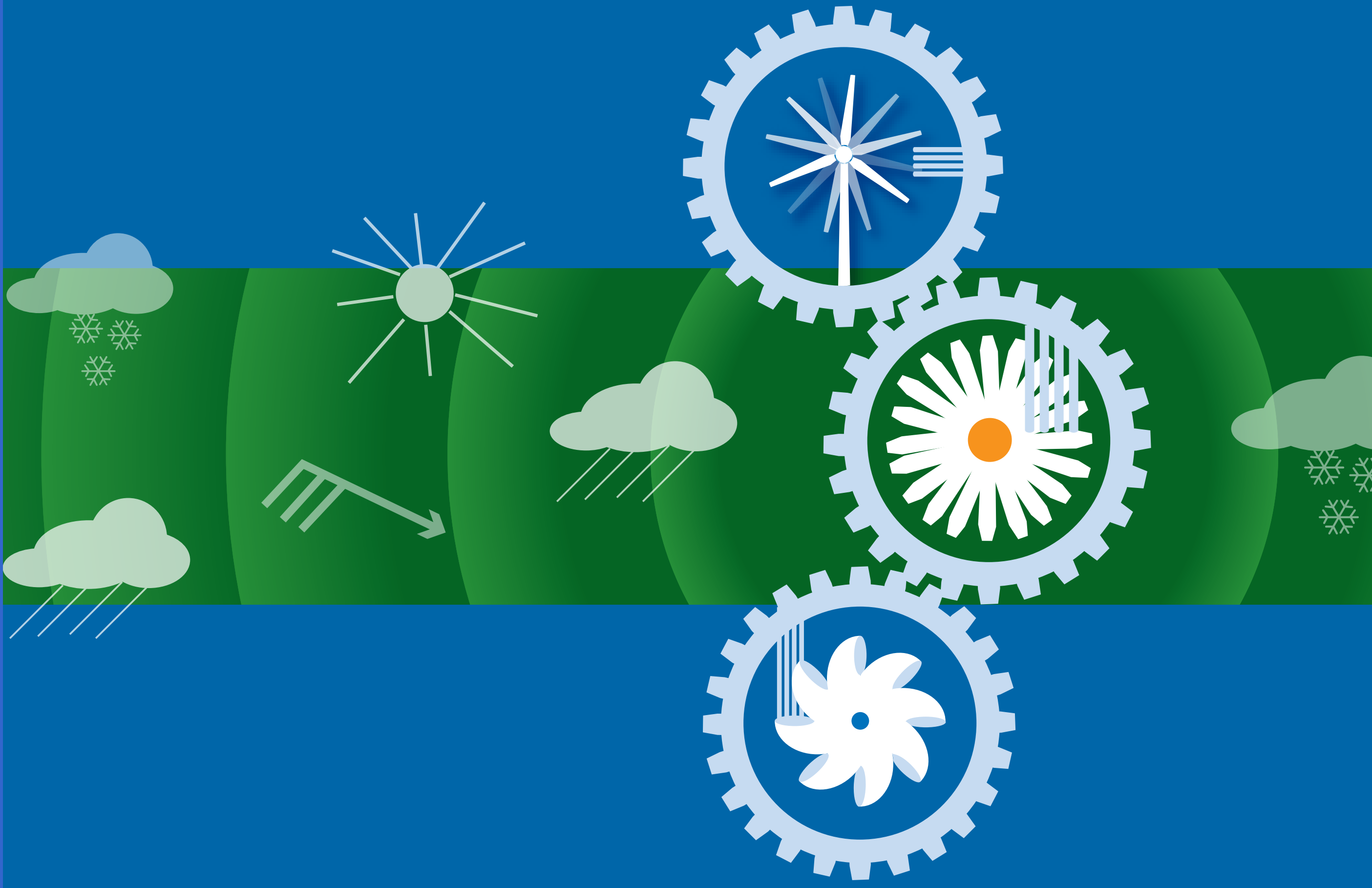
Nordic Energy Research

Conference on Future Climate and Renewable Energy: Impacts, Risks and Adaptation

31 May - 2 June 2010
Soria Moria Hotel and Conference Center, Oslo, Norway

Conference proceedings



CES Nordic Project on Climate and Energy Systems

Conference proceedings

Future Climate and Renewable Energy: Impacts, Risks and Adaptation

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RISKS, POTENTIAL AND ADAPTATION

Welcome to the conference "Future Climate and Renewable Energy: Impacts, Risks and Adaptation"

We welcome you to the international conference *Future Climate and Renewable Energy: Impacts, Risks and Adaptation*. The conference is convened by the Nordic-Baltic project *Climate and Energy Systems* which is funded by *Nordic Energy Research*, the Nordic Energy sector and the participating national institutions. The Conference is co-convened by the *Norwegian Water Resources and Energy Directorate,* and co-sponsored by the Norwegian Meteorological Institute, Statkraft and Norsk hydrologiråd.

The goal of the Climate and Energy Systems project is to look at climate impacts in the near future and assess the development of the Nordic electricity system for the next 20-30 years. The project started in 2007 and will finish this year. It has addressed how the conditions for the production of renewable energy in the Nordic area might change due to global warming. It has also focused on potential production and the future safety of the production systems as well as uncertainties.

The *Climate and Energy Systems* project is the fourth Nordic project studying the impacts of climate change on Nordic Energy resources and systems. The first project started in 1991 with a start-up conference in Iceland in 1991. This project was funded by the Nordic Council of Ministers and was in many ways a front runner of climate impact assessments internationally, focusing on the Nordic energy sector. In the early 2000s, an initiative by Nordic Energy Research led to a pre-project called *Climate, Water and Energy* that developed a comprehensive research program addressing the impact of climate change on the Nordic energy system. This resulted in the funding of a four year Nordic-Baltic project called *Climate and Energy* running from 2003-2006 with its main focus the impact of climate change on production capabilities as well as the development of the Nordic energy system. The *Climate and Energy System* project running from 2007-2010 is a follow up project focusing on the improved assessment of the impact of climate change on energy resources. The project also addresses the importance of improved decision frameworks within the energy sector, which aim to take advantage of the positive aspects as well as addressing the increased risks associated with change.

The recent development and implementation of the Top-level Research Initiative, TFI, by the Nordic Council of Ministers, managed by the three Nordic institutions of ***NordForsk***, ***Nordic Innovation Centre*** and ***Nordic Energy Research*** shows the serious approach taken by the Nordic Council of Ministers regarding the Nordic response to the impact of climate change. The TFI has opened up possibilities and reinvested the network resources set up in the climate projects described above. One possibility is to extend the activities within the present network and another possibility is to reach out for new partners to address an expanded set of questions asked by society. Partners to the *Climate and Energy* Systems project have taken a leading role in several applications. The first application to be funded is *ICEWIND* under the program *Integration of large-scale wind power* of the TFI led by Risö in Denmark. The second application is *SVALI* under the program *Interaction between climate change and the cryosphere,* led by the University of Oslo and the Icelandic Meteorological Office, and finally the *Climate Change Impacts and Adaptation (CCIA)* application led by the Icelandic Meteorological Office, which has made it through the first round of application for the *Effect studies and adaptation to climate change* program. This demonstrates show the success of the investment by the Nordic system in building up the capabilities, technology transfer and research innovation that is essential in addressing the challenges of the future in adapting to climate change.

We would like to thank the Organizing Committee and the staff from NVE for making the organization of this conference possible. We would also like to thank the Scientific Committee, the keynote speakers, the chairpersons, presenters and the sponsors for their contribution to a successful conference.

We hope that the time invested in this comprehensive conference and the key results of the Nordic-Baltic project *Climate and Energy Systems* are worth your while, and that the venue will also create possibilities for exchange and future collaboration within this complex and fast evolving field of research.

Árni Snorrason	Hege Hisdal
Project Manager for Climate and Energy Systems	Chair of the Scientific and Organizing committee

Stakeholder relevance of the CES project

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A structured dialogue has been held with a Swedish stakeholder, Vattenfall. The objectives have been to discuss stakeholder relevance of the CES project and methods for stakeholder communication in the existing project phase as well as to propose methods and approaches to increase the stakeholder involvement and relevance in future research programmes on climate effects on renewable energy. A further objective has been to raise the awareness of the CES project in general and of its results and energy relevance in particular. The results presented in this abstract reflect the viewpoints from the particular persons who have been participating in the dialogue and shall not be considered a common viewpoint from neither Vattenfall nor the energy sector in general. The persons involved in the dialogue are hereafter referred to as the "dialogue group".

The background for the stakeholder dialogue has been the intention of the CES project to increase the stakeholder involvement in the project. The energy sector is represented in the programme committee and contributes to the financing of the programme. Another effort to increase the stakeholder involvement has been made by direct dialogues and in depth discussions with some stakeholders from the Nordic energy sector. IVL Swedish Environmental Research Institute has been responsible for one such dialogue.

The method used has been telephone and direct discussions. The dialogues have focused on three issues;

- Stakeholder relevance, i.e. discussion about the content of the CES project and how the results can be used by a Swedish energy company,
- Stakeholder communication, i.e. in what form the results and information is communicated to the stakeholders (e.g. web page, fact sheets, reports, other publications) and the user friendliness of the material, and
- Suggestions for improvement for a future research programme, i.e. suggestions for an improved stakeholder relevance, dialogue and communication.

One result from the stakeholder dialogue is that the CES project deals with very relevant issues that may considerably affect the energy sector. However, the potential effects of climate change on the energy sector are by many stakeholders considered uncertain and long-term. Therefore, these topics may be less prioritised than other issues of more immediate (and everyday) importance for the energy sector (such as mitigating greenhouse gas emissions, maintenance etc.). All research was considered relevant by the "dialogue group". The work within the Risk Assessment Group was believed most stakeholder friendly by the "dialogue group" and the risk assessment procedure was appreciated and considered stakeholder relevant.

Regarding the communication material from the CES project, the "dialogue group" discussed the web page, the fact sheets and some available publications. The "dialogue group" believed that the web page is a very important source of communication. However, it could be improved e.g. by making it more simple and easy to grasp. The list of publications is important, but at present the publications cannot be downloaded. A future improvement would be to have a list of downloadable publications. A substantial improvement would be executive summaries of publications adapted for stakeholders. Fact sheets could be an important material to inform stakeholders about the research. However, the fact sheets need to be more concise with less text focusing on the main messages for stakeholders.

To increase the stakeholder involvement in future R&D programmes on climate and energy, the "dialogue group" has suggested several actions. The recommendations are illustrated in Figure 1. The "dialogue group" believed that one of the most important actions to increase the involvement from stakeholders is direct contact with stakeholders at a strategic level, e.g. by visits, meetings and workshops. The steering group could also be an important communication channel to other stakeholders.

