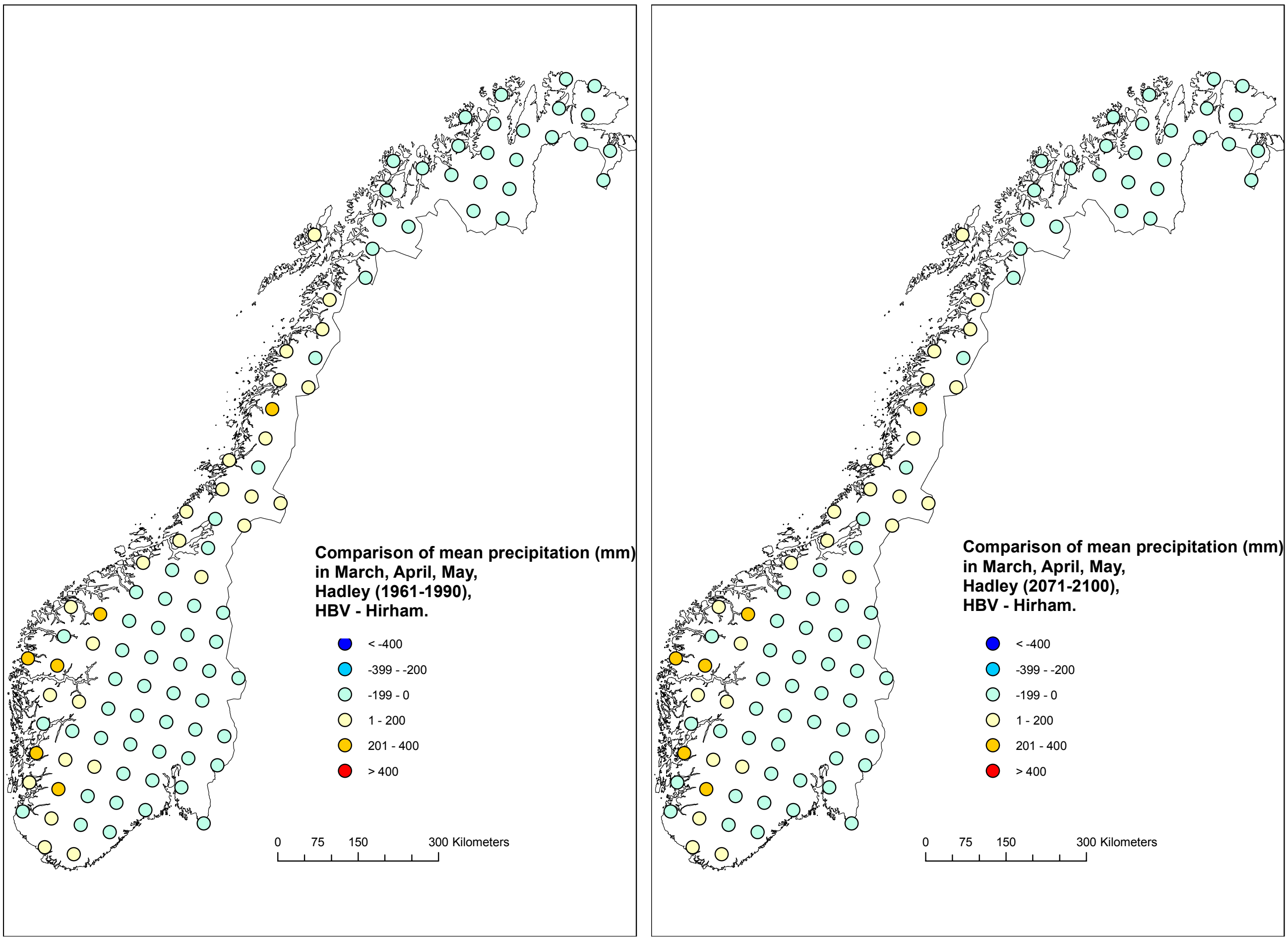

Figure 28: *Comparison of modelled mean precipitation (mm) during March, April and May for a) the control period 1961-1990 and b) the scenario period 2071-2100. The precipitation values are differences between the HBV model and the HIRHAM model. Only the Hadley climate model is shown.*

5.2 Changes from current (1961-1990) to future climate (2071-2100)

In this Section we have calculated change in mean precipitation (mm) from the control period (1961-1990) to the scenario period (2071-2100) for both the HIRHAM and the HBV models. Calculations are carried out for:

- the winter months December-February (Figures 29a,b), and
- the spring months March-May (Figures 30a,b)

Results for both the Hadley and the Echam climate models are included in the Figures. To better compare the modelled change values from the HIRHAM and the HBV models, two scatter plots are included in Figures 31a,b. Only results for the Hadley climate model are presented in the scatter plots. Overall, the HIRHAM and the HBV models provide quite similar change values (mm) in the same order of magnitude.

