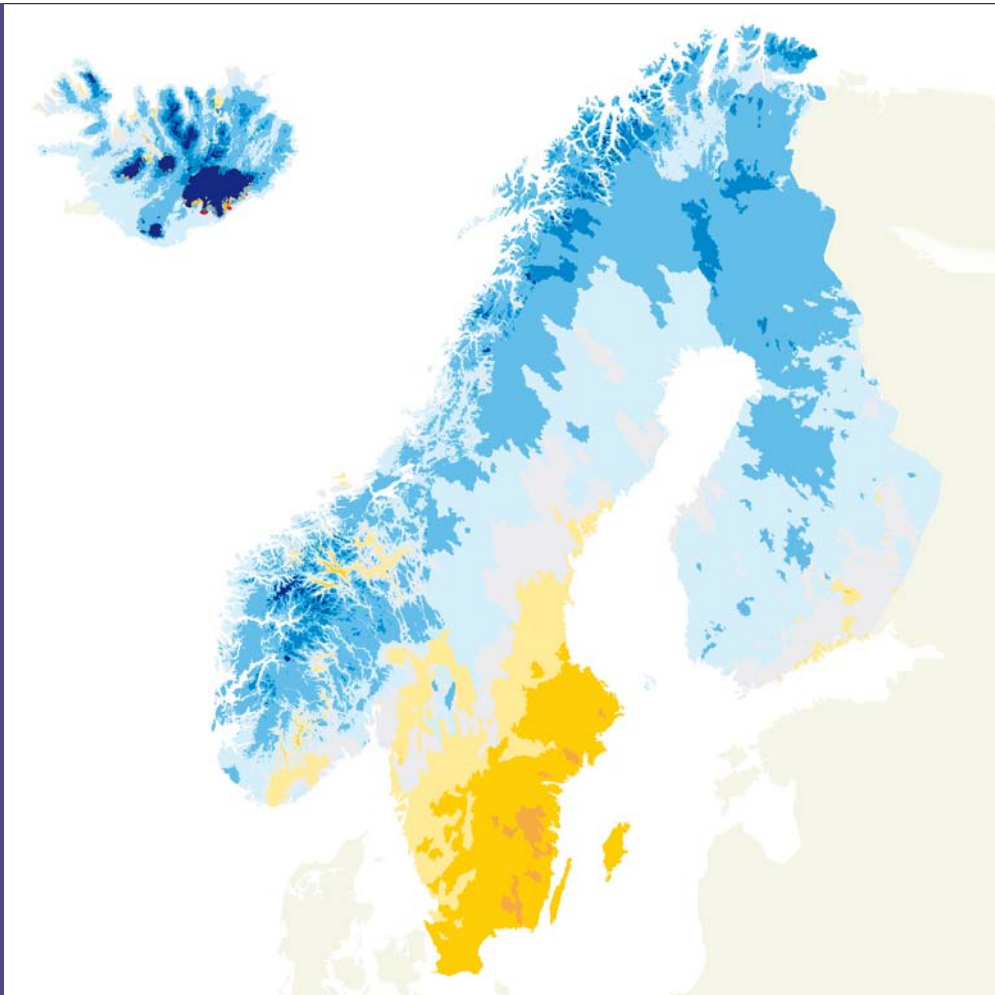


Hydrological climate change maps of the Nordic countries

Based on RegClim HIRHAM and Rossby Centre
RCAO regional climate model results

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Report No. 4

Hydrological climate change maps of the Nordic countries based on RegClim HIRHAM and Rossby Centre RCAO regional climate model results

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Summary: Maps of water resources for the Nordic region under present (1961-1990) and future (2071-2100) conditions have been produced using model simulation results from the national hydrological institutes of Finland, Iceland, Norway and Sweden.

Key words: Climate change, water resources, Nordic region, hydrological model, HBV, WaSiM-ETH

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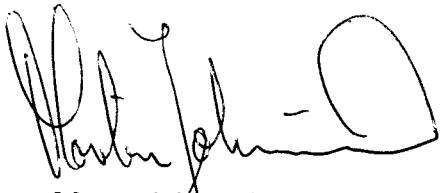
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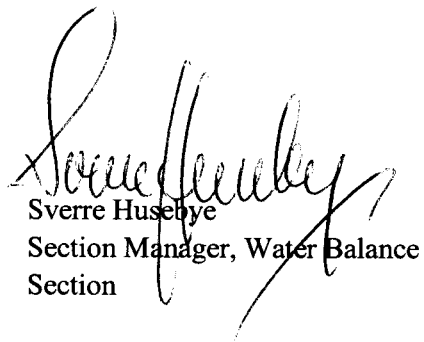
Preface

Production of electricity in the Nordic countries is dependent on runoff, and possible changes in hydropower production capacity are therefore of large economical importance. Assessment of the future hydrological regime is a production chain where changes in external forcing caused by greenhouse gas emissions are introduced into general circulation models and regional climate models. The climate model results are used for driving hydrological models which determine time series or statistics of hydrological state variables and fluxes for present and future climate conditions. Maps presenting spatial distributions of these statistics, e.g. annual or seasonal mean values and extremes are a useful way of communicating the results from modelling hydrological impacts of climate change. The results presented in this report have been produced by the Hydropower, Hydrological Models group of the Nordic research project Climate and Energy (CE). This project has the objective of a comprehensive assessment of the impacts of climate change on renewable energy sources in the Nordic countries, the Baltic States and Northwest Russia. The CE project is funded by the Nordic Energy Research, the Nordic energy sector and national institutions of the participating countries.

Oslo, August 2006



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Summary

Maps of water resources for the Nordic region under present (1961-1990) and future (2071-2100) conditions have been produced using the hydrological models HBV and WaSiM-ETH. The maps have been assembled from simulations performed in Finland, Iceland, Norway and Sweden using models from the national hydrological institutes of each country. Although model structure, process parameterisation, input data and spatial resolution vary, the maps present a relatively consistent view of hydrological conditions in the Nordic region. Present conditions were assembled from a control run using observed meteorological data. Future conditions were based on simulations from the global climate models HadAM3H and ECHAM4/OPYC3 with the IPCC SRES A2 and B2 emission scenarios. The global climate model results were downscaled using the Rossby Centre RCAO regional climate model (Finland, Sweden) and the RegClim HIRHAM regional climate model (Iceland, Norway). Present and future conditions for hydrological state variables and fluxes are shown. In particular, there are maps presenting annual and seasonal runoff, annual evaporation, annual maximum snow water equivalent, number of days per year with snow covered ground, and annual maximum soil moisture deficit.

1 Introduction

Production of electricity in the Nordic countries is dependent on runoff, and possible changes in hydropower production capacity are therefore of large economical importance. Assessment of the future hydrological regime is a production chain where changes in external forcing caused by greenhouse gas emissions are introduced into general circulation models and regional climate models. The climate model results are used for driving hydrological models which determine time series or statistics of hydrological state variables and fluxes for present and future climate conditions. Maps presenting spatial distributions of these statistics, e.g. annual or seasonal mean values and extremes are a useful way of communicating the results from modelling hydrological impacts of climate change. The results presented in this report have been produced by the Hydropower, Hydrological Models group of the Nordic research project Climate and Energy (CE). This project has the objective of a comprehensive assessment of the impacts of climate change on renewable energy sources in the Nordic countries, the Baltic States and Northwest Russia. The CE project is funded by the Nordic Energy Research, the Nordic energy sector and national institutions of the participating countries.

Within the CE project a set of common maps of water resources under present and future conditions based on climate scenarios and hydrological modelling techniques have been produced. This may serve as a foundation for assessments of the future production potential of hydropower in the Nordic area. The maps are based on three climate scenarios resulting from two general circulation models, forced with respectively one and two greenhouse gas emission scenarios. Climate change scenarios differ substantially due to uncertainties with regard to the climate forcing caused by greenhouse gas emissions, uncertainties caused by imperfect representation of processes in the atmospheric models, and uncertainties with regard to initial conditions. Hydrological climate change maps which are based on ensembles of climate change simulations from model runs using different approaches to predict the future represent one way of quantifying this uncertainty.

2 Methods

Results from the Max Planck Institute atmosphere-ocean general circulation model ECHAM4/OPYC3 (Roeckner *et al.*, 1999), and from the general circulation model HadAM3H developed from the atmospheric component of the Hadley Centre atmosphere-ocean general circulation model HadCM3 (Gordon *et al.*, 2000) have been used for assessment of climate change impacts on water resources in the Nordic countries. Observed fields of sea-surface temperature and sea-ice dataset were used as lower boundary conditions in the control simulation with HadAM3H. In the climate change experiments, the sea-surface temperature anomaly described by HaDCM3 was added to the observed data to be used as the lower boundary forcing. Assumptions about future greenhouse gas emissions were based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) A2 and B2 scenarios (Nakićenović *et al.*, 2000). The general circulation model simulations were used as boundary conditions for dynamical downscaling with two regional climate models. For

Finland and Sweden, the Rossby Centre Regional Atmosphere-Ocean (RCAO) model (Döscher *et al.*, 2002) was run with boundary conditions supplied by the HadAM3H and ECHAM4/OPYC3 models forced with the A2 and B2 emission scenarios. Regional climate model results for Iceland and Norway were supplied by the HIRHAM model (Bjørge *et al.*, 2000) with boundary conditions from the HadAM3H model forced with the A2 and B2 emission scenarios, and the ECHAM4/OPYC3 model forced with the B2 emission scenario. HIRHAM model results were provided by the Regional Climate Development Under Global Warming (RegClim) project (<http://regclim.met.no>).

The hydrological simulations used the time slice approach whereby model simulations representing a slice of time in present climate (control) and in a future climate (scenarios) were performed. The time slice for the control climate was 1961-1990 and for the future climate 2071-2100. The hydrological impact studies were done with off-line simulations with the hydrological models. Observed meteorological data were used as a control climate in Finland and Sweden. In Iceland observed data were replaced by results from the MM5 atmospheric model (Grell *et al.*, 1994), while in Norway observed data were replaced by HIRHAM model results downscaled to meteorological station sites.

Daily precipitation and temperature from the regional climate models were downscaled to meteorological station sites using two different procedures. The approach applied for hydrological modelling in Finland, Iceland and Sweden transferred changes in meteorological variables between the control and the scenario simulations from the regional climate model to a database of observed meteorological data. This can be referred to as the delta change approach, e.g. Hay *et al.* (2000) and is a common method of transferring the signal of climate change from climate models to hydrological models. Monthly relative precipitation changes and absolute temperature changes predicted by the regional climate models were used to modify the daily meteorological data driving the hydrological models for the baseline period 1961-1990. The same monthly precipitation changes were used for all years of the impact simulations and for extreme values as well as for average conditions. The number of precipitation days was not changed in the scenario climate. Temperature changes were applied differently. Constant monthly temperature changes for all temperature intervals were applied for the impact simulations in Iceland, while the Finnish and Swedish simulations used a temperature dependent function to take into account that temperature changes in the climate scenarios are most pronounced at low temperatures. The approach applied for hydrological modelling in Norway transferred RegClim HIRHAM model results to meteorological station sites using an empirical adjustment technique which preserves the frequency of precipitation and temperature events as predicted by the climate models, aiming at reproducing observed monthly means and standard deviations for the control period (Engen-Skaugen, 2004).

Hydrological simulations were performed with the conceptual HBV model (c.f. Lindström *et al.*, 1997) for all countries except for Iceland, where the WaSiM-ETH model (Schulla *et al.*, 2001) was used. The HBV model is a conceptual, semi-distributed precipitation-runoff model originally developed for operational streamflow forecasting. The model is usually run on a daily time step and includes routines for snow accumulation and melt, soil moisture accounting, groundwater response and river routing. It exists in different versions in each of the Nordic countries. The national version of the HBV model was used by each country. Due to the geological conditions prevailing in

Iceland, the hydrological model structure must be able to describe groundwater flow in aquifers with large vertical extent. WaSiM-ETH was chosen because it allows the user to choose modules with different levels of complexity for simulation of single hydrological processes, including subsurface processes. The hydrological models were calibrated to catchments representing different runoff regimes and land surface characteristics in each country. Landscape elements which could be expected to have similar hydrological behaviour were parameterised in the same way, and calibrated parameter sets were transferred to ungauged catchments based on a classification of land surface properties.

The model simulations have not considered land use changes caused by climate change or human transformation of the land surface, with one exception: A dynamical glacier model was used for modelling changes in the extent of Icelandic glaciers. However, it is likely that changes in land-cover may interact with climate, leading to different projections of future hydrological conditions (Bronstert, 2004). The uncertainty of hydrological climate change impact simulations increases due to the lack of consideration of possible land use changes.

The hydrological simulations performed by the Hydropower, Hydrological Models group of CE have generated a large amount of time series on hydrological variables and fluxes for the land surface computational elements used by the hydrological models. Annual and seasonal mean values and annual maxima of several of these hydrological characteristics have been determined and the results are presented as maps in the Appendix. Table 1 gives a summary of the water resources characteristics presented in the maps.

Evaporation is generally determined as the sum all latent heat fluxes from the land surface to the atmosphere; evaporation of intercepted water, transpiration, soil evaporation and open water evaporation. However, there are some exceptions which are explained in the sub-sections on the hydrological modelling in the different countries. Mean annual maximum snow water equivalent and soil moisture deficit is the mean of annual maxima for all years in the control or scenario periods. Mean annual minimum soil moisture is the mean of annual minima for all years in the control or scenario periods.

Table 1. *Water resources characteristics presented as maps for the control climate (1961-1990) and the scenarios HadAM3H A2, B2 and ECHAM4/OPYC3 B2 for the future climate (2071-2100); or as maps displaying changes in water resources characteristics from the control climate to the future climate*

Water resources characteristics maps	Units
Mean annual runoff	mm
Mean winter runoff (Dec., Jan., Feb.)	mm
Mean spring runoff (Mar., Apr., May)	mm
Mean summer runoff (Jun., Jul., Aug.)	mm
Mean autumn runoff (Sep., Oct., Nov.)	mm
Change in mean annual runoff	%, mm
Change in mean winter runoff (Dec., Jan., Feb.)	%, mm
Change in mean spring runoff (Mar., Apr., May)	%, mm
Change in mean summer runoff (Jun., Jul., Aug.)	%, mm
Change in mean autumn runoff (Sep., Oct., Nov.)	%, mm
Change in mean annual evaporation	mm
Mean annual maximum snow water equivalent	mm
Change in mean annual maximum snow water equivalent	%
Mean annual number of days per year with snow covered ground	days
Change in mean annual number of days per year with snow covered ground	days
Mean annual maximum soil moisture deficit	mm
Change in mean annual minimum soil moisture	mm

2.1 Hydrological modelling, Finland

The hydrological simulations for Finland were done with the Watershed Simulation and Forecasting System (WSFS) developed and operated by the Finnish Environment Institute. The WSFS is a conceptual watershed model based on the Swedish HBV model (Bergström, 1995). The WSFS is a partly distributed model comprising of several small lumped models. The WSFS has a daily time step and it describes the physical processes of water cycle in a simplified way. These processes include areal precipitation, snow accumulation and melt, calculation of soil moisture and evaporation, groundwater accumulation and water storage and runoff on rivers and lakes (Vehviläinen and Huttunen, 2002). The model consist of a rainfall-runoff model and river, flood area and lake models. The main parts of the rainfall-runoff model are rainfall, snow, surface/depression storage, soil water, middle storage and ground water models. The model has three storages and runoff is generated from the bottom two storages. The necessary inputs to the model are precipitation and temperature. The watersheds in the model have been divided into sub-catchments of approximately 100 km². Each of the sub-catchments has its own set of parameters and simulated storages and is divided into 1 km² grid cells. The WSFS has been calibrated with about 40 years of weather and watershed observations. The automated calibration process uses direct search Hooke-Jeeves

optimisation (Hooke and Jeeves, 1961) to fit the simulated values to snow, discharge and water level observations (Vehviläinen and Huttunen, 2002).

In climate change simulations, the areal temperature and precipitation calculations based on observations are changed with the delta change approach. Temperature dependent temperature change is used to take into account that the colder temperatures change more than the warmer temperatures. The temperatures of each month are however scaled so that the average temperature of the month changes according to the change in the climate scenario used. In climate change related calculations, potential evaporation was calculated in the watershed model by using the air temperature, precipitation and time of year, which is correlated to available radiation (Vehviläinen and Huttunen, 1997). The effect of climate change was taken into consideration by the changes in temperature and precipitation. The actual soil evaporation was calculated from the potential evaporation using soil moisture. Evaporation presented in the maps is land evaporation. Lake evaporation is not included in the results and may change quite differently than land evaporation since there is no shortage of water. Runoff presented in the maps is runoff from land. Lake water balance is not included.

2.2 Hydrological modelling, Iceland

Present conditions in Iceland were evaluated from a control run using the grid based hydrological model WaSiM-ETH (Schulla and Jasper, 2001) and input data from the mesoscale meteorological model MM5. The hydrological model was calibrated against runoff data from 70 watersheds covering 1/3 of the country. Then, model parameters were evaluated for ungauged watersheds, by comparing model parameters from nearby watersheds with similar characteristics based on a recent hydrological classification of watersheds. The meteorological data were available at spatial resolution 8 by 8 km² while the hydrological model was applied at a 1 by 1 km² grid.

The Icelandic climate change simulations were based on a HIRHAM model (Björge *et al.*, 2000) run with boundary conditions from the HadAM3H model. From the scenarios, monthly delta change values were determined for temperature and precipitation. For temperature, an average was estimated for the whole country, while, for precipitation, four different sets of values were estimated for four different parts of the country. Little difference was observed in monthly averages between the A2 and B2 emission scenarios, therefore, an average of the two scenarios was applied to the hydrological model and only one scenario was produced.

Glaciers cover a substantial part of Iceland and climate change will have great influence on glaciers and the glacier fed rivers. A scenario of glacier geometry for the year 2085 was produced by the Hydropower, Snow and Ice group of CE, using a dynamic glacial model for the three largest glaciers in Iceland, Vatnajökull, Langjökull and Hofsjökull (Jóhannesson *et al.*, 2006). The glacier scenario was used in the simulation of future runoff. Snow cover on glaciers can be defined either as being the seasonal snow cover that falls during the winter and melts to some extent during the summer or as being the sum of seasonal snow, ice and firn on glaciers. In the maps the seasonal snow cover is shown both for the number days with snow cover as well as for maximum annual snow water equivalent.

2.3 Hydrological modelling, Norway

A spatially distributed version of the HBV model (Beldring *et al.*, 2003) was used for hydrological climate change impact simulations in Norway. The model performs water balance calculations for 1 by 1 km² square grid cell landscape elements characterized by their altitude and land use. Each grid cell may be divided into two land use zones with different vegetations, a lake area and a glacier area. A regionally applicable set of parameters was determined by calibrating the model 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. This 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. The model was calibrated using available information about climate and hydrological processes from all gauged basins in Norway with reliable observations, and parameter values were transferred to other basins based on the classification of landscape characteristics.

The precipitation stations used in this study were classified in five exposure classes with fixed correction factors for rain, snow and mixed type precipitation according to a Nordic study (Førland *et al.*, 1996). The precipitation data were accordingly given a simplified precipitation type classification. Precipitation and temperature values for the model grid cells were determined by inverse distance interpolation of observations from the three closest precipitation stations and the two closest temperature stations. Differences in precipitation and temperature caused by elevation were corrected by site specific precipitation-altitude gradients and fixed temperature lapse rates for days with and without precipitation, respectively. The temperature lapse rates for days with and without precipitation were also determined by calibration, however, the same values were used for all grid cells.

The hydrological impact simulations applied an empirical adjustment technique in order to downscale regional climate model results to meteorological station sites. This technique preserves the frequency of precipitation and temperature events as predicted by the climate models, aiming at reproducing observed monthly means and standard deviations for the control period. Lake evaporation was not considered in the hydrological model simulations. Glacier mass balance simulations were included in the model, but glacier dynamics were not. Although runoff from glaciers will increase due to higher temperatures, a decrease of glacier volumes in Norway will eventually reduce runoff from areas which are covered by glaciers today (Andreassen *et al.*, 2006). The spatial extent of glaciers in Norway was based on current conditions, therefore, climate change impact simulations may overestimate the increase in runoff, at least for glacier margins.

2.4 Hydrological modelling, Sweden

The HBV-96 model (Lindström *et al.*, 1997) was used for interpretation of the impacts of climate change on water resources in Sweden. The model, referred to as HBV-Sweden, was originally set up to calculate runoff and associated transport of nitrogen to the sea (Brandt and Ejhed, 2002). The model simulates hydrological processes in Sweden with more than 1000 sub-basins, which gives an average spatial resolution of approximately 450 km². HBV-Sweden uses gridded (4 by 4 km²) data of temperature and precipitation, which has been calculated from most of the climate stations in Sweden using optimal

interpolation (Johansson, 2002). The equations behind the database also take into consideration the effects from topography, wind direction and wind speed. The HBV-Sweden model was calibrated regionally against measured discharge for the period 1985 to 1999, whereas the period 1961-1990 was used as the baseline climate in the climate change impact simulations.

Changes in precipitation, temperature and potential evaporation between the scenario and the control simulations of the RCAO model were processed in a model interface and thereafter transferred to the observed climate database (1961-1990) which was used for off-line simulations with the HBV model. The changes in temperature were transferred to the observed database using a set of linear functions, one for each month. These functions are temperature dependent so that the changes in temperature in the scenarios were strongest at low temperatures and less pronounced at higher temperatures, as suggested by the RCAO model runs. Evaporation was calculated using a temperature index approach for the control and the scenario climates. The effect of climate change was thus taken into account by changes in temperature. This approach generally gives somewhat larger increases in evaporation than is suggested by the RCAO model. Evaporation was calculated using a temperature index approach. Changes in lake evaporation were considered in the Swedish simulations.

3 Results and discussion

The hydrological simulations have generated a large amount of data on hydrological state variables and fluxes. Maps of the projected changes of annual and seasonal runoff for the Nordic region show that the potential for hydropower production will increase, although water shortage may become a problem in some locations for the summer season. Annual runoff will generally increase, except for southern parts of Sweden. Seasonal runoff changes vary, with increase in winter and decrease during spring and summer with the possibility for more severe droughts. Autumn runoff will generally increase in northern and high elevation parts of the Nordic region, while a decrease is expected in southern parts. Runoff changes in the Nordic countries are strongly linked to changes in snow regime. Snow cover will be more unstable and all scenarios indicate increase in winter and autumn runoff in areas where the snow cover has a major impact on runoff in the control climate.

In addition to the runoff maps, there are maps presenting present and future conditions and changes from the present to the future for annual maximum snow water equivalent, number of days per year with snow covered ground, and annual maximum soil moisture deficit. Finally, maps showing evaporation changes from the present to the future have been produced. The effects of changes in these variables are accounted for in the runoff simulations and the runoff maps, but these changes may also influence other sectors than the hydropower industry, e.g. snow cover changes may be important for tourism and infrastructure, while soil moisture changes may influence the production capacity in agriculture and forestry.

The projected changes in runoff differ between the two general circulation models HadAM3H and ECHAM4/OPYC3 due to different modes of natural climate variability

represented by the two models. These two general circulation models result in different dominating atmospheric circulation patterns, with increasing dominance from the west in ECHAM4/OPYC3 scenarios and a more easterly pattern in the HadAM3H scenarios. This results in different distributions of precipitation, runoff and other hydrological variables. Furthermore, the two IPCC SRES scenarios A2 and B2 result in different projections of future radiative forcing and temperature changes, with A2 yielding the largest increase in greenhouse gas concentrations and temperature. These differences influence the hydrological cycle, leading to different changes in hydrological state variables and fluxes.

Although model structure, process parameterisation, input data and spatial resolution vary between the hydrological models applied in the different countries, the maps present a relatively consistent view of hydrological conditions in the Nordic region. Nevertheless, there are gradients in the values presented by the maps across the borders between Finland, Norway and Sweden. These gradients are to a large extent caused by differences in model structure, model calibration, spatial discretisation and spatial interpolation of precipitation and temperature data to the computational elements of the hydrological models.

A second set of maps where hydrological modelling in Norway was based on downscaling Rossby Centre RCAO results to meteorological station sites using the delta change approach was presented by Beldring *et al.* (2006). The data sets for the remaining countries were not changed. The two sets of maps are consistent regarding whether an increase or a decrease in runoff and other hydrological fluxes and state variables will occur in Norway, but the magnitudes of the changes differ. The differences between the maps presenting the results from the hydrological climate change impact simulations imply that there are differences between the Rossby Centre RCAO and RegClim HIRHAM regional climate models, which was confirmed by Rummukainen (2006) in a comparison of the regional climate scenarios applied in the CE project. However, the transfer of the climate signal from the regional climate models to the hydrological models introduced another source of uncertainty. The delta change approach and the empirical adjustment technique transfer the climate change signal to the hydrological model in a different manner, with resulting differences in hydrological scenarios.

4 Conclusions

Projections of climate change impacts on water resources in the Nordic countries have been quantified using combinations of two greenhouse gas emission scenarios, two general circulation models, two regional climate models and two hydrological models. Overall the maps show an increase in the available water resources, but in some areas dryer conditions are indicated. The latter may be due to decreased precipitation or an increase in evaporation that overrides the increase in precipitation. A closer look at the seasonal maps shows that water shortage may become a problem in some locations. The use of several global climate scenarios gives an indication of the involved uncertainties. The hydrological climate change scenarios vary due to different dominance of atmospheric circulation patterns in the general circulation models and different external forcing caused by greenhouse gas emissions.

The results from the Hydropower, Hydrological Models group of the CE project show that impact of global warming on the hydropower sector can be quite strong. It will shorten the Nordic winter and make it less stable. This leads to more river flow the year around, a profitable situation for the industry. There is also potential for increased production as the highest modelled increase in river flow is simulated in areas with extensive development of hydropower, i.e. the Scandinavian mountains.

Hydrological processes influence the natural environment at a range of spatial and temporal scales through their impacts on biological activity and water chemistry. Furthermore, water is a primary weathering agent for rocks and soils, breaking them down, dissolving them, and transporting the resulting sediments and dissolved solids to the sea. Freshwater discharge and energy fluxes to the ocean, latent and sensible heat fluxes, glacier mass balance, snow cover and permafrost conditions influence the global climate through feedback effects involving atmospheric and ocean circulations. The water resources maps presented in this report are therefore useful for climate change impact studies in natural and social sciences where land surface hydrological conditions exert a major control on the phenomena under consideration.

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Appendix

Water resources maps produced by the Hydropower, Hydrological Models group of the Climate and Energy project are presented on the following pages. The general circulation model results were dynamically downscaled with the HIRHAM model of the RegClim project before being applied as input to hydrological modelling for Iceland and Norway, while the Rossby Centre RCAO model was used for Finland and Sweden. As HIRHAM model results do not include the ECHAM4/OPYC3 A2 scenario, the maps of future conditions are based on the HadAM3H A2 and B2 scenarios and the ECHAM4/OPYC3 B2 scenario. The HadAM3H A2 and B2 scenarios are designated H/A2 and H/B2 in the map legends, while the ECHAM4/OPYC3 B2 scenario is designated E/B2.

Runoff maps present total runoff (mm) per year or season, while runoff change maps and evaporation change maps (mm) present change in total annual or seasonal values.

Annual and seasonal runoff

Page 21	Mean annual runoff for 1961-1990
Page 22	Mean winter (DJF) runoff for 1961-1990
Page 23	Mean spring (MAM) runoff for 1961-1990
Page 24	Mean summer (JJA) runoff for 1961-1990
Page 25	Mean autumn (SON) runoff for 1961-1990
Page 26	Mean annual runoff for 2071-2100 for the HadAM3H/A2 scenario
Page 27	Mean winter (DJF) runoff for 2071-2100 for the HadAM3H/A2 scenario
Page 28	Mean spring (MAM) runoff for 2071-2100 for the HadAM3H/A2 scenario
Page 29	Mean summer (JJA) runoff for 2071-2100 for the HadAM3H/A2 scenario
Page 30	Mean autumn (SON) runoff for 2071-2100 for the HadAM3H/A2 scenario
Page 31	Mean annual runoff for 2071-2100 for the HadAM3H/B2 scenario
Page 32	Mean winter (DJF) runoff for 2071-2100 for the HadAM3H/B2 scenario
Page 33	Mean spring (MAM) runoff for 2071-2100 for the HadAM3H/B2 scenario
Page 34	Mean summer (JJA) runoff for 2071-2100 for the HadAM3H/B2 scenario
Page 35	Mean autumn (SON) runoff for 2071-2100 for the HadAM3H/B2 scenario
Page 36	Mean annual runoff for 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 37	Mean winter (DJF) runoff for 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 38	Mean spring (MAM) runoff for 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 39	Mean summer (JJA) runoff for 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 40	Mean autumn (SON) runoff for 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Percentage change in annual and seasonal runoff

Page 41	Percentage change in mean annual runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 42	Percentage change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario

Page 43	Percentage change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 44	Percentage change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 45	Percentage change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 46	Percentage change in mean annual runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 47	Percentage change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 48	Percentage change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 49	Percentage change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 50	Percentage change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 51	Percentage change in mean annual runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 52	Percentage change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 53	Percentage change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 54	Percentage change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 55	Percentage change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Annual and seasonal runoff change

Page 56	Change in mean annual runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 57	Change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 58	Change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 59	Change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 60	Change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 61	Change in mean annual runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 62	Change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 63	Change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 64	Change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario

Page 65	Change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 66	Change in mean annual runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 67	Change in mean winter (DJF) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 68	Change in mean spring (MAM) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 69	Change in mean summer (JJA) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario
Page 70	Change in mean autumn (SON) runoff from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Evaporation change

Page 71	Change in mean annual evaporation from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 72	Change in mean annual evaporation from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 73	Change in mean annual evaporation from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Mean annual maximum snow water equivalent

Page 74	Mean annual maximum snow water equivalent for 1961-1990
Page 75	Mean annual maximum snow water equivalent for 2071-2100 for the HadAM3H/A2 scenario
Page 76	Mean annual maximum snow water equivalent for 2071-2100 for the HadAM3H/B2 scenario
Page 77	Mean annual maximum snow water equivalent for 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Percentage change in mean annual maximum snow water equivalent

Page 78	Percentage change in mean annual maximum snow water equivalent from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
Page 79	Percentage change in mean annual maximum snow water equivalent from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
Page 80	Percentage change in mean annual maximum snow water equivalent from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Number of days per year with snow covered ground

- Page 81 Mean annual number of days per year with snow covered ground for 1961-1990
- Page 82 Mean annual number of days per year with snow covered ground for 2071-2100 for the HadAM3H/A2 scenario
- Page 83 Mean annual number of days per year with snow covered ground for 2071-2100 for the HadAM3H/B2 scenario
- Page 84 Mean annual number of days per year with snow covered ground for 2071-2100 for the ECHAM4/OPYC3/B2 scenario

Change in number of days per year with snow covered ground

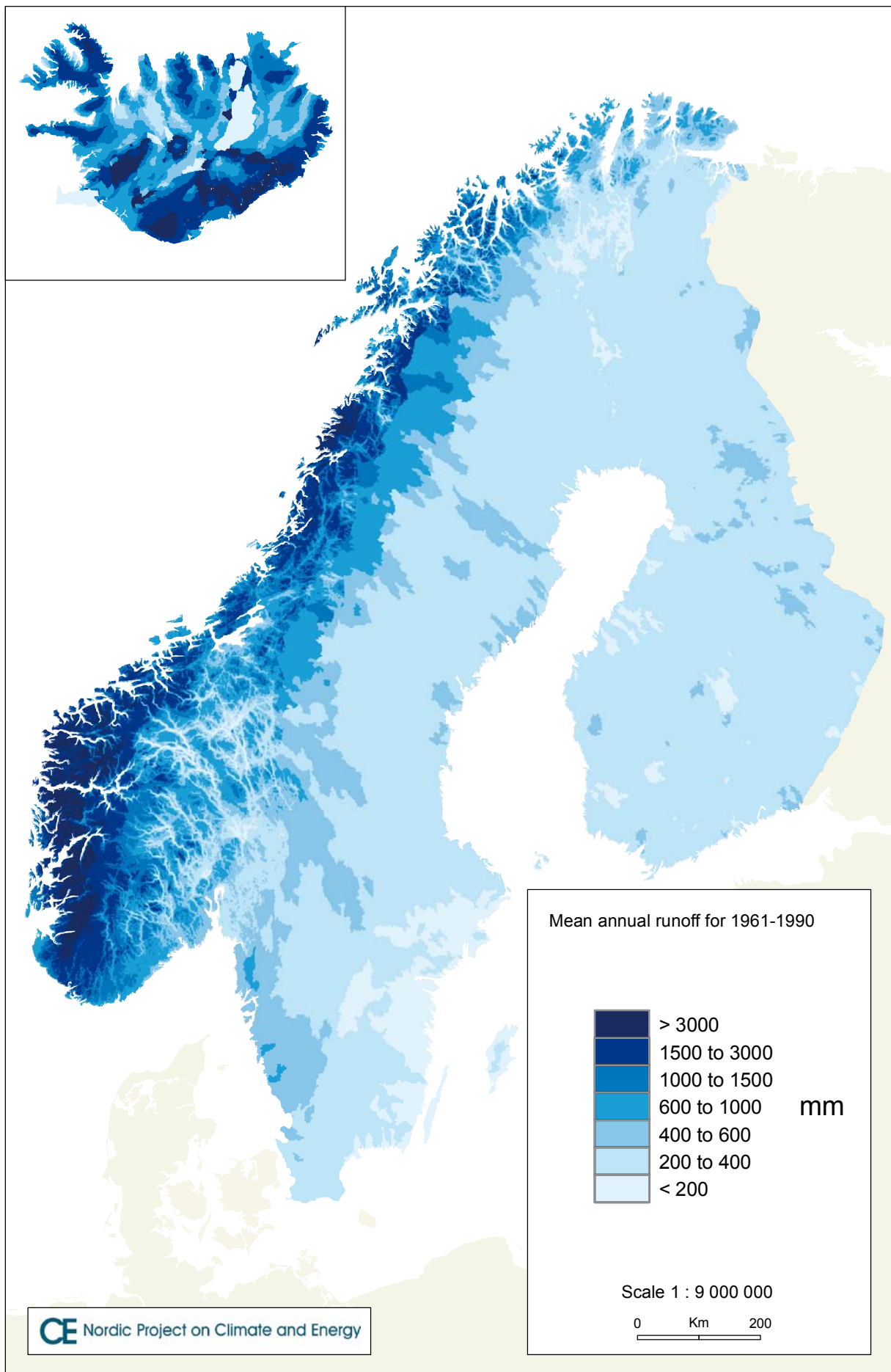
- Page 85 Change in mean annual number of days per year with snow covered ground from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
- Page 86 Change in mean annual number of days per year with snow covered ground from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
- Page 87 Change in mean annual number of days per year with snow covered ground from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

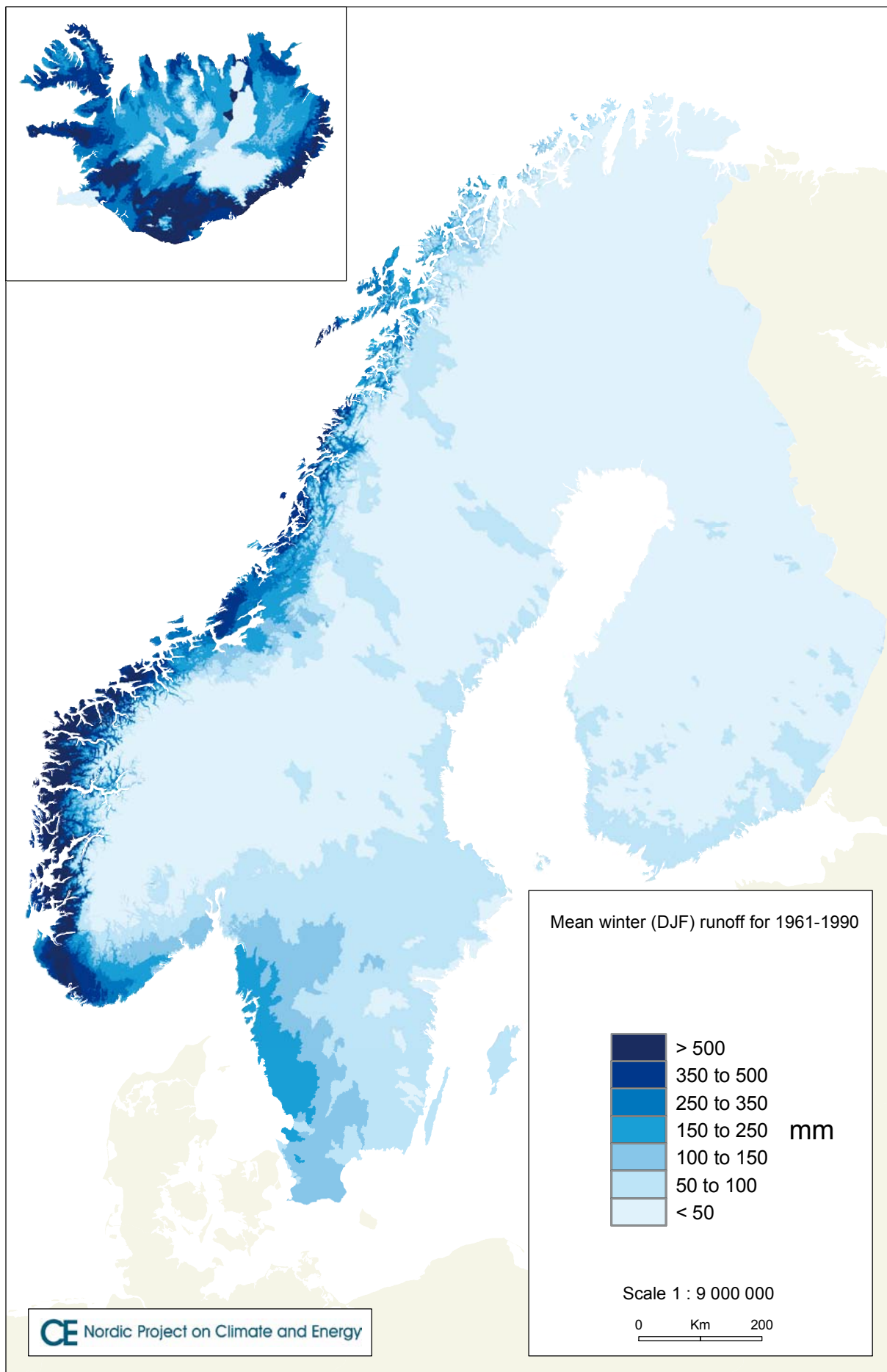
Mean annual maximum soil moisture deficit