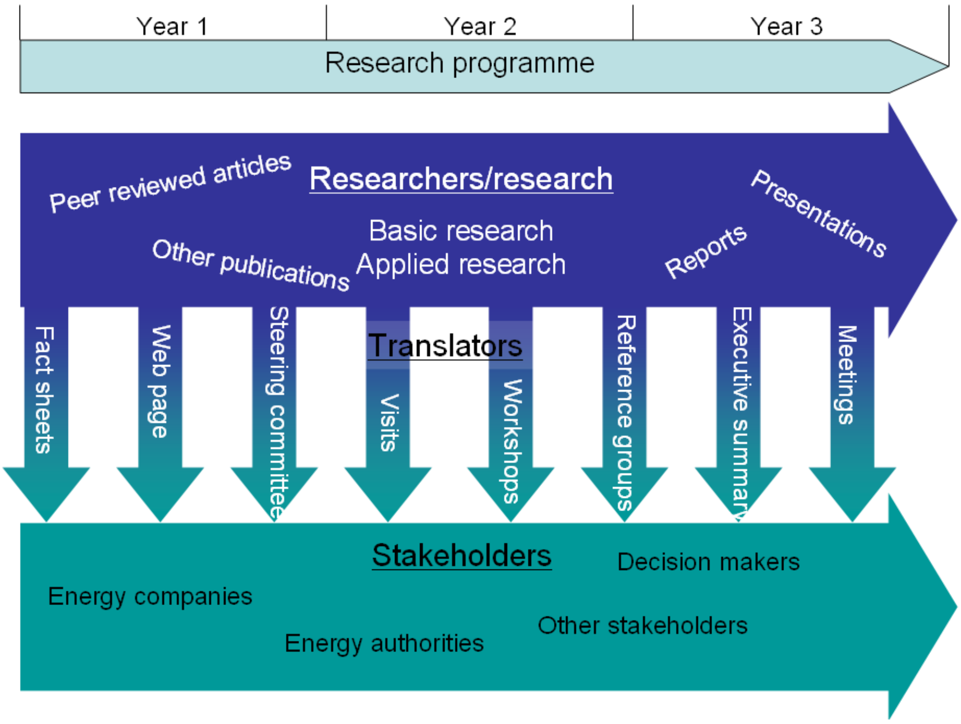

Figure 1. Suggestions for stakeholder involvement in a future R&D programme on climate and energy.

Some conclusions:

- The research within the CES project is relevant.
- The communication with stakeholders can be improved e.g. by making the web page more simple, user friendly and by publishing more stakeholder friendly summaries.
- The stakeholder involvement could be improved by more direct contact with stakeholders e.g. by visits, meetings and workshops. The steering group also has an important role to forward and spread information to other stakeholders.

Analysis of past snow conditions in Norway
- Time periods 1931-60, 1961-90 and 1979-08

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Snow is an important part of the climate system and changes in snow conditions are also of hydrological significance, such as in hydropower production or as a threat related to flooding and avalanches etc. We expect the climate in Norway to become warmer and wetter over the next decades (Hanssen-Bauer et al., 2009), which will have significant affect on snow conditions. Changes in these depend strongly on both temperature and precipitation, thus studying variations in past snow conditions is essential to understanding expected future development.

In the present research we analyse observed trends in annual maximum snow depth and number of days with snow on ground (snow days) within three 30-year periods; 1931-60 (period I), 1961-90 (period II), and 1979-2008 (period III). The non-parametric Mann-Kendall test is applied to compute trends, and a 95% confidence level is used to evaluate the significance of trends for the three time periods. Linear trend slopes are computed and plotted against long-term average NDJFM temperature (mean NDJFM temperature) extracted from the climate grids presented at www.senorge.no (Engeset et al., 2004), with the intention of illustrating the relationship between temperature and nature of trends in snow parameters. To further investigate snow parameters‟ sensitivity to variations in winter climate, we performed an analysis of correlation with time series of mean winter temperature and accumulated winter precipitation.

Results show a transition from more and more negative trends in number of snow days throughout the entire study period, while trends in max snow depth go from mostly positive in period I to mostly negative in period II, and both negative and positive in period III. Positive trends in annual maximum snow depth occur mostly in colder regions, where precipitation comes as snow at the height of winter. Number of snow days has decreased in both warm and cold regions, as a result of higher temperatures which cause a later start and earlier end of snow season. Figure 1, showing correlations between snow parameters and winter climate, indicate that number of snow days is highly sensitive to temperature changes in all parts of the country (negative correlation). However, in colder regions, such as inner parts of Southern Norway, annual maximum snow depth is even more sensitive to precipitation changes (positive correlation).

A collaborative study between Norwegian Meteorological Institute (met.no) and Norwegian Water Resources and Energy Directorate (NVE) on annual maximum snow amount started in 2010. We consider certain regions with a wide number of observations from low elevations (met.no stations) and high elevations (NVE stations) for different periods in the past. By combining observations from the NVE and met.no networks, we are able to obtain results from the entire elevation profile.

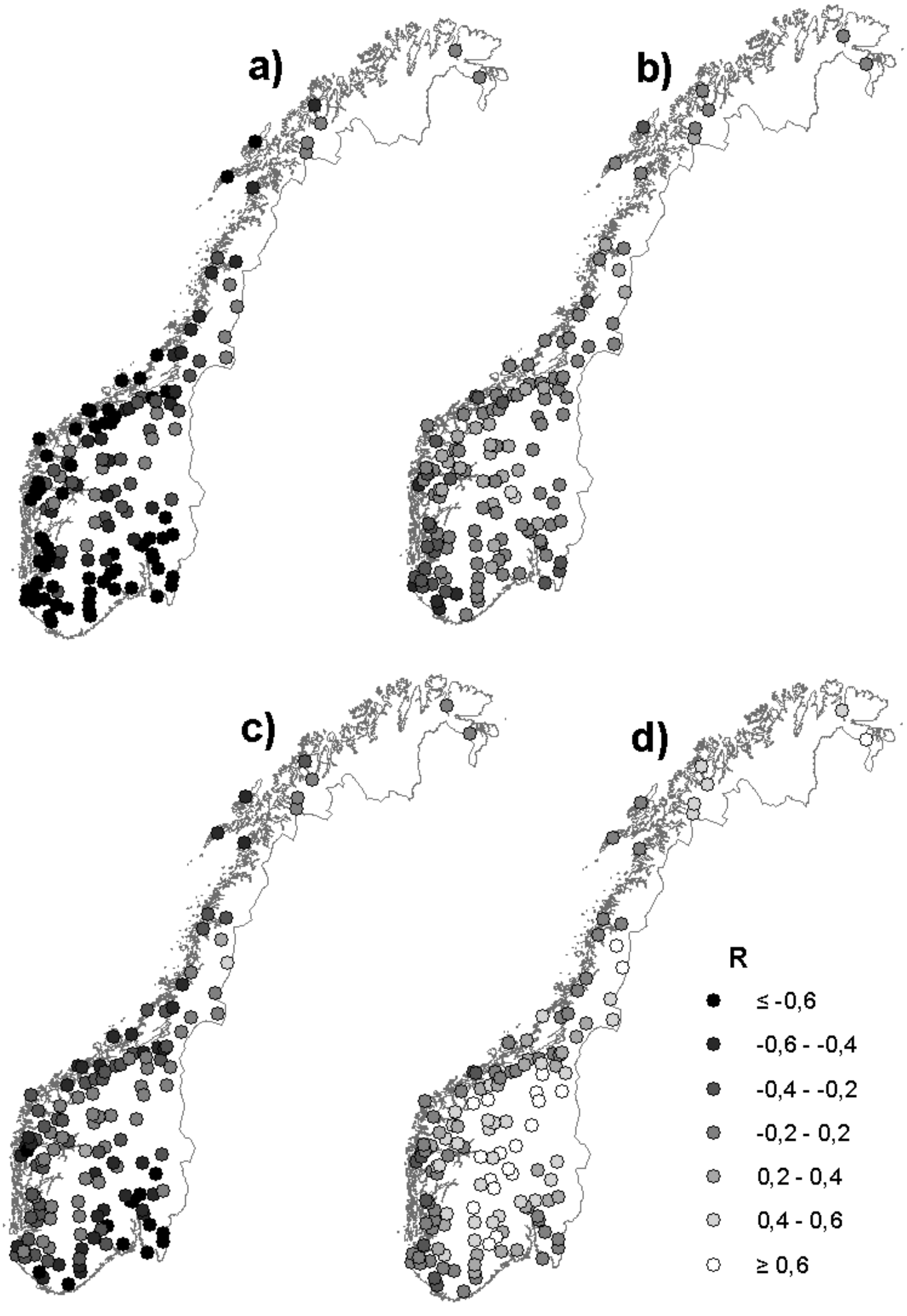

Figure 1: Correlation coefficient (R) between time series of: a) number of snow days and winter temperature, b) number of snow days and winter precipitation, c) annual maximum snow depth and winter temperature, and d) annual maximum snow depth and winter precipitation. Darker (lighter) colors indicate negative (positive) correlations.

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Impacts of historic climate variations on streamflow characteristics in Icelandic rivers

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This work aims to study the impact of climate variations, in particular temperature variations, on streamflow characteristics and hydro-resources in Iceland during the past decades. A set of 11 rivers with watersheds ranging in size from 42 km^2 to 5687 km^2 and with various origins of flow formation has been studied. Runoff from snow-covered areas and glaciers plays a fundamental role in the hydrology of Iceland and is expected to be sensitive to variations in temperature and type of precipitation. For this reason, observed streamflow properties such as seasonality, magnitude and flood characteristics are jointly studied with information about snowpack condition, snow and glacial melting rates, and rainfall, derived from high resolution gridded precipitation and temperature data sets and a simple degree-day snow and ice melt model.

The study deals with cold, warm and intermediate years, respectively, in order to give an idea of the observed range of streamflow variations over approximately the last 30 to 50 years, depending on catchment. Results indicate that inter-annual temperature variations have an impact on the snowpack and the resulting snowmelt rate and timing for all catchments. The sensitivity of the snowmelt to temperature variations depends on catchment altitude. The catchments located at lower elevations are most affected by temperature increase. Those at higher altitudes are also affected since the altitude range in Iceland is moderate, with an average of 500 m a.s.l and a maximum close to 2000 m a.s.l. Consequently, catchments having a hydrological regime influenced by snow and glacial melt show signs of sensitivity to temperature variations.

The mean annual catchment-averaged temperature difference between the 25% warmest and 25% coldest years ranges from 1.5°C to 1.8°C depending on catchment. It is found that a mean annual temperature difference of this magnitude is associated with a substantial difference in hydrological characteristics such as earlier (later) spring peak and lower (higher) peak magnitude and higher (lower) autumn–winter flow during warmest (coldest) years. For catchments without glaciated areas, the summer flow is lower (higher) in warmest (coldest) years. For catchments with glaciated areas, a larger glacial melting in summer during the warmest years compensates for the reduction of spring snowmelt and maintains the summer streamflow at similar or higher levels than for the coldest years. As an example, Figure 1 presents the daily mean evolution of snow water equivalent of the snowpack, the mean daily snow and glacial melting rates and the mean daily streamflow for Vestari Jökulsá, a catchment with a glaciated area located in central Iceland, considering the 25% warmest years and 25% coldest years between 1971 and 2006 and the average of the 1971–2000 period.