Why do the two models provide different modelled precipitation values for the control period and for the scenario period individually, while the change values are much more similar? This result is actually expected because the same scaling factors were applied for both the control and the scenario periods during the adjustment of temperature and precipitation data to local stations (Engen-Skaugen et al., 2002; Engen-Skaugen, 2004). This adjustment procedure preserves the statistical properties (particularly monthly mean and variance of daily values) (see also Section 2.4.1).

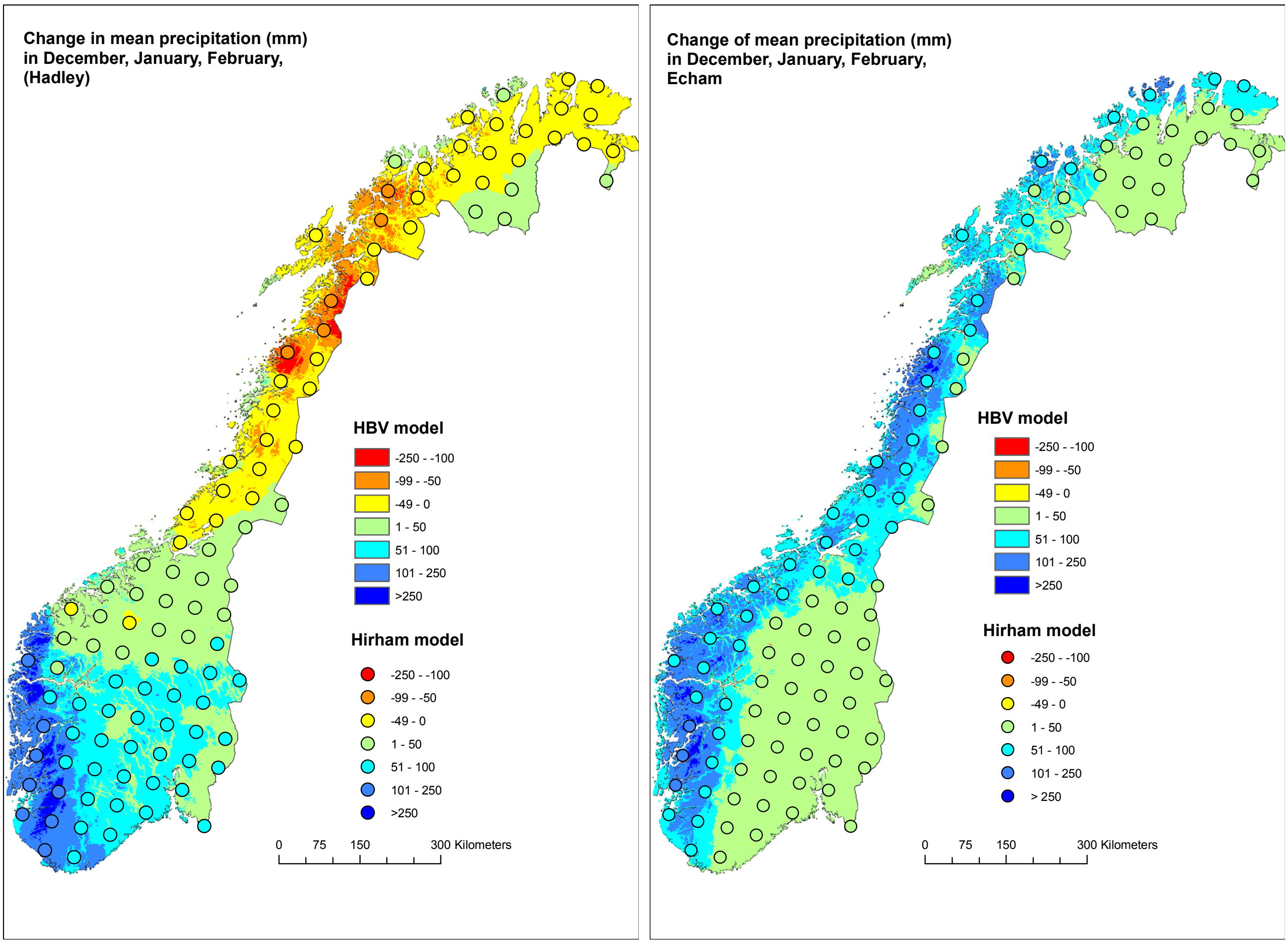

Figure 29: *Change in mean precipitation during December to February (mm). Results for both the HBV model and the HIRHAM model are shown. Calculated difference between the future scenario (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam.*