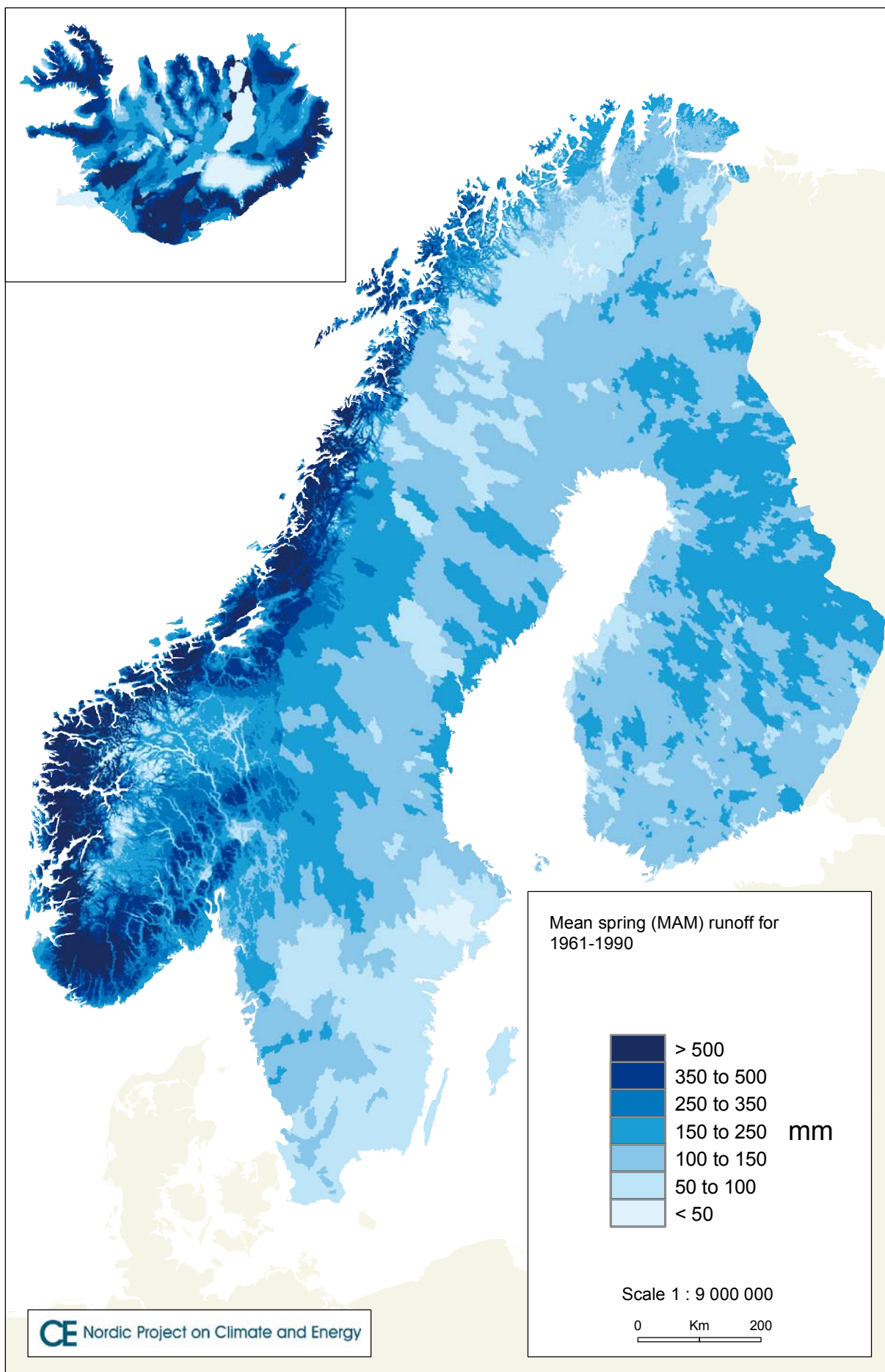
- Page 88 Mean annual maximum soil moisture deficit for 1961-1990
- Page 89 Mean annual maximum soil moisture deficit for 2071-2100 for the HadAM3H/A2 scenario
- Page 90 Mean annual maximum soil moisture deficit for 2071-2100 for the HadAM3H/B2 scenario
- Page 91 Mean annual maximum soil moisture deficit for 2071-2100 for the ECHAM4/OPYC3/B2 scenario

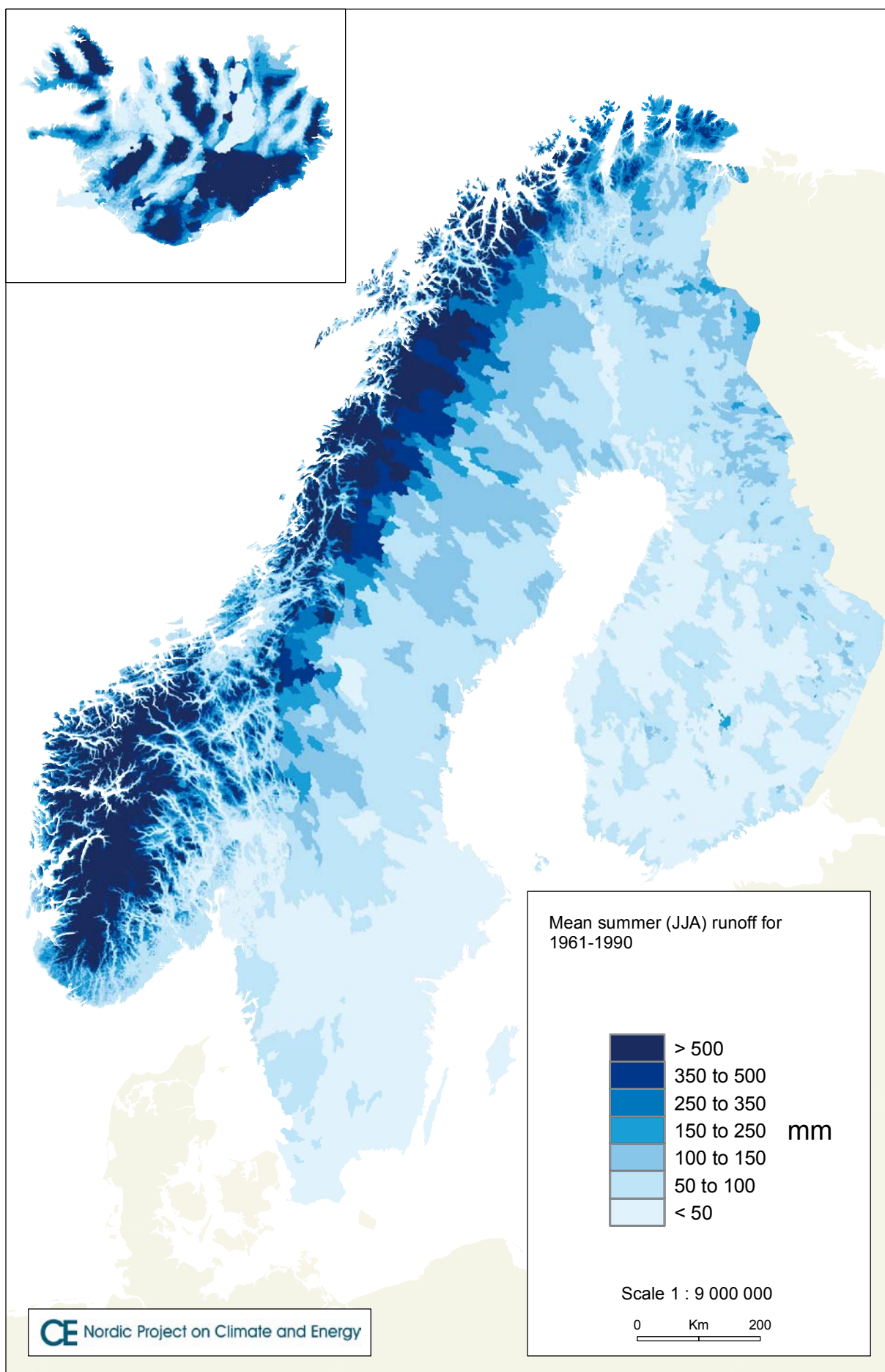
Change in mean annual minimum soil moisture

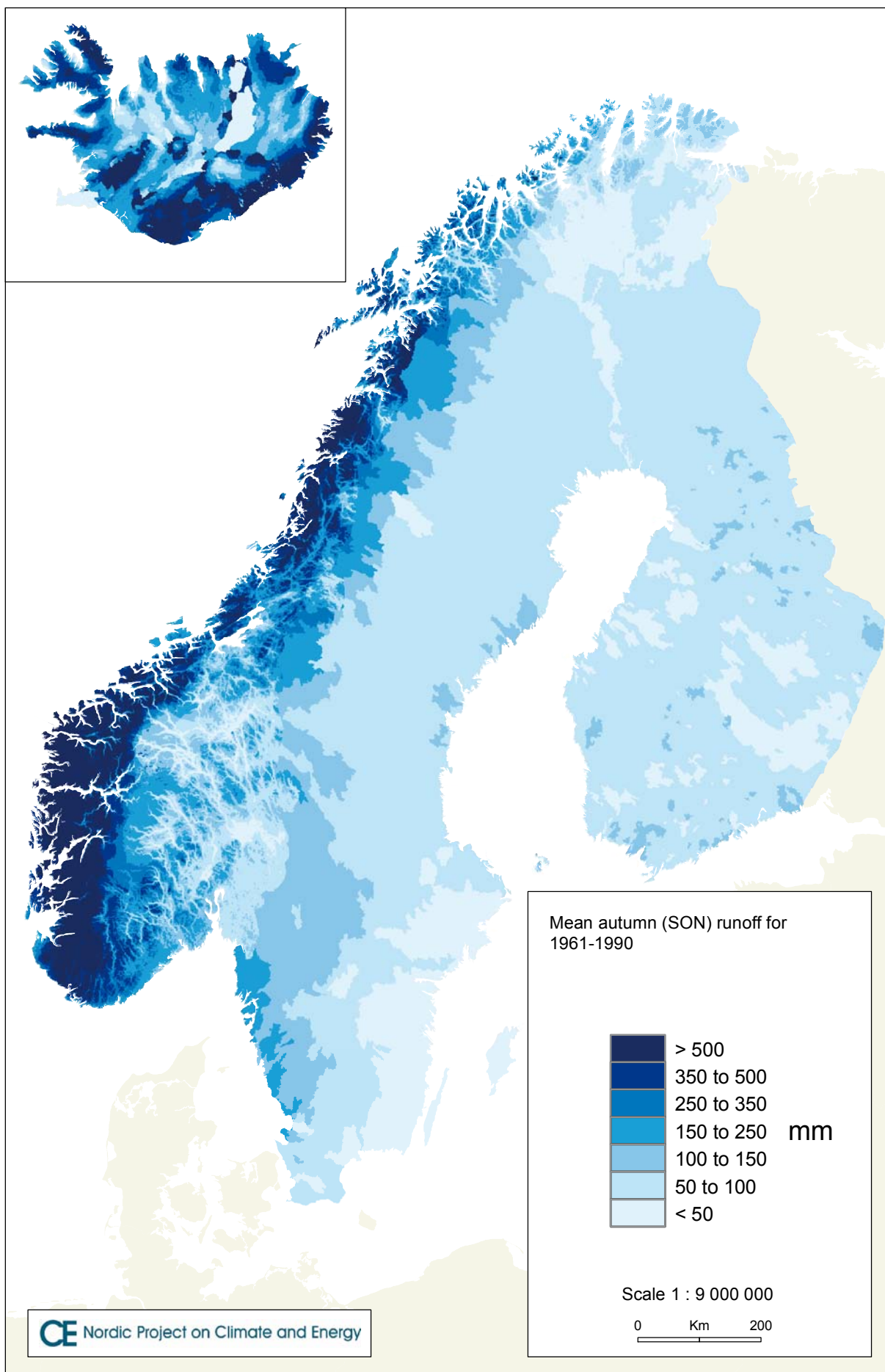
- Page 92 Change in mean annual minimum soil moisture from 1961-1990 to 2071-2100 for the HadAM3H/A2 scenario
- Page 93 Change in mean annual minimum soil moisture from 1961-1990 to 2071-2100 for the HadAM3H/B2 scenario
- Page 94 Change in mean annual minimum soil moisture from 1961-1990 to 2071-2100 for the ECHAM4/OPYC3/B2 scenario