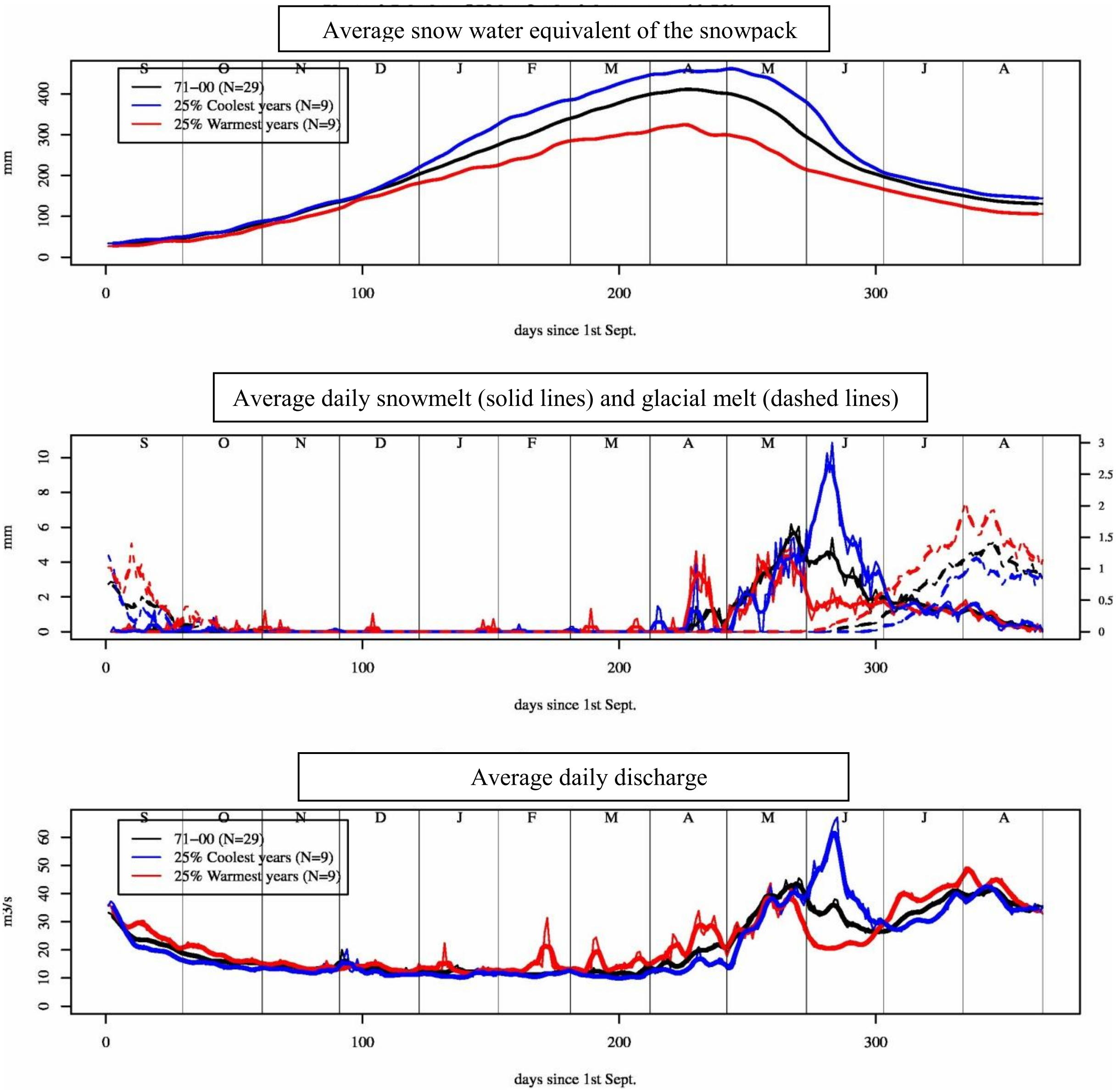

Figure 1: Average snow water equivalent of the snowpack, snow and ice melt, and discharge for “cold”, “warm” and 1971-2000 years, for the catchment Vestari Jökulsá (850 km^2 with 11.5% glacial coverage)

The impact of temperature variations on runoff characteristics is clearly illustrated in this example. During the warmest years, the snow water equivalent of the snowpack (Fig. 1, top) reaches its maximum around mid-April while in coldest years, it is observed at the end of April beginning of May. The maximum amount of snow water equivalent during the warmest years is 30% lower in average than in the coldest years. The rate of snowmelt reaches a peak twice lower in average, in the warmest years than in the coldest years, and takes place earlier (Fig. 1, middle). On the contrary, the glacial melting is substantially larger in the warmest years than in the coldest years. The streamflow characteristics reflect the runoff contribution from snowmelt and glacial melt quite well, both in terms of timing and magnitude (Fig 1, bottom).

Regional temperature, precipitation and runoff series in the Baltic countries

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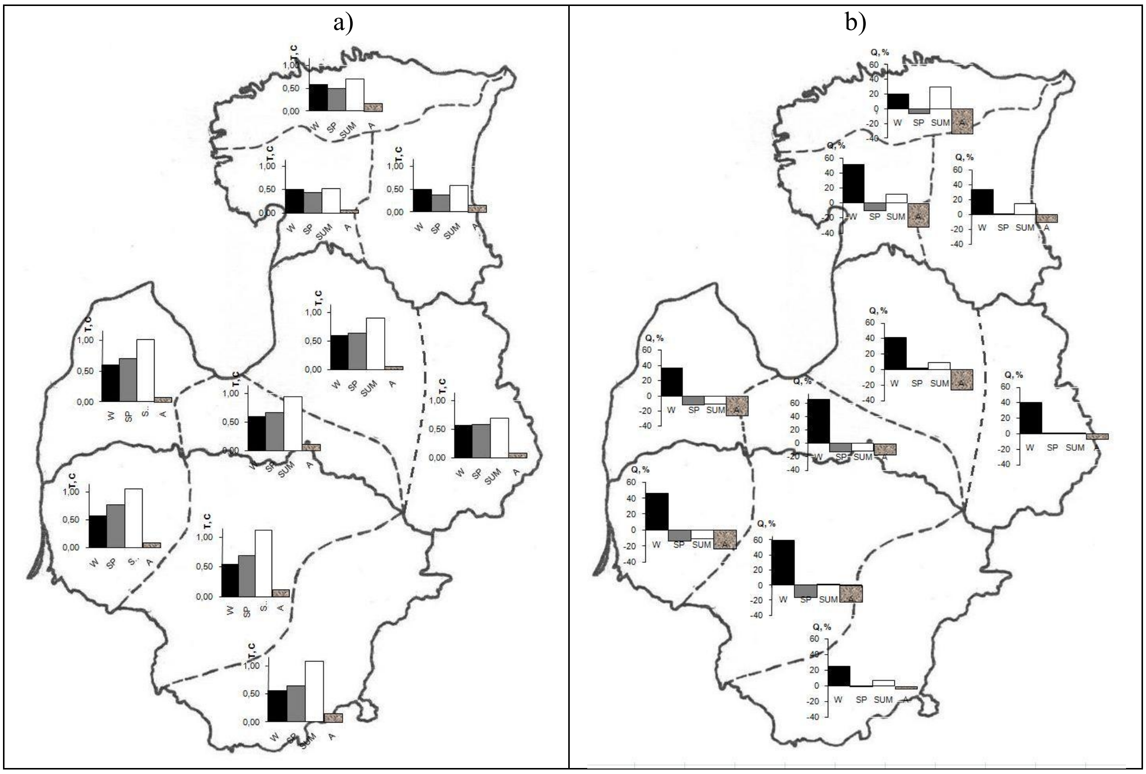
The climate change impact on water resources is observed in all Nordic and Baltic countries. These processes became more active in the last decades. Although the territory of Baltic countries (Lithuania, Latvia, Estonia) is not large (175000 km²), climatic differences are quite considerable. The amount of precipitation varies from 850 mm per year in the Uplands of Latvia to 560 mm per year in the Central Lithuania. The hydrological regime of the Baltic rivers depends not only on climatic factors (temperature and precipitation), but also on geomorphology, geology, land use type and soil structure. Depending on the hydrological regime, rivers in the Baltic region could be grouped into 3 major types – marine, transitional and continental (Reihan et al, 2007). The main source of feeding of marine type rivers is precipitation. The snow melt water rate is almost equal to the groundwater for continental type rivers. Regional patterns of precipitation, temperature and river runoff were done in all Nordic countries (Lindström et al, 2006). Regionalization of territory of the Baltic countries is needful for description of precipitation, temperature and river runoff patterns.

Long-term series of temperature, precipitation and runoff were compiled for 10 hydrological regions: Western, Central and Southeastern Lithuania; Western, Central, Southeastern and Northeastern Latvia; Western, Northern and Eastern Estonia. Long-term series of temperature (49 stations), precipitation (72 stations) and runoff (64 stations) were used for composition of regional series in the Baltic countries. Regional series were developed on monthly, seasonal and annual bases. All series were normalized with reference period of 1961-1990.

Comparison of the all regional series was done for period of last years (1991-2007) with data of reference period (1961-1990). The increase of annual and seasonal temperature was determined in all regions of the Baltic countries. Temperature anomaly above the reference level depends from geographical position of regions. In Estonia annual temperature increased to 0.8 ºC and in Lithuania – to 1.1 ºC. Positive changes of air temperature occurred in all seasons (Fig. 1a). Even more significant anomalies of air temperature have been observed during the summer season. The largest increase in temperature was observed in Lithuanian and Latvian (0.9 -1.1 ºC), and the smallest – in Estonia (0.5 -0.7 ºC). During the autumn season, slight changes of temperature have been observed in all regions of the Baltic States (0.5 -0.7 ºC).

Change of precipitation in the Baltic States happens almost synchronically. Comparing the precipitation of 1991-2007 with the reference period, it was observed that there was a considerable increase of precipitation in winter season for all Baltic countries. In the western and central regions precipitation increased by 10-16%, while in the eastern regions – even 15-29%. Changes of the spring season precipitation are different in individual regions. The amount of precipitation in summer season decreased the most in the western and central parts of Lithuania and in the eastern region of Estonia. In autumn season the precipitation decreased the most in the western regions of all countries (by 6-11%).


a)

b)

Fig. 1. Seasonal anomalies between years of 1991- 2007 and the reference period 1961-1990: a) temperature (in ºC), b) runoff (in %)

The anomaly of regional runoff series depends from type of climate (marine or continental) and sources of river feeding. There was increasing of winter season runoff in last years (20 - 60% comparing with reference period) for all regional series (Fig. 1b). Decreasing of spring season runoff (10 - 20%) was fixed in the Western regions of all Baltic countries (marine climate zone) but there were no changes of spring season runoff in the continental part of countries (Southeastern Lithuania and Latvia, Eastern Estonia).