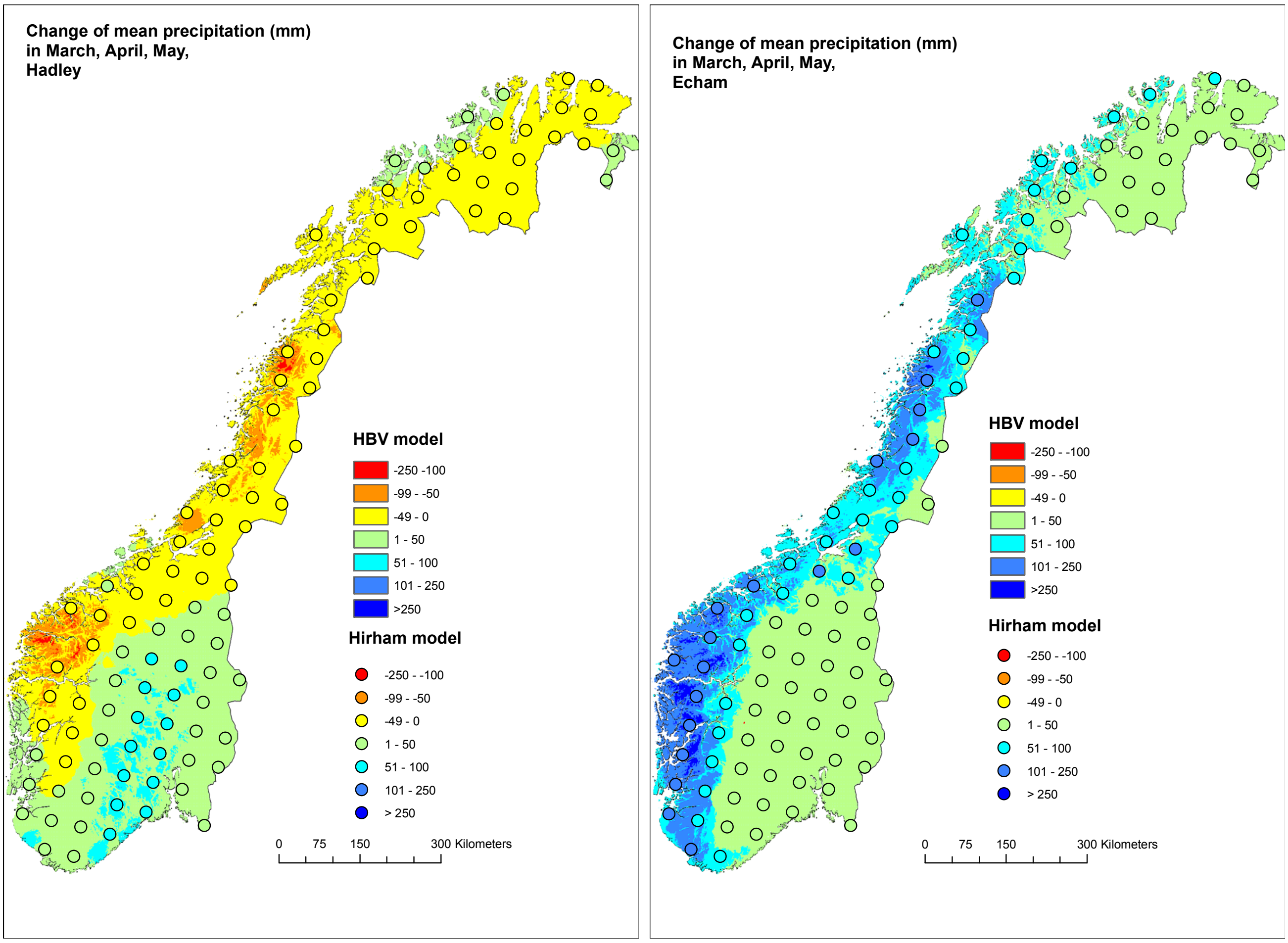

Figure 30: *Change in mean precipitation during March to May (mm). Results for both the HBV model and the HIRHAM model are shown. Calculated difference between the future scenario (2071-2100) and the control period (1961-1990). a) Climate model: Hadley, b) Climate model: Echam.*