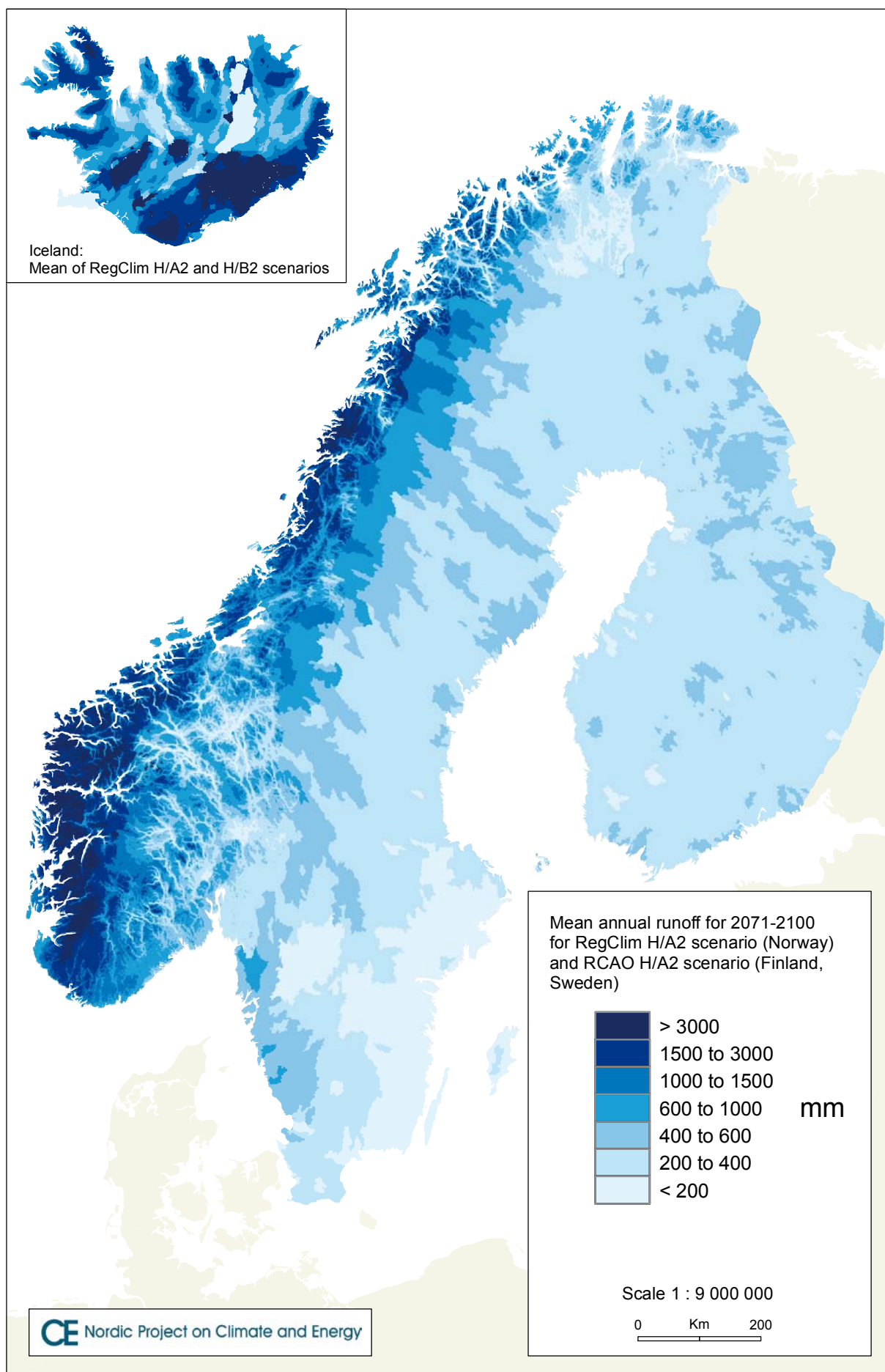


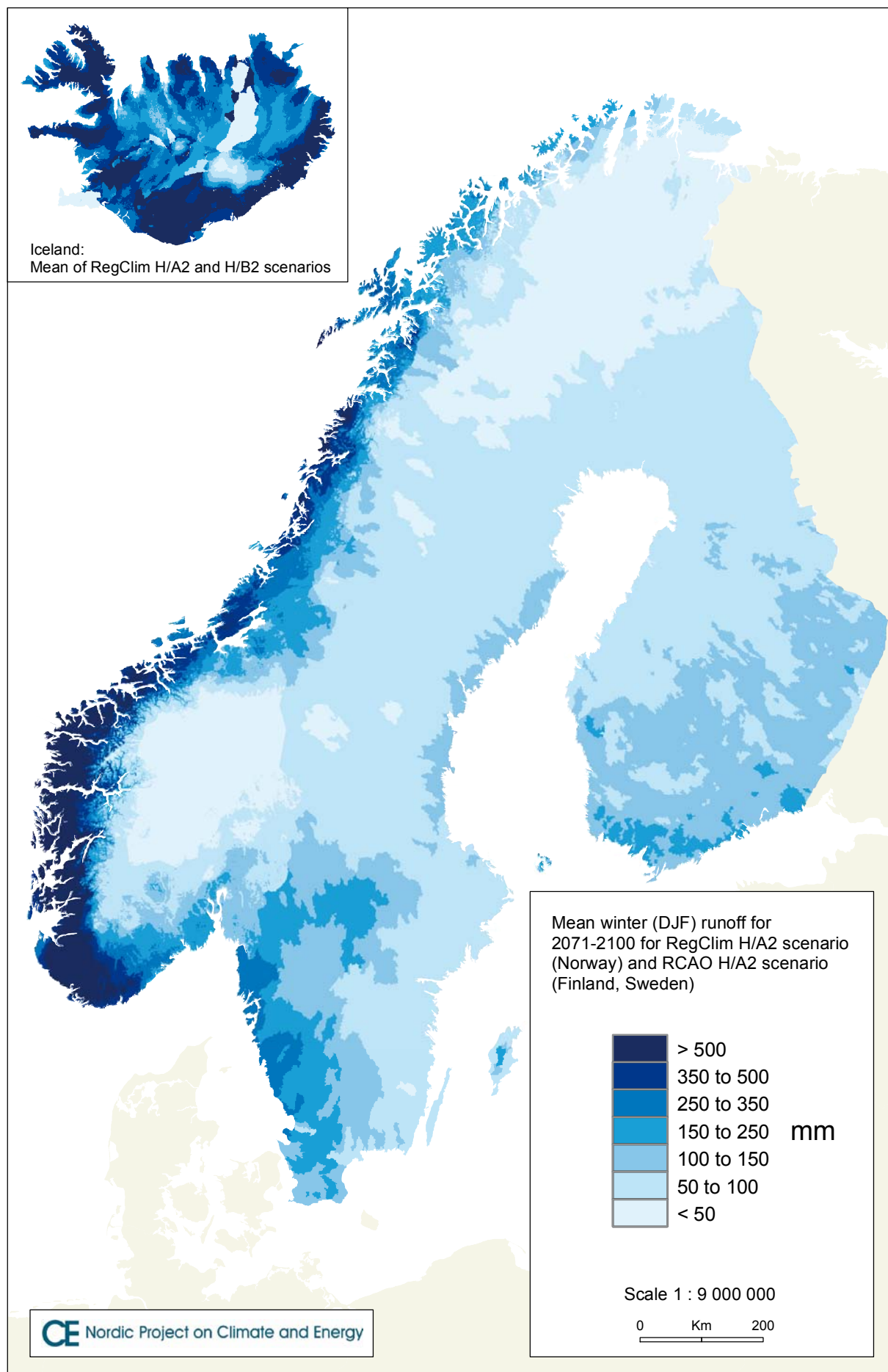


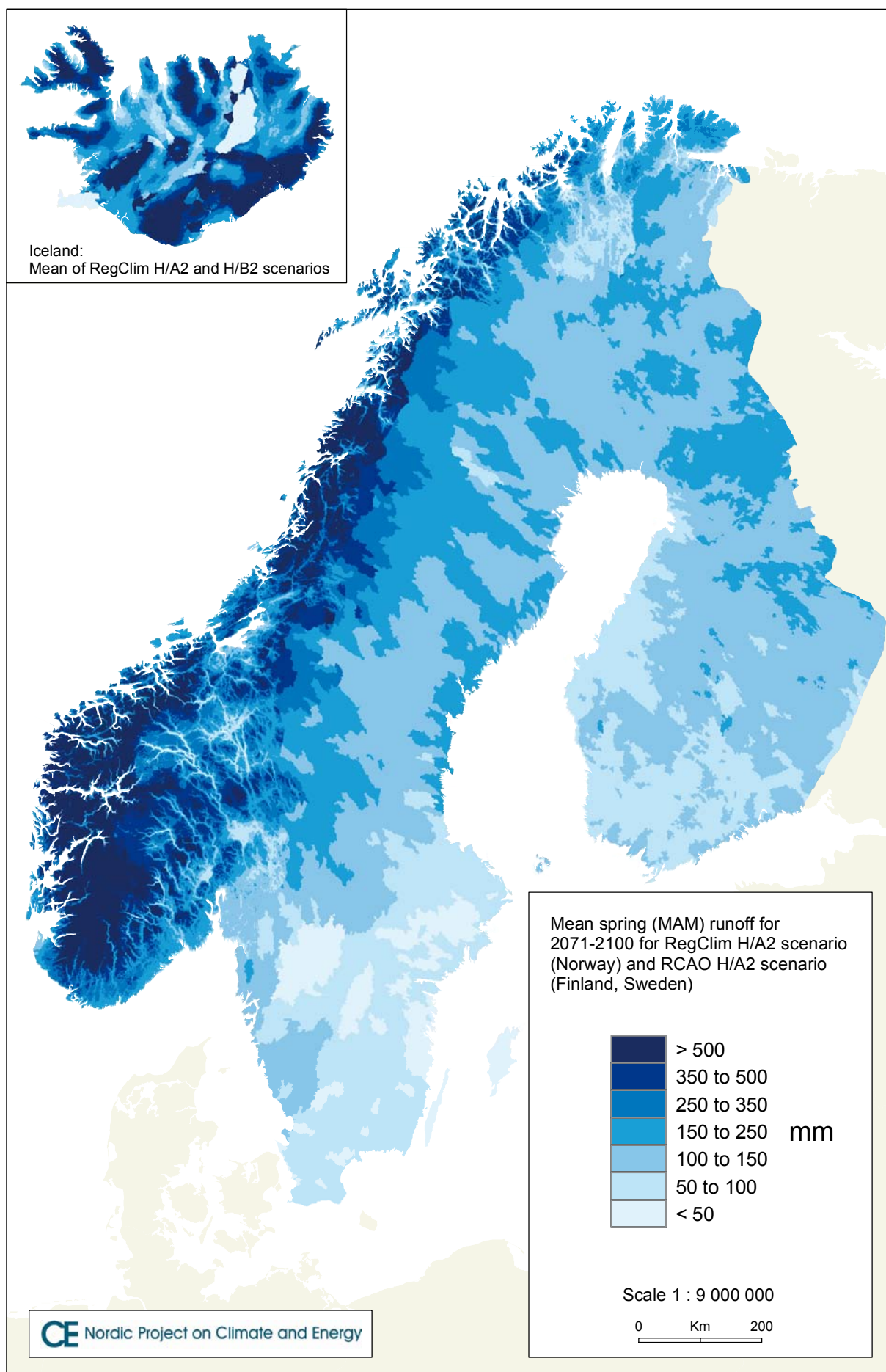


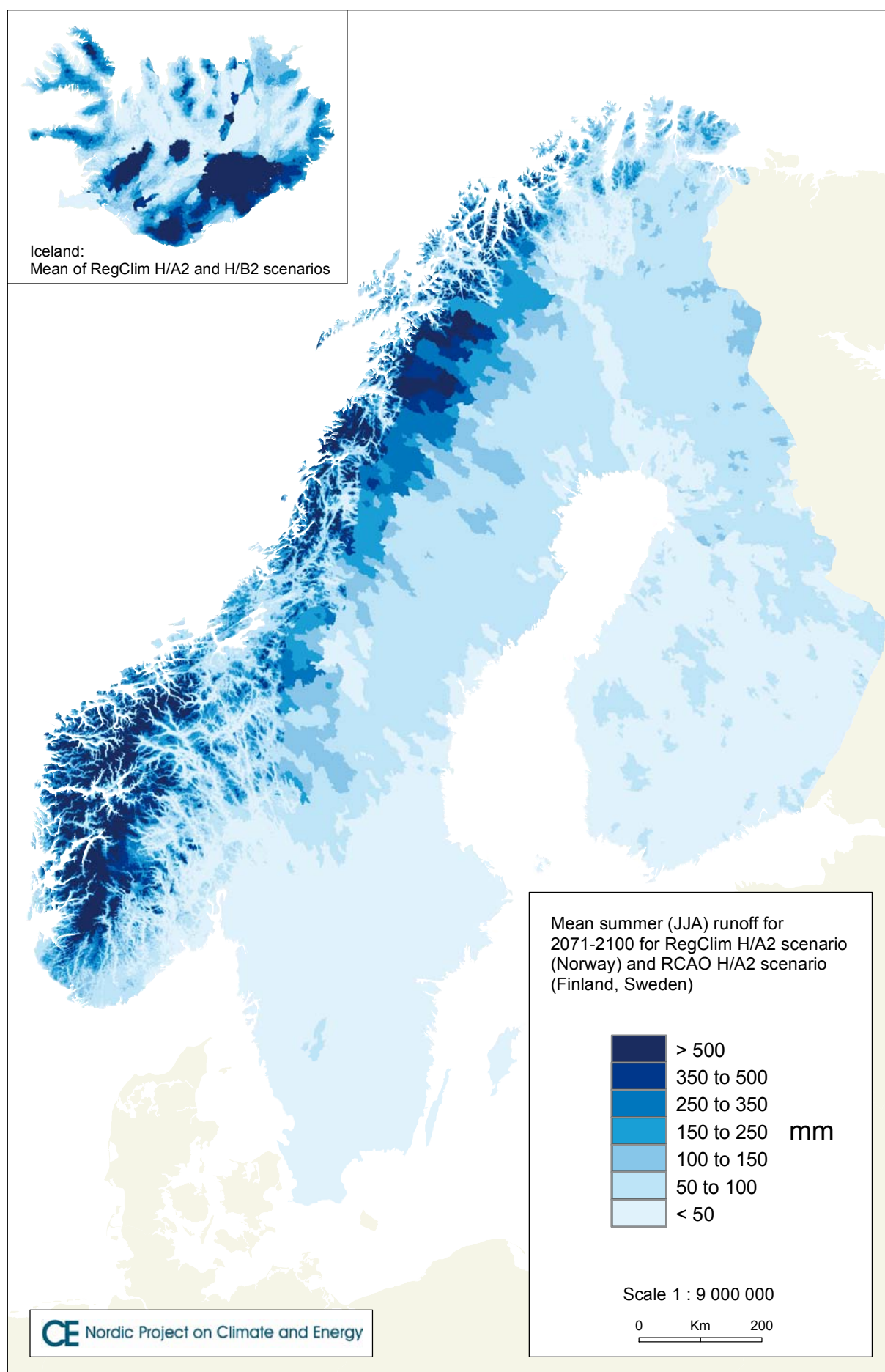


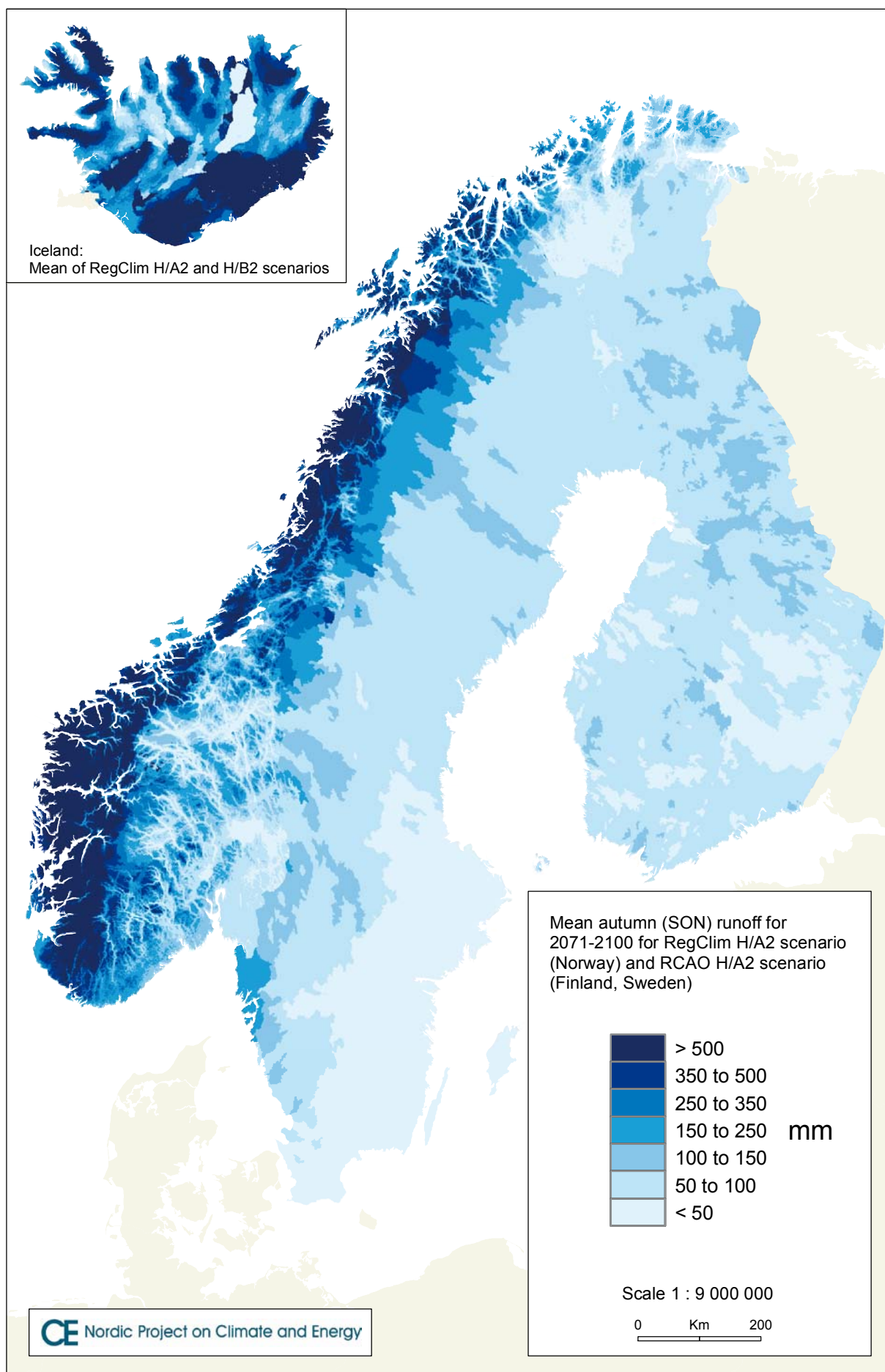


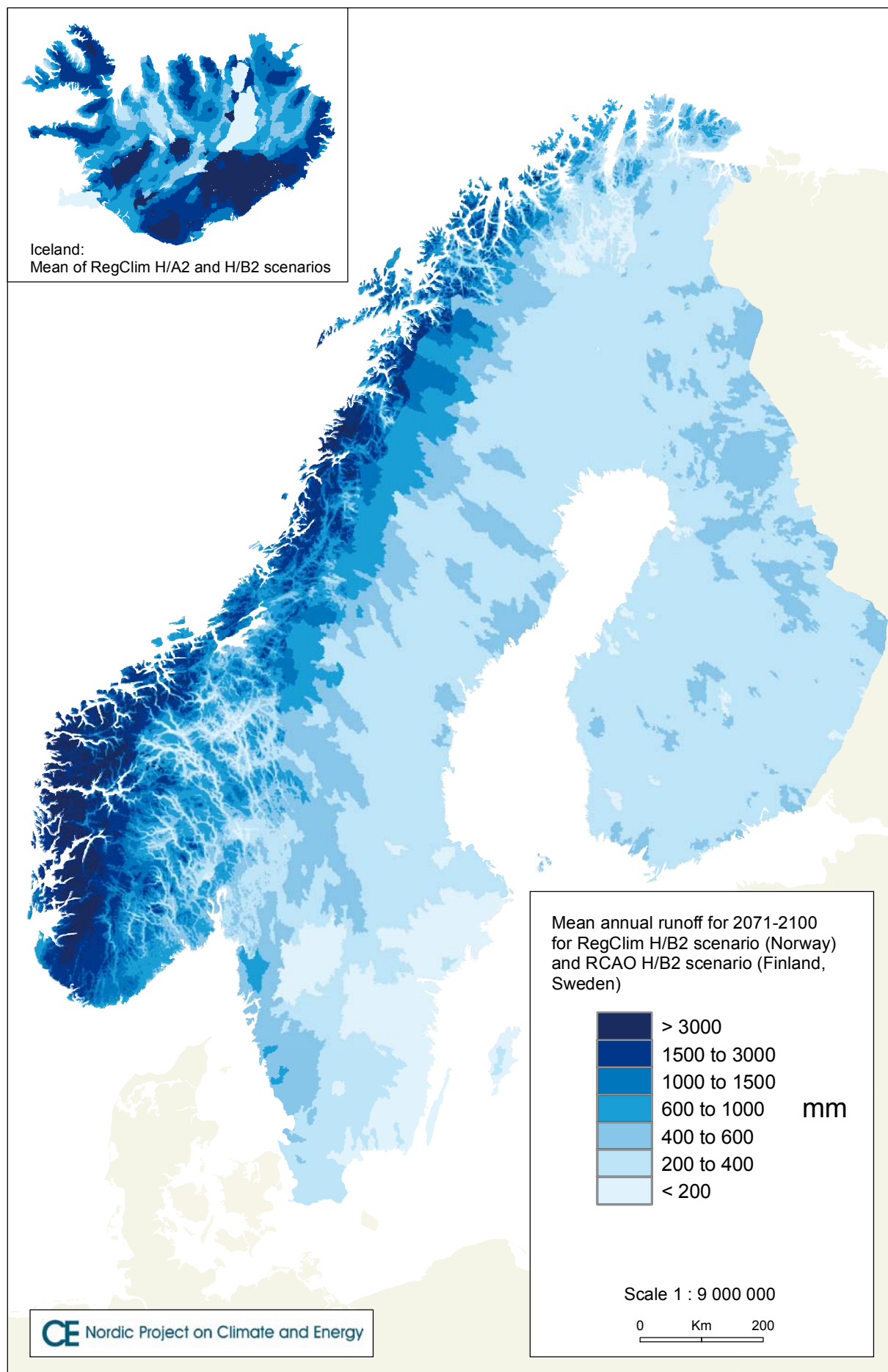


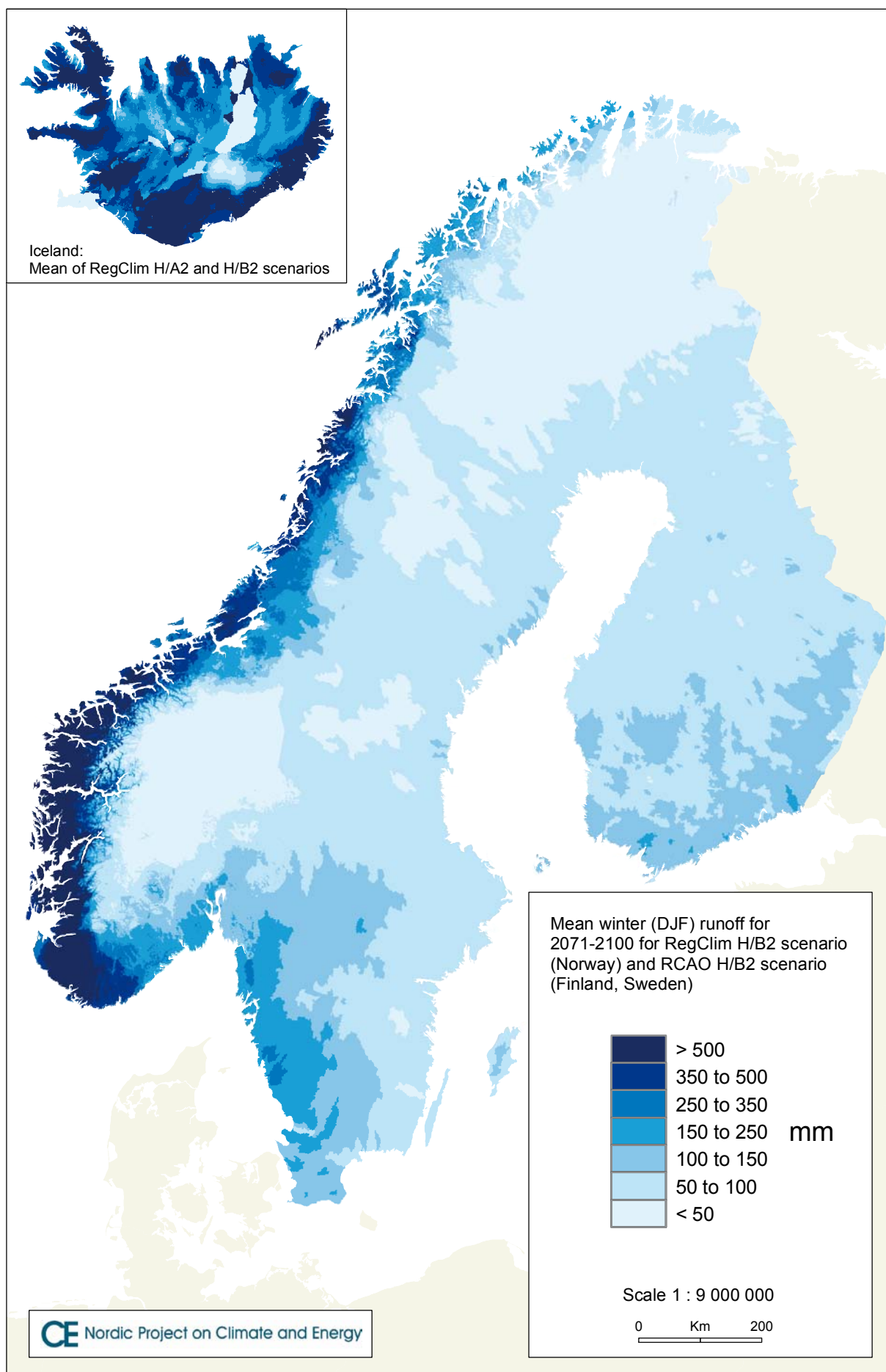


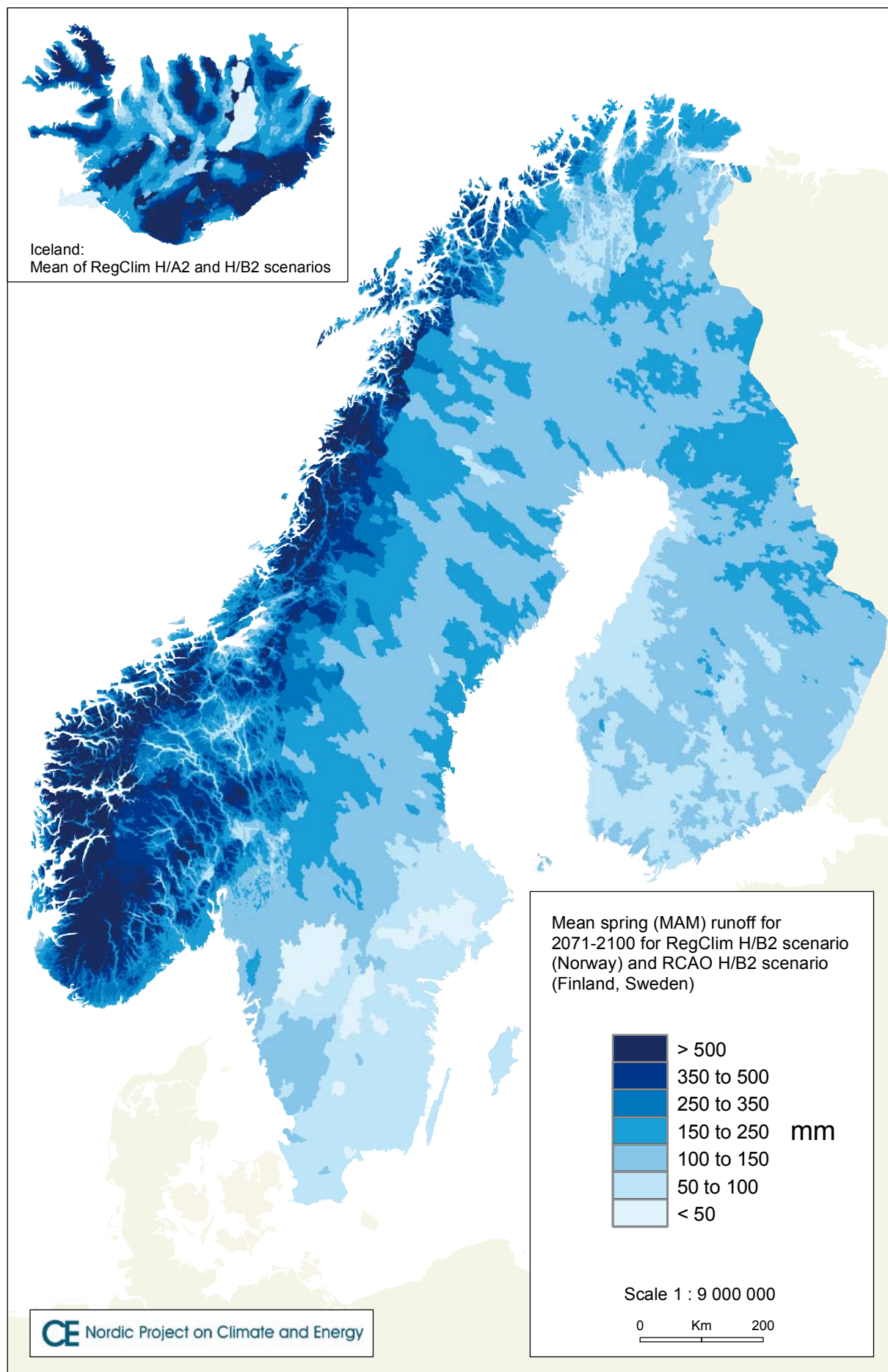


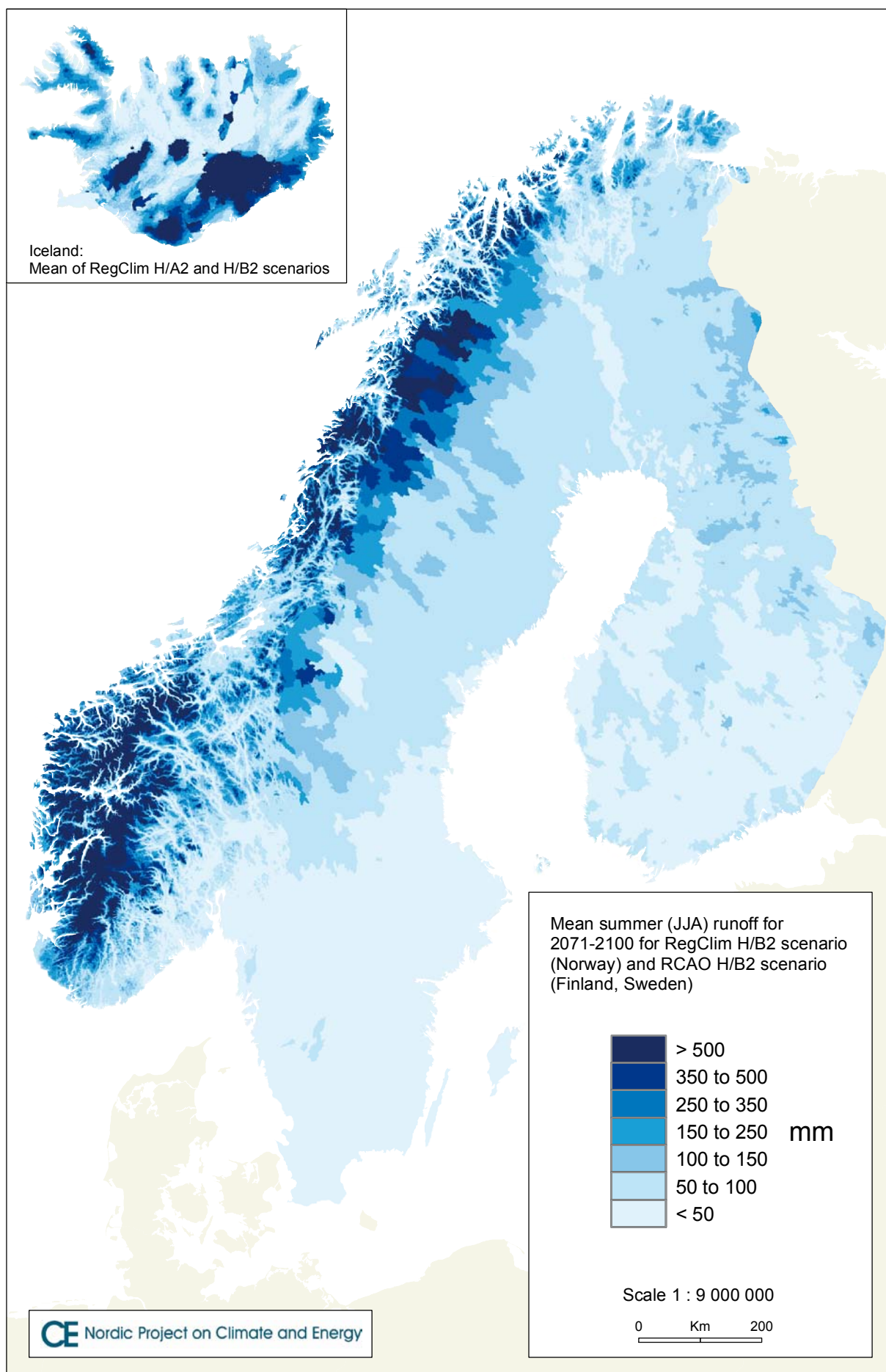


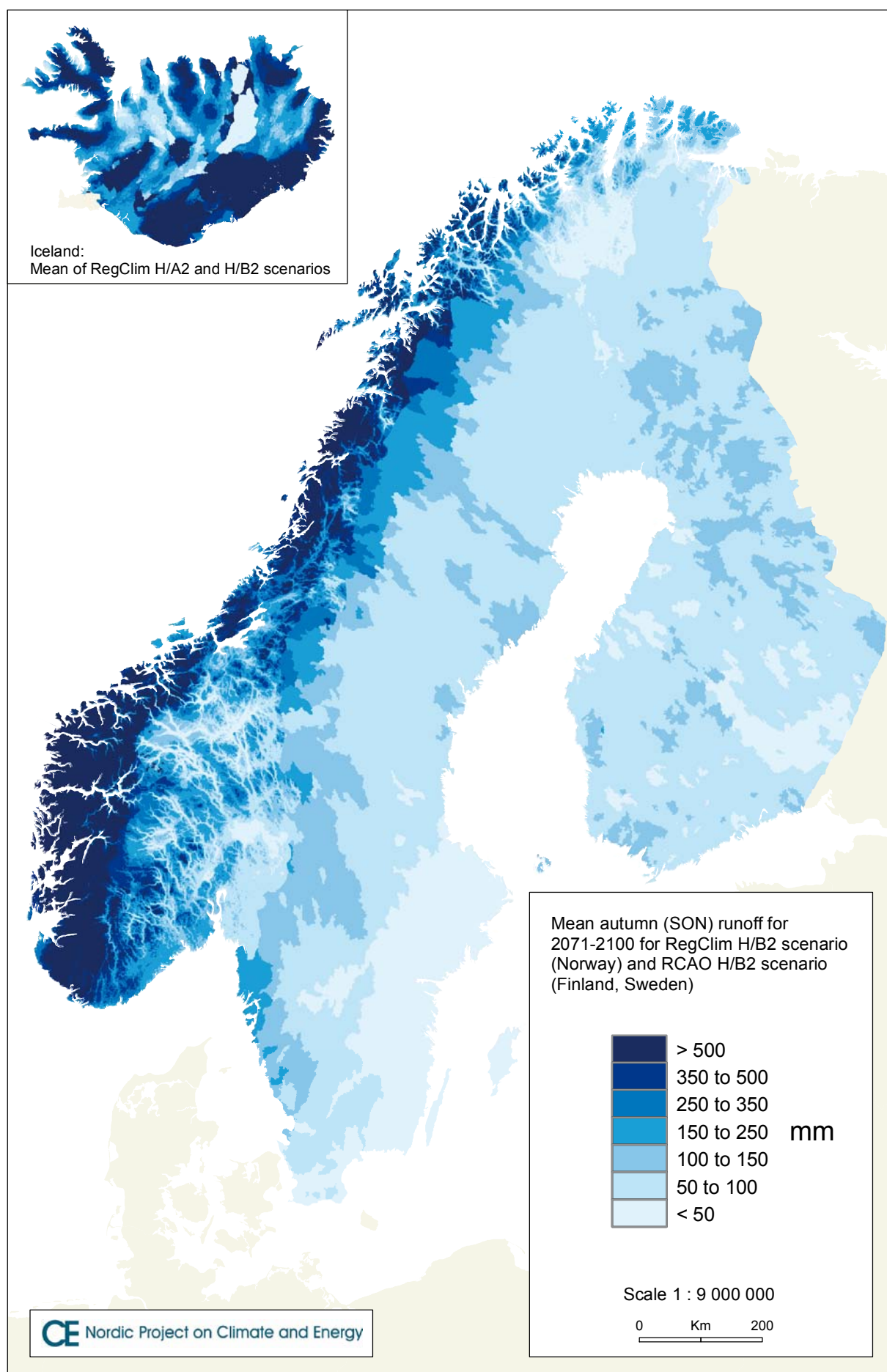


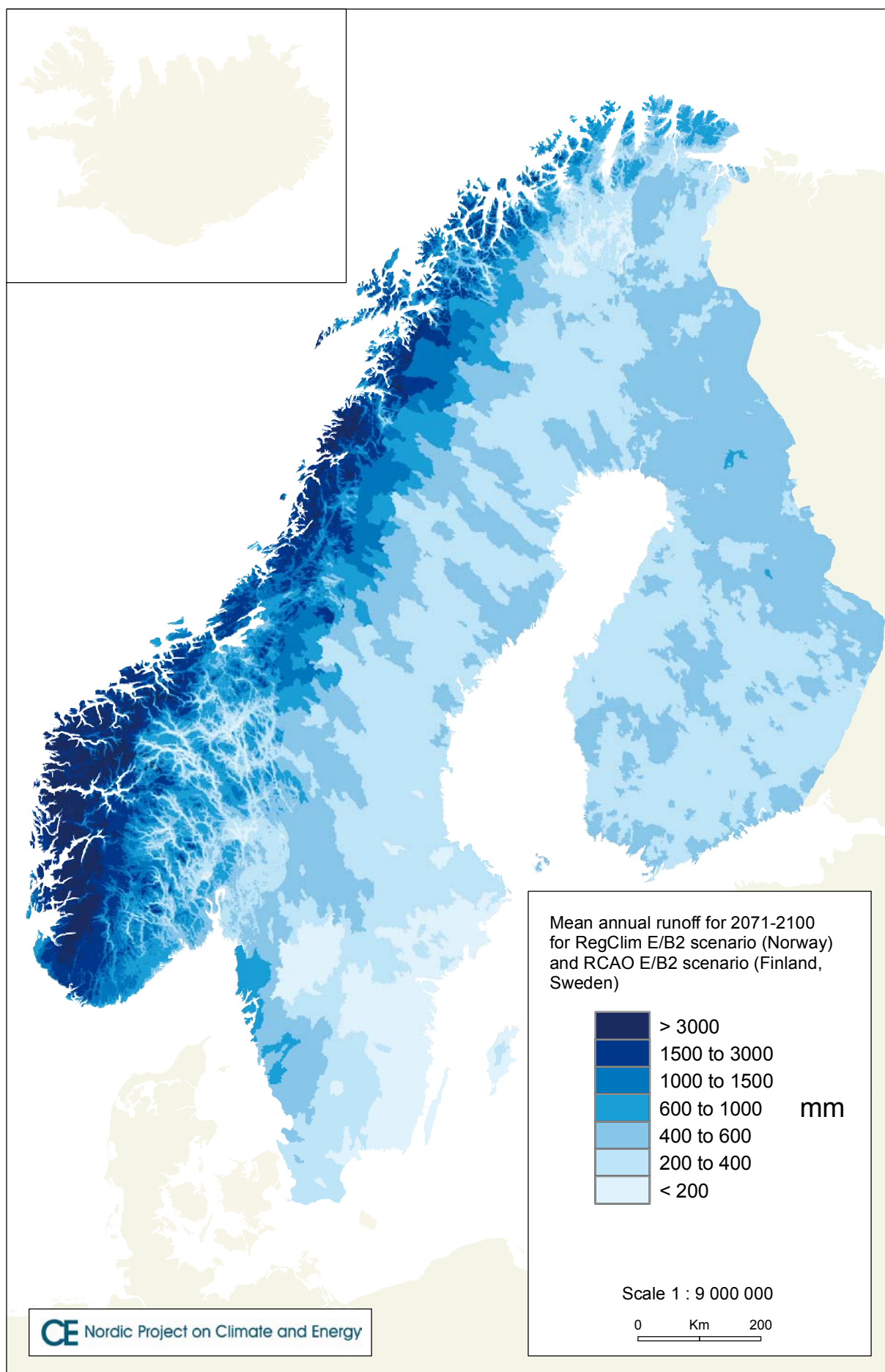


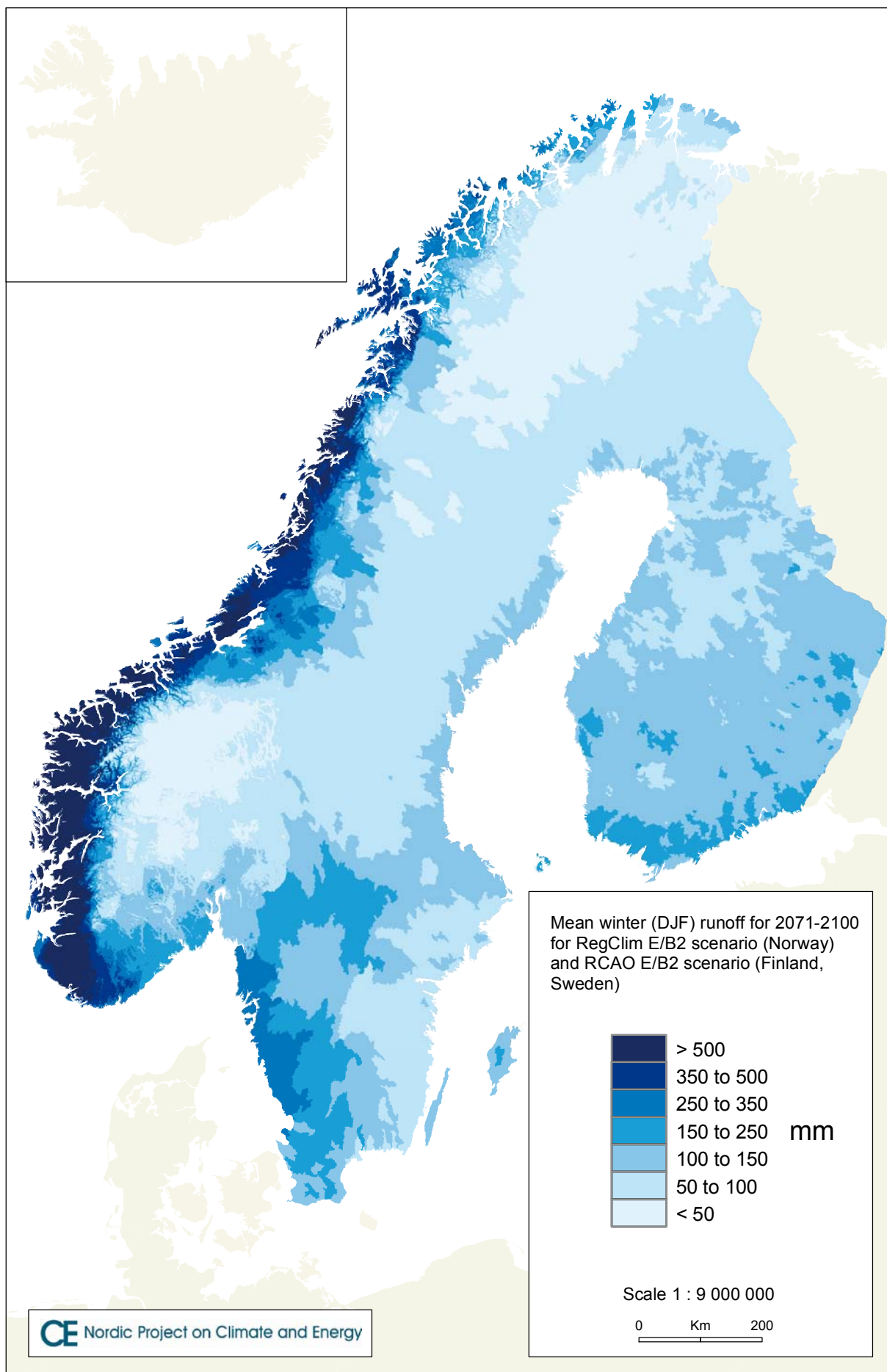