Conclusions. Annual and seasonal temperature anomalies of last years (1991-2007) above the reference level were positive in all regions of the Baltic States. The runoff anomalies in 1991-2007 were slightly positive in Lithuania and Latvia and slightly negative in Estonia comparing with reference period.

Acknowledgement: this work was supported by the project “Climate and Energy Systems”, funded by the Nordic Energy Research.

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Regional hydrological drought in north-western Europe and associated weather types

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Hydrological drought is defined in a relative way as a regional deficit in surface water or groundwater over an extended period of time. In this study, the focus is on summer streamflow drought, i.e. excluding low flows due to frost. In order to mitigate the negative effects of drought, forecast severe events or assess future drought characteristics, a good understanding of the hydroclimatological processes causing severe droughts is essential. In particular, the larger-scale processes leading to regional droughts are here of interest, as drought severity increases with duration and affected area. Streamflow responds to the combined effects of meteorological and hydrological input, transfer and storage processes. The main variables controlling hydrological drought development are precipitation and air temperature. However, these variables have a high spatial and temporal variability. For the study of larger-scale processes, atmospheric pressure data are a good alternative as they characterise synoptic patterns rather than local-scale variability. Furthermore, the quality of air pressure derived by General Circulation Models is higher than for precipitation, which may be important for the study of future drought characteristics. The use of weather types (WTs) has the additional advantage of describing the atmospheric situation over a region as a single nominal variable usually strongly correlated with many local meteorological variables.

The main objectives of this work (Fleig et al., in press 1) are to study regional hydrological droughts in north-western Europe and to investigate links between severe hydrological droughts and WTs. This is obtained through the following three tasks:

i. development of a daily Regional Drought Area Index (RDAI) and study of the regional hydrological drought characteristics;
ii. identification of the hydrological response time (i.e. the period during which WT-occurrences influence hydrological drought development);
iii. identification of WTs related to the development of severe historical droughts.

The study region, encompassing Denmark and Great Britain, lies in a temperate-humid climate zone. It has varying surface hydrology caused by regional variations in climatological and hydrogeological properties. Natural or naturalized daily discharge series from 22 basins in Denmark and 36 basins in Great Britain were used. WTs were defined by an objective version of the Hess-Brezowsky Grosswetterlagen (OGWL; James, 2007) modified for the COST733 Action[1]. The OGWL has been identified as well suited for regional hydrological drought studies in north-western Europe (Fleig et al., in press 2). It is derived on a domain covering the eastern North-Atlantic and Europe (30°-76°N; 37°W-58°E) and yields 29 WTs. The WTs are characterised by cyclonicity and main flow direction with respect to central Europe.

Daily streamflow drought series (1964-2001) were derived using the threshold level method, and six regions with homogenous drought behaviour were identified: west (DK1) and east (DK2) Denmark, north-east (GB1), west (GB2), south and east (GB3) Great-Britain and the central part of southern England (GB4). A daily Regional Drought Area Index (RDAI) was

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[1] COST733 Action - Harmonisation and Applications of Weather Types Classifications for European Regions (http://cost733.org).

developed, which represents the proportion of the drought affected area within a region. The total area of a region was defined as the sum over all basin areas in a region, and the drought affected area as the sum over all drought affected basin areas. Drought events were defined as periods during which RDAI>0.7. Regional drought characteristics, such as number and duration of events, were found to vary considerably between regions. Particularly severe droughts extending over all six regions, were observed in 1976 and 1996.

The *hydrological response time,* d_{reg}, i.e. the preceding time period during which WT-occurrences influence streamflow, was identified by a correlation analysis between the daily RDAI series and the total frequency of potentially drought supporting WTs over different preceding time windows. Potentially drought supporting WTs were identified based on composite maps of average precipitation amounts for each of the 29 WTs. d_{reg} was defined as the time window giving the first (local) maximum in the correlation to the daily RDAI. The values for d_{reg} were found to vary considerably according to regional basin storage properties (45 days in GB1 and GB2, 60 days in DK1 and DK2, 90 days in GB3 and 210 days in GB4).

For each of the six regions, WTs associated with hydrological drought development were identified based on frequency anomalies of the WTs during the periods leading up to the five most severe droughts as compared to the average frequency of a given WT for the same period of the year over the entire data record. A period equal to d_{reg} preceding the drought plus the 20 first days of the drought was used. All WTs with a net positive frequency anomaly over the five events were considered to be associated with drought development. It was found that the dominant drought-yielding WTs varied between the six regions as well as between events in a region. High pressure systems centred over the respective region were most frequently associated with droughts, along with WTs with a southern (S, SE or SW) air-flow over the British regions and a northern (N, NE or NW) air-flow over the Danish regions. As such, the identified WTs represent situations with air masses coming from land areas, which are during summer typically drier and warmer than air masses coming from sea areas. Furthermore, the location and relative proximity of high (H) and low (L) pressure systems to the region were relevant. Six WTs were associated with drought in all regions, mostly representing a northern H (i.e. over Great Britain, Fennoscandia or the Norwegian Sea).

The findings of this work will be used further to investigate regional hydrological drought characteristics during the 21st century based on frequencies of the herein identified drought related WTs in future climate scenarios (under the assumption that hydrothermal properties of WTs remain stationary). This will be done within the EU-Project WATCH[2]. Further research should also investigate potential relations between drought related WTs and larger-scale teleconnections, which could be used for monthly or seasonal drought forecasting.

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[2] WATCH – Water and Global Change (http://www.eu-watch.org).

An ensemble of regional climate change scenarios for the Nordic countries

Erik Kjellström[1], Martin Drews[2], Jens Hesselbjerg Christensen[2], Jan Erik Haugen[3], Hilde Haakenstad[3] and Igor Shkolnik[4]

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Here we present an analysis of a range of regional climate change scenarios that has been produced within the Nordic Climate and Energy Systems (CES) project and the European fp6 project ENSEMBLES (van der Linden and Mitchell, 2009). The joint ENSEMBLES/CES regional climate model (RCM) ensemble consists of more than 25 RCM simulations (see http://ensemblesrt3.dmi.dk/extended_table.php) covering most of Europe at 25 km horizontal resolution. All RCM scenarios are based on the SRES A1B emission scenario (Nakićenović and Swart, 2000). Focus for this study is changes in seasonal mean temperature, precipitation and wind speed in the Nordic region. We compare the future time period 2021-2050 to the control period 1961-1990. For the study we use 17 of the ENSEMBLES/CES RCM simulations forced with boundary conditions from four different GCMs (ECHAM5, BCM, Arpège, HadCM3). In case of HadCM3 there are two additional versions with perturbed physics, apart from the reference version, thus making the total number of GCMs six.

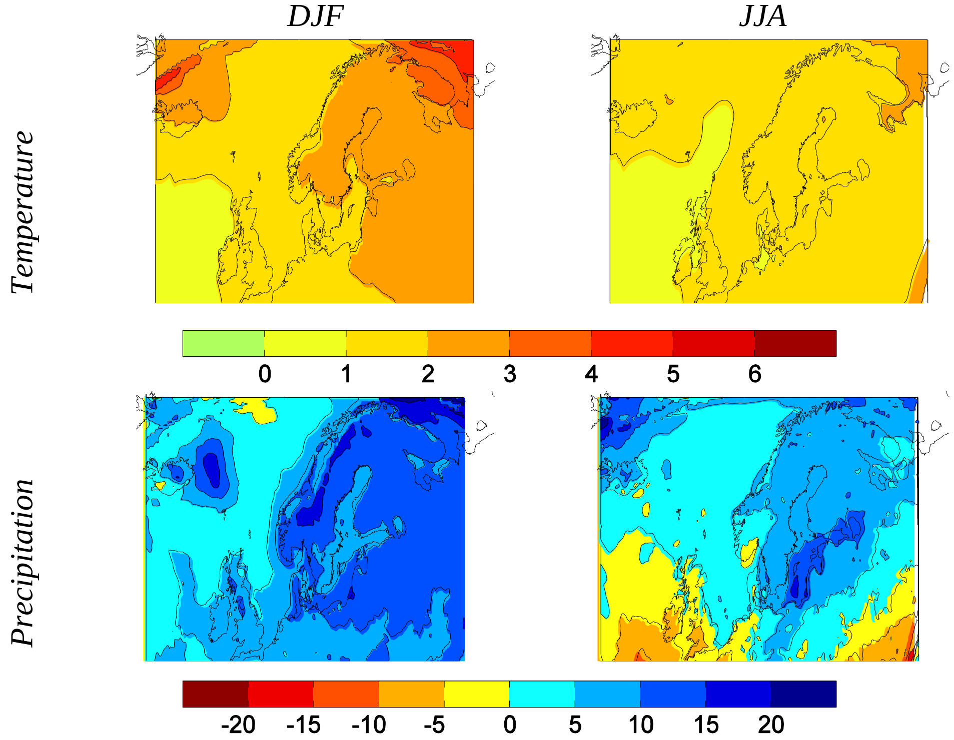

Figure 1. Ensemble mean change in seasonal mean temperature (upper) and precipitation (lower) for winter (DJF, left) and summer (JJA, right). Changes are given in °C for temperatures and mm/month for precipitation.

Changes in temperature are largest for the winter season and most so in the north and east parts of the model domain, i.e. including the domain of interest in CES. Changes in winter temperatures in this area are between 1 and 5°C in the individual models 1 and 4°C in the ensemble mean shown in Fig. 1. The results show a weaker change over the North Atlantic and in some simulations also for Iceland. In all areas, including the North Atlantic and Iceland, a clear climate change signal compared to the spread between the simulations is seen. The standard deviation calculated from 17 of the simulations are less than 1°C in all areas apart from Iceland where it reaches between 1 and 2°C and in parts of the Barents Sea where it reaches between 3 and 4°C (not shown). In summer the climate change signal in temperature is smaller with between 1 and 3°C in all Nordic land areas in the models and between 1 and 2°C in the multi-model mean (Fig. 1). Also the spread between the simulations is smaller with the inter-model standard deviation being less than 1°C in all of the area (not shown). Summertime changes are relatively larger over parts of the Baltic Sea and the ocean areas surrounding Iceland and in parts of the Barents Sea. These larger changes are connected to reduction of sea-ice in these areas.

Precipitation is projected to increase in large parts of northern Europe in varying degree by all RCMs in both winter and summer (Fig. 1). The increase is largest over parts of the Scandinavian region, most notably over the Scandes in winter and over the Baltic Sea in summer. Possibly there is a connection to high sea surface temperatures and less sea-ice here (cf. similar connection in the earlier CE and PRUDENCE projects, Kjellström and Ruosteenoja (2007)). The results also give that there is a strong connection between change in precipitation and choice of forcing GCM (not shown). This is manifested by large differences in absolute numbers between different RCM simulations. For the Nordic region the spread between different simulations is about equally large in the Scandinavian countries and in Iceland. Compared to temperature we find that the spread is relatively larger for precipitation indicating a larger degree of uncertainty.