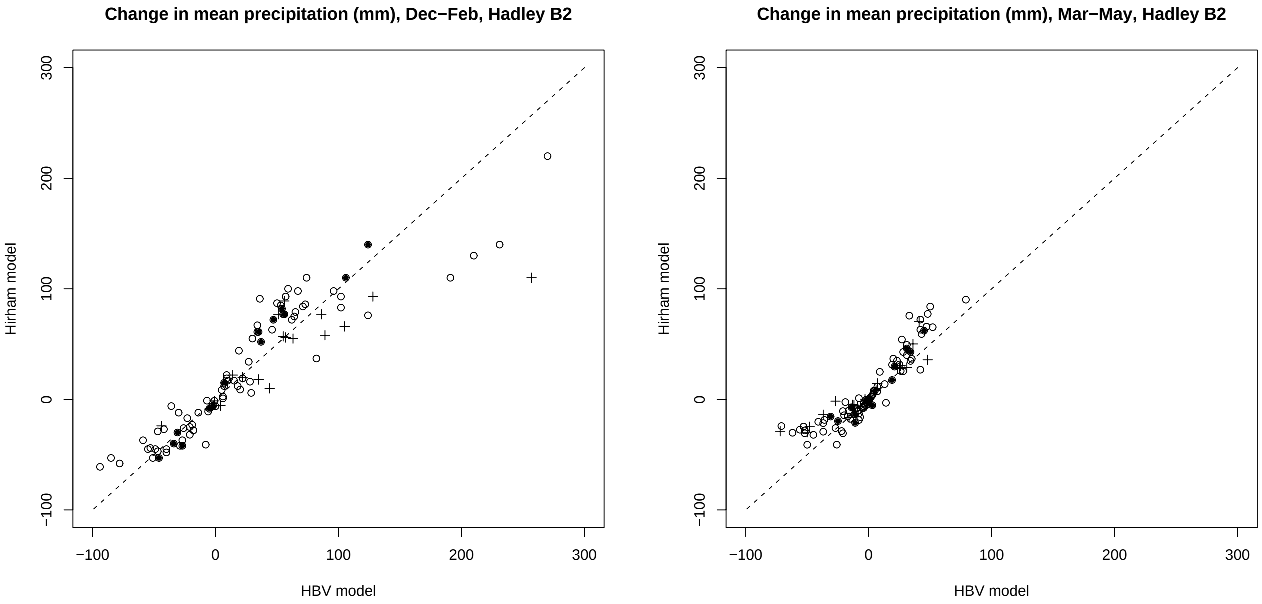

Figure 31: *Scatter plot comparing the HBV model and the HIRHAM model and the change in mean precipitation (mm) during a) December to February, and b) March to May. Calculated difference between the future scenario (2071-2100) and the control period (1961-1990). Only the Hadley climate model is shown. Filled circles represent locations below 200 m a.s.l. Open circles are areas located between 200 and 1000 m a.s.l. Crosses are locations above 1000 m a.s.l.*

6 Summary and conclusions

This report compares the output variable "snow water equivalent" from the regional climate model HIRHAM, and the spatially distributed water balance model HBV. The comparison is made for present climate (1961-1990) and for future scenarios (2071-2100). In addition to snow water equivalent, the derived variable "mean number of days per year with snow cover" as well as precipitation modelling in HIRHAM and HBV has also been studied.

6.1 Snow water equivalent

For both the present climate (1961-1990) and for a future climate (2071-2100), the modelled snow water equivalent (mm) from the HIRHAM and the HBV model generally shows this pattern:

Topography:

- Below 200 m a.s.l., both models provide snow water equivalent values in the same order of magnitude.
- With increasing altitude, the estimated snow water equivalent values from the two models deviate increasingly.
- Above 1000 m a.s.l., the HBV model estimates much higher snow water equivalent values than the HIRHAM model. The largest deviations of estimated snow water equivalent values are found in these altitudes.

Geopgraphy:

- Smallest deviations between the two models are found in eastern parts of South-Norway as well as in Finnmarksvidda in North-Norway.
- Largest deviations between the two models are found in western parts of South-Norway.