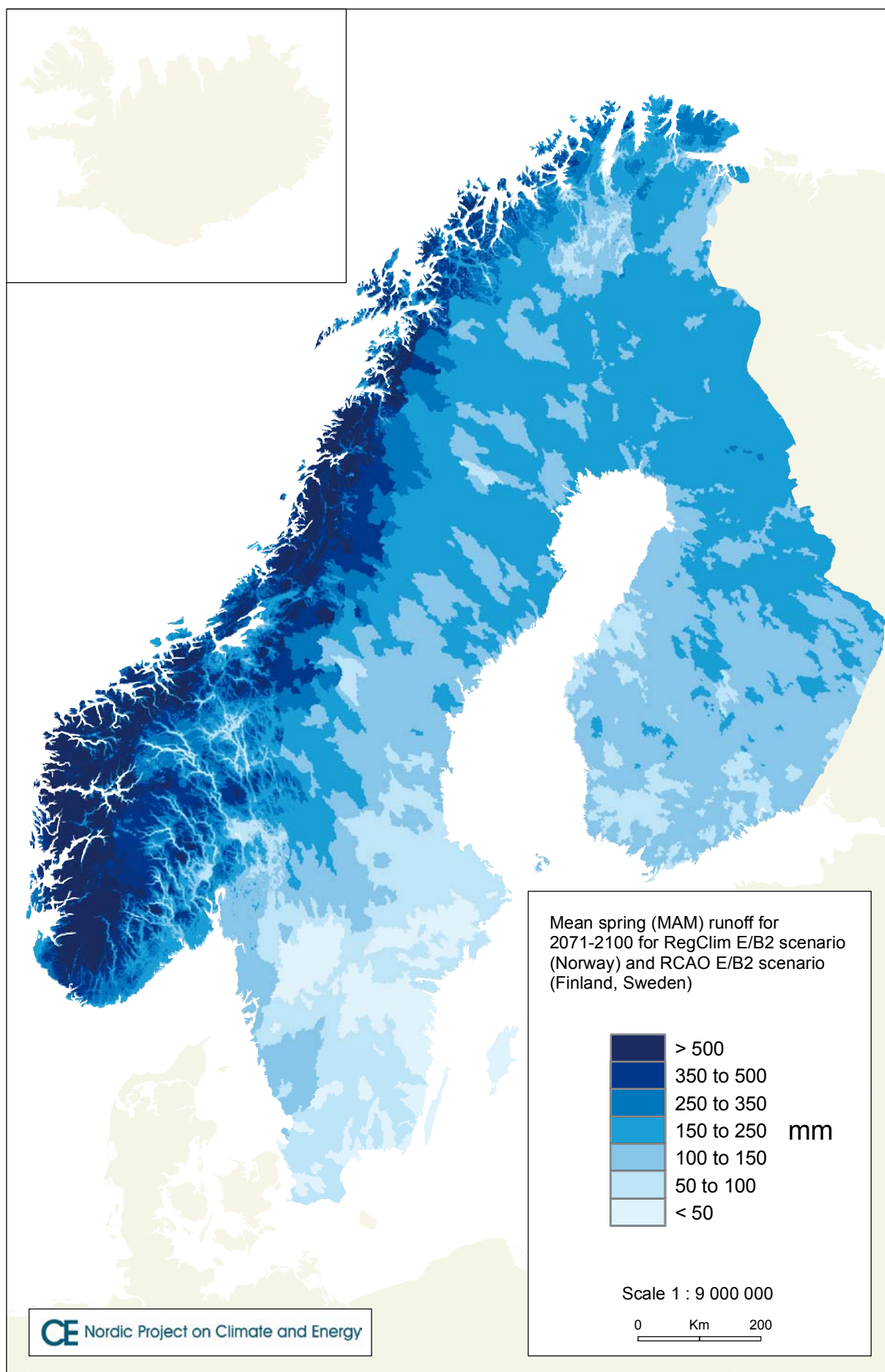


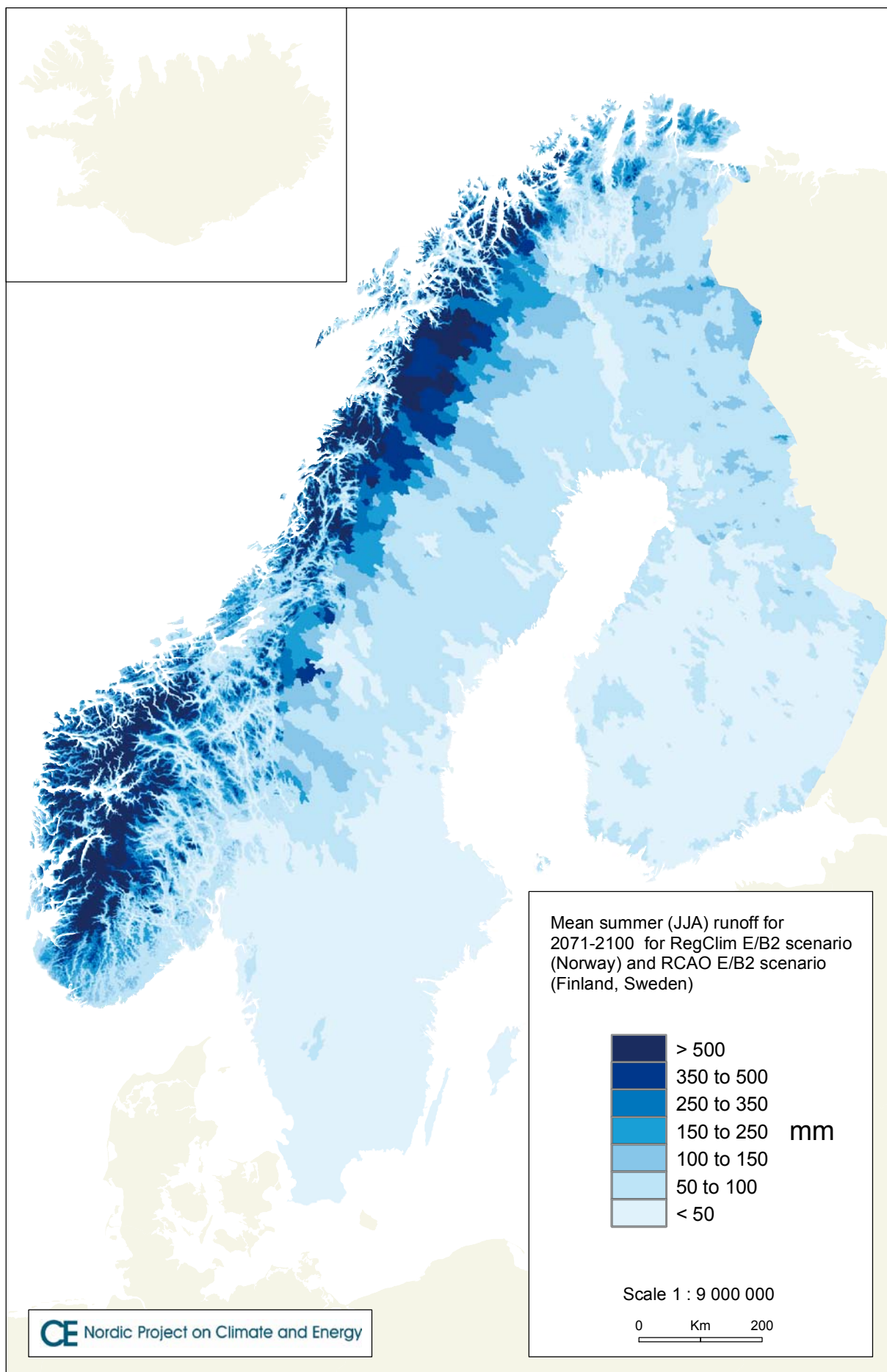


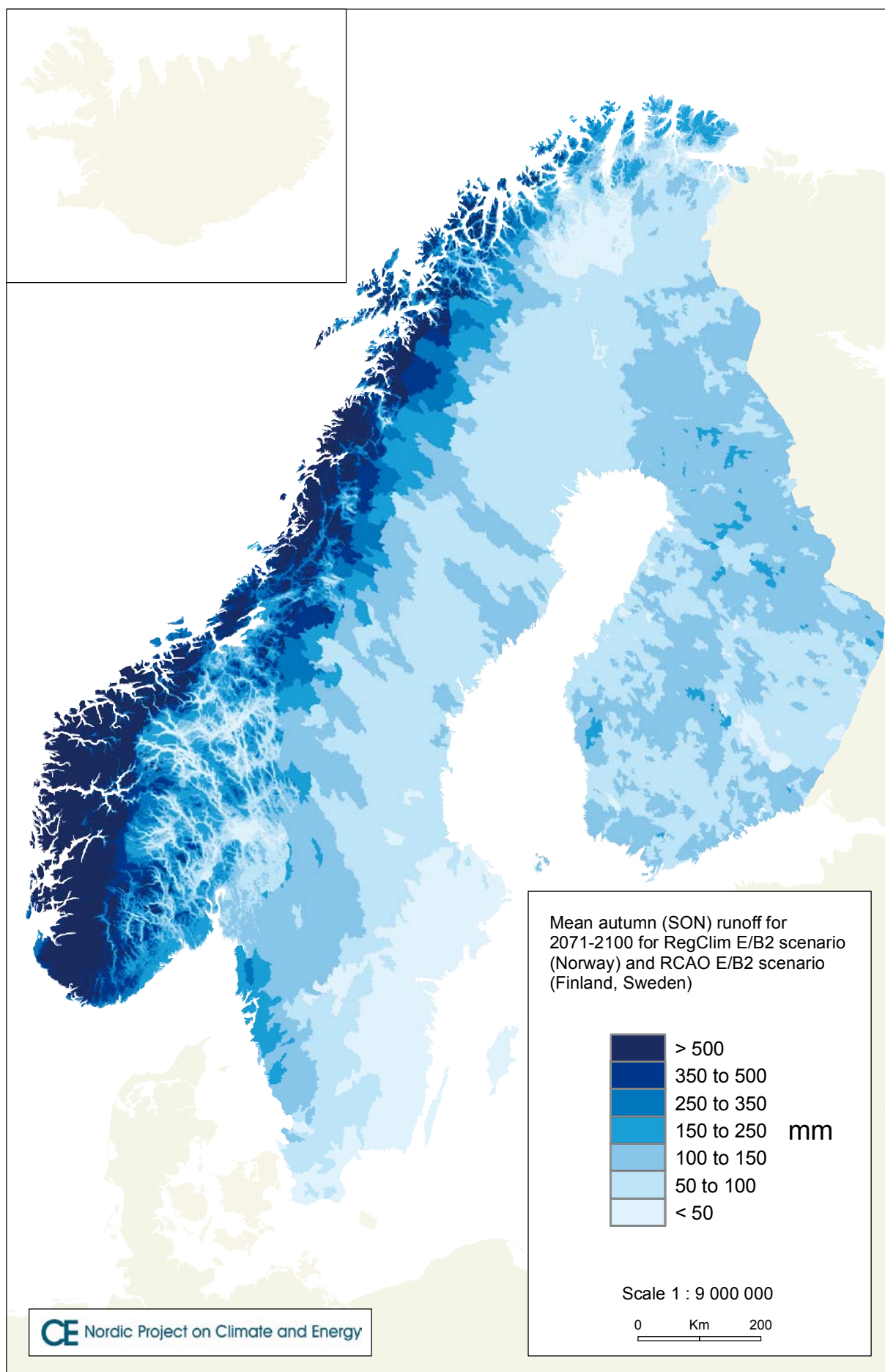


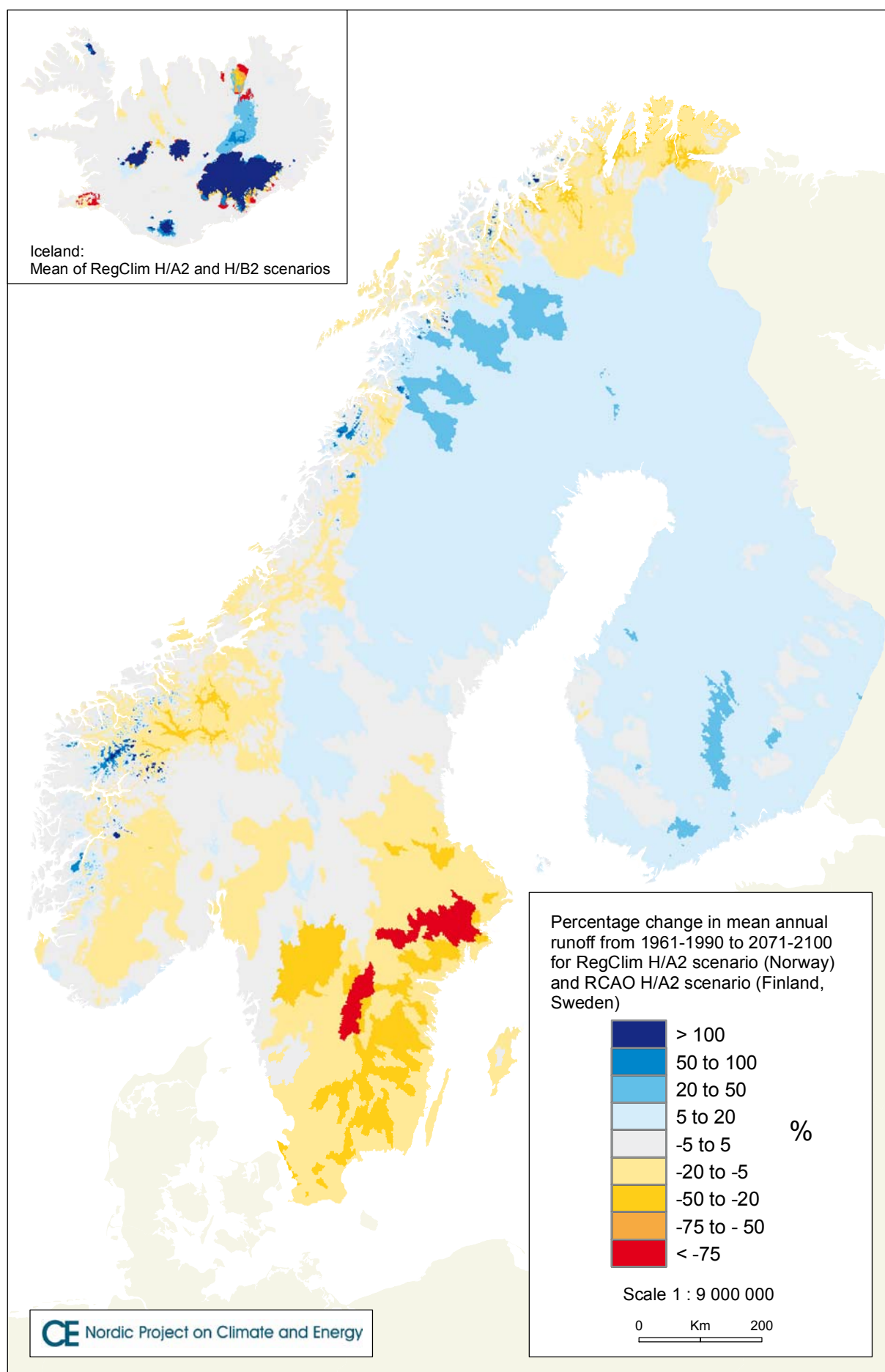


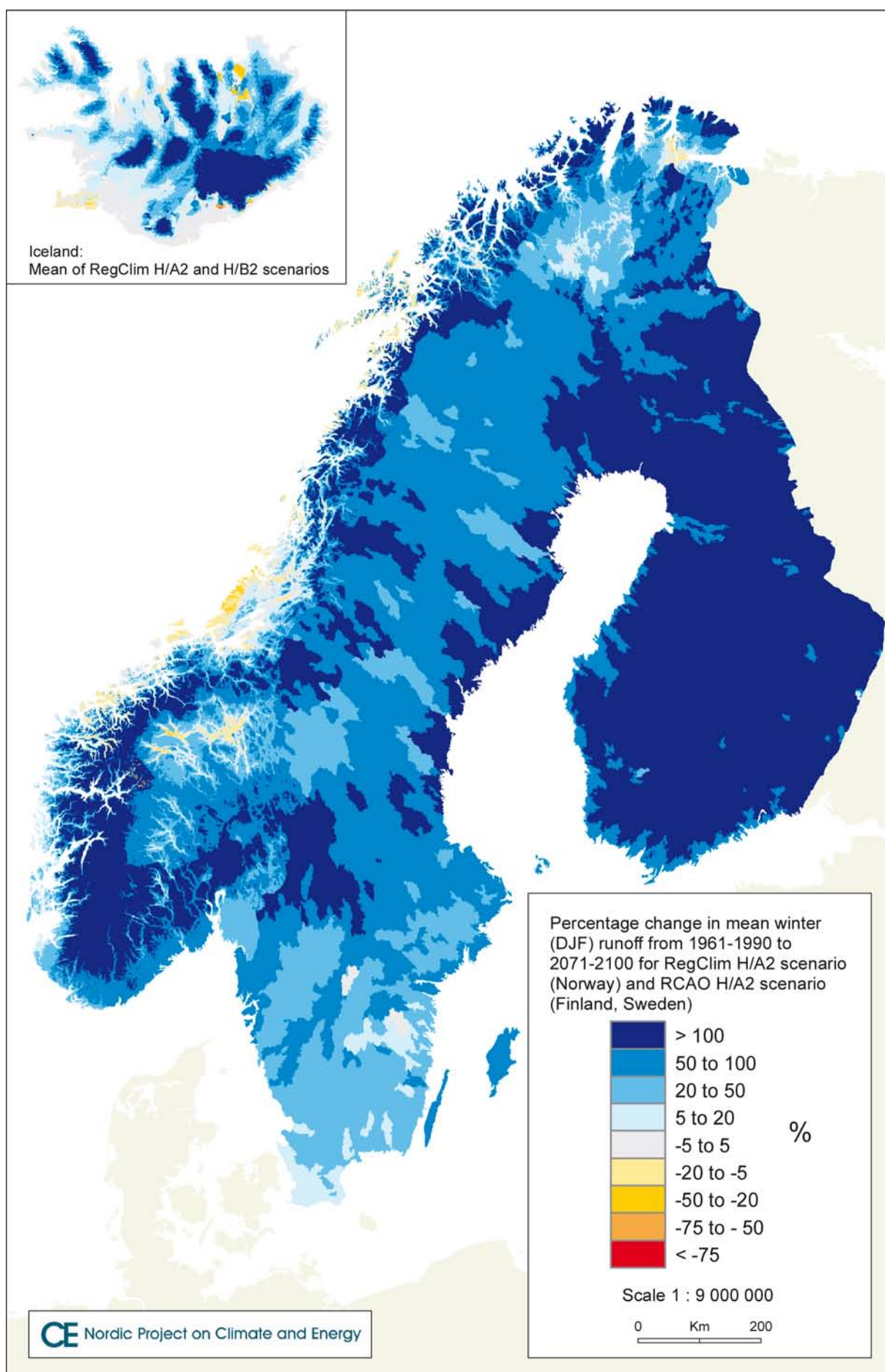


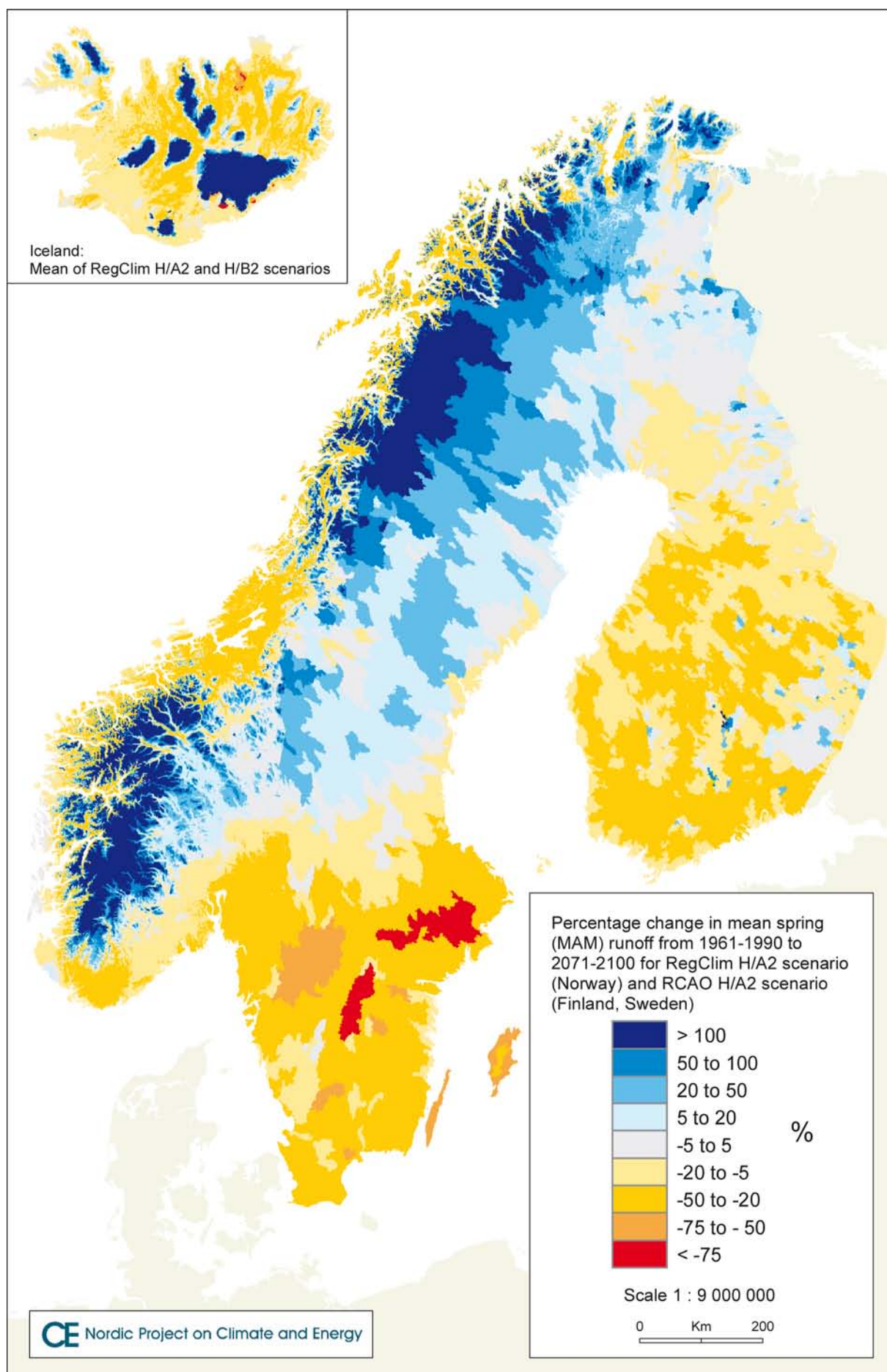


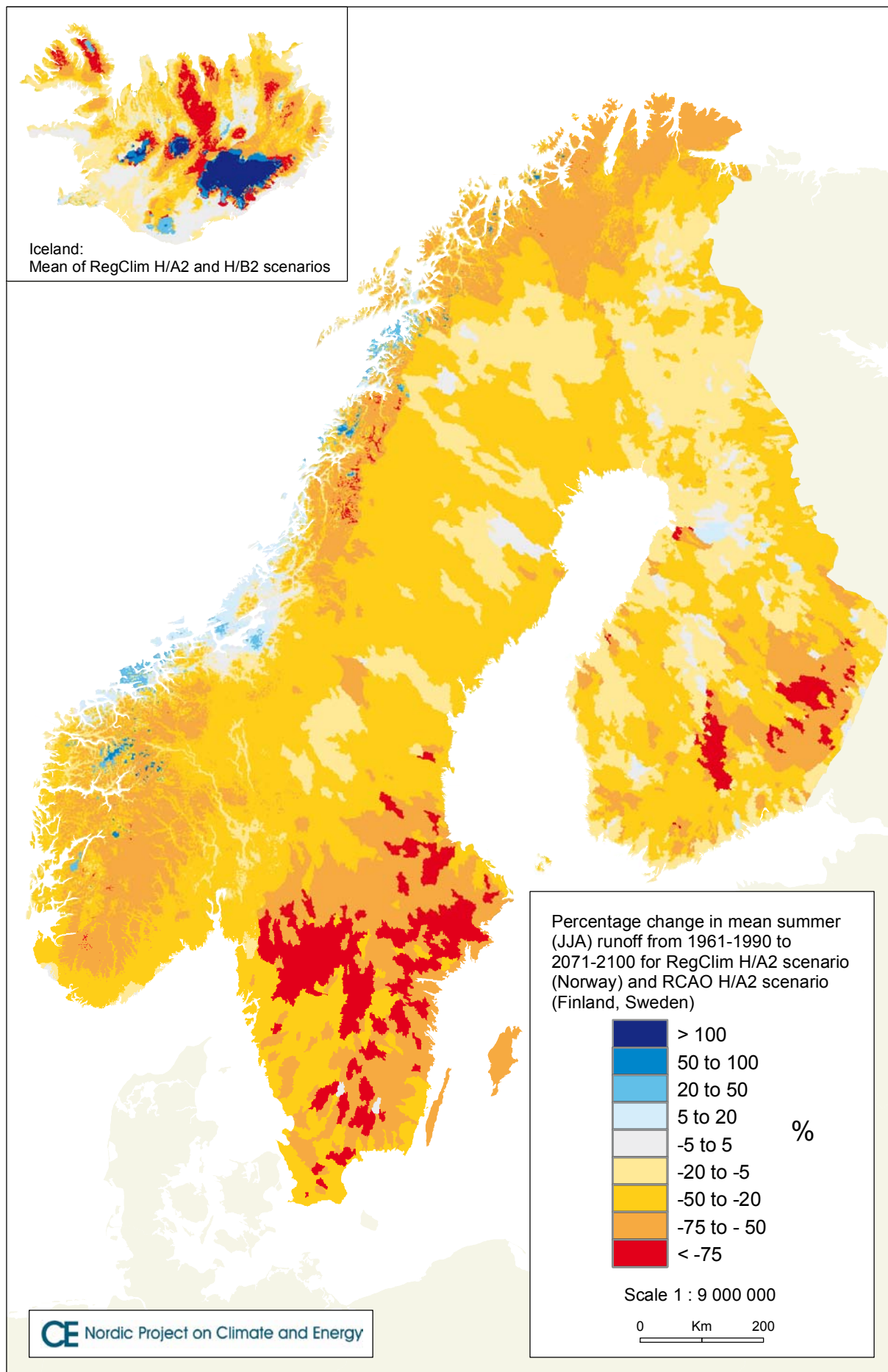


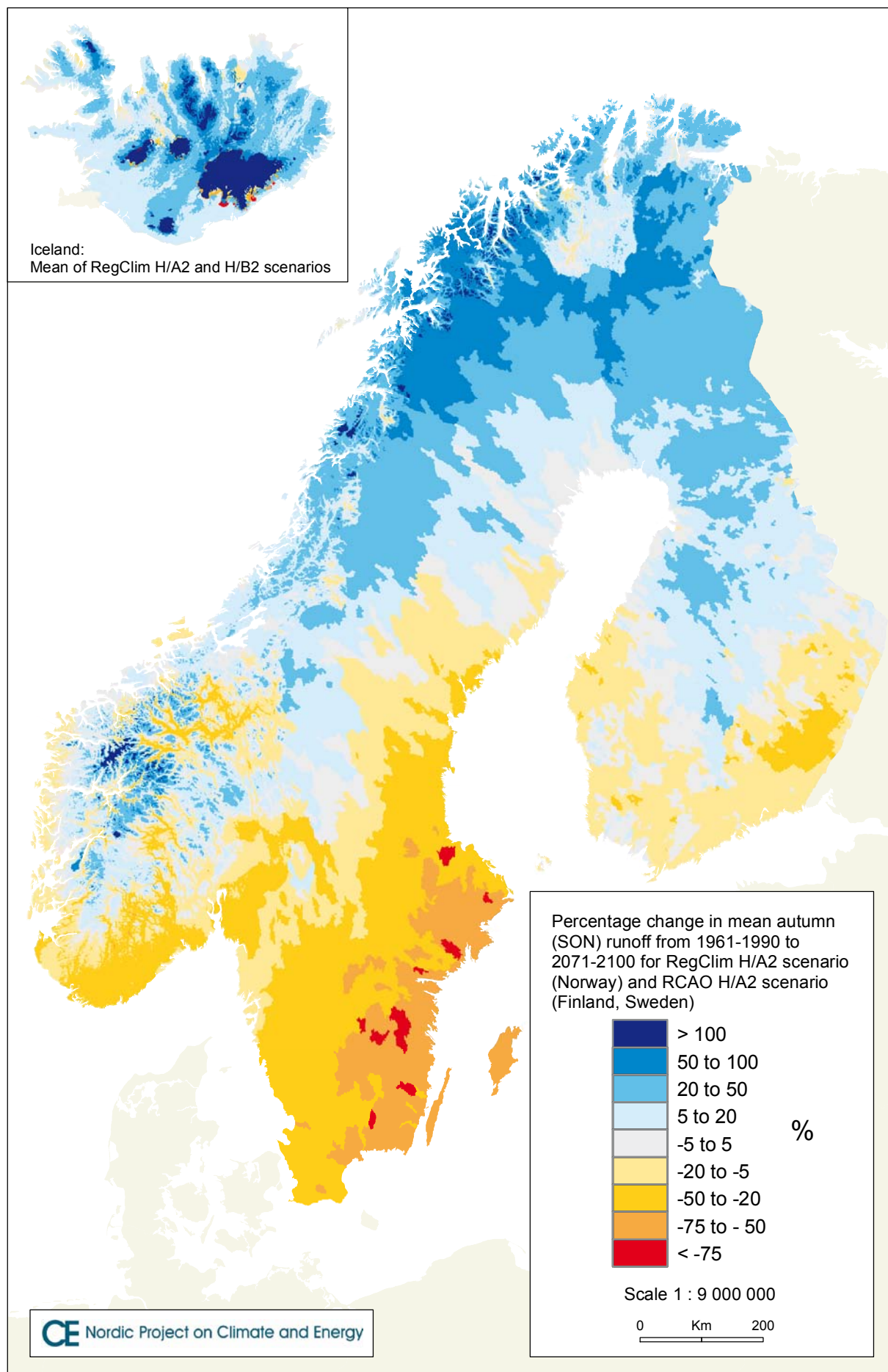


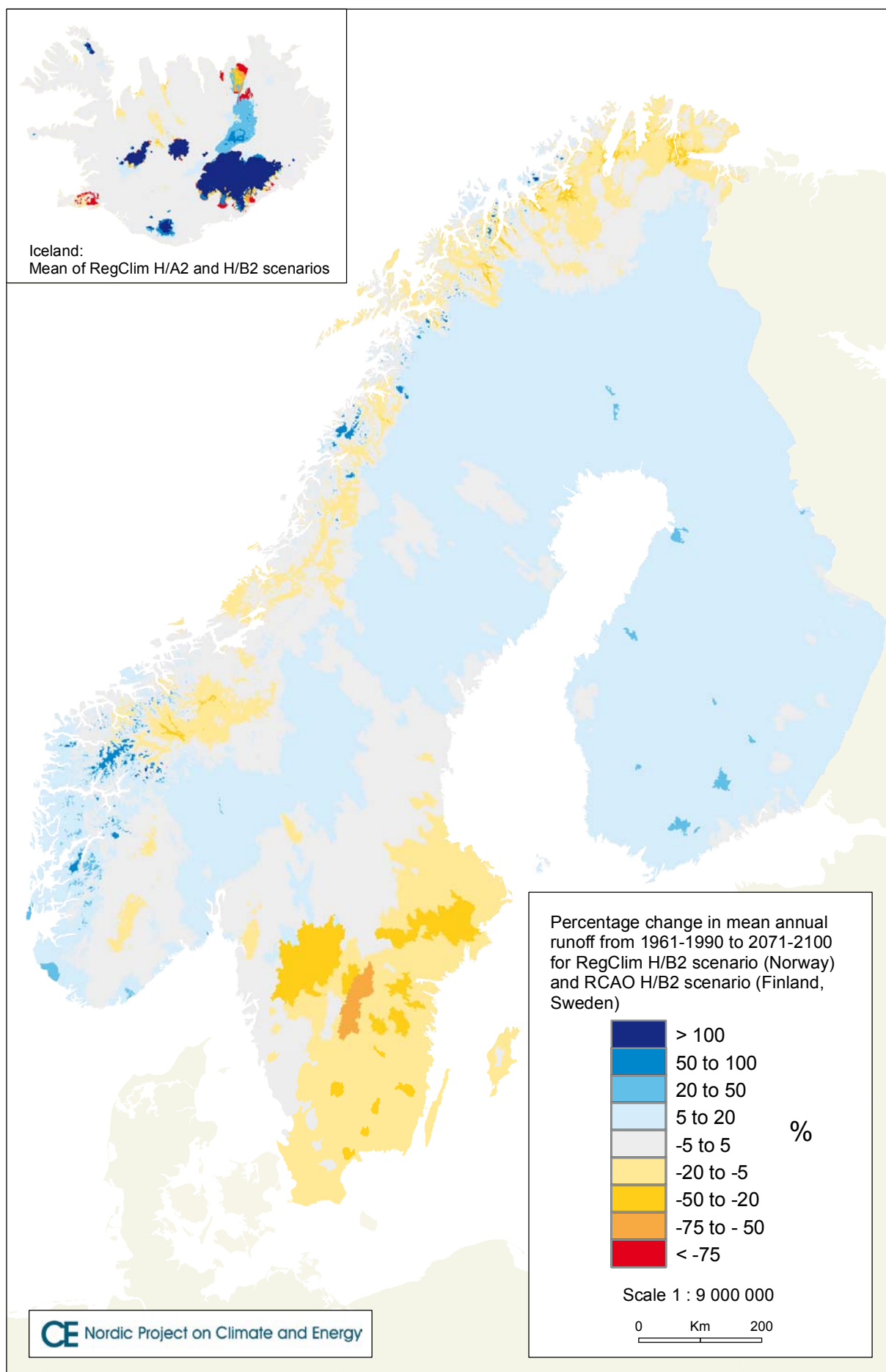


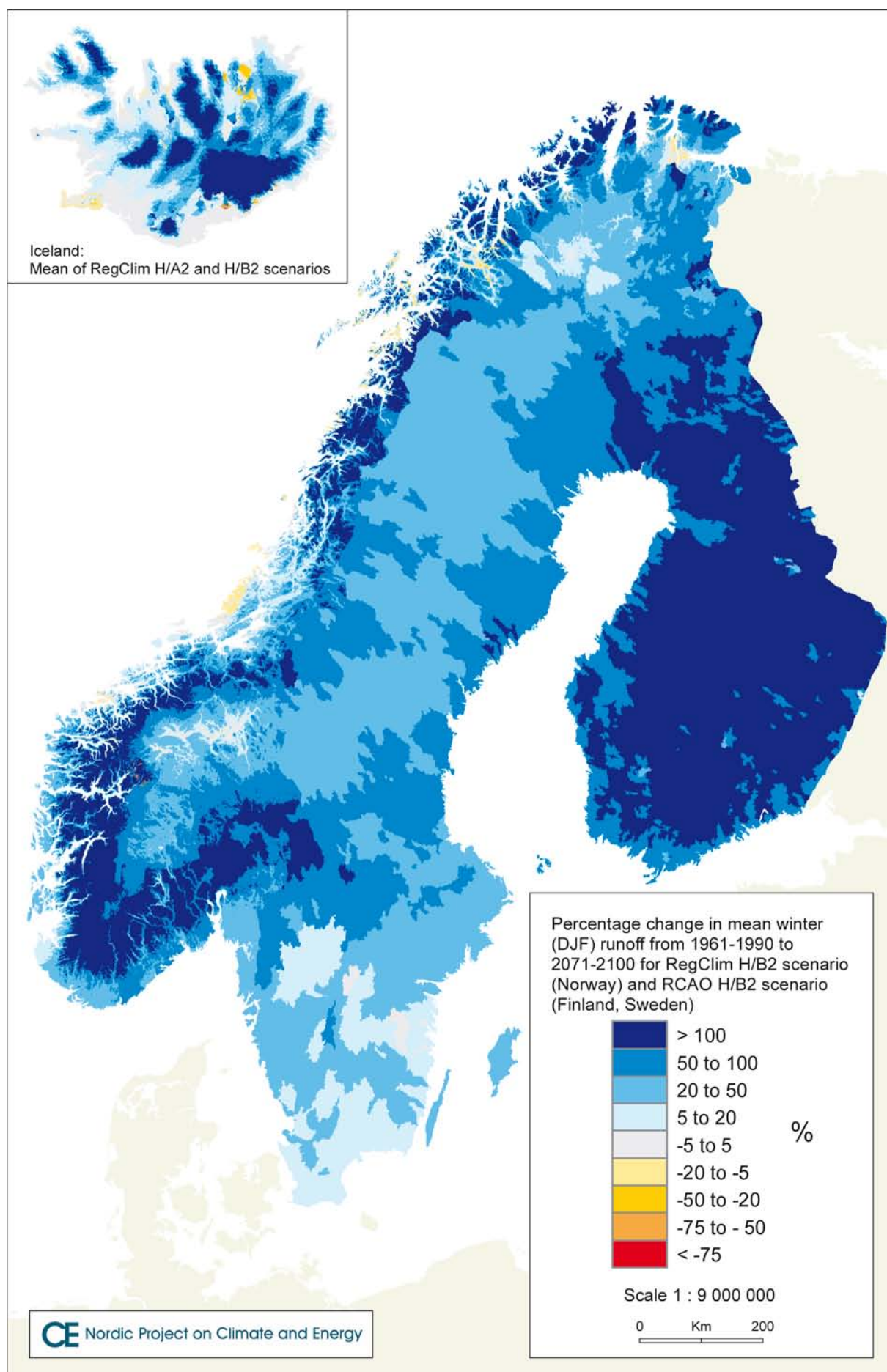


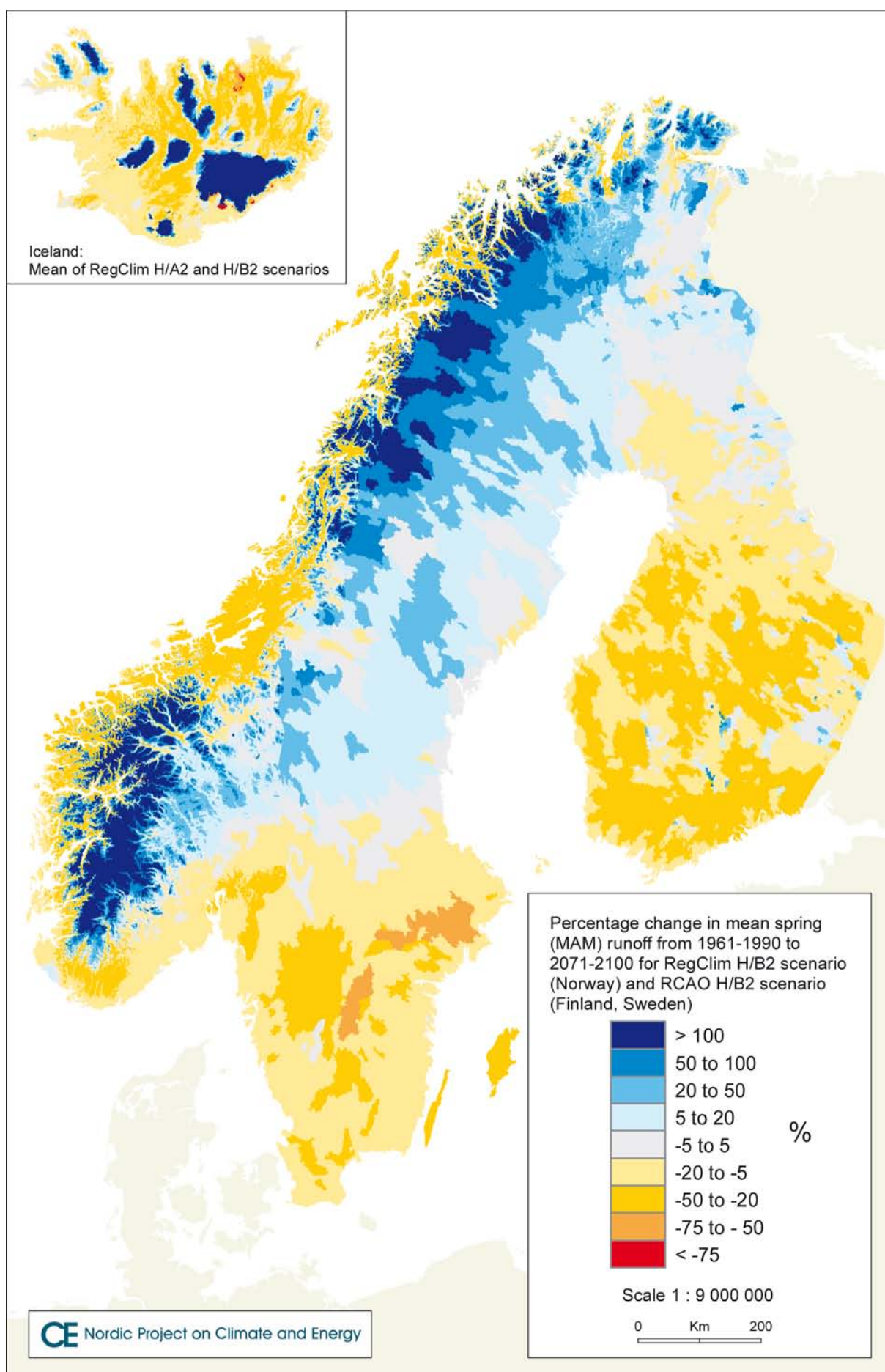