Projected changes in wind speed are relatively small in most simulations on a regional scale and differs depending on choice of forcing GCM (not shown). Locally, changes of up to about 10% can occur in some areas in the simulations. The largest changes are seen over parts of the oceans (Barents Sea, parts of the North Atlantic north of Iceland, the Baltic Sea) again probably connected to changes in sea ice (less sea ice implies less stably stratified conditions implying that more momentum can be mixed down towards the surface). On an annual mean basis the ensemble mean show only small changes in wind speed (i.e. less than 5% in all land areas) and the spread between models is large indicating that uncertainty here is even larger than for precipitation.

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An analysis of simulated and observed storm characteristics

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Storms represent one type of extremes that can have dramatic influence on society and ecosystems, through damages caused by high winds, storm surges and precipitation. Good wind measurements are sparse, but storms are characterised by local minima in the mean sea level pressure (SLP) fields, strong pressure gradients, high vorticity, and high winds. Mid-latitude storms are also referred to as low-pressure systems. Global climate models (GCMs) are often run at too coarse resolution to provide a good description of storm statistics and extreme winds, but regional climate models (RCMs) with higher resolution are more appropriate tools (e.g. Rummukainen, 2010).

A calculus-based cyclone identification (CCI; Benestad & Chen, 2006) method was applied to SLP data from re-analysis products and from RCM simulations. This includes; the ERA interrim reanalysis (ERAINT; Dee and Uppala, 2008), the 20th Century re-analysis from NOAA (http://www.esrl.noaa.gov/psd/data/20thC_Rean/), and the HIRHAM RCM (50x50km^2, driven by HadAM3H for 1950-2050 with C20 & SRES A1b emissions; van der Linden and Mitchell, 2009). The HIRHAM data have been interpolated onto a longitude-latitude grid. The analysis has been applied to the whole year.

The storm frequency for events with central pressure below a threshold values of 960, 970, 980 and 990hPa were examined, and the gradient wind from the simulated storm systems were compared with corresponding estimates from the re-analysis. The analysis also yielded estimates for the spatial extent of the storm systems, which was also included in the RCM cyclone evaluation.

The results of this evaluation and trends in the statistics suggests little trend in the storm statistics such as gradient wind or number of cyclones with central pressure lower than (Fig. 1). For a larger domain, results based on the 20th century reanalysis do indicate trends in both maximum wind speeds and storm frequency (not shown), and that a limited region may give a different impression about trend than a larger region covering most of the north Atlantic (Benestad, 2010).

The RCM indicates higher gradient wind than the same analysis repeated for ERAINT (From Fig 1a, ~80m/s compared to ~50m/s). The number of cyclones with the core pressure below the set of threshold values, however, were in better agreement with ERAINT (Fig.1b). A closer examination of the structures, suggested that the RCM cyclones had smaller spatial extent, but the core pressure was slightly greater than the ERAINT analysis (Benestad, 2010).

The domain size of the RCM may have an impact on the storm statistics, as smaller domains may limit the RCM to develop SLP characteristics that differ from the driving GCM. The coarse spatial resolution in both ERAINT and GCMs may further limit the description of SLP gradients associated with storm systems. Increasing the resolution by use of a RCM may improve the situation. But, so far, the analysis has only been applied to RCM simulations where a GCM has provided the boundary conditions. Furthermore, there is no comprehensive comparison between storm statistics derived from different data products or using different methods (Neu, Benestad, & the IMILAST team, 2009). A comparison between geostrophic wind estimated through triangulation of SLP suggest discrepancies between regional climate models (some from PRUDENCE in addition to HIRHAM shown here) and station measurements (Benestad, 2010). Thus, storm statistics including wind still represents one of the more challenging variables to model realistically.

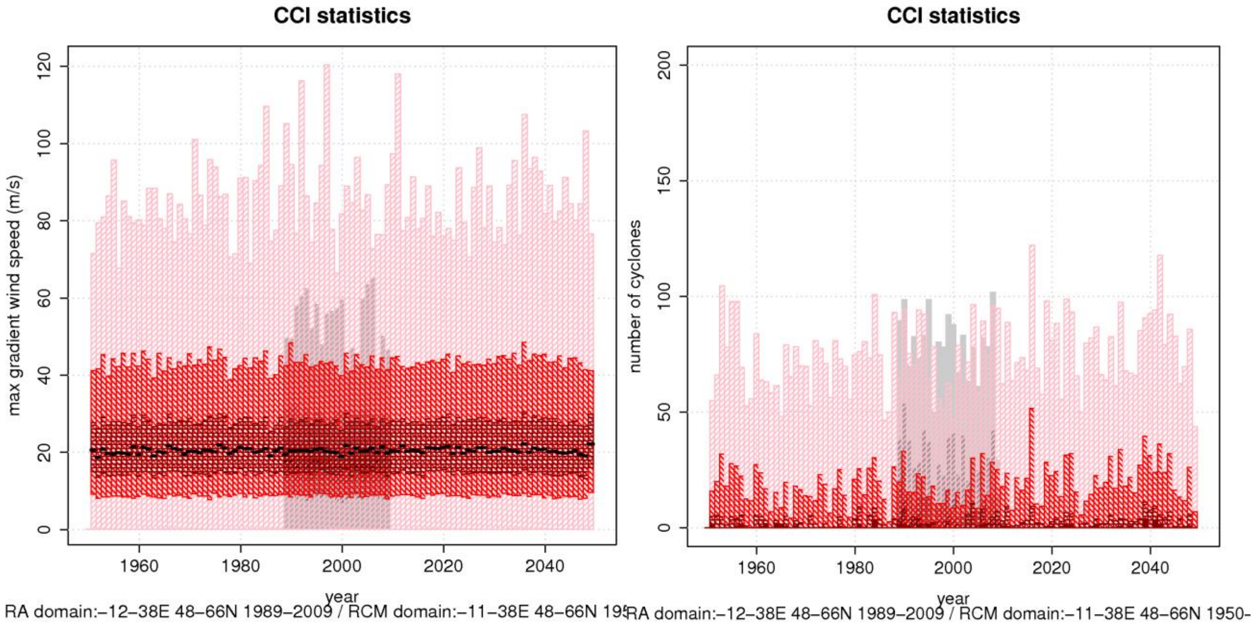

Fig 1: Time evolution of the annual statistics of gradient wind speed (a) and storm counts (b) based on the HIRHAM PRUDENCE simulation (red) and ERAINT re-analysis (black). The different colours and hatching in panel (a) mark the annual maximum value, the 95-percentile, 75-percentile, 25-percentile and the 5-percentile each year. In panel (b), the different levels shown by colour and hatching mark threshold values of 990hPa, 980hPa, 970hPa and 960hPa.

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Probability distributions of monthly-to-annual mean temperature and precipitation in a changing climate

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Weather conditions vary from year to year. Traditionally, the characteristics of this variation have been estimated from past observations. With a sufficient period of observations (30 years or more is desirable) available, the probability distributions that describe the observed climate variability can be estimated.

However, in a world with ongoing climate change, past statistics give a potentially biased estimate of the present climate and the climates that can be expected in the near future. Recently, Räisänen and Ruokolainen (2008) proposed a method for correcting this bias, and thus estimating the true present-day and near-future climates. The method adjusts observed time series of the local climate for global climate change, to make them representative of present or future climate conditions. The adjustment combines changes in the global mean temperature (observed for the past, simulated for the future) with model-based estimates of how the local mean climate and interannual variability should change with increasing global mean temperature. From the adjusted time series, the distribution of interannual variability can be estimated in the same way as from the original observations.

Within the CES project, we have applied this technique to estimate the temperature (precipitation) climate at 120 (230) Nordic observation stations, up to the year 2050 (Räisänen 2009). The results are provided as tables available at *http://www.atm.helsinki.fi/~jaraisan/ CES_D2.4/Tables_T and Tables_P*. The observations, collected within the European Climate Assessment & Dataset project (*http://eca.knmi.nl/*), were adjusted using climate change estimates based on the output of 19 global CMIP3 (Meehl et al., 2007) and 13 regional ENSEMBLES (van der Linden and Mitchell, 2009) model simulations. The details of the technique and the models used are documented in Räisänen (2009).

As an example, tables representing the January mean temperature and precipitation in Helsinki, Finland are shown in the next page. The first two lines represent two alternative baseline periods (1961-1990 and 1961-2008), while the next line gives an estimate of the true present-day (year 2010) climate. The last two lines show best-estimate projections for 2030 and 2050, under the SRES A1B emission scenario. The first table suggests that the median January mean temperature, which was -5.2ºC in 1961-1990 and -3.9ºC in 1991-2008, is now about -2.9ºC and should increase to about -0.5ºC by the middle of the century. A slight narrowing of the distribution with time is also projected, with a larger warming in the coldest than in the mildest Januaries. However, some individual relatively cold Januaries are still expected to occur even in the middle of this century.

A similar analysis for precipitation (lower table) reveals a much lower signal-to-noise ratio: the changes projected for the first half of this century are still relatively small compared to the interannual variability of precipitation. In Helsinki, for example, almost one January out of three is still projected to be "dry" (precipitation below the median for 1961-1990) in the middle of this century. For the other months, when the signal of precipitation change is weaker, this fraction is even larger (not shown).

Temperature, January (°C)

Year(s)	5%	10%	25%	50%	75%	90%	95%	Very cold	Cold	Warm	Very warm
1961-1990	-13.6	-11.7	-8.6	-5.2	-2.3	-0.3	0.8	10%	50%	50%	10%
1961-2008	-12.1	-10.0	-7.0	-3.9	-1.6	0.1	1.1	6%	38%	62%	13%
2010	-10.6	-8.6	-5.8	-2.9	-0.7	0.9	1.8	3%	29%	71%	20%
2030	-9.3	-7.4	-4.7	-1.9	0.3	1.8	2.7	2%	21%	79%	31%
2050	-7.6	-5.8	-3.2	-0.5	1.6	3.1	3.9	1%	12%	88%	48%

Precipitation, January (mm)

Year(s)	5%	10%	25%	50%	75%	90%	95%	Very dry	Dry	Wet	Very wet
1961-1990	16	20	28	40	55	70	79	10%	50%	50%	10%
1961-2008	16	21	31	45	61	76	85	9%	40%	60%	15%
2010	17	22	33	47	63	78	87	8%	37%	63%	17%
2030	18	24	35	49	66	81	91	7%	33%	67%	20%
2050	20	25	37	52	69	85	95	5%	30%	70%	23%

Table 1. *Probability distributions of (top) January mean temperature and (bottom) precipitation in Helsinki, Finland. The first seven columns give the 5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles of the observed distributions for the periods 1961-1990 and 1961-2008, and the model-adjusted distributions for the years 2010, 2030 and 2050. The last four columns give the probabilities of very cold (very dry), cold (dry), warm (wet), and very warm (very wet) Januaries, using threshold temperatures (precipitation sums) defined by the 10th, 50th and 90th percentiles of the distribution in 1961-1990.*

We have assumed in our calculations that the signal of anthropogenic climate change varies smoothly in space and can therefore be estimated from the information available from global and regional climate model simulations. To the extent that this assumption is violated, for example due to local water bodies and small-scale variations in topography, such variations are not captured by the present method. Furthermore, the tables introduced here are based on a best-estimate (multi-model-mean) projection of climate change; the changes in the real world might proceed faster or slower.