The HIRHAM and the HBV models were also compared with respect to absolute changes (mm) and relative changes (%) from the present climate to a future climate. Generally, both models project reduced amounts of snow in Norway. Both models also project largest decrease in snow water equivalents (mm) at inner parts of Southwest-Norway. Looking at the absolute changes (mm), both models project changes in the same order of magnitude below 200 m a.s.l. However, above this altitude, the HBV model projects much larger reductions in snow amounts than the HIRHAM model. This is consistent for both the Echam and Hadley B2 climate scenarios. Looking at the relative changes (%) the results for the Echam and the Hadley B2 climate scenarios are different.

6.2 Mean number of days per year with snow cover

The variable “mean number of days per year with snow cover” is a not a direct output from the HBV or the HIRHAM models. For the HBV model days with snow cover are counted when more than 50% of the ground is covered by snow. For the HIRHAM model, days with snow are counted when there is more than 0 mm snow water equivalent. Overall, there are major similarities between projections from the HBV and the HIRHAM models:

- Both models project a shorter snow season duration in the entire country.
- Smallest change in snow season duration is projected in the high mountains of South Norway.
- Largest reduction in snow season duration is projected along the coast, and especially at the innermost parts of the coastal areas in West-Norway, Mid-Norway and North-Norway.

6.3 Precipitation

To explain differences in estimated snow water equivalent values from the HIRHAM and the HBV models, the modelling of precipitation is studied. For both the present climate (1961-1990) and for a future climate (2071-2100), differences in the estimated precipitation (mm) from the HIRHAM and the HBV models generally show this pattern:

Topography:

- For the winter months (Dec-Feb) the two models estimate similar precipitation values in areas located below 200 m a.s.l. Above 1000 m a.s.l. the HBV model estimates much higher precipitation values than the HIRHAM model.
- For the spring months (Mar-May) this topographical pattern is not very distinguished. Generally, there is a larger span in precipitation values estimated by the HBV model as compared to the HIRHAM model.

Geography:

- The HBV model gives higher precipitation values than the HIRHAM model around the fjords and in the coastal areas of West-Norway as well as in the coastal parts of Nordland.
- The HBV model gives lower precipitation values than the HIRHAM model in South-East Norway and in inner parts of Finnmark.

This pattern seems to be consistent for both the winter and the spring months, for both the present climate (1961-1990) and for a future climate (2071-2100).

6.4 Concluding remarks

- The differences in the modelled snow water equivalent values from the HBV model and the HIRHAM model are partly caused by effects of the very different spatial resolution in the two models. The scale of the HIRHAM model is about 55 km while it is 1 km for the HBV model. This means that local effects related to the representation of the topography and also the precipitation are handled differently in the two models. The HBV model uses a digital terrain model of 1 km $\times$ 1 km for the modelling of both temperature and precipitation. In this way, the HBV model has a better starting point than the HIRHAM model for modelling correct snow water equivalent values, at least at local scale.
- The differences between the two models are largest at high altitudes. This is probably partly due to the different scale in representing the topography, which also influences the modelled precipitation. The maximum altitude in the HIRHAM terrain model was 1281 m a.s.l., while the maximum altitude in the HBV terrain model was 2256 m a.s.l. Furthermore, the elevation correction used for interpolating the precipitation values in the HBV model (10% increased precipitation per 100 m elevation below 1200 m a.s.l. and 5% increased precipitation per 100 m elevation abowe 1200 m a.s.l.) possibly gives too high values particularly at high altitudes.
- Differences in snow algorithm and parameters applied when running the two models also affect the resulting snow water equivalent.
- This study represent a first approach for comparing the HIRHAM and the HBV models. An improvement of the comparison method is recommended in a future study. Instead of extracting the 1 km $\times$ 1 km grid cell that is located at the center point of the 55 km $\times$ 55 km grid cell, it would be interesting to study e.g. an average of all 1 km $\times$ 1 km HBV grid cells located inside a 55 km $\times$ 55 km HIRHAM grid cell.

- More studies should be carried out in comparing and evaluating the two models with the aim to improve the modelled snow water equivalent estimates. An evaluation could also compare estimations from the present climate (1961-1990) with observations from e.g. snow pillows or weather stations. A comparison with ground truth data will facilitate the determination of which of the models that gives most reliable results under various conditions in the different climatic regions in Norway.

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