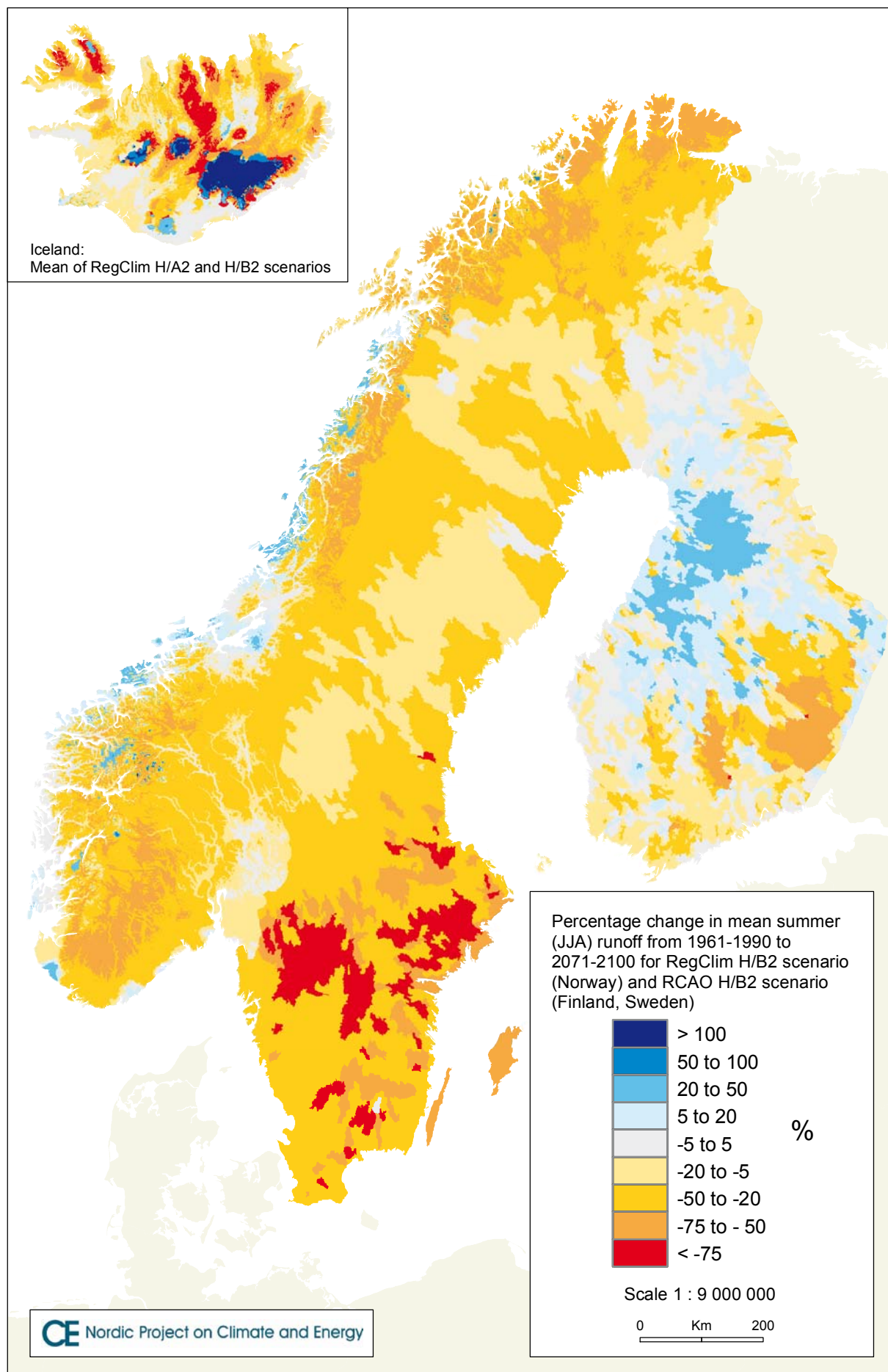


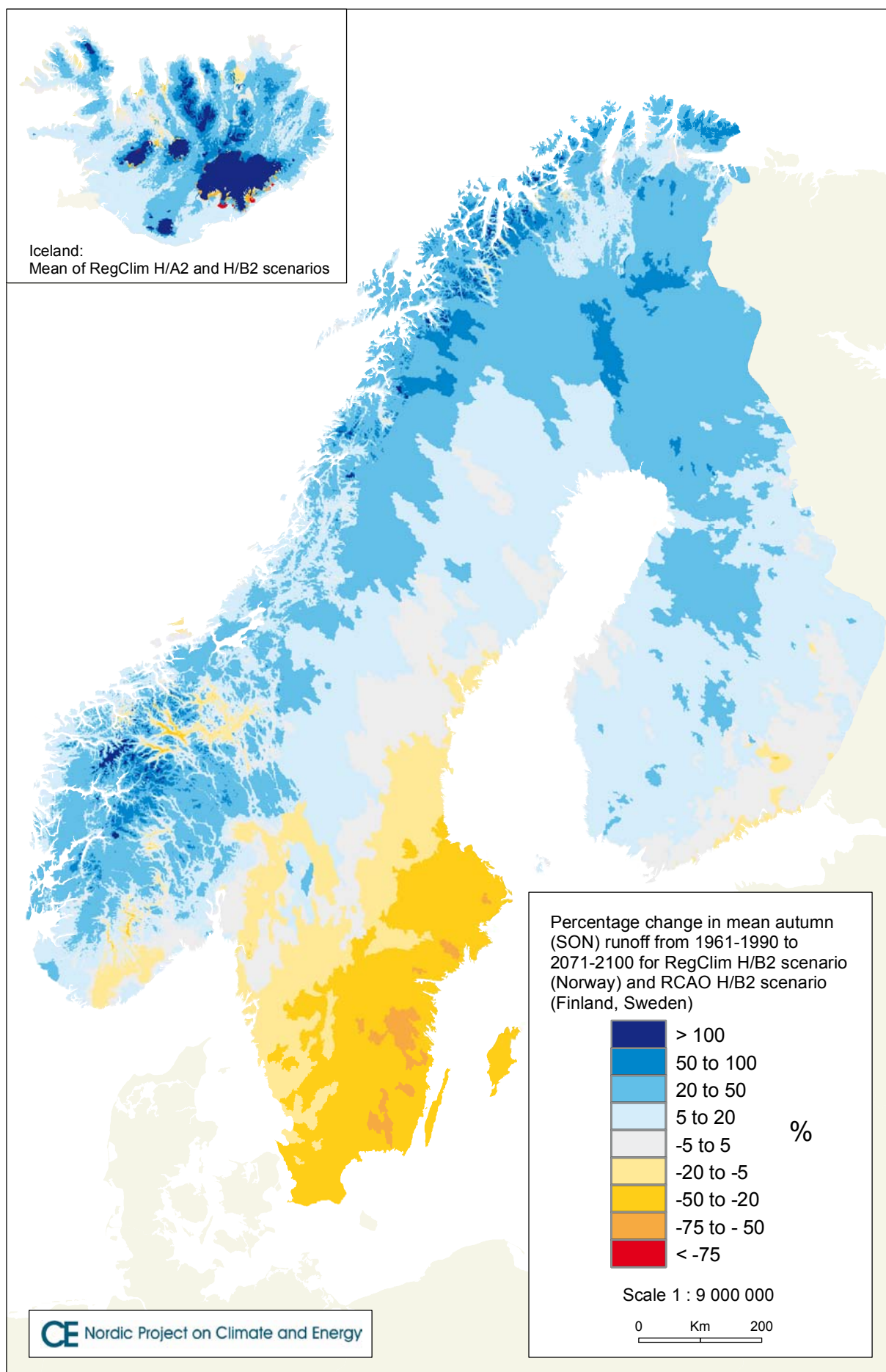


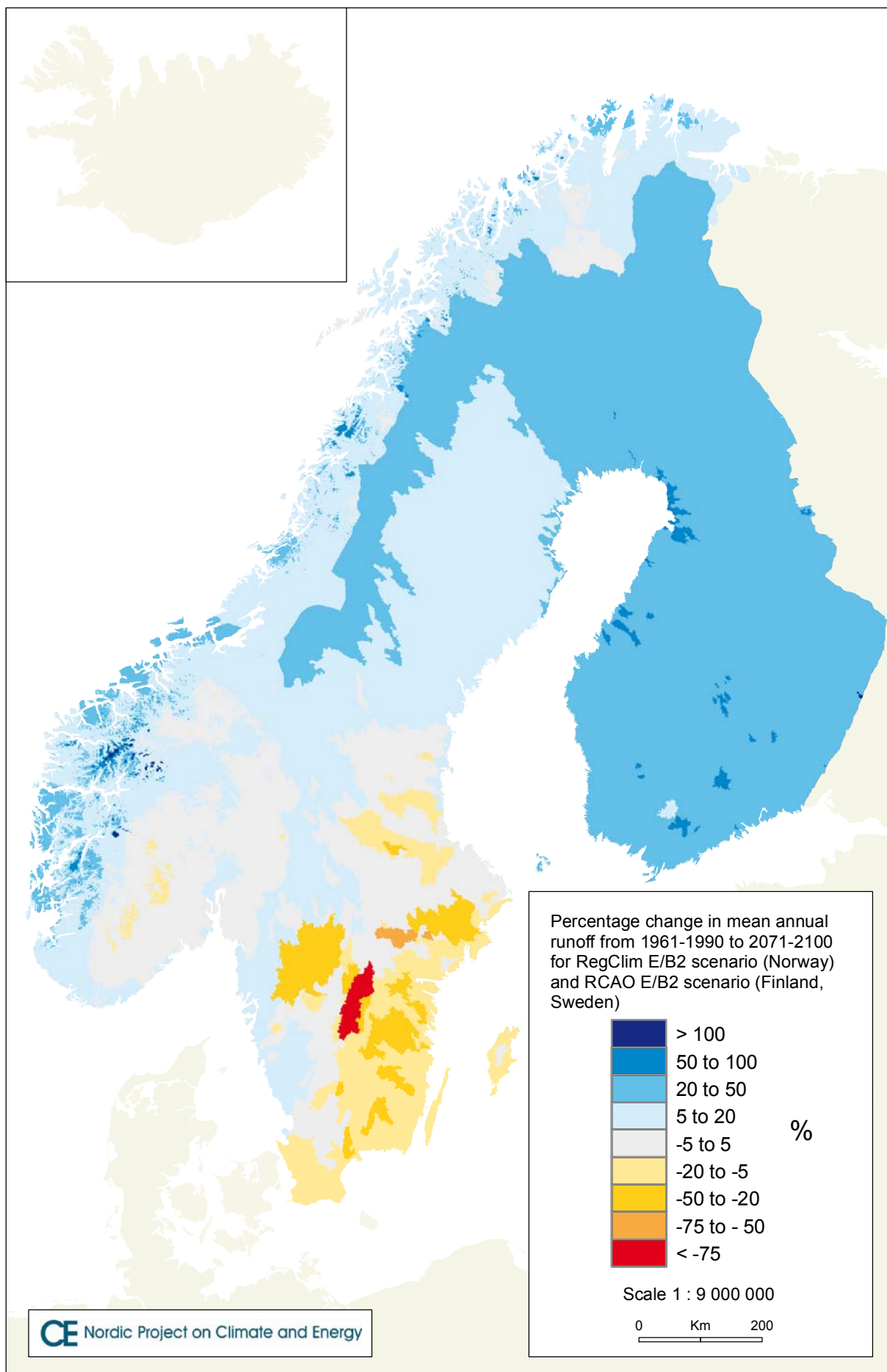


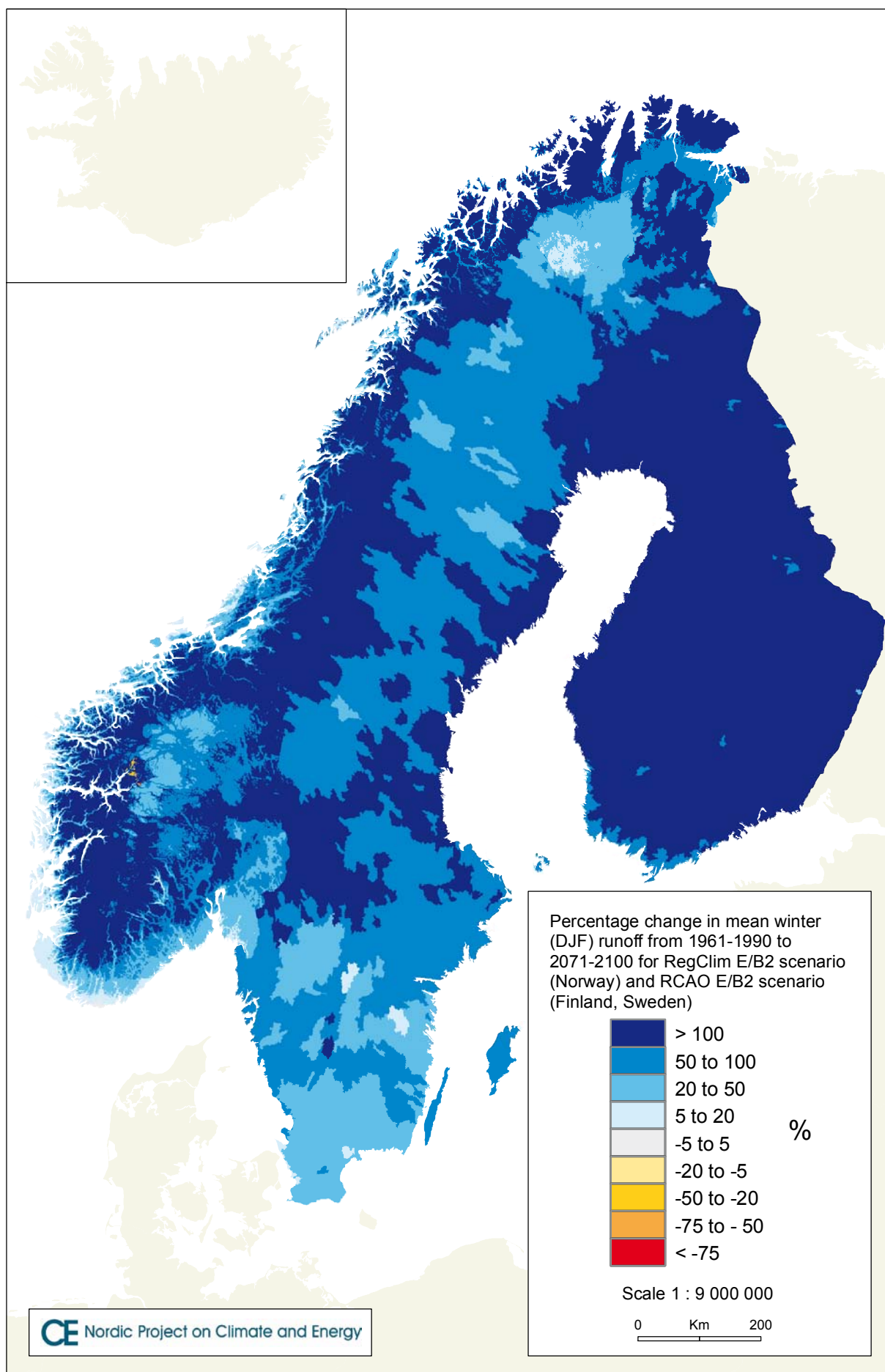


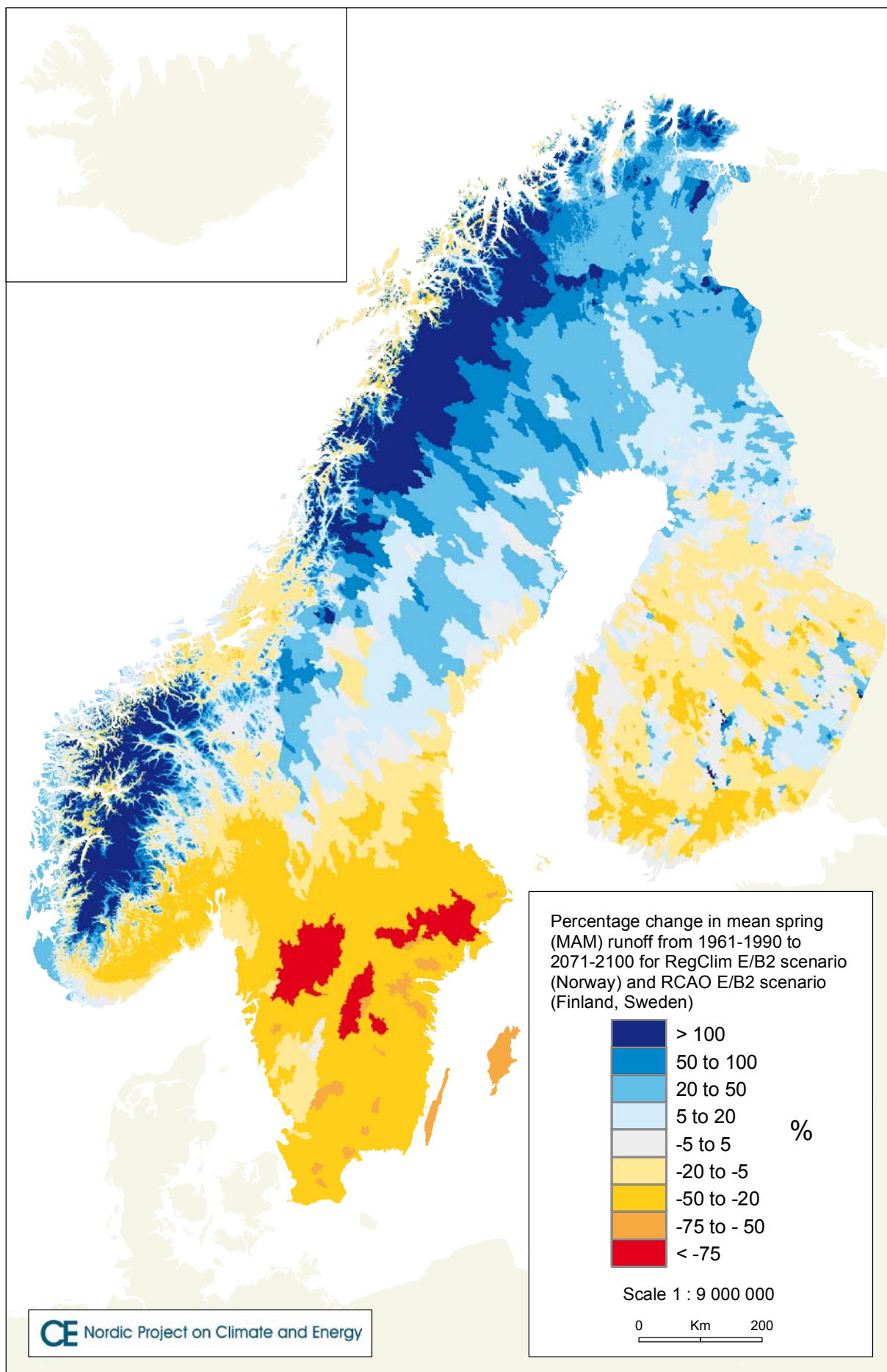


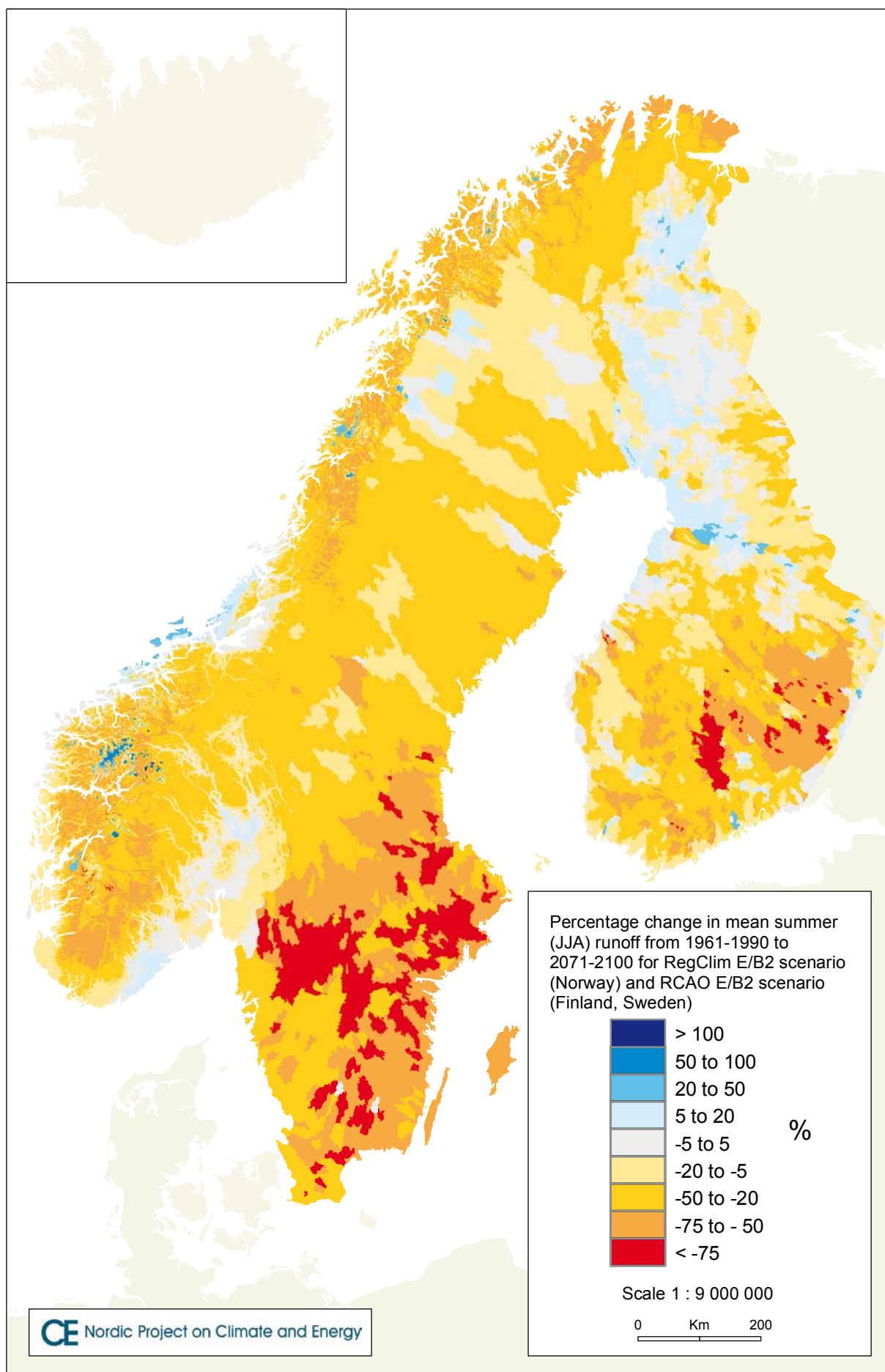


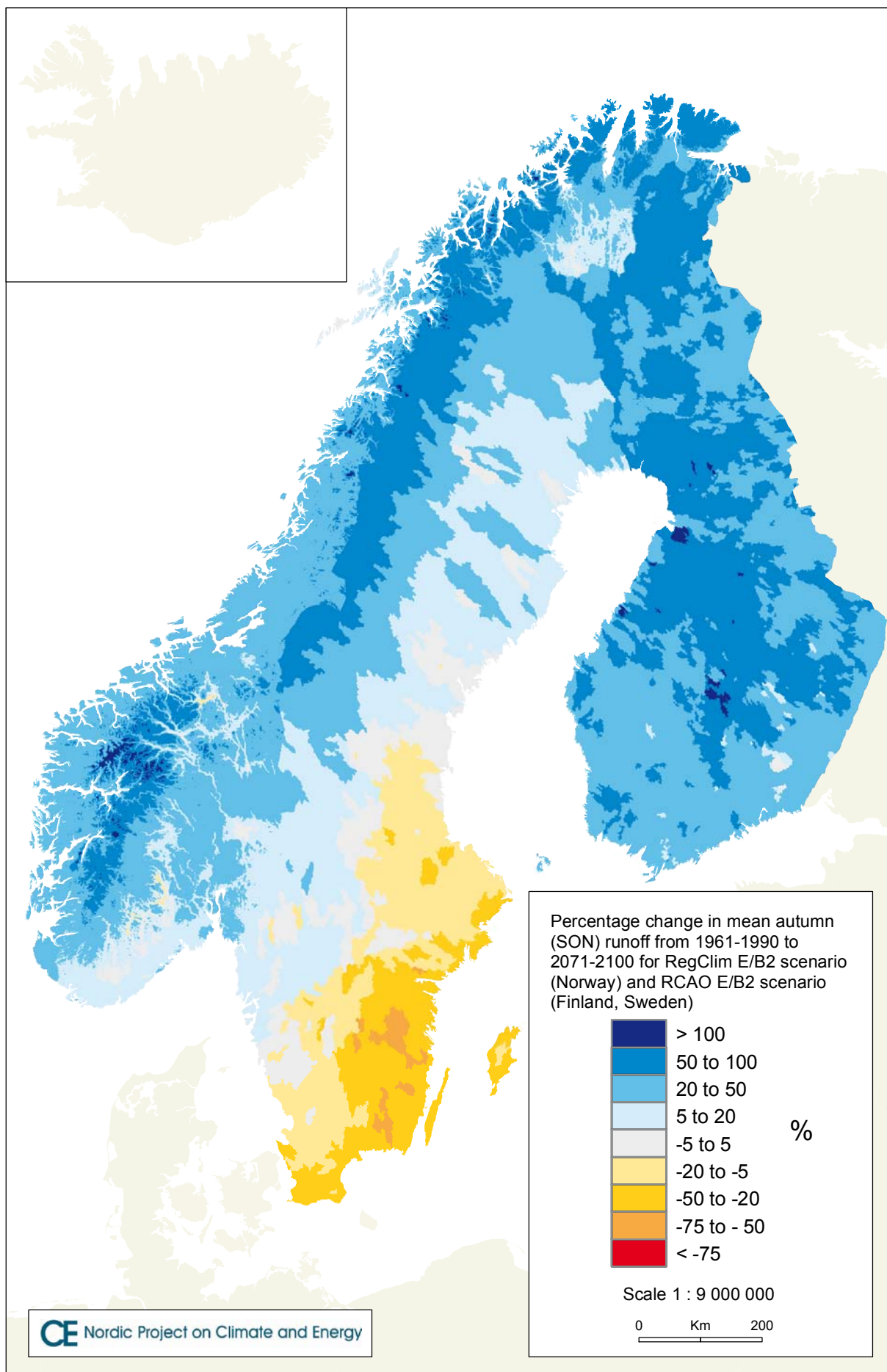


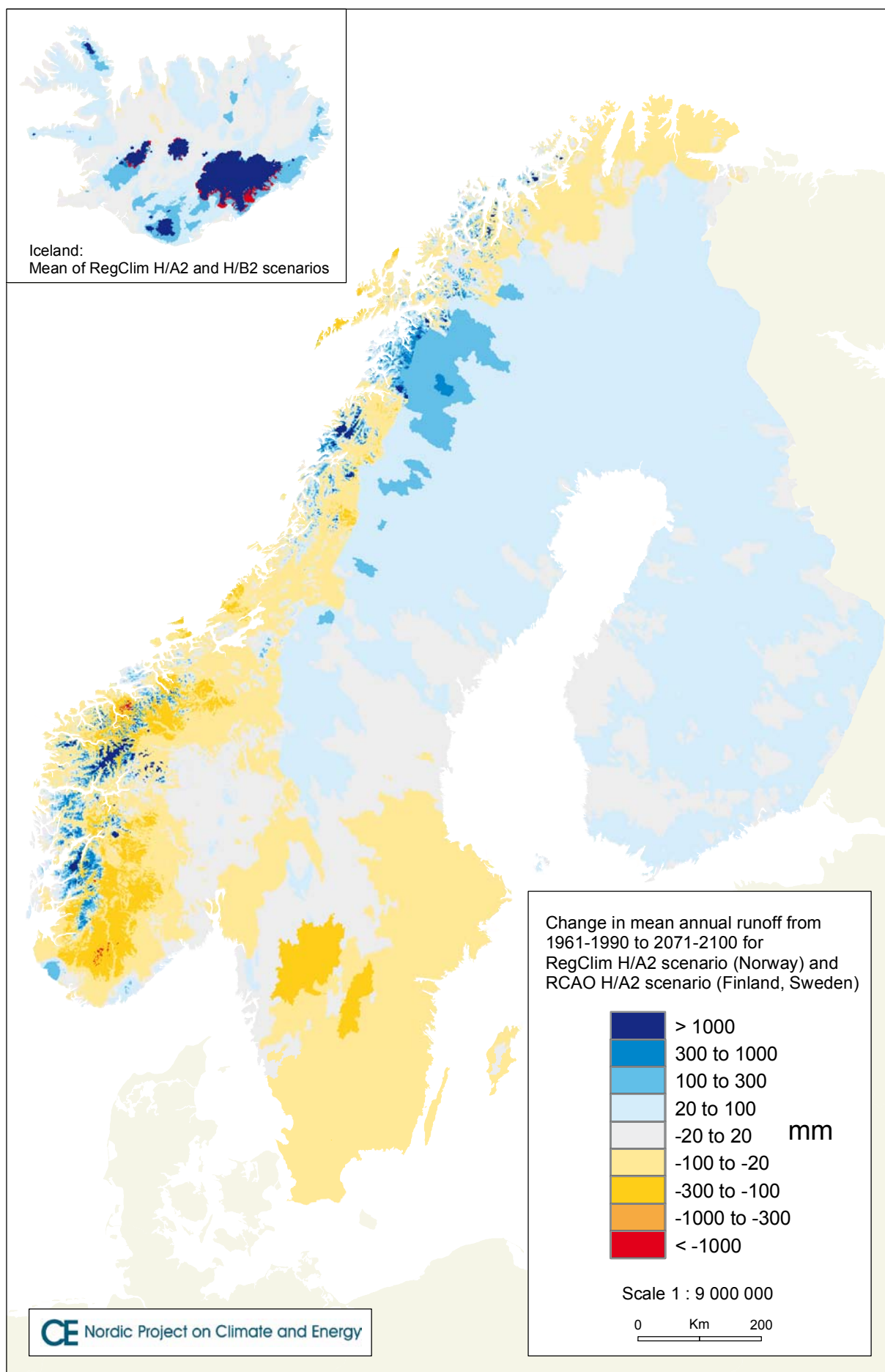


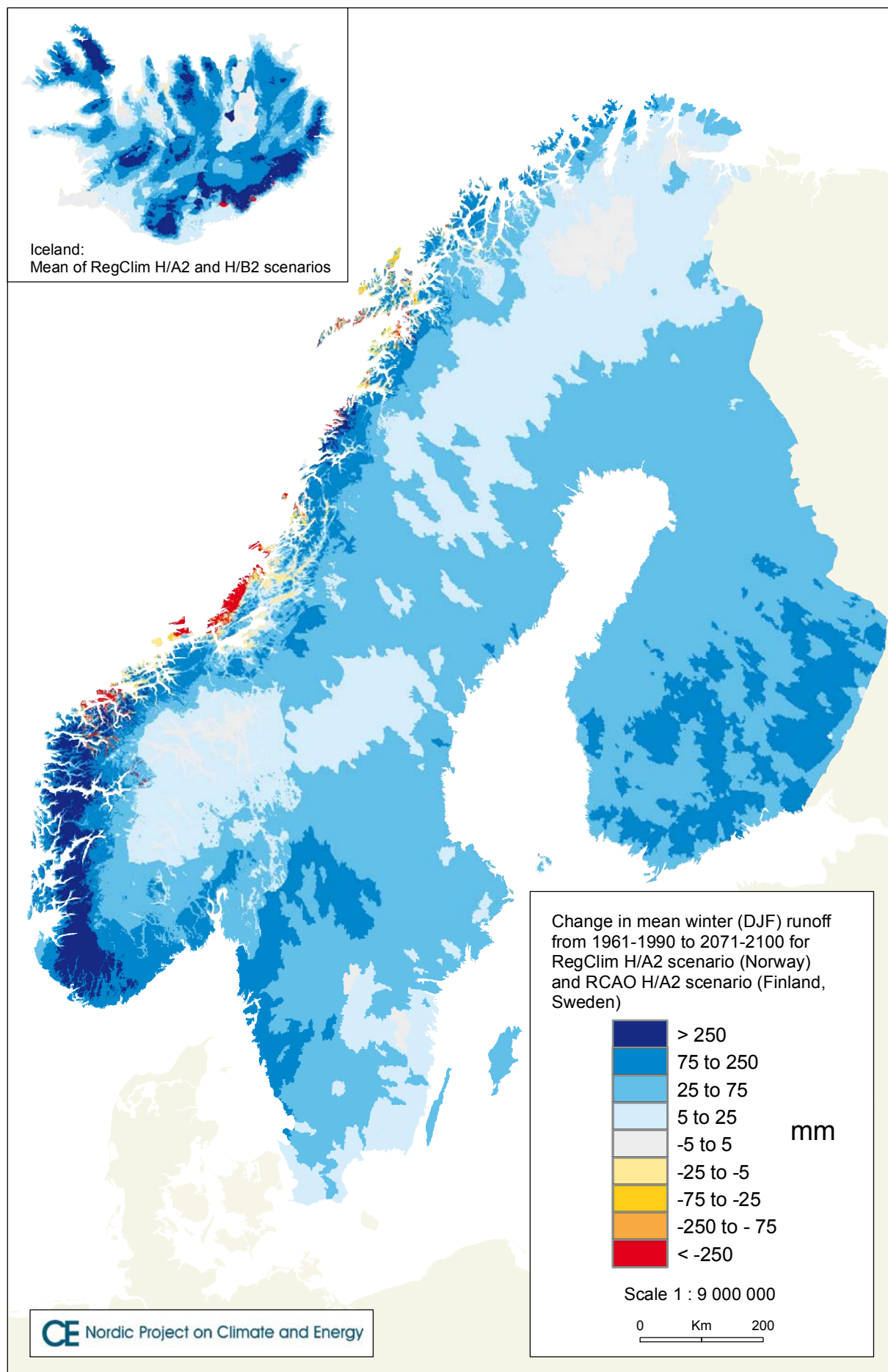


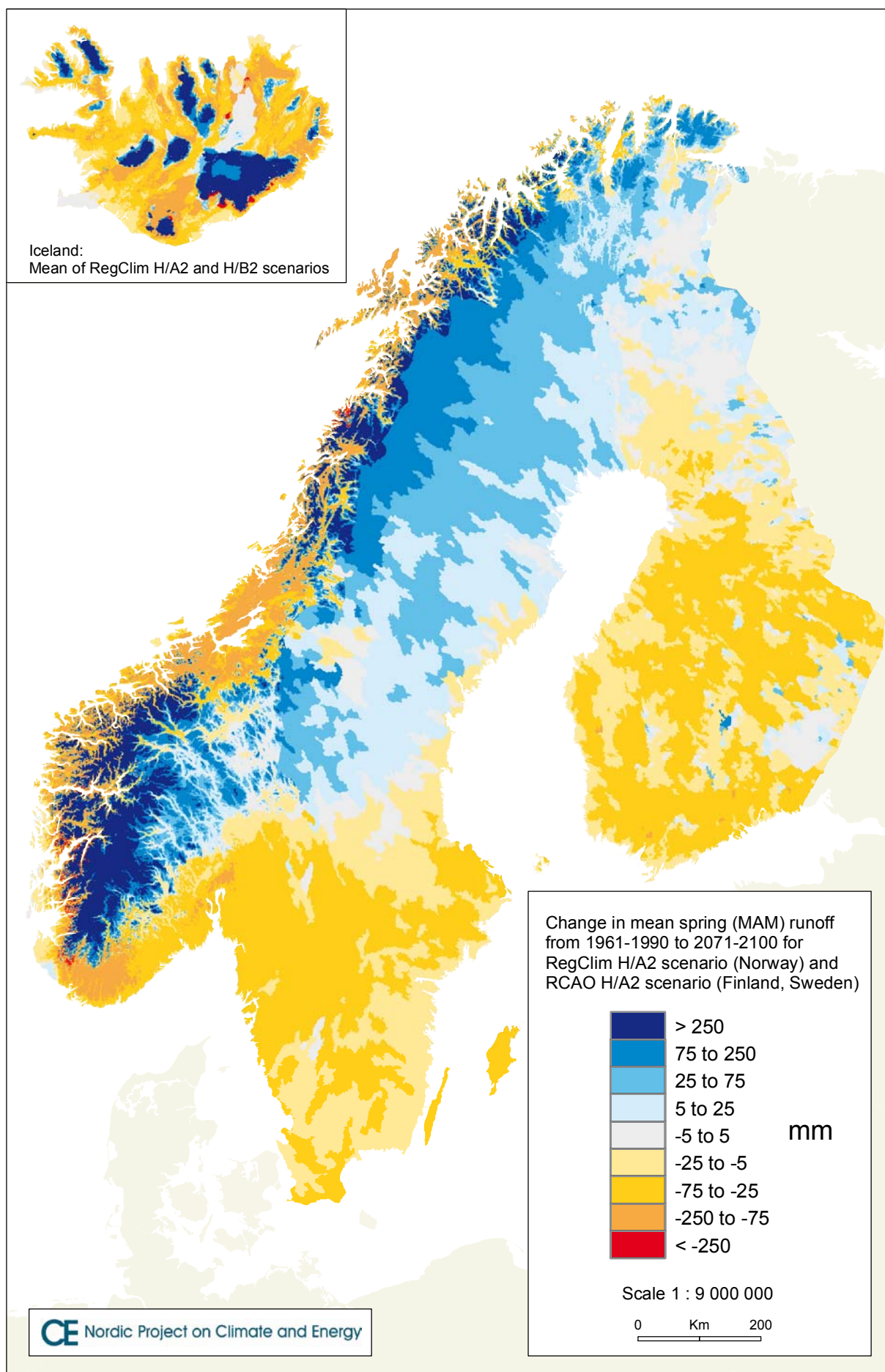


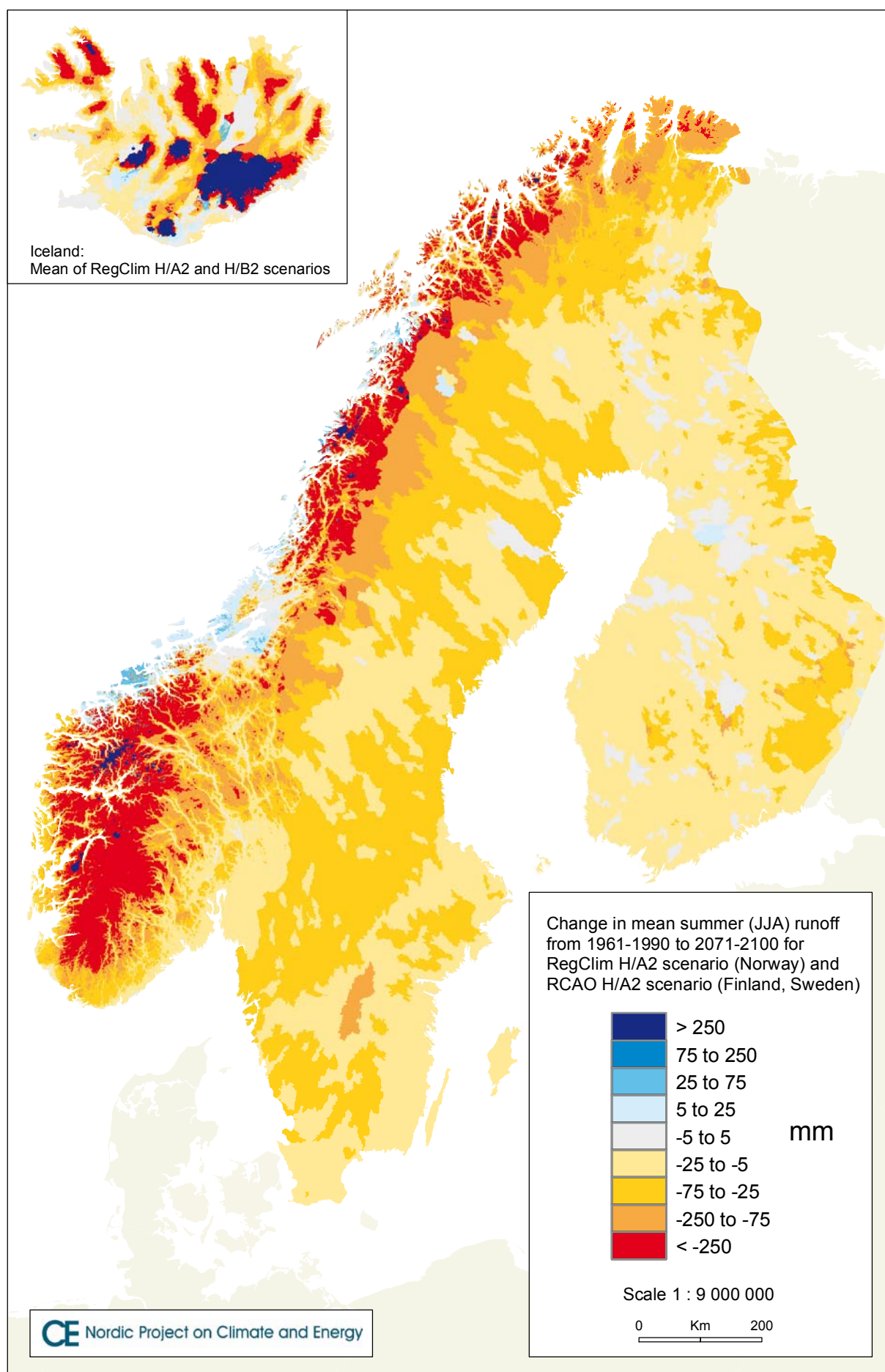


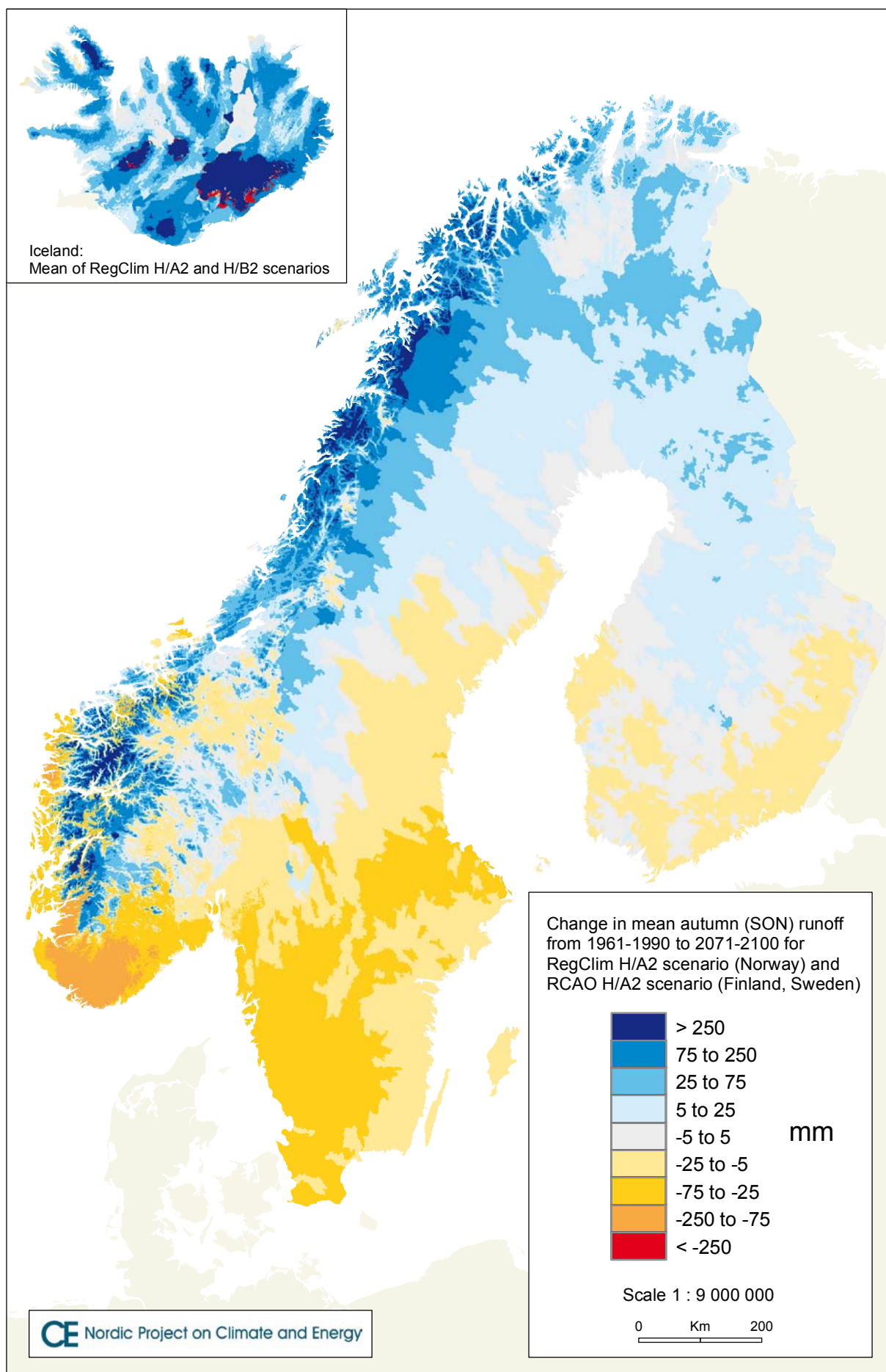