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Nordic weather extremes as simulated by the Rossby Centre Regional Climate Model: Model evaluation and future projections

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Statistics of temperature, precipitation and wind extremes over Scandinavia is examined in an ensemble of climate simulations performed with the Rossby Centre Regional Climate Model - RCA3 driven by six different global climate models (GCMs) under the A1B emission scenario. The present ensemble of six members allows us to estimate uncertainties in regional climate change projections related to driving GCMs and more specifically the degree of dependency of the simulated temperature, precipitation and wind extremes on driving GCMs.

The extreme events are expressed in terms of 20-year return values of annual maximum/minimum daily temperature at 2 meters, winter and summer maximum of accumulated daily precipitation and annual maximum of daily maximum gust wind. The 20-year return value is defined as the magnitude of an extreme event which occurs once in a 20-year period. The simulated results for temperature and precipitation extremes are evaluated against a daily high-resolution gridded observational data set (E-OBS) (Haylock et al., 2008).

For the control period (1961-1990, CTL) all ensemble members strongly underestimate warm extremes (about 10 °C) over Scandinavia comparing to E-OBS. However, about 70% of this negative bias is related to the fact the observations represent only the open-land temperature while the simulated temperature is individually calculated for forest and open land and then averaged. Cold extremes are underestimated over Scandinavia (up to 12 °C) in a simulation driven by the ERA40 Reanalysis and about 30% of the bias is also related to the open-land issue. Nevertheless, errors in the large-scale circulation from the driving global models strongly dominate biases in cold extremes over this region that are of opposite sign among the simulations driven by GCMs. The projected future changes (2071-2100, SCN) are in good agreement among the simulations and the ensemble mean shows an intensification of warm extremes (2-4 °C) and a weakening (up to 12 °C) of cold extremes. Such warming results in reduction of recurrence time of warm extremes from 20 years in CTL to 2-4 years in SCN while cold extremes, defined for CTL, almost disappear in the future.

Spatial patterns of biases (compared to E-OBS) in precipitation extremes for CTL show a complex, spotty structure since intense precipitation has a high degree of geographical variability defined by local topographical and meteorological conditions. The multi-model average only slightly smoothes local biases but a common tendency to a general overestimation of precipitation extremes can be identified with the exception of the south part of the Scandinavian mountains where an underestimation is evident. The ensemble mean intensity of precipitation extremes is projected to increase by 10-30% in summer and 20-40% in winter for the SCN period. Such an increase results in a corresponding reduction of recurrence time of excessive precipitation from 20 years to 6-10 years in summer and even more, to 2-4 years in winter.

The projected changes in wind extremes show a large spread among the six simulations that can reach up to 10 m s^{-1} (Fig. 1). In the ensemble mean the strongest strengthening of extreme gust winds (up to 4 m/s) is found over the Barents Sea where reduction in sea ice leads to more unstable conditions in the boundary layer and consequently to an increase in wind gusts.

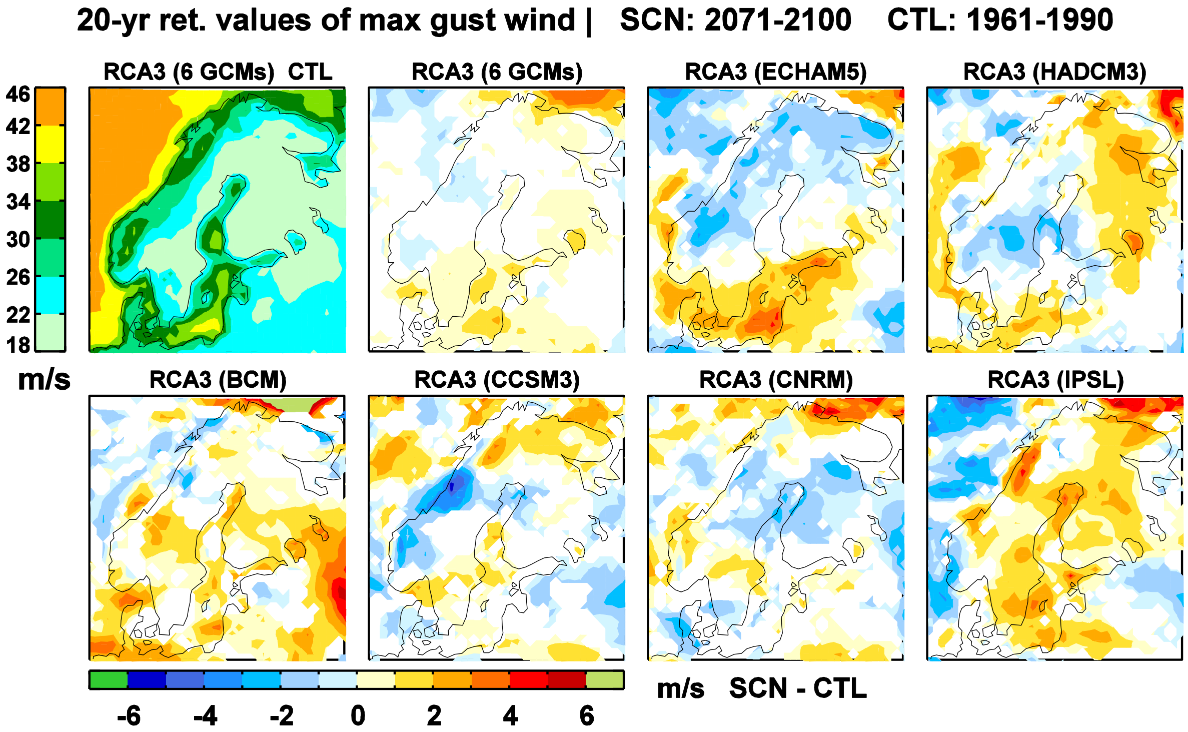

Figure 1 (top, left) The ensemble mean of the 20-year return levels of annual maximum wind gust for 1961-1990 [m s^{-1}] and the projected changes in the return levels for six individual simulations and their ensemble mean. Only the changes significant at the 10% significance level are shown.

The climate change signal over Barents Sea is robust in the sense that all simulations project strengthening of extreme gust winds there. Another region with smaller (1-2 m/s) but significant strengthening of wind extremes is southern Scandinavia with several maxima over the Baltic Sea. The Baltic Sea here is also a region where five of six simulations more or less agree in a strengthening of wind extremes that can reach 5 m s^{-1} in the individual simulations. At the same time we note that regional details of the ensemble mean changes in wind extremes are sensitive to the number of simulations in the ensemble.

For the present ensemble we can conclude that changes in temperature extremes are more robust compared to changes in precipitation extremes, since they show a consistent geographical pattern of the change that is not the case for precipitation extremes. However, we have much less confidence on the possible future changes in wind extremes for which even the ensemble mean depends on the number of simulations in the ensemble.

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Summertime Precipitation in Finland under Recent and Projected Climate

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In this study, past and projected future mean precipitation in May-September for two areas in Finland are presented using 13 regional climate model simulations and three observational datasets (Ylhäisi et al, 2010).

One of the areas is located in the south-west (SW) Finland with slight maritime influence on climate and the other in the north-east (NE) where the climate is more continental. The regional climate model simulations (1961-2100) were developed in the ENSEMBLES project (http://www.ensembles-eu.org) as well as one of the observational datasets (1961-2000), E-OBS (Haylock et al., 2008). The other two observational datasets were a high-resolution, 10 x 10 km precipitation dataset based on observations in Finland in 1908-2008 (denoted hereafter as FMI-grid) and a gridded dataset (1961-2000) provided by Climate Research Unit, CRU (Mitchell and Jones, 2005).

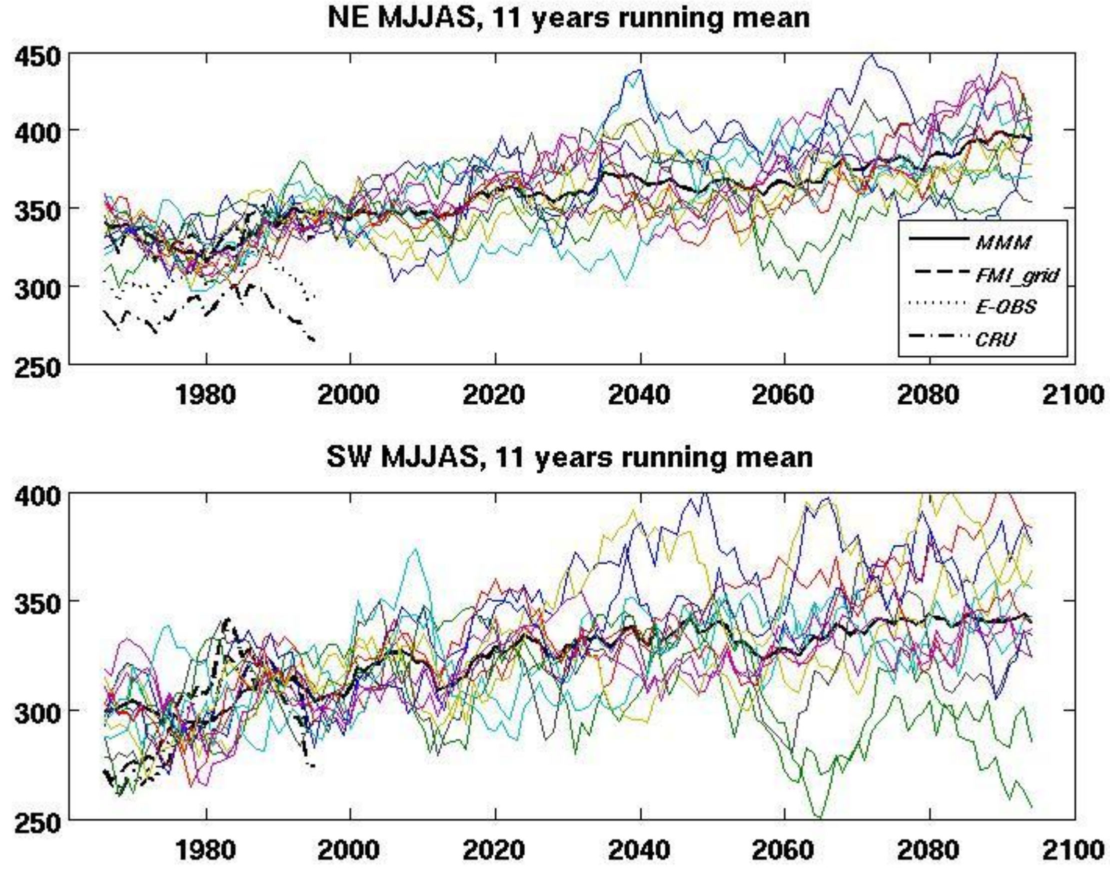

Figure 2. 11-year running means in the different observational datasets and simulations (MMM = multi-model mean) for the MJJAS precipitation sum. The model simulations are scaled so that the mean value in 1961-2000 corresponds with the mean value of FMI-grid.

Time series of monthly precipitation sum reveal considerable year-to-year variations during the period 1908-2008. Statistically significant long-term tendencies were found for June in SW and for May, July and the sum from May to September (MJJAS) in NE, suggesting increases in precipitation. In many cases, however, the long-term trends were not statistically significant and varied in sign from month to month and between the two study areas. Almost invariably, the three observational datasets agreed on the sign of the changes, whether these were statistically significant or not.

Differences between FMI-grid and the two other observational datasets during 1961-2000 were rather large in NE, whereas in SW the datasets agreed better. The larger differences in NE are likely mainly related to the smaller number of observation stations in the region. Model performance was evaluated by comparing the simulated precipitation sums and trends during the baseline period 1961-2000 to those based on the observed datasets. The models commonly overestimate precipitation. The bias was smallest in July or August, depending on the study area.

According to the multi-model mean trends over the 140-year time period 1961-2100, precipitation will increase both in SW and NE (Figure 1). All the multi-model mean trends are statistically significant. In general, the increase in rainfall is somewhat larger in NE than in SW: the increase in the MJJAS precipitation sum is 3.2 mm/10 years in SW and 4.4 mm/10 years in NE.

The increase in the monthly mean precipitation from 1961-2000 to 2061-2100 is fractionally largest in May, whereas the absolute increase is largest for July in SW and May-June in NE. Thus, in SW, the difference in the precipitation sum between the rainiest and the driest month of the summer becomes somewhat larger in the future. By contrast, in NE, the difference in the precipitation between the early summer (May-June) and July-August becomes smaller.

The large inter-decadal variability of precipitation emphasizes the use of long-term trends when examining past trends and making projections for the future precipitation amounts.

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Intense and extreme wind speeds over the Nordic countries

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1. Introduction and objectives

Our objective is to quantify possible changes in wind climates over the Nordic countries as a result of global climate change. We have a specific focus on intense and extreme wind speeds, and place particular emphasis on robust assessment of the ability of Regional Climate Models (RCM, specifically the RCA3 and HIRHAM5) and probabilistic (empirical) downscaling tools to capture current conditions, and on identification of the sources of uncertainty in wind climate projections. Since our application is to wind energy we fit a two-parameter Weibull distribution to the wind speed data (equation 1), and use the Weibull A and k to derive any percentile of the wind speed distribution (in this case the 90th percentile wind speed as a representative estimate of intense winds). Further we conform to the Wind Turbine design criteria and define extreme wind speeds as the 50-year return period wind speed (U_{50yr}) determined using the Gumbel distribution (equation 2), where α and β are the distribution parameters. For the dynamical downscaling these parameters are derived from the annual maxima approach. For the probabilistic downscaling we derive α and β from the Weibull A and k following the procedure outlined in the European Wind Turbine Standards II.

$$P(U) = 1 - \exp\left[-\left(\frac{U}{A}\right)^{k}\right] \qquad (1) \qquad\qquad U_T = \frac{-1}{\alpha}\ln\left[\ln\left(\frac{T}{T-1}\right)\right] + \beta \qquad (2)$$

2. Results

We evaluated the probabilistic and dynamical downscaling tools (RCM) for wind climates in the historical period relative to *in situ* measurements. The results imply substantial skill in simulating extreme wind speeds (U_{50yr}), but that the RCA3 RCM is biased low. See Table 1 for an example of extreme wind speeds for the historical period (1961-1990) computed by downscaling the ECHAM5 AOGCM using two RCMs and the probabilistic approach relative U_{50yr} derived from measurements at a long-term meteorological station in northern Germany.

Table 1. U_{50yr} (and 1.96σ) (m s^{-1}) estimated for 1961-1990 using *in situ* data from the Westermarkelsdorf meteorological station, output for the closest grid-cell from the RCM simulations (HIRHAM nested within the ECHAM5 Atmosphere-Ocean coupled Global Climate Model, the ERA-40 reanalysis data set, and RCA3 (both simulations) in ECHAM5) and from the closest station for which the probabilistic downscaling was undertaken. The uncertainty on U_{50yr} represents the 95% confidence intervals.

Downscaling model / nesting Global Climate Model/Reanalysis	**Latitude (°N)**	**Longitude (°E)**	**U_{50yr} (m s^{-1})**	**Uncertainty on U_{50yr} (m s^{-1})**
Westermarkelsdorf 1	54.55	11.10	26.62	3.69
HIRHAM5/ECHAM5	54.53	11.28	24.34	1.80
HIRHAM5/ERA-40	54.53	11.28	28.31	3.81
RCA3/ECHAM5 – 1st member	54.63	11.08	17.57	2.15
RCA3/ECHAM5 – 2nd member	54.63	11.08	17.72	2.28
Probabilistic: ECHAM5	54.57	12.33	26.40	1.63

We have quantified the degree of sensitivity of our wind climate downscaling to:

(i) Nesting Atmosphere-Ocean Global Climate Model (AOGCM), and to the specific AOGCM simulation (referred to herein as member) (see Tables 1 and 2).
(ii) The RCM /downscaling method applied (see Table 1 and Figure 1).
(iii) The emission scenarios (SRES) (see Table 2)

(iv) Stochastic influences within AOGCM simulations (Table 2)

We have also contextualized possible changes in extreme and intense wind speeds within downscaling uncertainties and inherent climate variability (Figure 1). Our results indicate that the major source of uncertainty in future wind climates derives from the AOGCMs used for the global climate simulations, and that natural (inherent) variability in extreme and intense winds exceeds a climate change signal until towards the end of C21st.

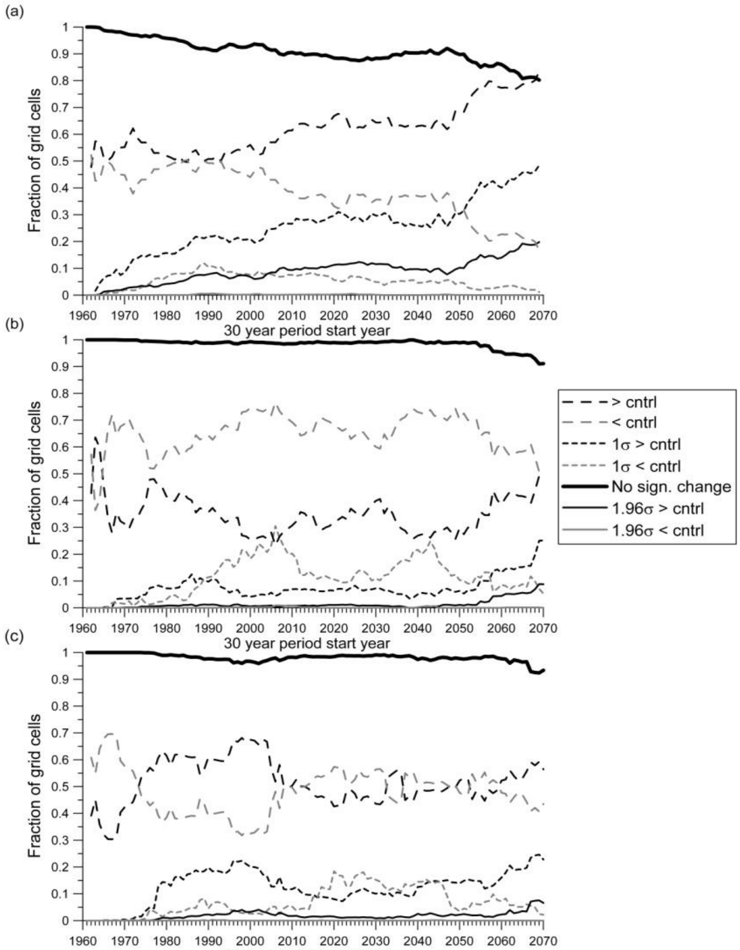

Figure 1. Fraction of the total number of grid cells in the (a) HIRHAM5 simulation of ECHAM5 member#3, (b) RCA3-simulation of ECHAM5 member #1, (c) RCA3- simulation of ECHAM5 member #2 that exhibits a U_{50yr} from a given 30-year period that is (i) above or below the U_{50yr} estimate from 1961-1990 (> cntrl and < cntrl, respectively), (ii) 1-σ above or below the U_{50yr} estimate from 1961-1990 (1 σ > cntrl and 1 σ < cntrl, respectively), (iii) above or below the 95% confidence intervals on U_{50yr} estimate from 1961-1990 (1.96σ > cntrl and 1.96σ < cntrl, respectively). Also shown is the number of grid cells for which the U_{50yr} from a given 30-year period is within the 95% confidence intervals on the 1961-1990 estimate (No sign. change). All of the AOGCM simulations assume the A1B emission scenario (SRES).

Table 2. Sensitivities of downscaled 90th percentile wind speed for 46 stations across northern Europe from the probabilistic approach. The results show the range of differences in the 90th percentile wind speed computed for 2081-2100 versus 1961-1990. Thus is the range is ±X%, the projected period lies with X% of conditions during the historical period. The variation with specific AOGCM member is shown in the last row and indicates that two simulations with the same AOGCM differ by upto ±15% (Pryor and Schoof, 2010).

Parameter	# AOGCMs	SRES	Range of estimates
AOGCM architecture	10	A2	±25%
Stochastic w/in AOGCM	5	A2 (station)	95% of realizations w/in ±10%
SRES	1	A2, A1B, B1, Commit	±15%
AOGCM member	1	2 × 20th century	±15%

3. Acknowledgements

Financial support was supplied by the National Science Foundation (grants # 0618364 & 0647868), Nordic Energy Research and the energy sector in the Nordic countries.

4. References

Pryor S.C. and Schoof J.T. (2010): Importance of the SRES in projections of climate change impacts on near-surface wind regimes *Meteorologische Zeitschrift (in review).*

Climate Change Impacts on Hydrological Regime in Latvia

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Climate change and changing meteorological conditions are closely related to changes in hydrological processes and have a direct impact on the production of hydro energy as well as on dam safety. The biggest hydropower plants in Latvia produce approximately 50% of electricity consumed per year in the country. Climate change impacts on hydrological regime might have a significant effect on a hydropower production.