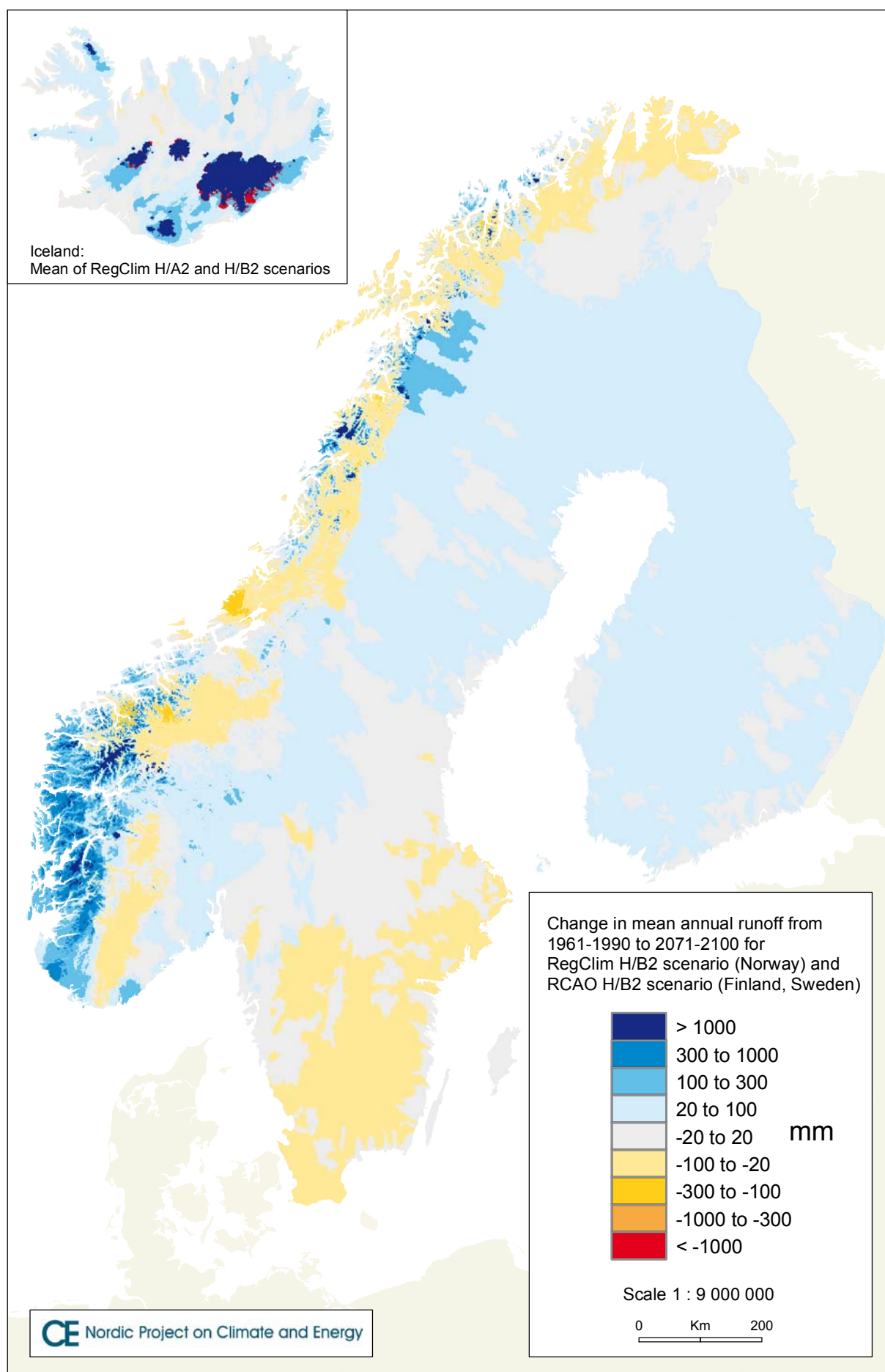


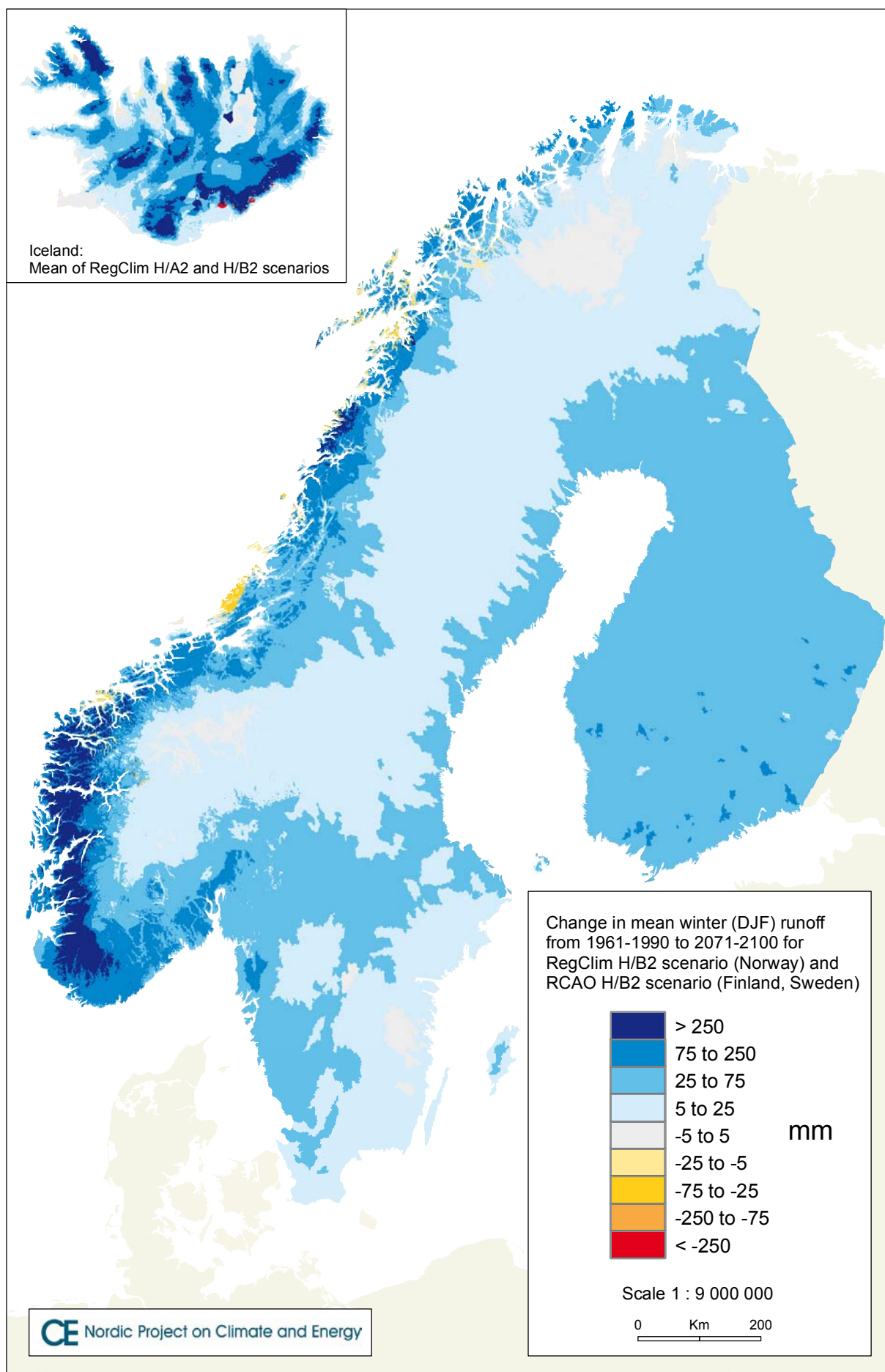


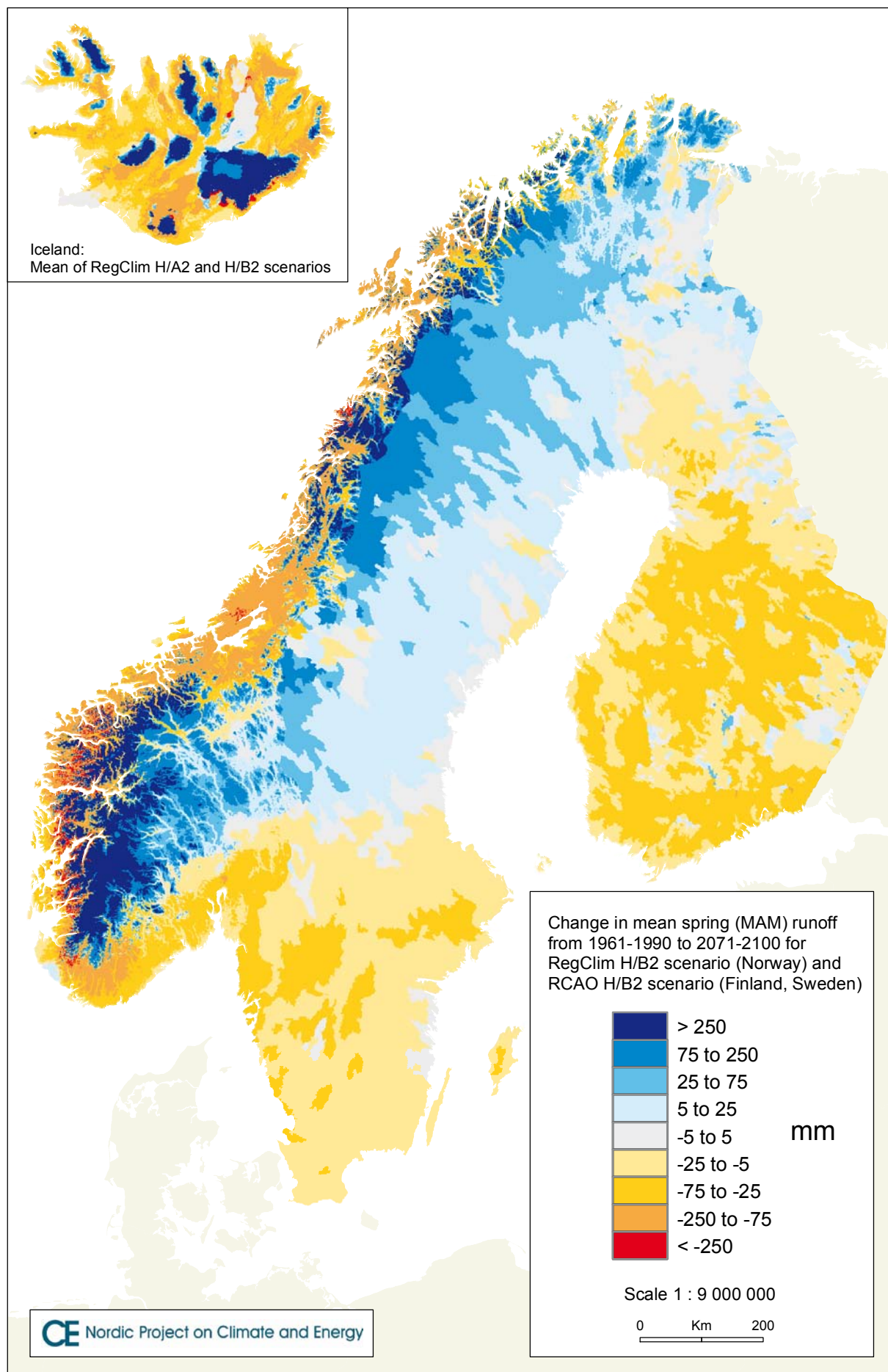


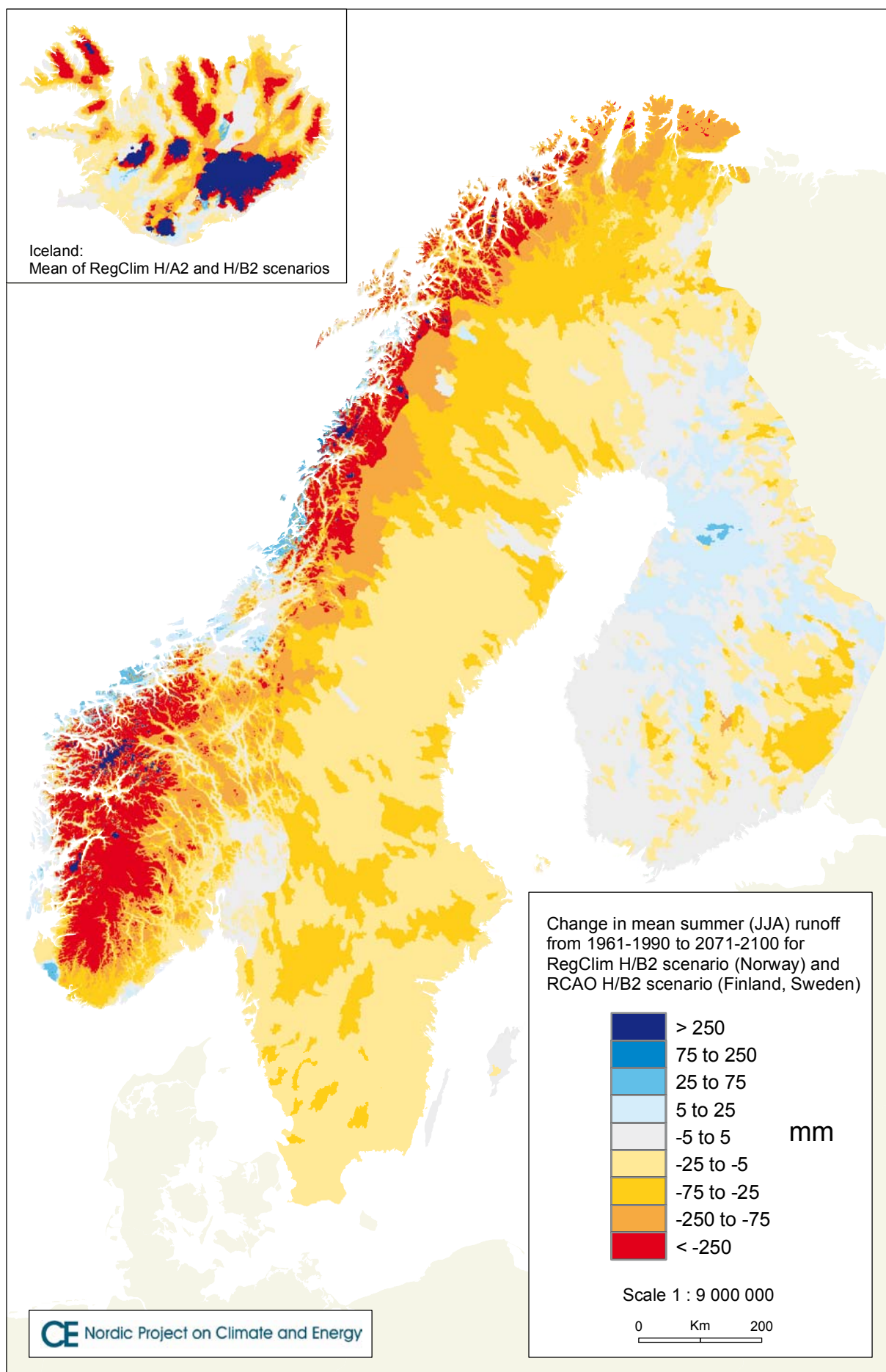


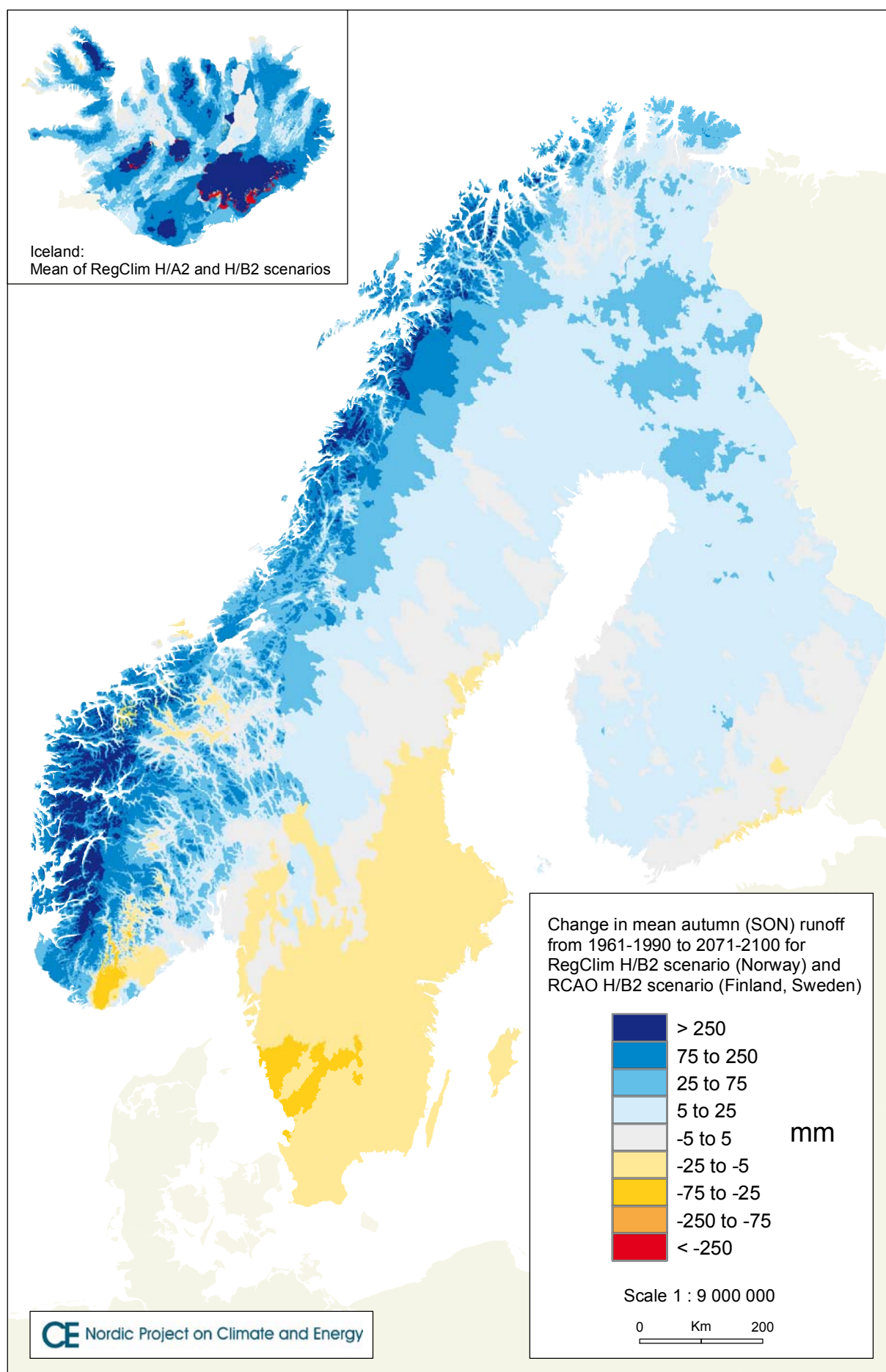


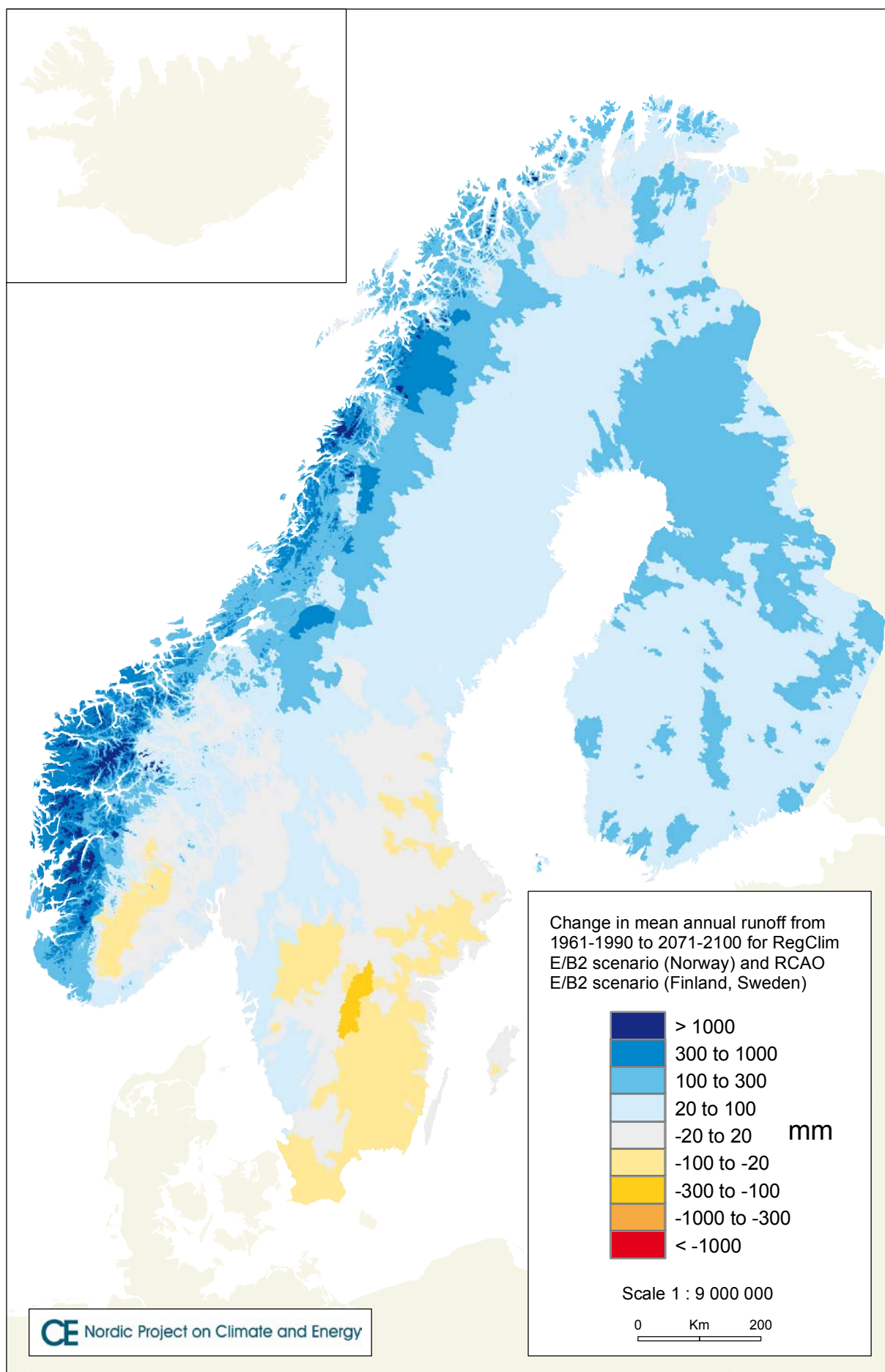


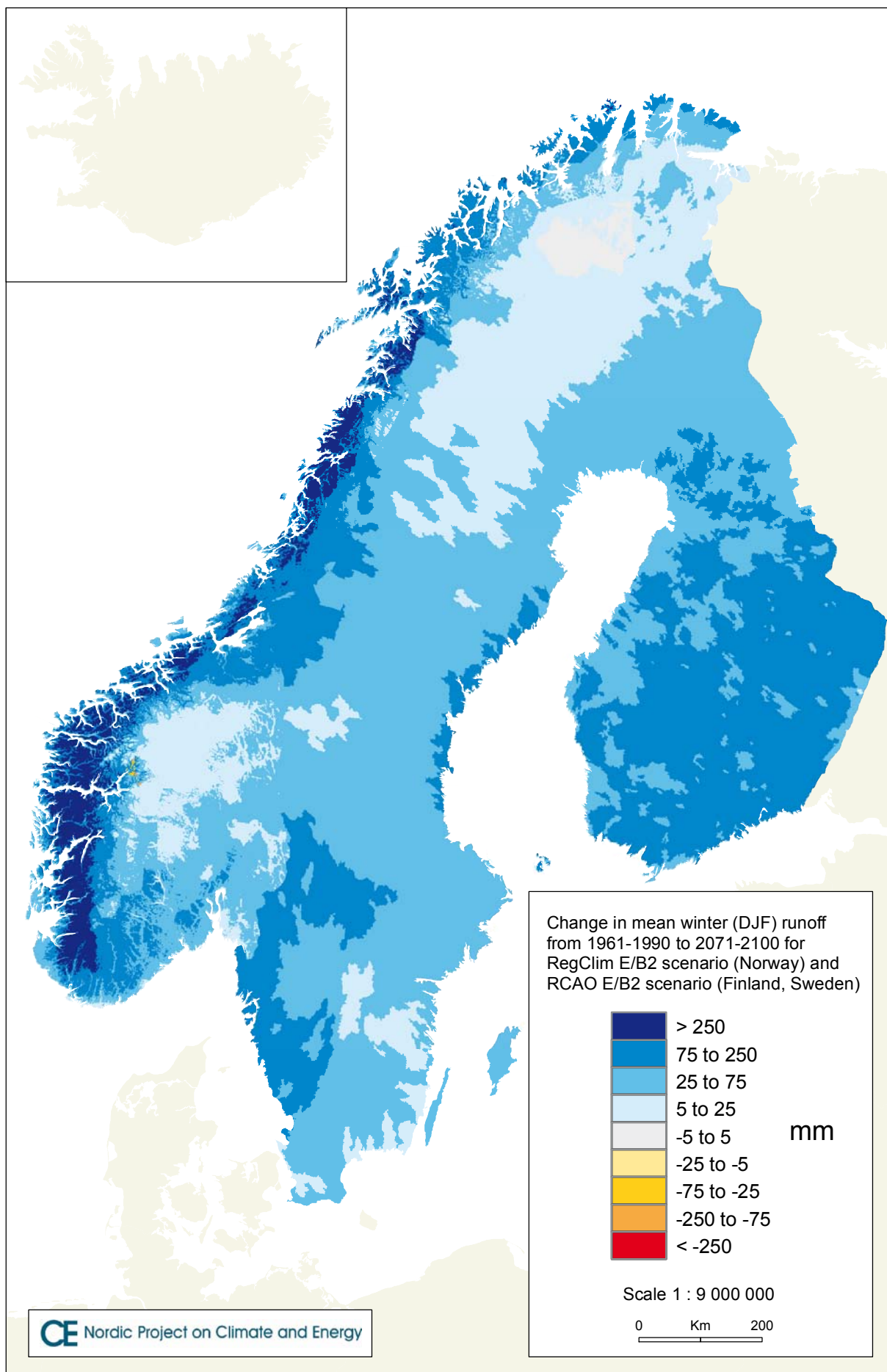


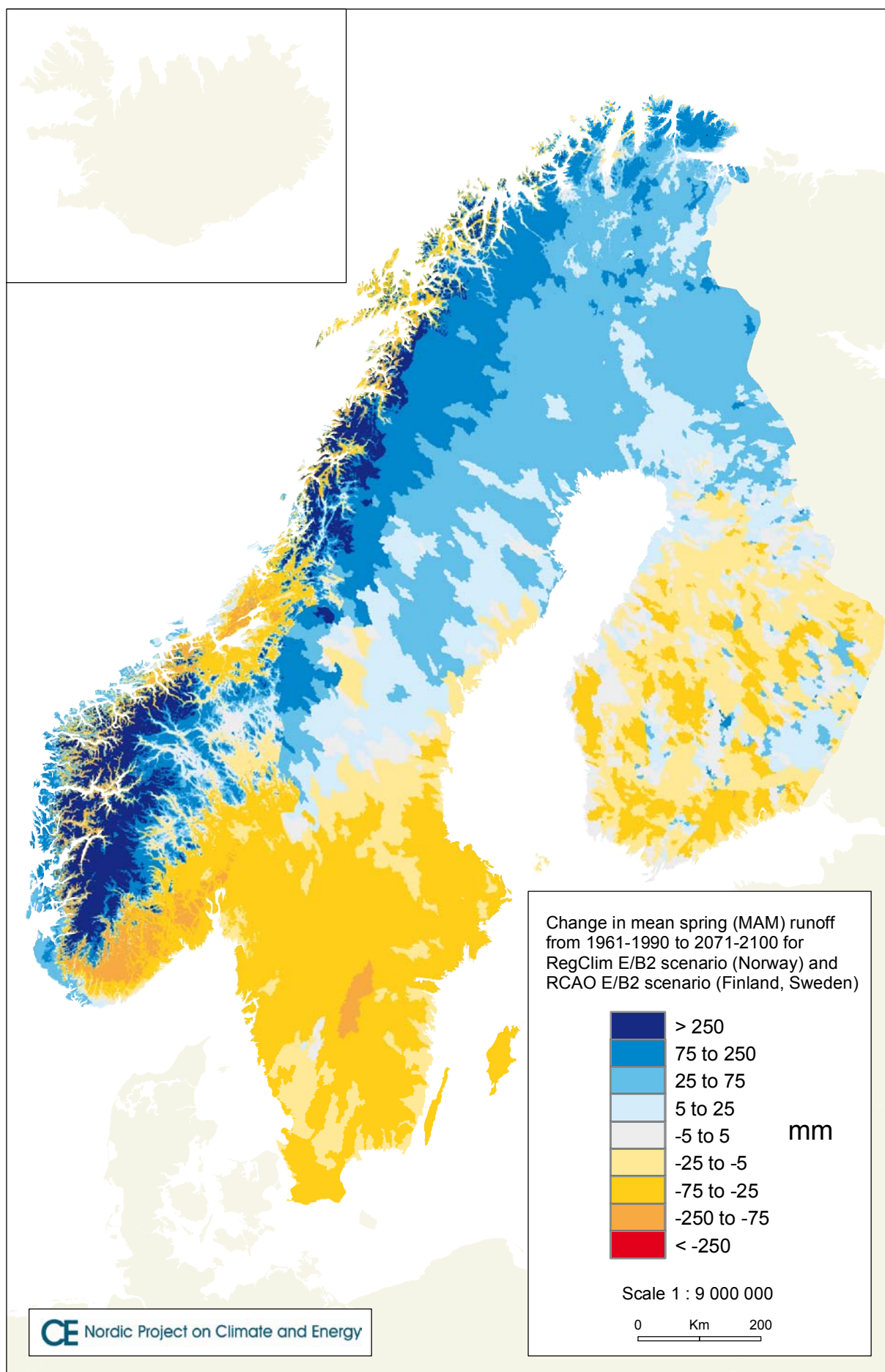


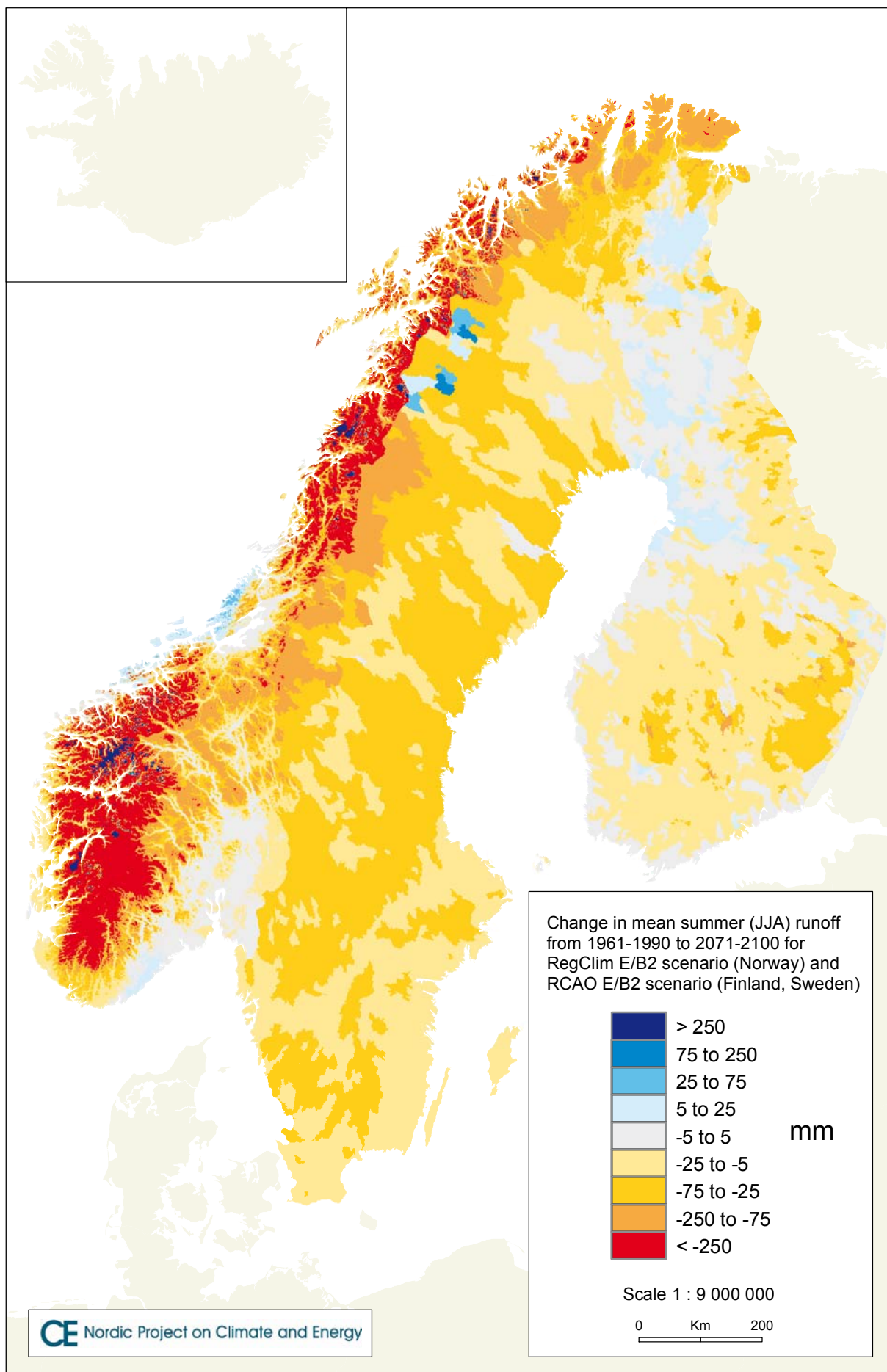


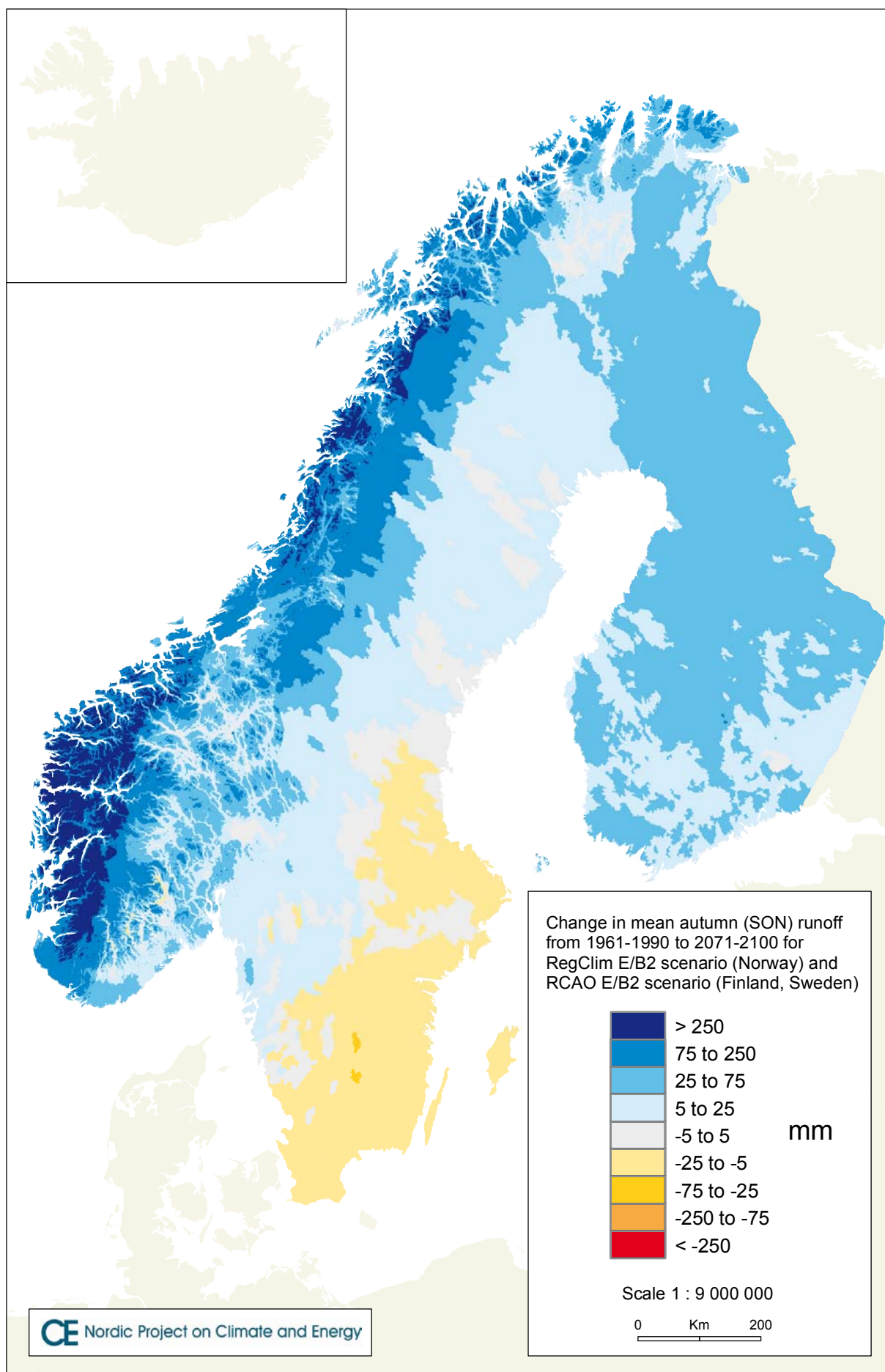


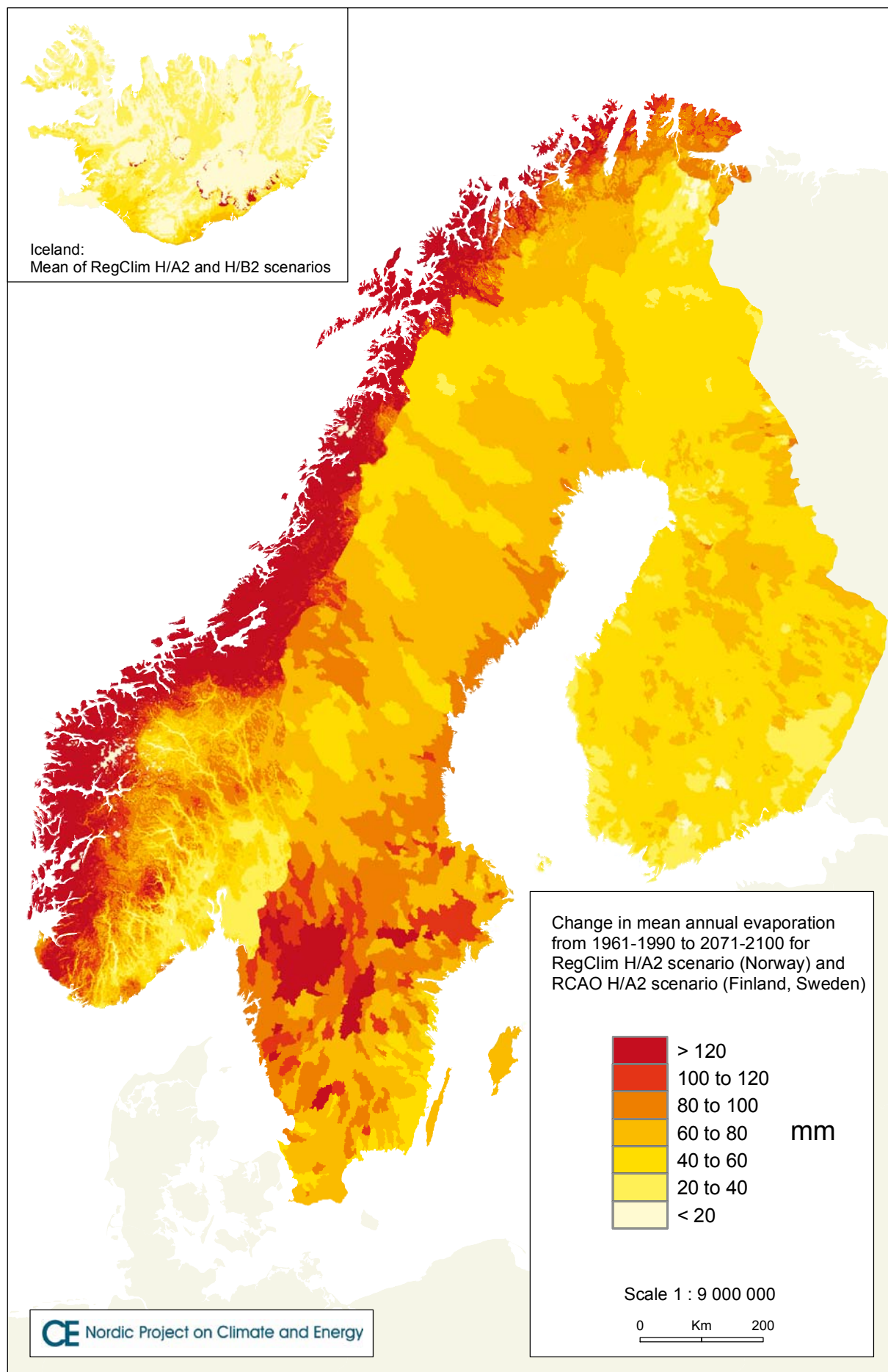


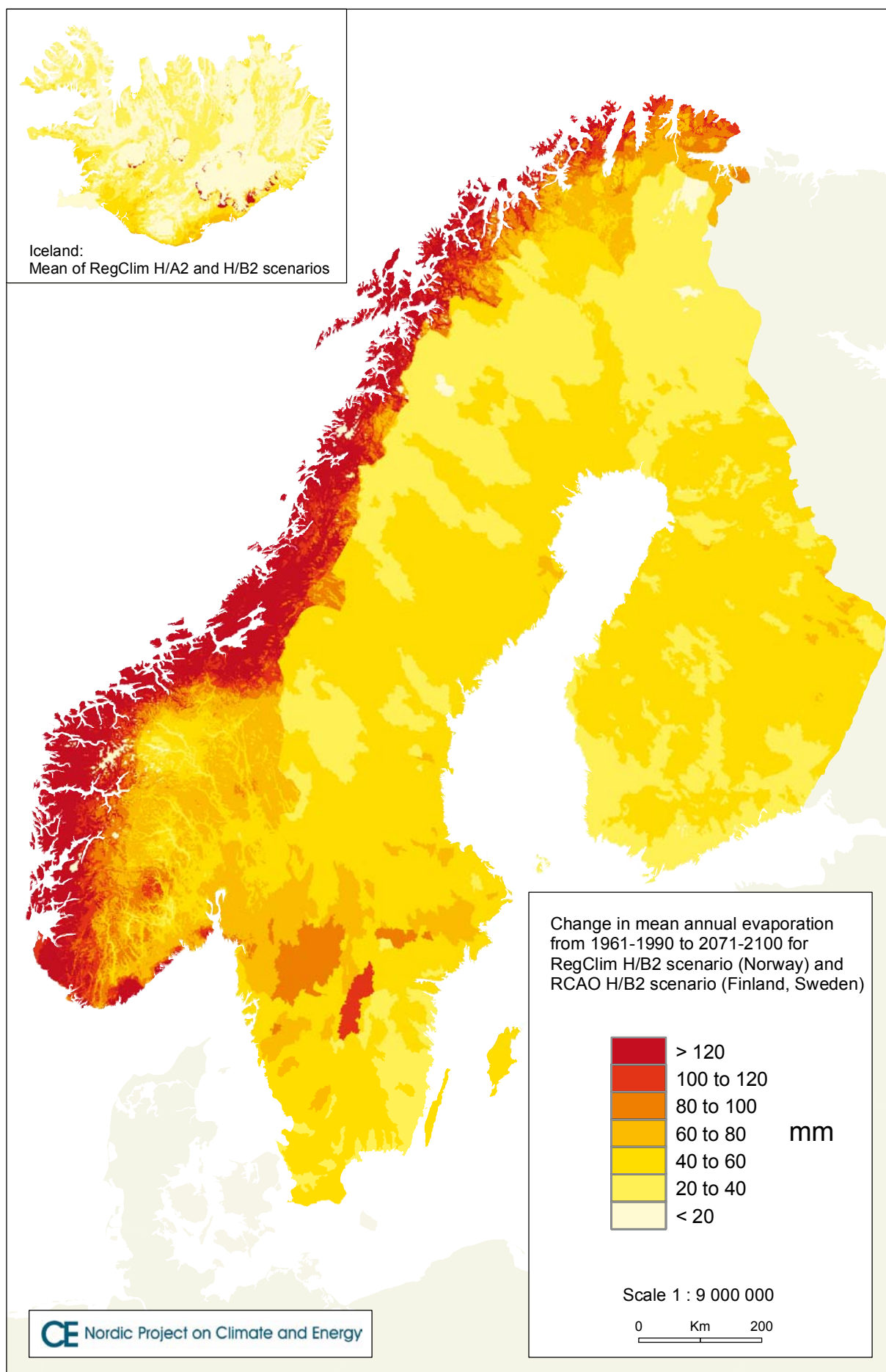


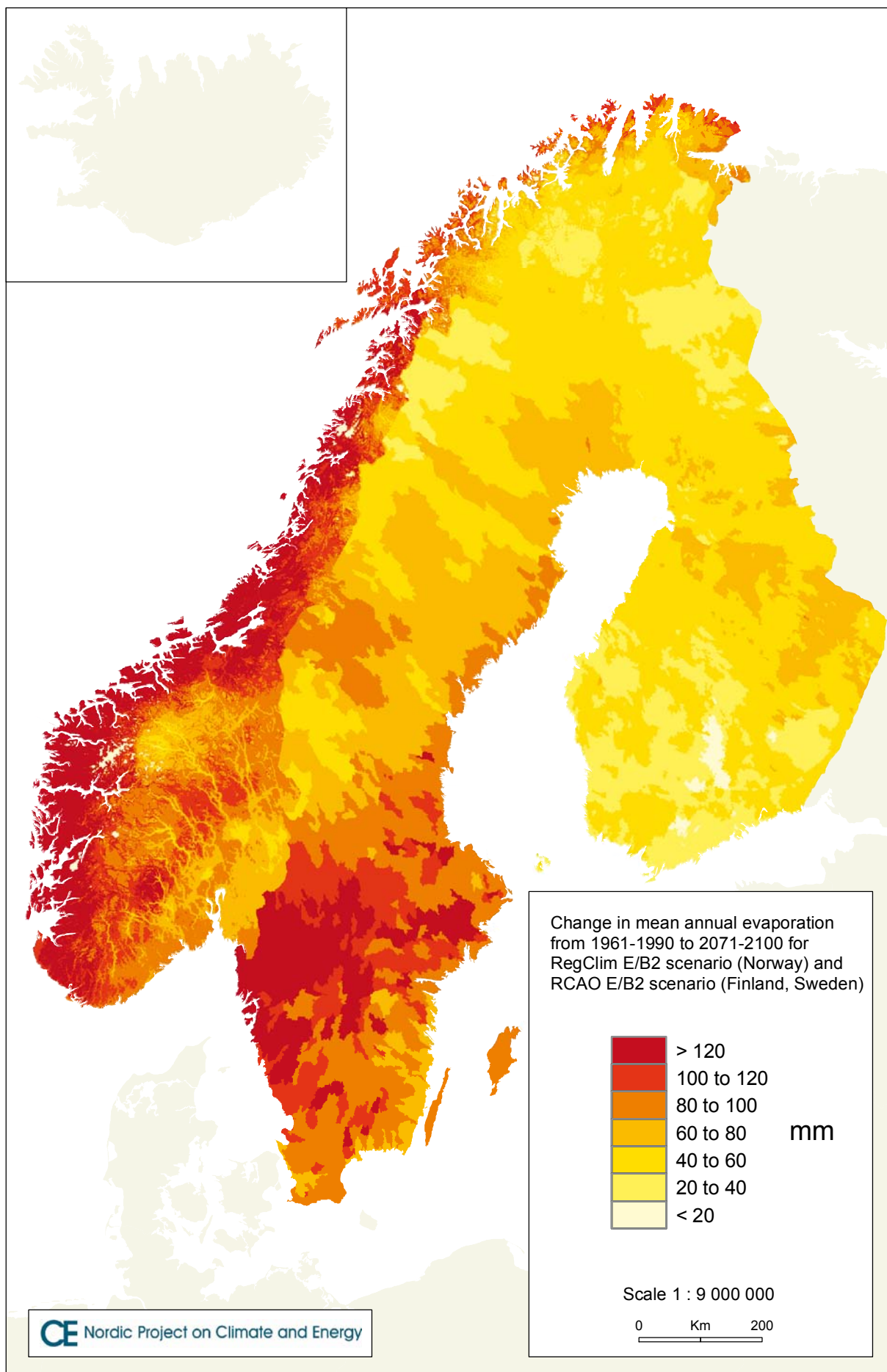


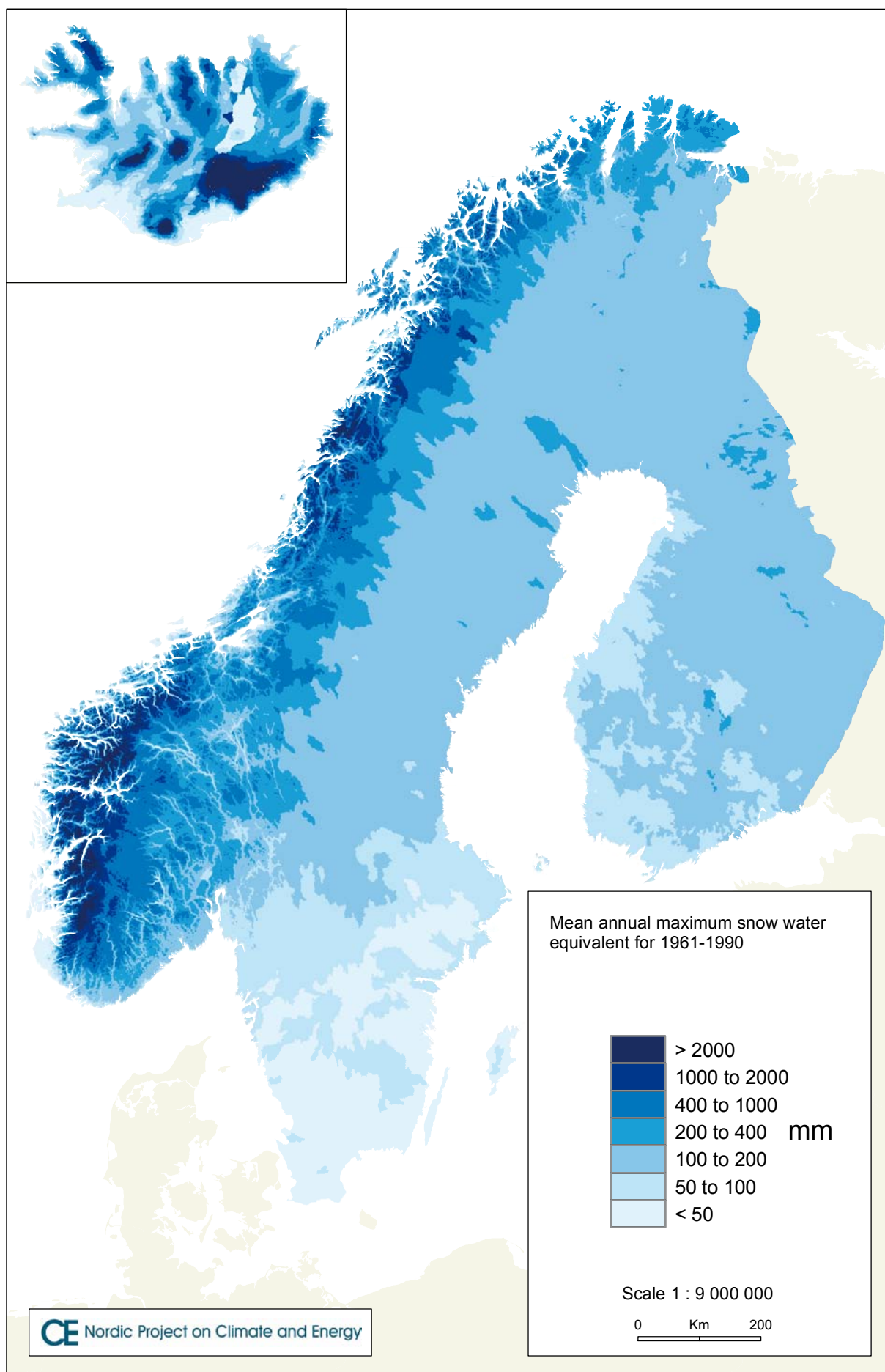


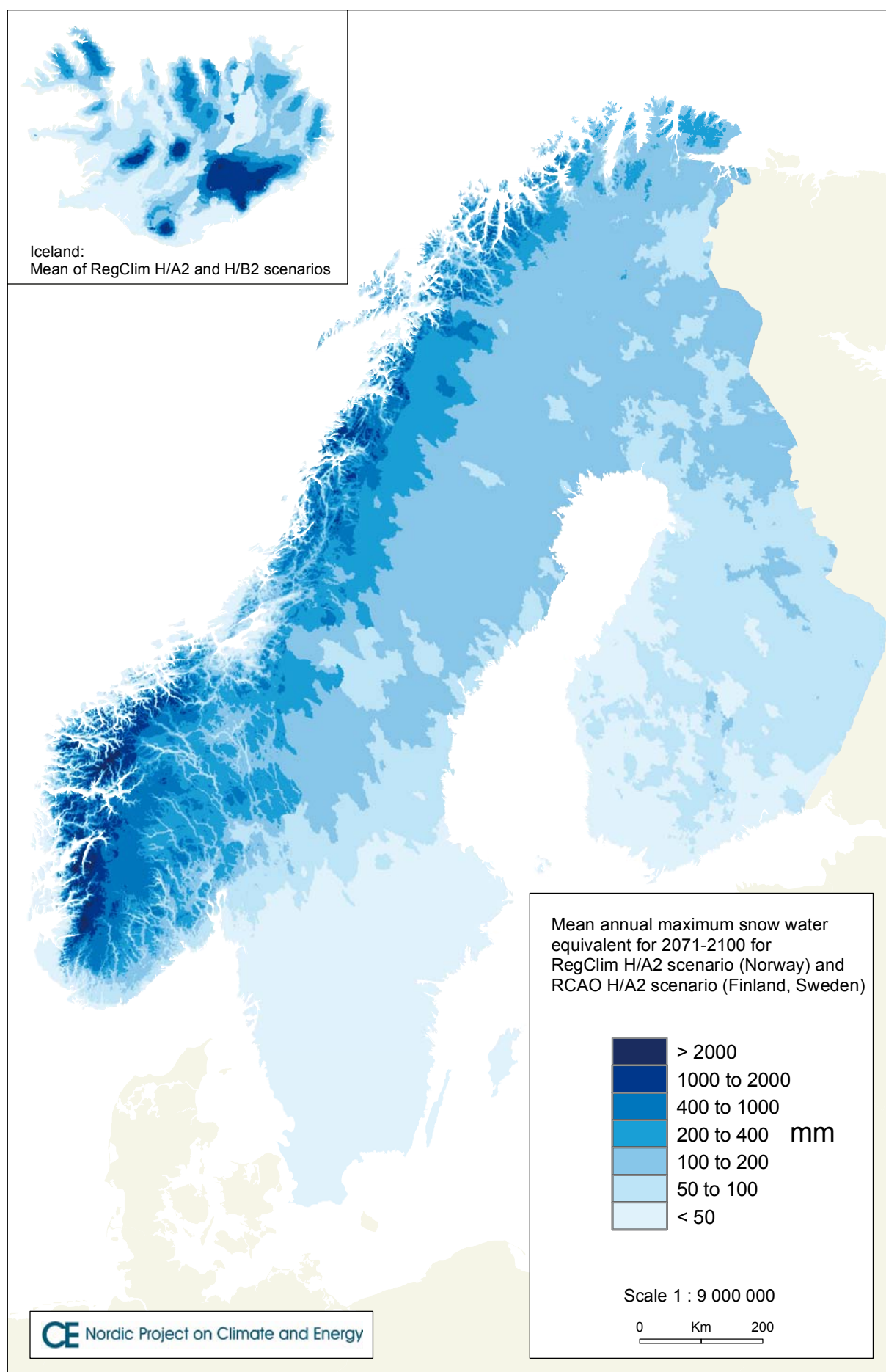


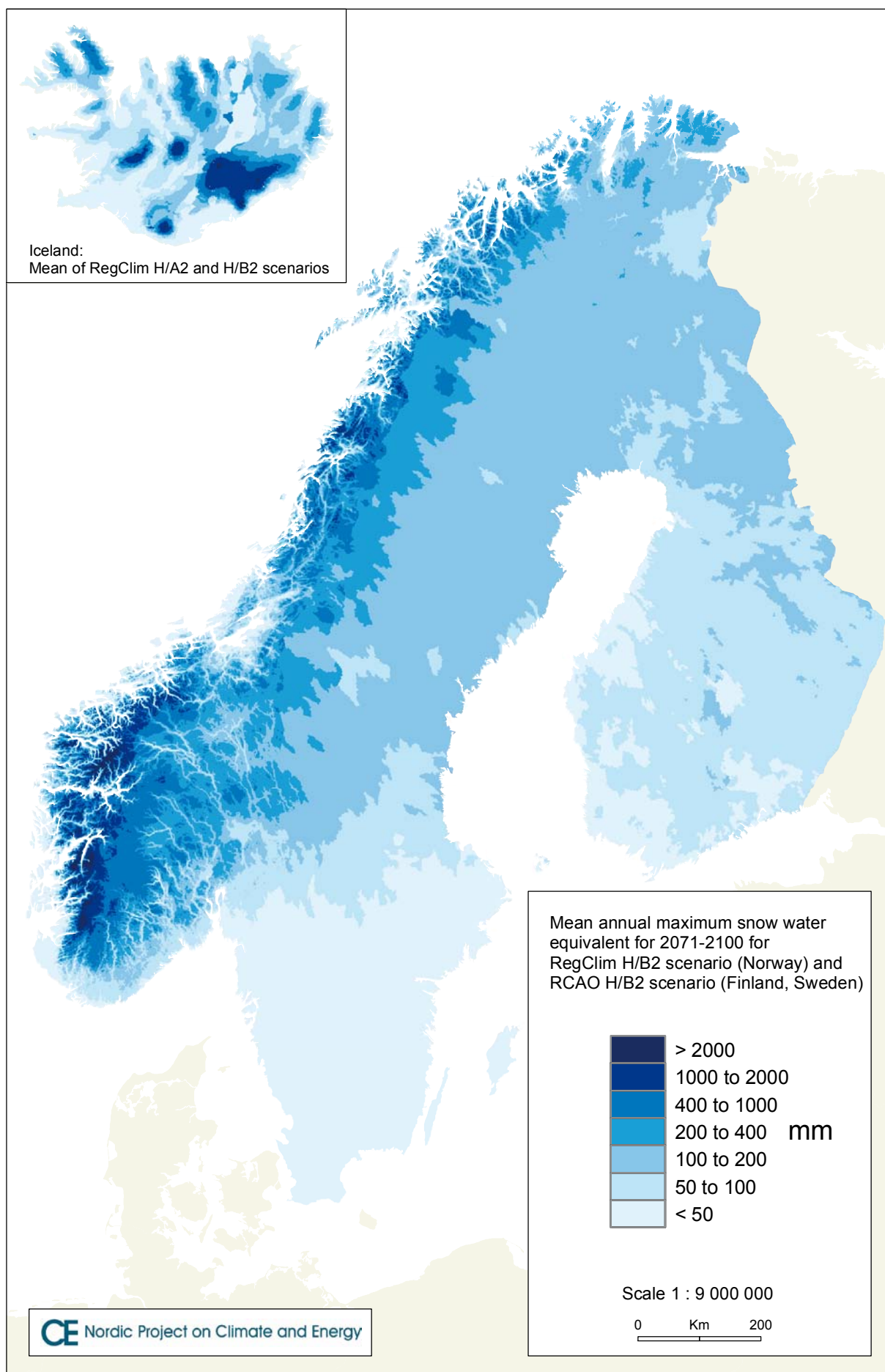


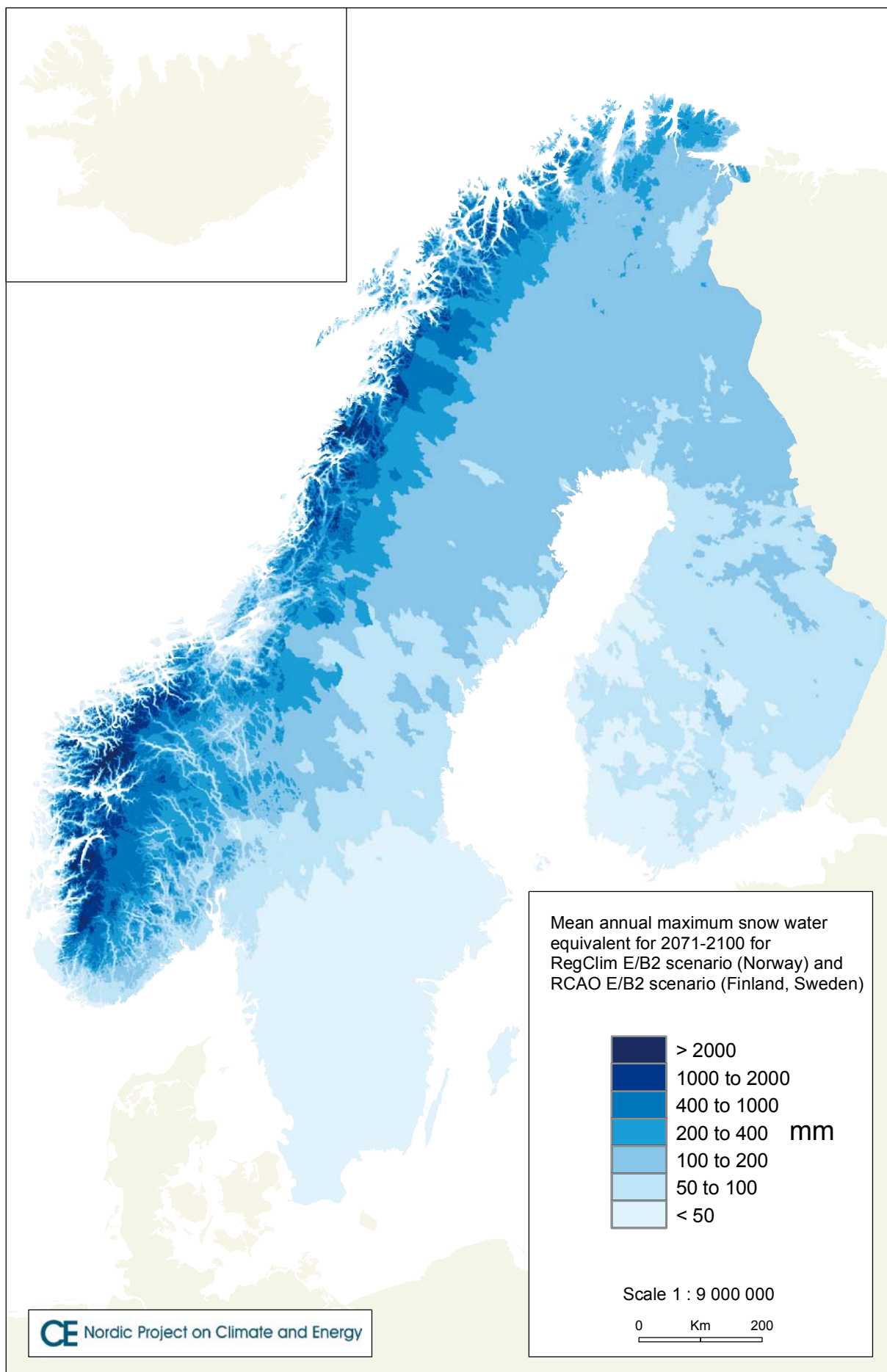


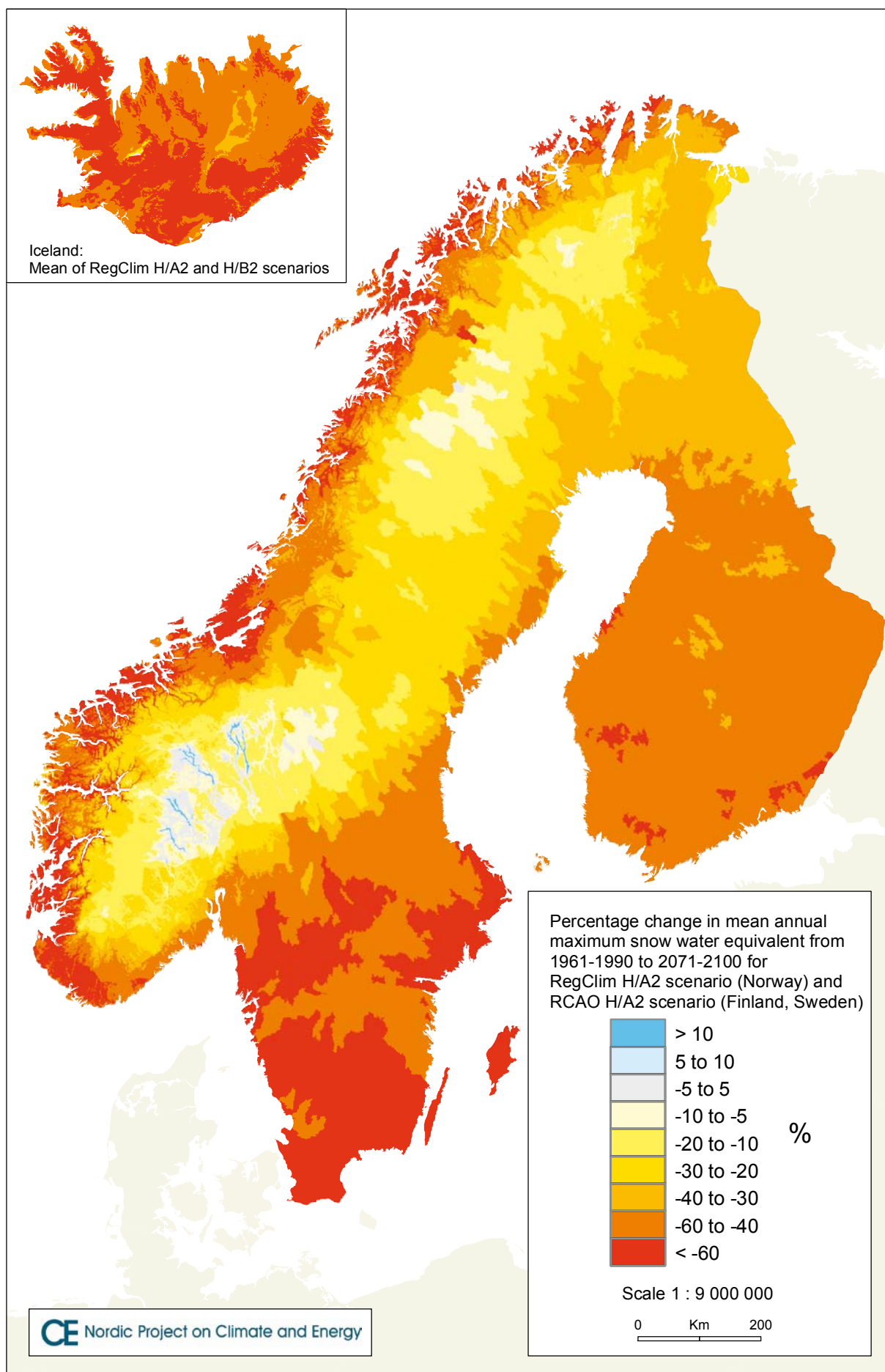


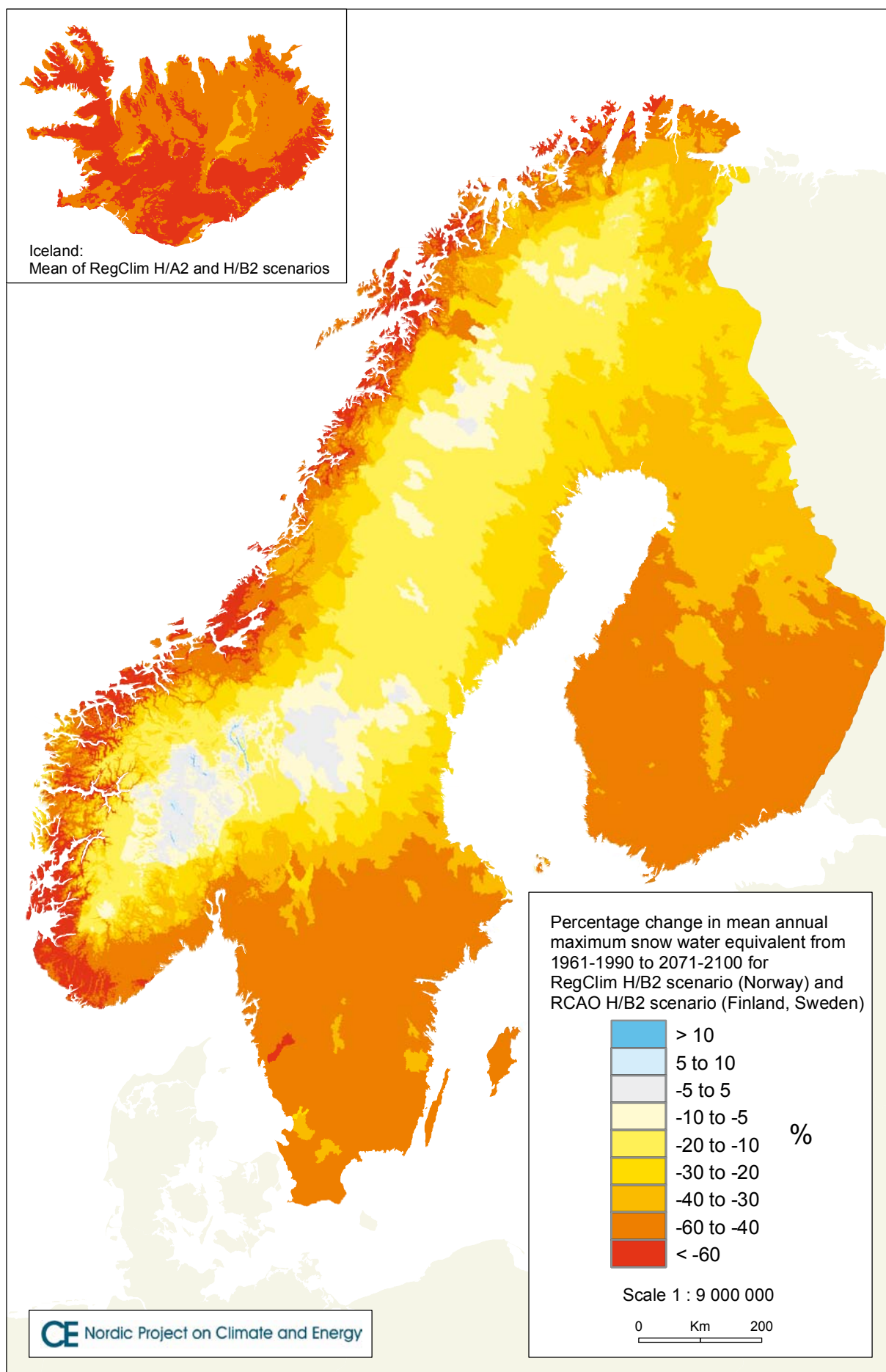


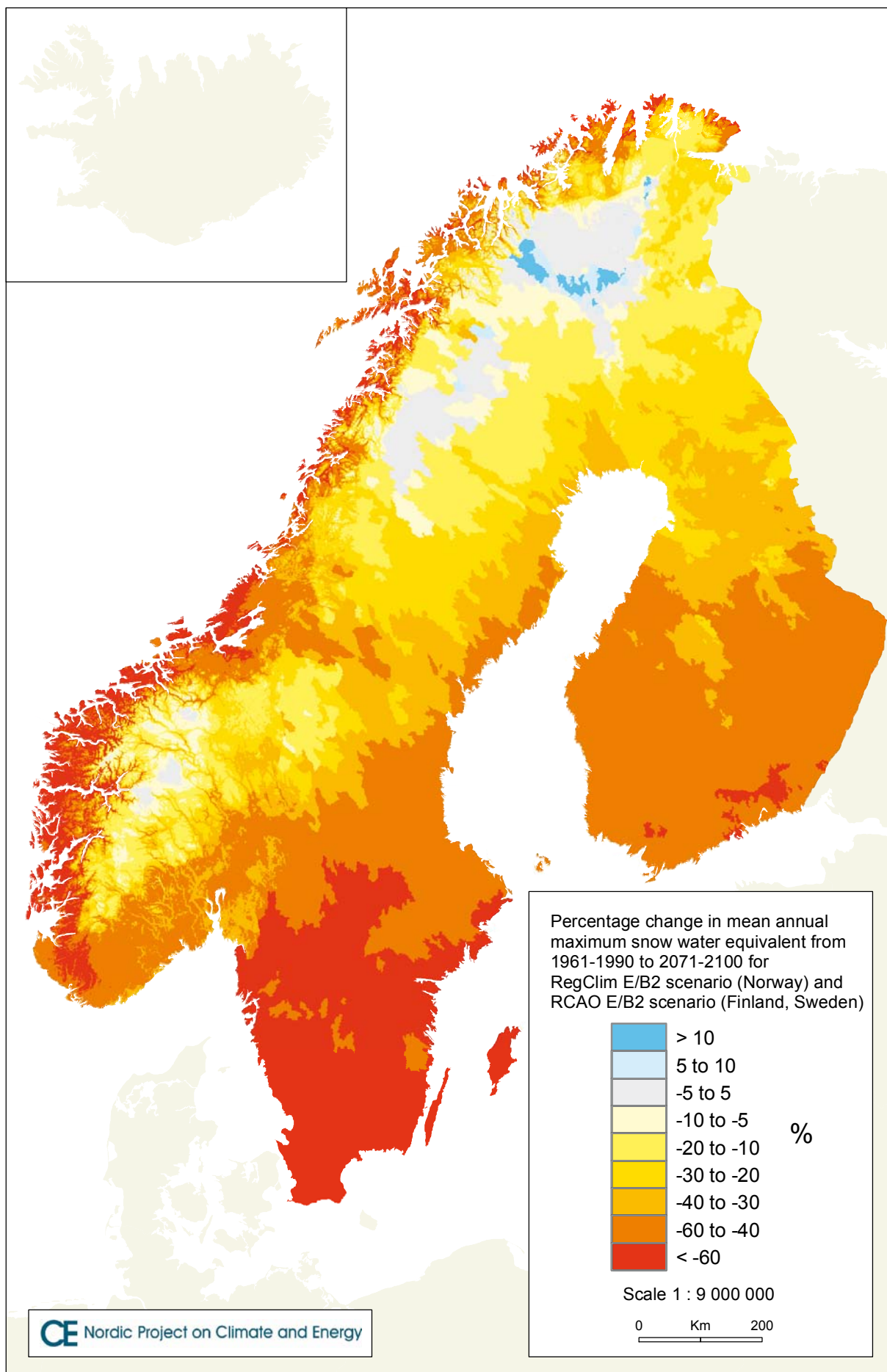


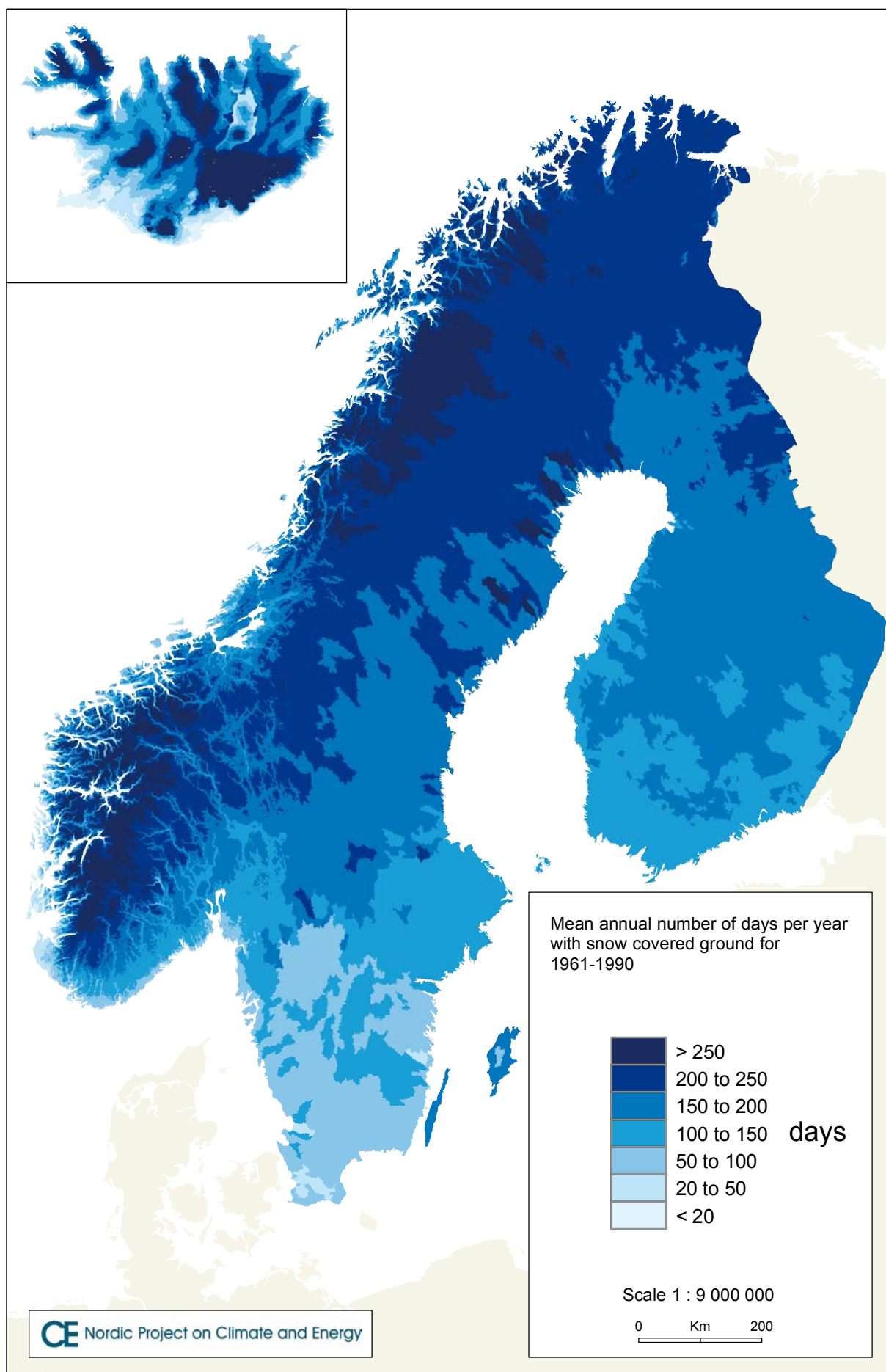


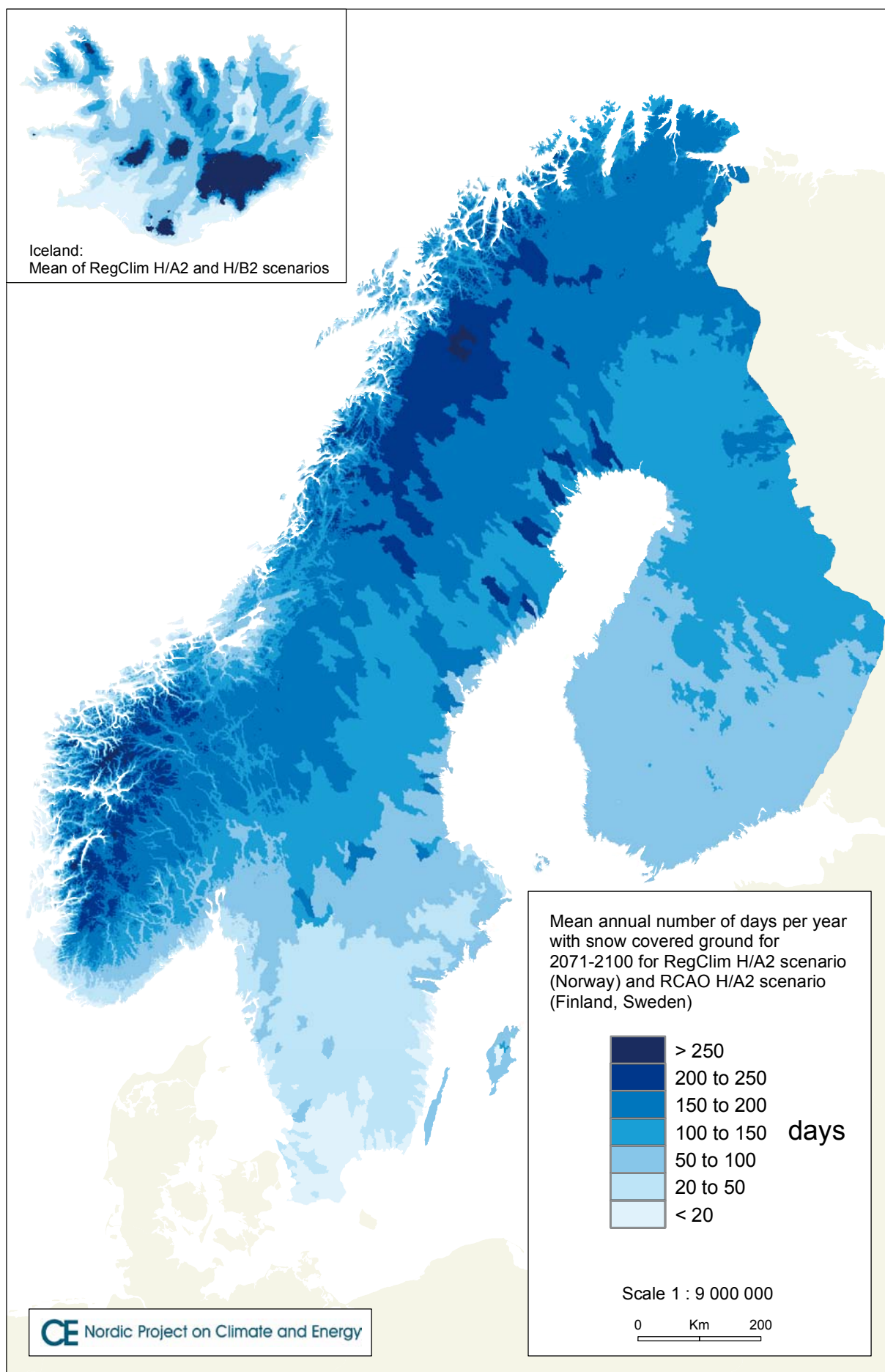


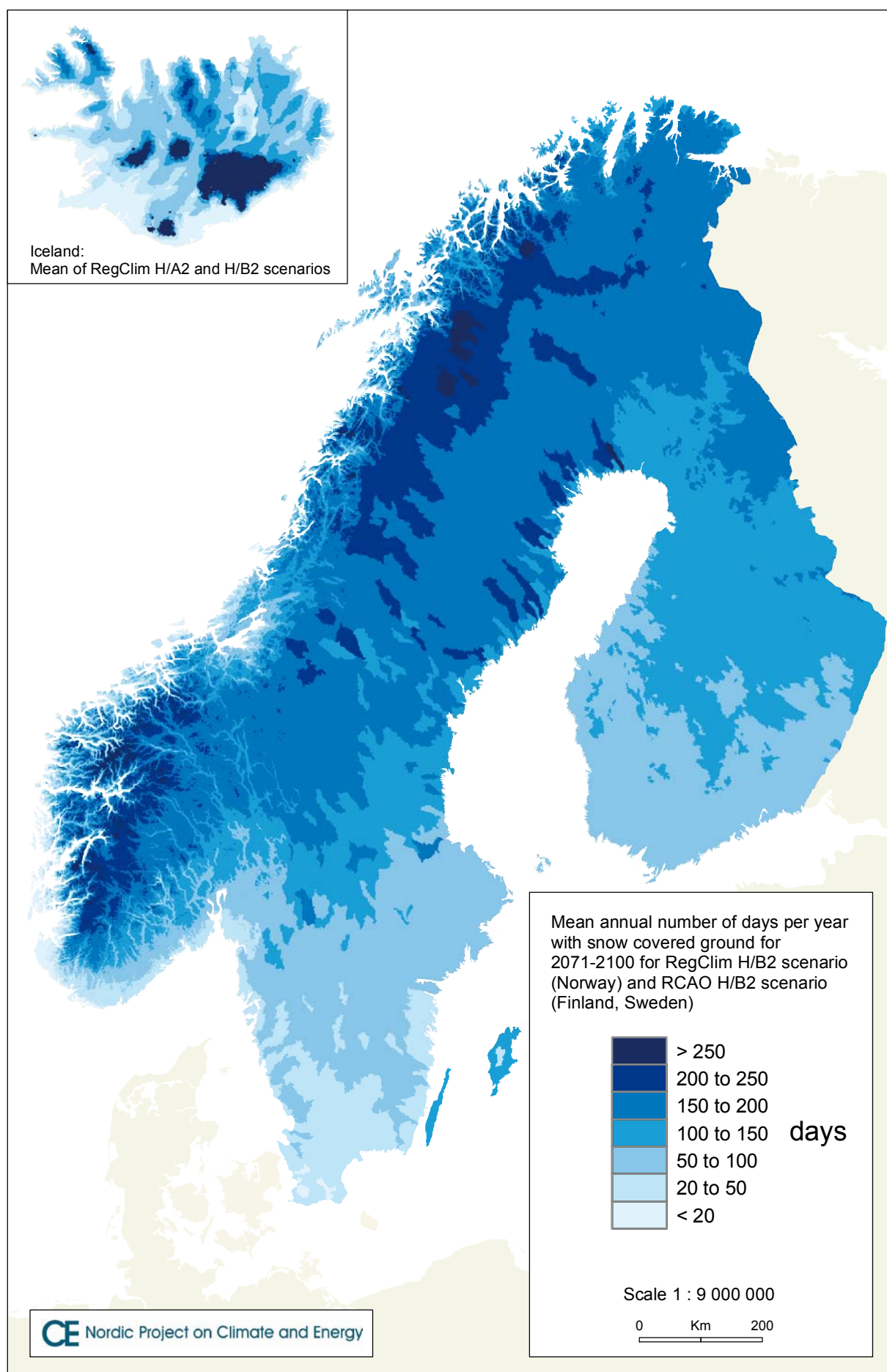


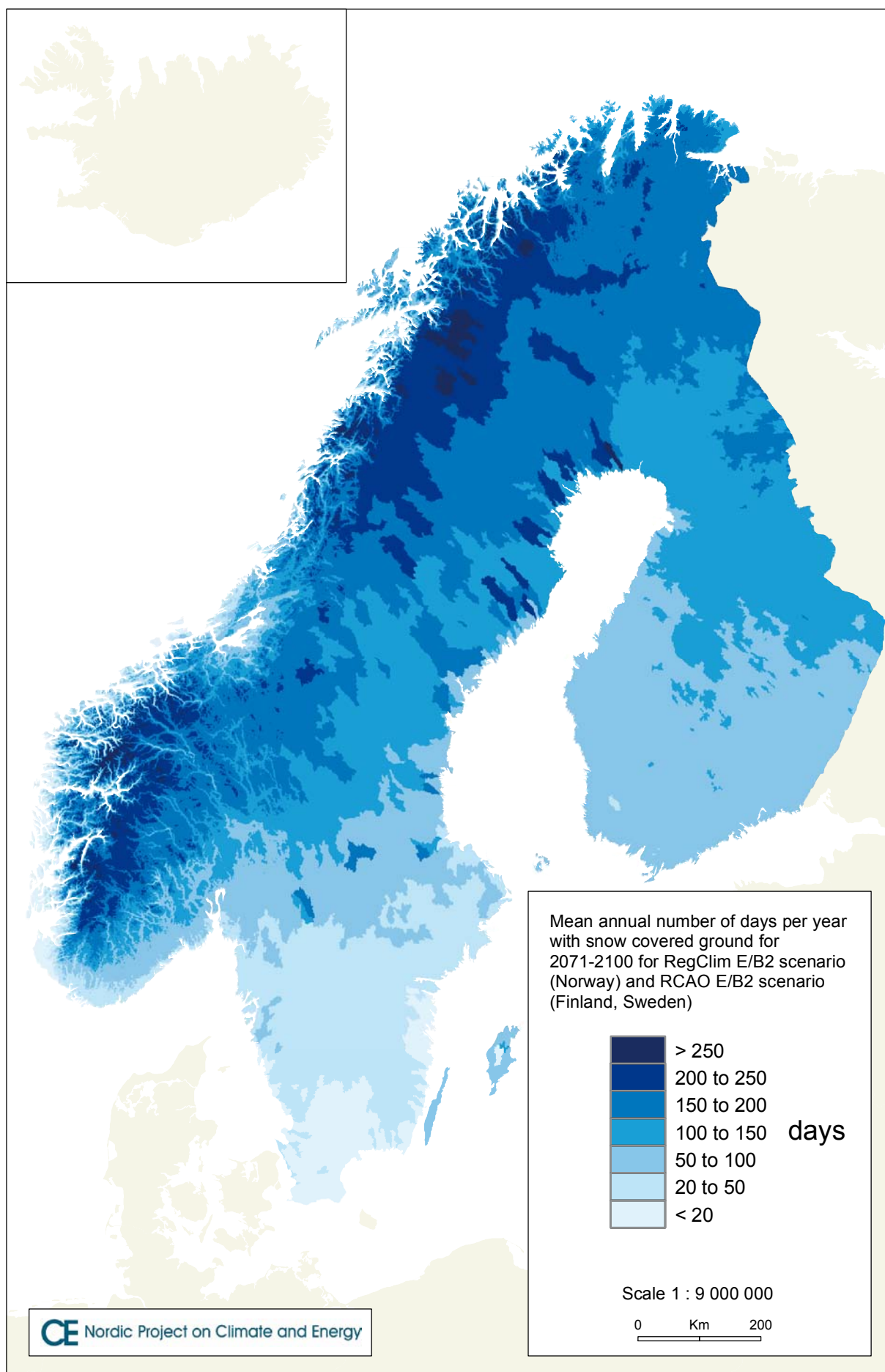


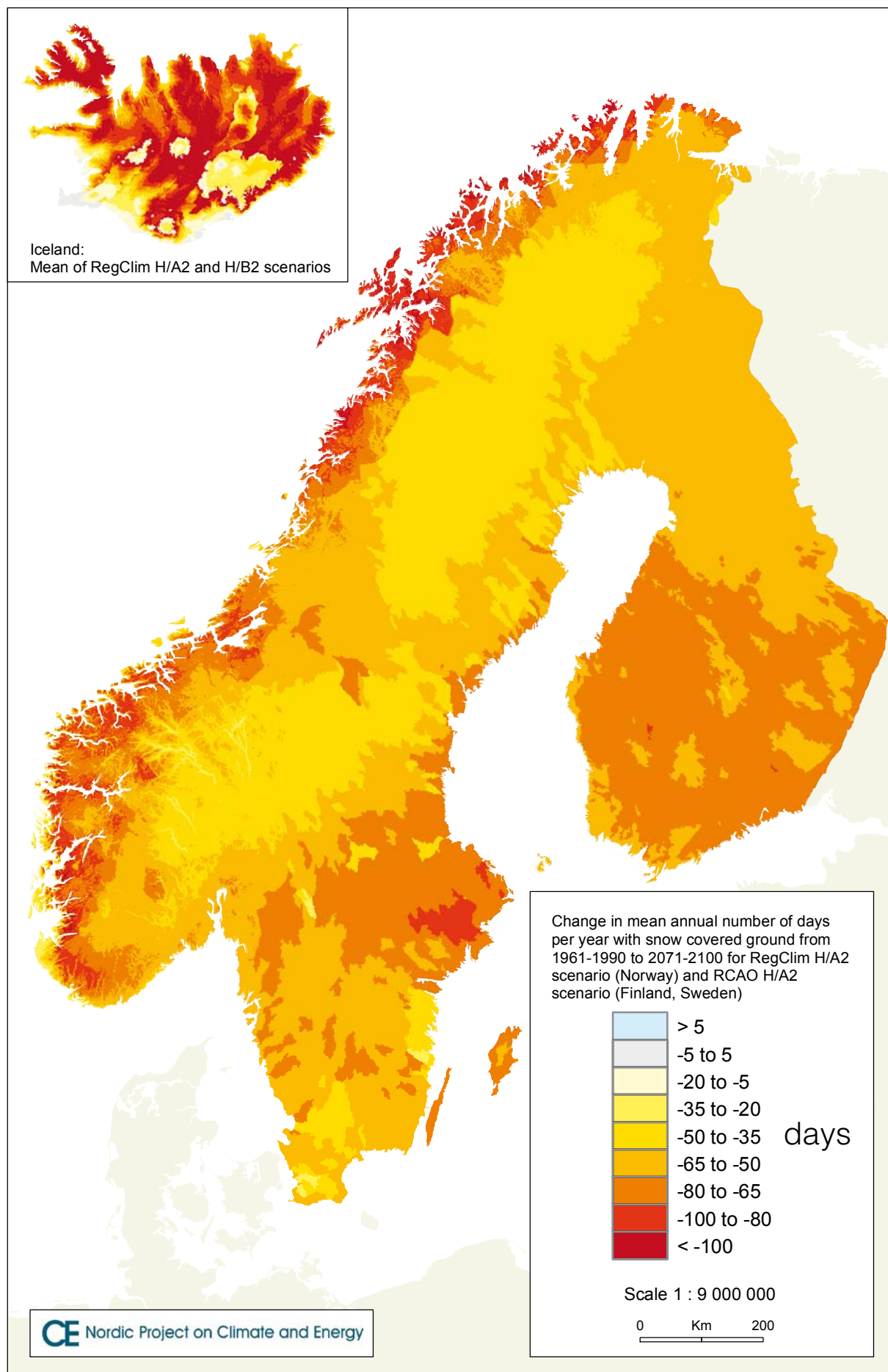


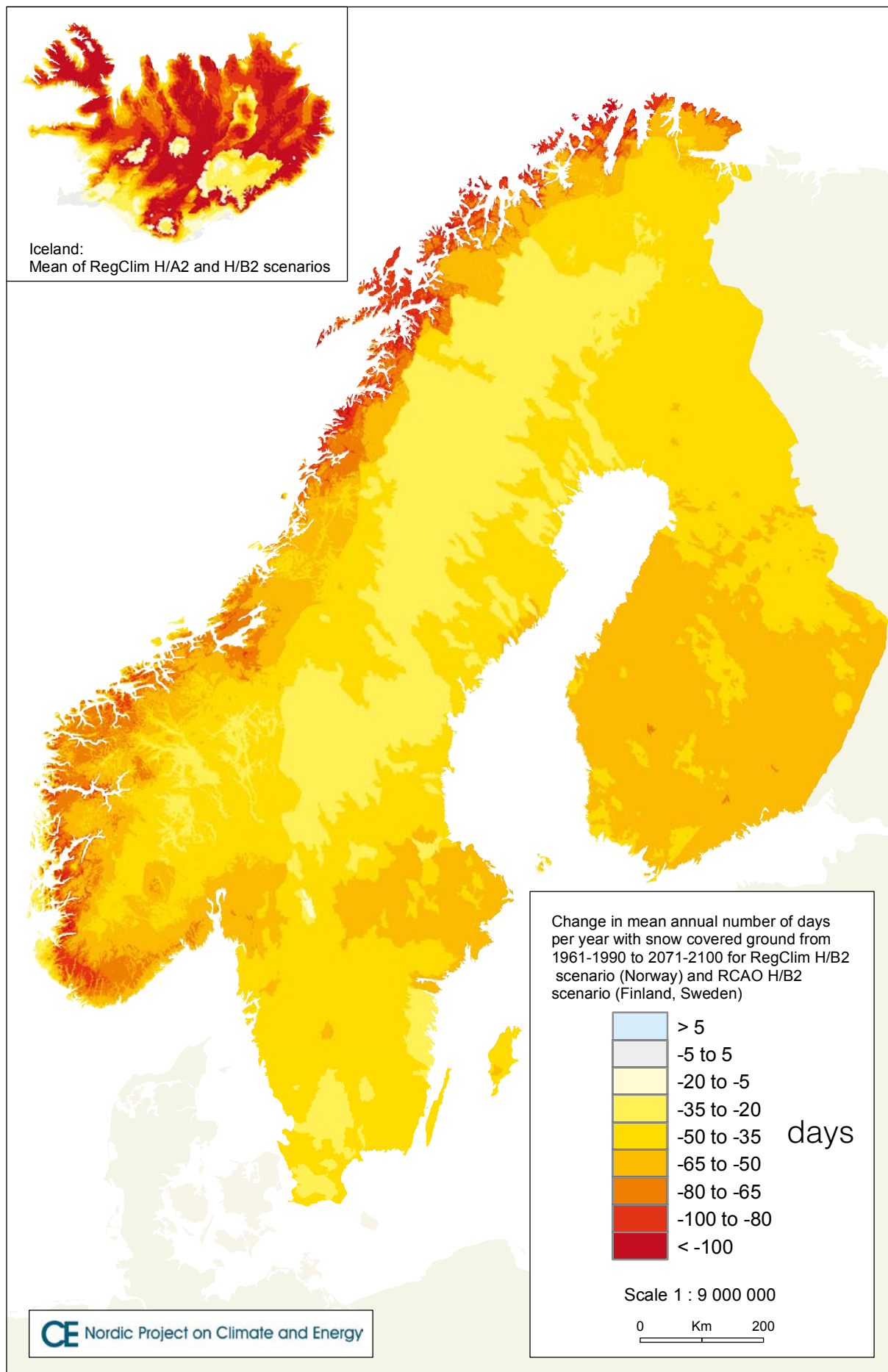


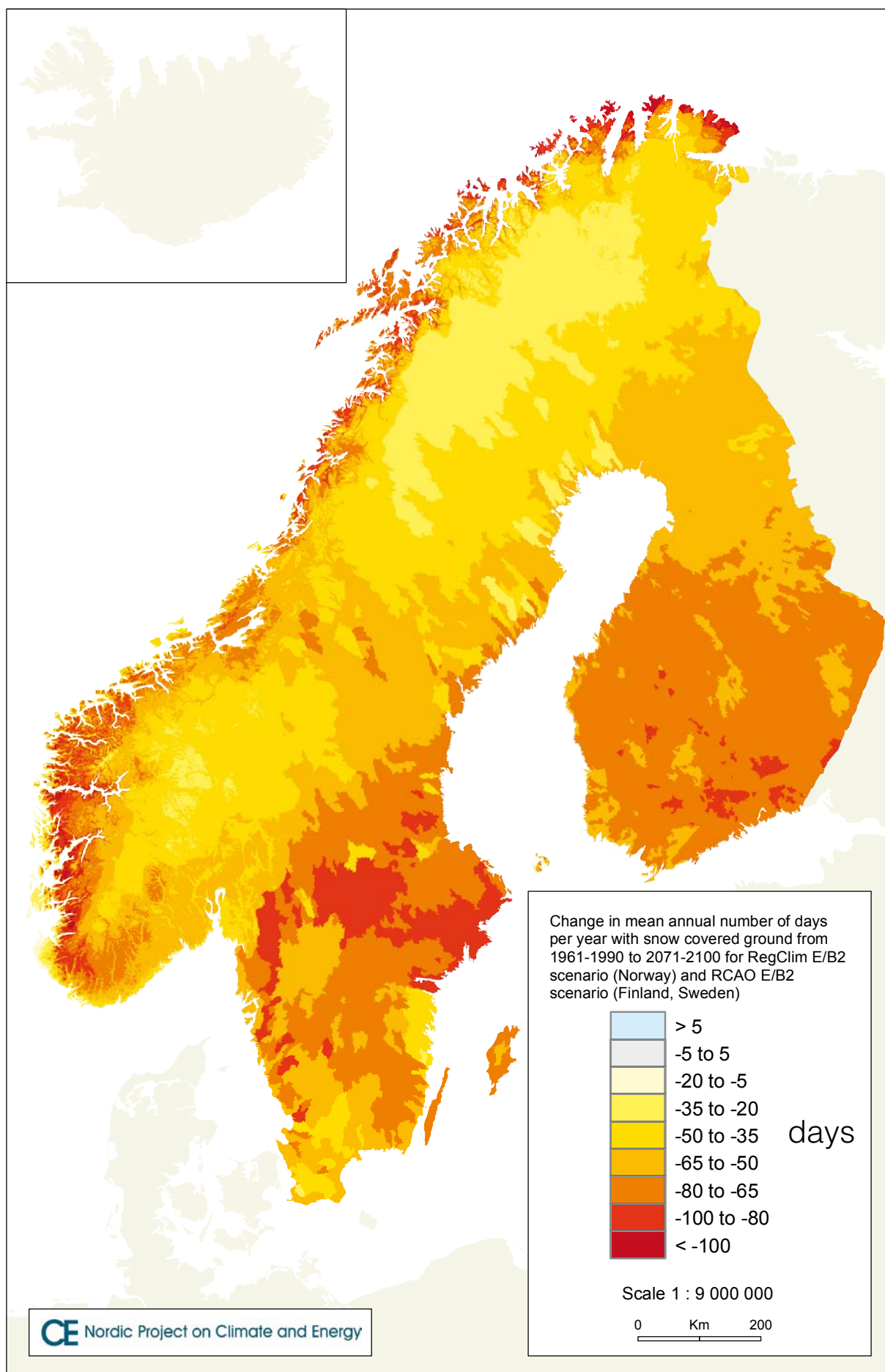


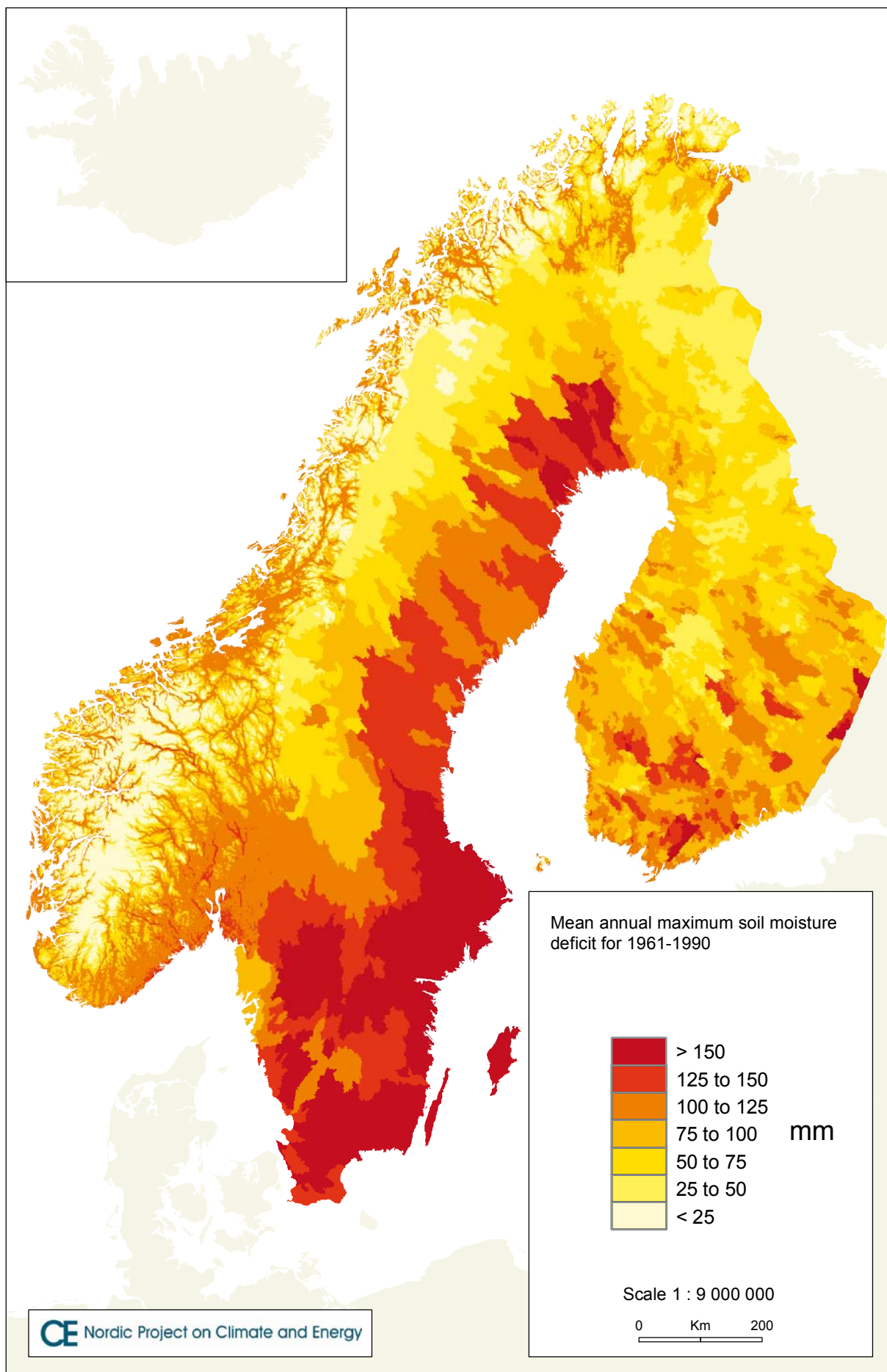


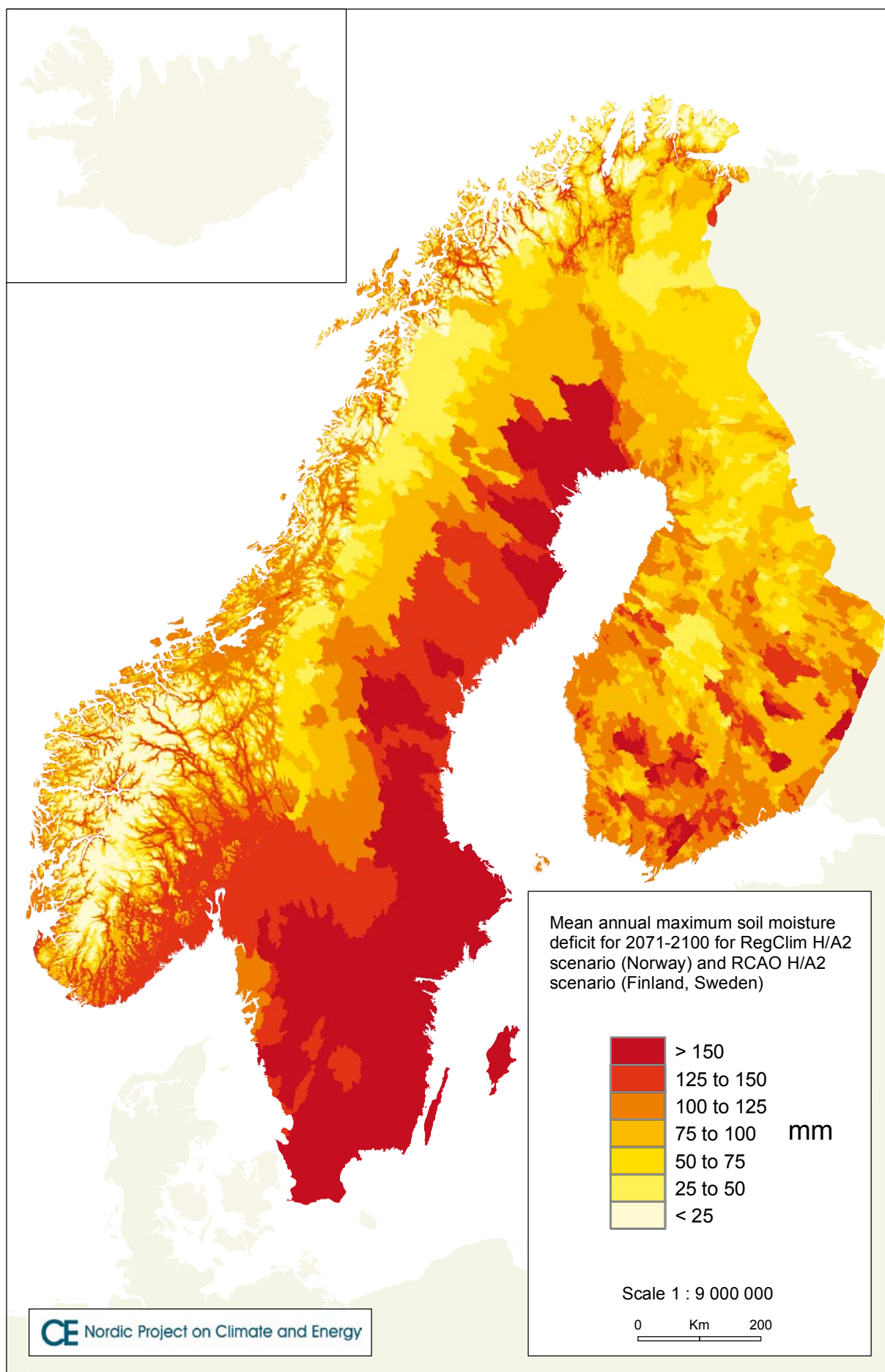


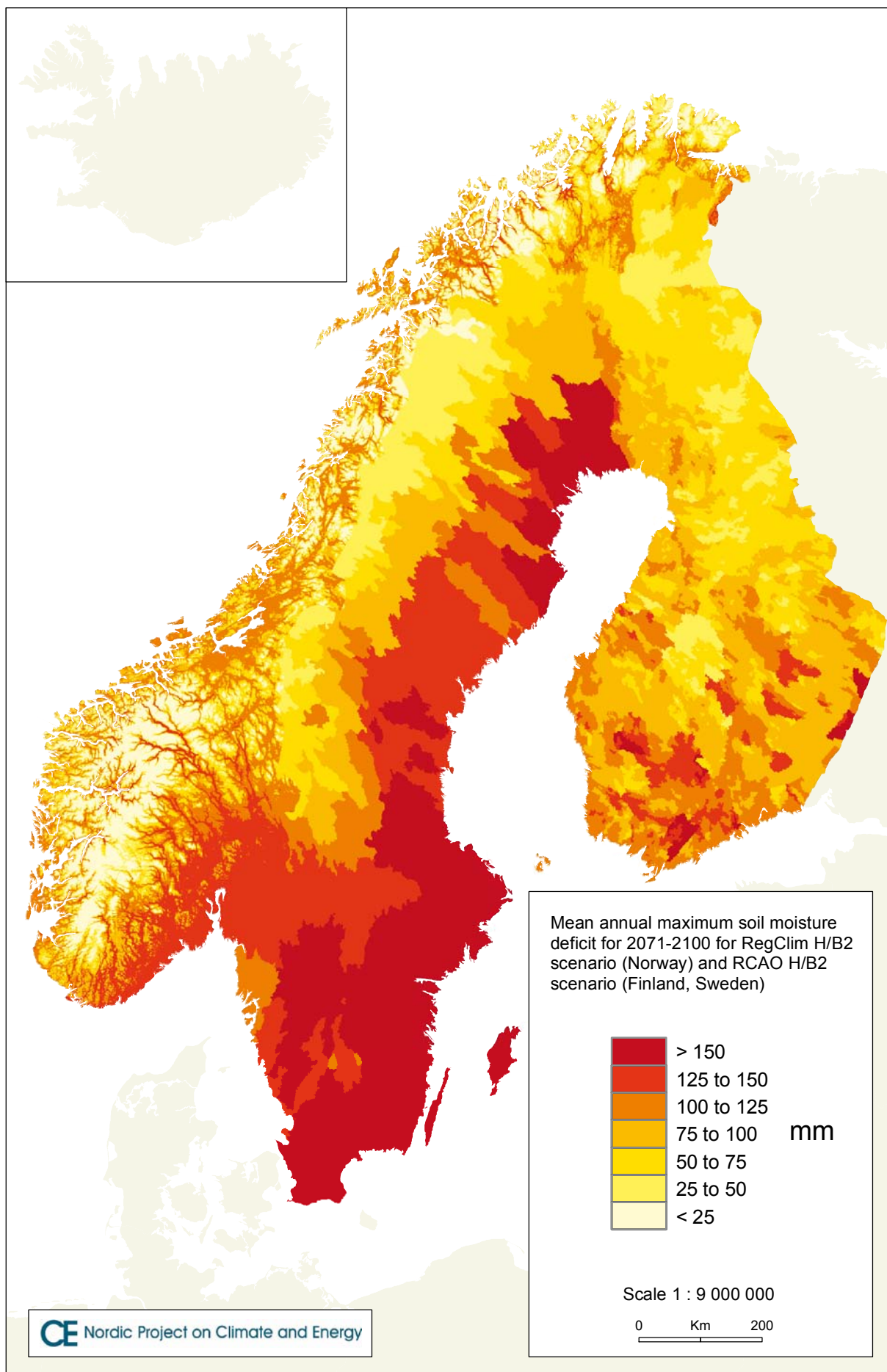


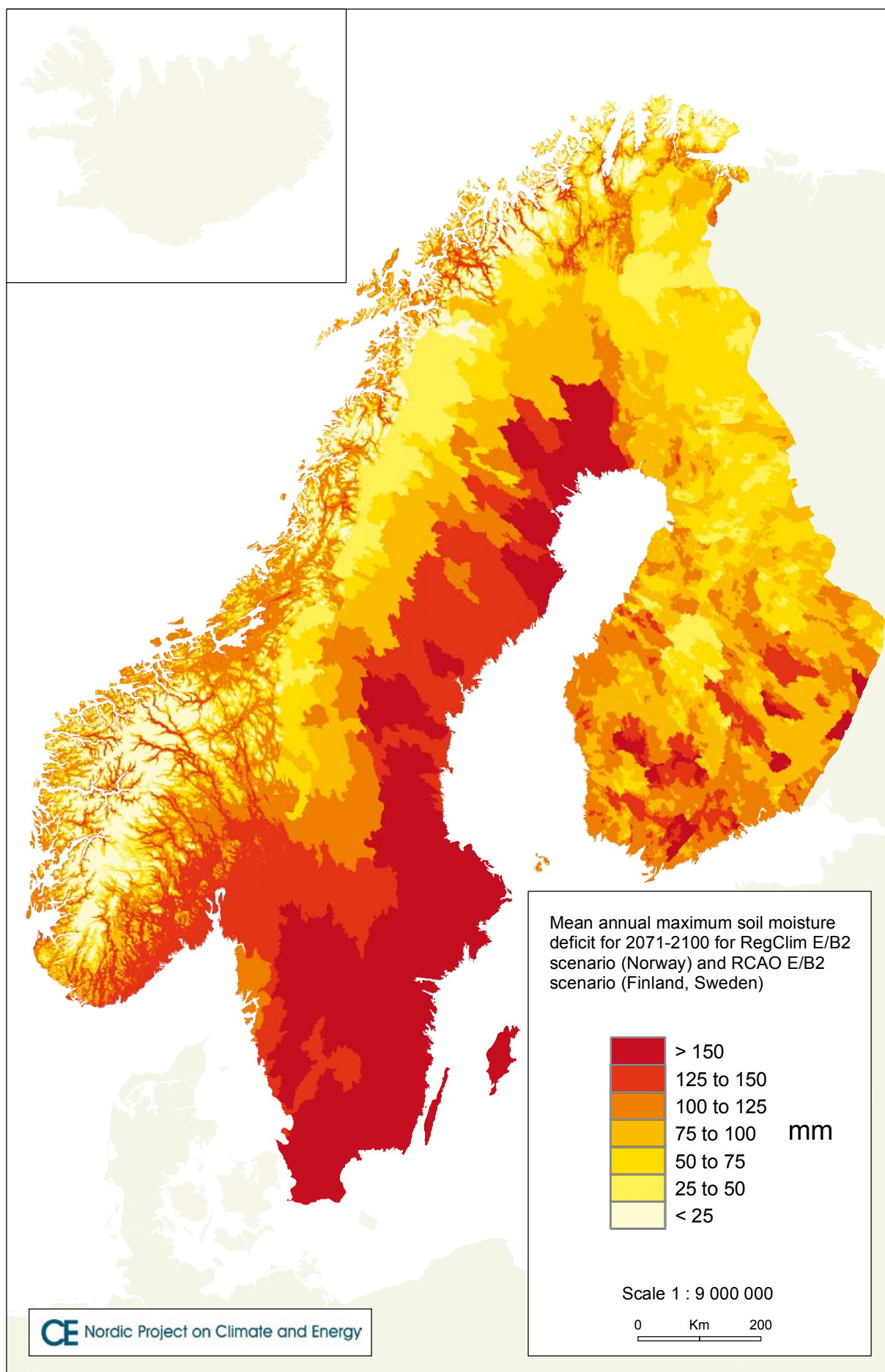


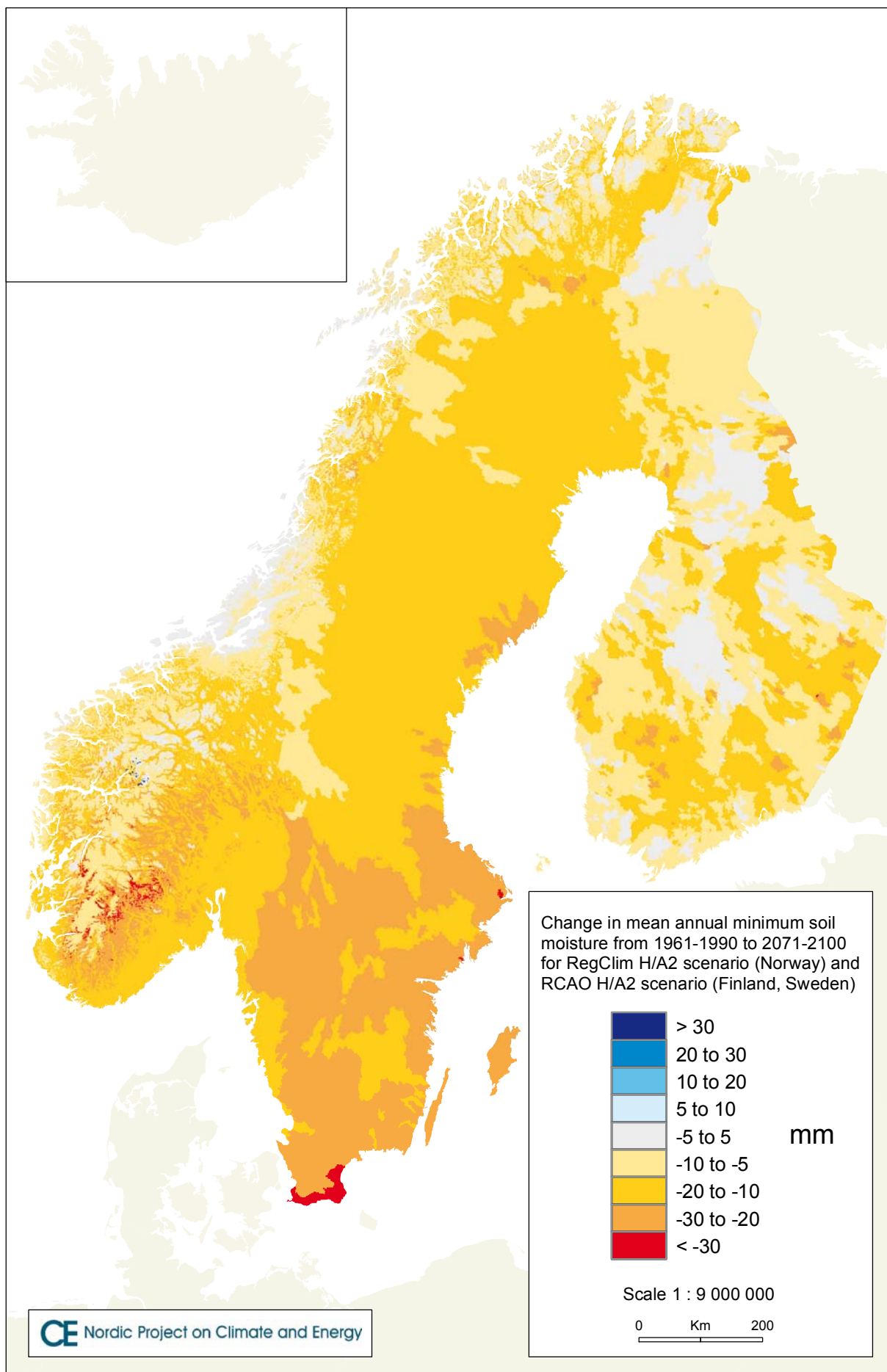


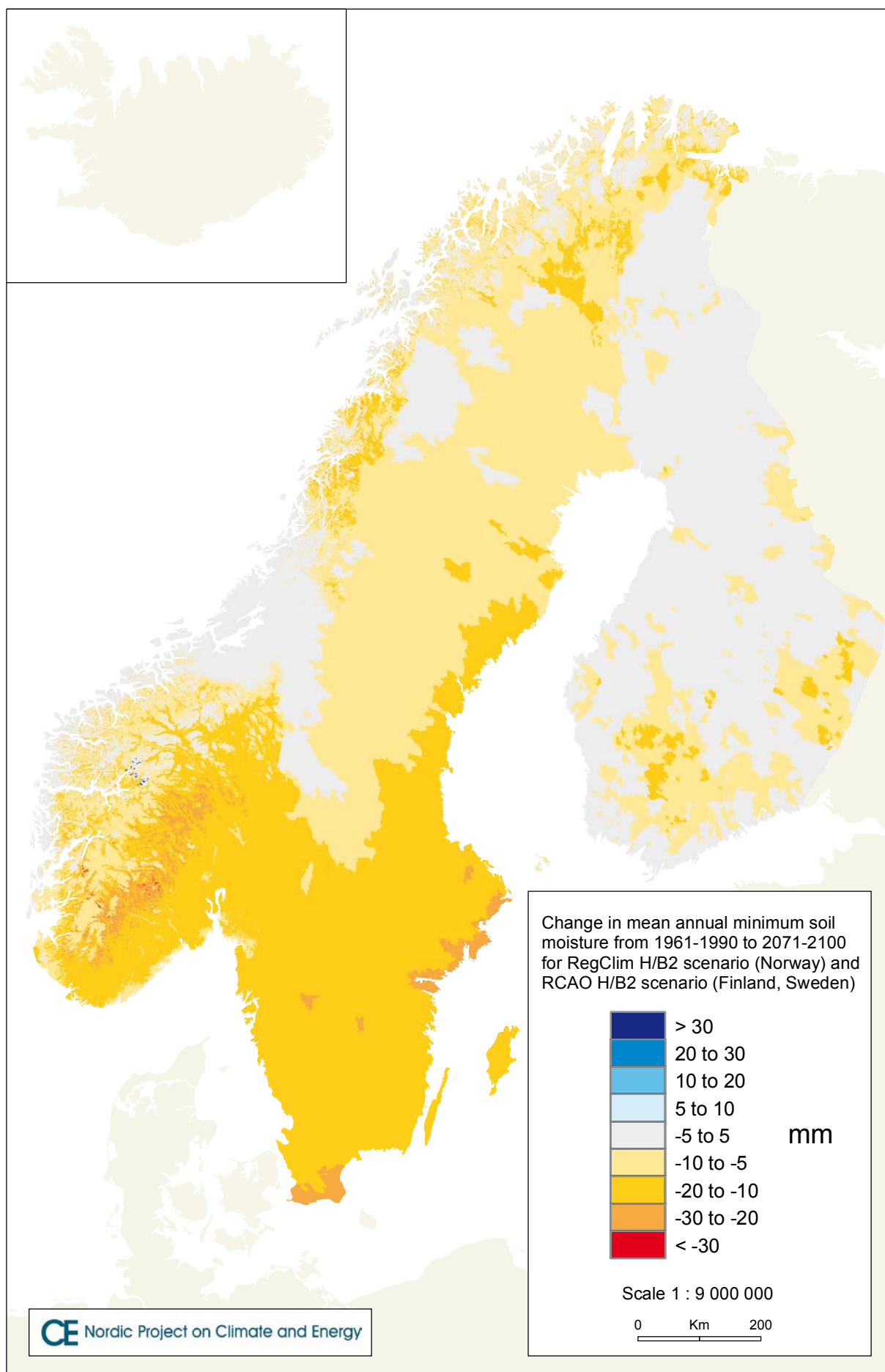


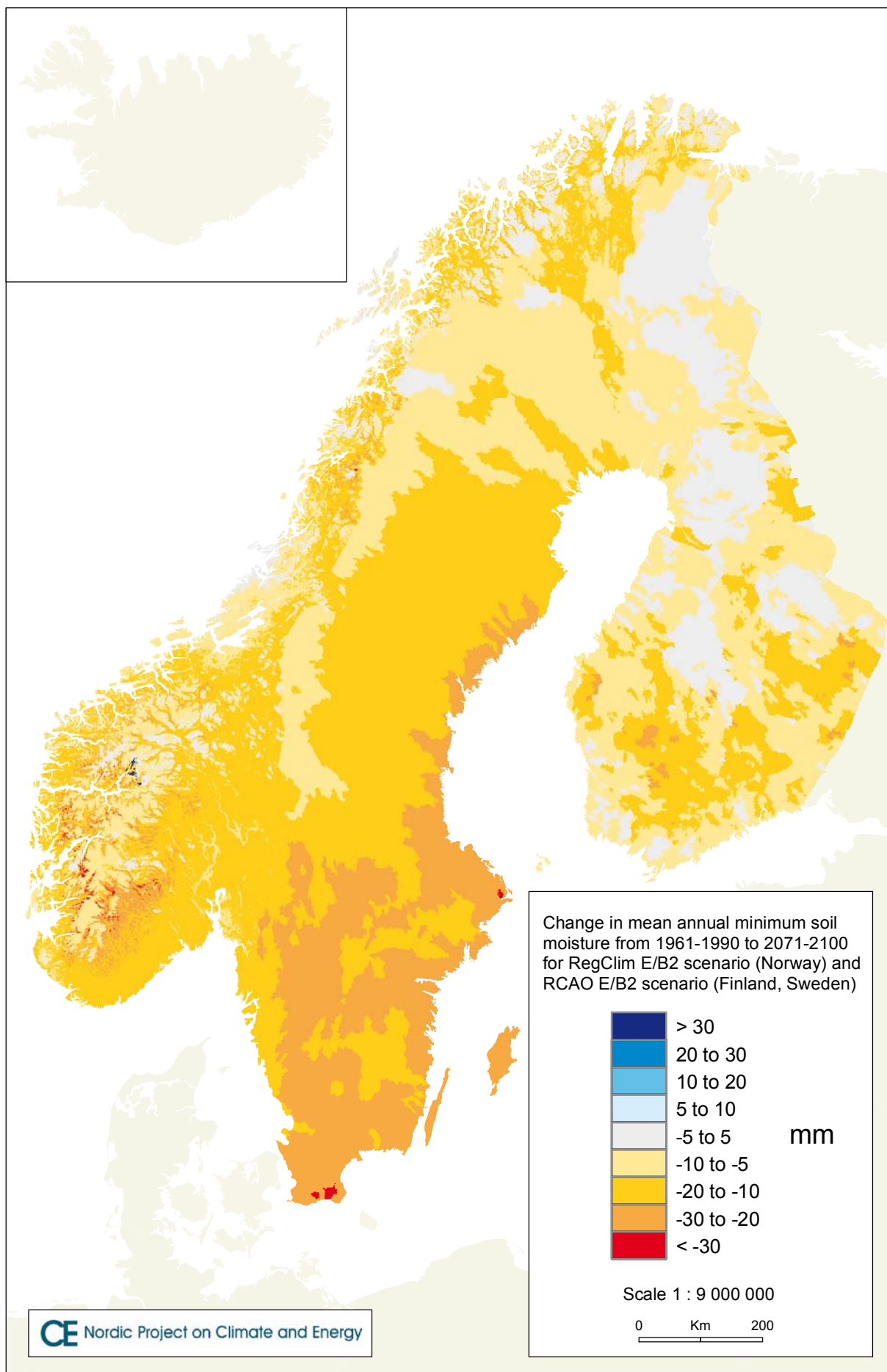












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