The paper presents the results of study on climate change impact on hydrological regime in Latvia river basins. The HBV model was used for the possible climate change scenarios studies. The Plavinas HPP on Daugava River and the Aiviekstes HPP on Aiviekste River were the objects of the case study.

The HBV model was calibrated and validated for both river basins. The results of calibration showed a good coincidence between the observed and simulated daily discharges from 1961 to 1990: the Nach-Sutcliffe efficiency R^2 for both basins were 0.83. The validation of model was done for the 5-years period from 2005 to 2009. The statistical efficiency R^2 obtained for validation period varies from 0.74 for Aiviekstes HPP to 0.92 for Plavinu HPP.

The assumption of future (2021-2050) climate conditions was based on results of the three climate models DMI-HIRLAM-ECHAM5, MetNo-HIRLAM-HadCM3, SMHI-RCA3-BMC with the SRES A1B. The climate model results were downscaled using statistical downscaling method (Sennikovs and Bethers, 2009). The comparison of mean annual runoff, seasonal runoff, and winter-spring and summer-autumn flood maximum has been done between simulations for control period 1961-1990 and scenarios period.

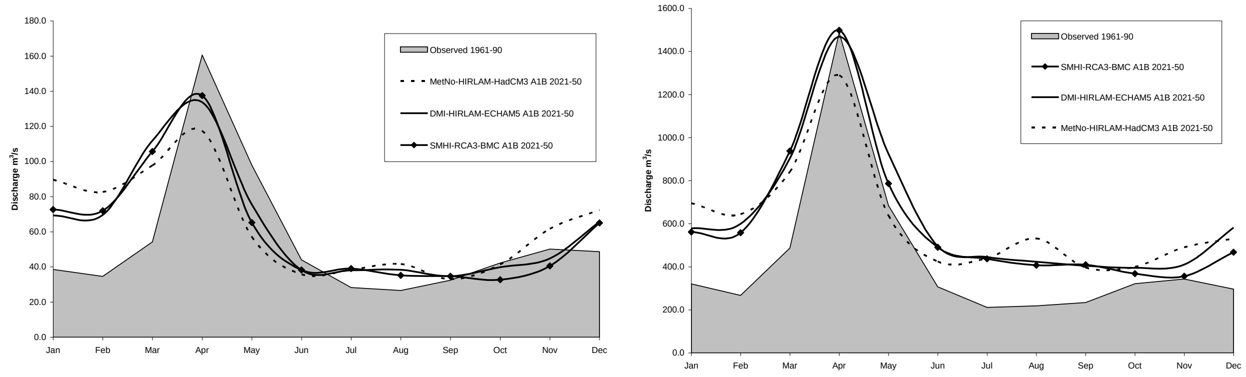

Figure 1. Monthly distribution of runoff under present and future conditions. Left: Aiviekste HPP, Right: Plavinas HPP.

According to all scenarios the annual runoff is going to increase by 19-27%. The most remarkable increase of runoff was found for winter (DJF) season (by 30-70%). All scenarios showed the decrease of runoff for the period April-May (by 6-39%), except SMHI-RCA3-BMC scenario showed small increase of runoff for Plavinu HPP in April (Figure 1).

The analysis of flood maximum shows that under all three scenarios for Aiviekste HPP the winter-spring flood will be reduced by 6 to 20 % whereas for Plavinas HPP scenarios will cause insignificant changes in range of increasing by 2% to decreasing by 10%. The summer-autumn flood maximum will generally decrease for Aiviekste HPP and increase for Plavinas HPP. Increasing of winter and summer flows is obvious in both basins. Streamflow changes in winter are strongly linked to changes in snow regime.

Positive runoff tendency in summer season will lead to a positive effect on the work of the HPP and energy production as a whole. The negative trends of maximum discharge in spring are conductive to a safe work of the HPP during extreme floods.

Sennikovs, J. and Bethers, U. 2009. *Statistical downscaling method of regional climate model results for hydrological modeling.* 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009 http://mssanz.org.au/modsim09

Floods in Norway under a near future 2021-2050 climate: Hydrological projections for rainfall *vs.* snowmelt floods and their uncertainties

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Hydrological projections from three ENSEMBLES scenarios (DMI/ECHAM5/HIRHAM5; SMHI/BCM/RCA3; Met.no/HadCM3Qref/HIRHAM) and 25 HBV models, calibrated for each of 115 catchments in Norway, were used to investigate likely changes in flooding between a 1961-1990 reference period and a 2021-2050 future period. Two downscaling methods, the delta change method, and an empirical adjustment method (Engen-Skaugen, 2007), were used to transfer the climate change signal to a 1 by 1 km grid. These input data and models generated an ensemble of 150 hydrologic scenarios for each catchment. Simulated discharge was analysed using flood frequency estimation based on the annual maximum flood series, and the magnitude of the 200-year flood was estimated for each scenario. The percentage change in the magnitude of the flood between the reference and the future periods was calculated, and the results were compiled as probability functions for each catchment, as described in Lawrence, *et al.*, 2008. The median percentage change and the change with a 90% likelihood of non-exceedence, are illustrated for the 115 catchments in Figure 1.

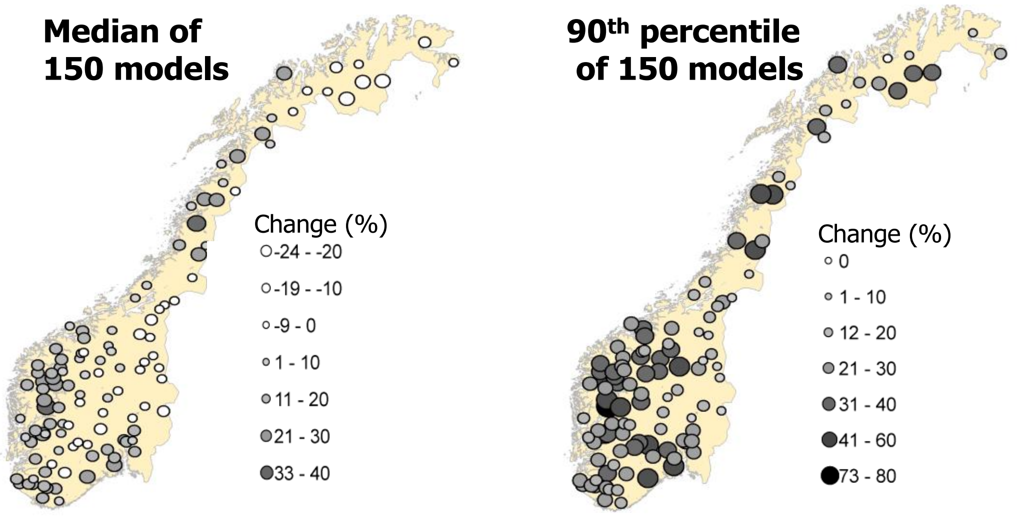

Figure 1. Percentage change in the 200-year flood between the reference period (1961-1990) and the future period (2021-2050).

The results indicate a general regional pattern in which the magnitude of the 200-year flood is expected to increase in western and southwestern Norway and along much of the coast. In more inland areas currently dominated by snowmelt flooding, the magnitude of the 200-year flood is expected to decrease based on the ensemble median. These results are consistent with previous hydrological projections for the period 2071-2100 (*e.g.* Beldring, *et al.*, 2008). The 90th percentile represents a more extreme case in that 90% of the projections for each catchment indicate an increase in the 200-year flood which is equal to or less than the given value. The overall pattern is generally similar to the median of the projections, although some differences are also apparent.

For example, the three catchments associated with the largest decreases (-20 to -24%) based on the median show disproportionately larger increases in the 200-year flood (31 to 40%) when the 90th percentile of the ensemble is considered. This discrepancy reflects the larger uncertainty in the projections for these catchments, and this is also found in other catchments currently dominated by snowmelt flooding in other regions.

A seasonal analysis was also applied to investigate projected changes in rainfall flooding. An increase in the occurrence of rainfall-induced floods within the annual maximum flood series was found in nearly all of the catchments currently dominated by annual snowmelt floods. In several of the smaller catchments amongst these, the largest event within the 30-year annual maximum series for the 2021-2050 period is rainfall-induced, occurring in the autumn, although no rainfall-induced autumn/winter flooding events are found in the annual maximum series during the reference period. Rainfall floods were analysed using a peak over threshold (POT) series, extracted based on the mean annual rainfall flood during the 1961-1990 reference period for each catchment. Event clusters were identified based on the pattern of input precipitation and the flood recession in each catchment. Changes in the number of events between the 1961-1990 and 2021-2050 periods support the increased frequency of high flow events associated with heavy rainfall, with smaller catchments exhibiting more sensitivity to this change. The increase in rainfall floods is supported by projections for changes in extreme precipitation M5, the 24-hour precipitation with a return period of five years. This has been analysed for the 115 catchments considered here, and the largest increases in M5 are often associated with inland catchments for which the annual flood series is currently dominated by seasonal snowmelt flooding.

Uncertainties in projections were analysed based on the multiple RCMs, the downscaling methods, the 25 HBV models for each catchment, and the fitting of the extreme value function for estimation of the 200-year return periods. Larger uncertainties in the projections tend to be associated with catchments currently dominated by snowmelt flooding, as flood generation in these catchments is sensitive to both temperature and precipitation changes in the RCMs. In some cases, the magnitude of HBV model uncertainty is, however, as large as the difference between the projections for individual RCMs. Downscaling methods also contribute to differences in projections for individual catchments, with the delta change method often indicating larger increases in the occurrence of rainfall floods. Uncertainty associated with the fitting of the extreme value function for estimating the 200-year return period dominates uncertainty, however, and is generally of a magnitude greater than or equal to the uncertainty derived from the ensemble of climate projections.

Beldring, S., et al. 2008. Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological stations. *Tellus* 60A, 439–450

Engen-Skaugen, T. 2007. Refinement of dynamically downscaled precipitation and temperature scenarios. *Climate Change*. 84:365-382.

Lawrence, D. et al. 2008. Integrated framework for assessing uncertainty in catchment-scale modelling of climate change impacts: Application to peak flows in four Norwegian catchments. In Sveinsson, O.G.B., S.M. Gardarsson, and S. Gunnlaugsdottir (eds.): *XXV Nordic Hydrologic Conference*, NHP Report No. 50, 182-190.

Climate change and lake regulation in Finland
Impacts and adaptation possibilities

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In this study, the impacts of climate change on hydrology and water resources of Finland and the possibilities to adapt to these changes by altering lake regulation practices were estimated (Veijalainen et al. In press). The study was carried out in Finnish Environment Institute (SYKE) as a part of Finnish national WaterAdapt-project and Nordic CES-project financed by Nordic Energy Research.

In Finland there are more than 300 regulated lakes, which are regulated mainly for hydropower, flood protection and recreational purposes. Lake regulation requires a legal regulation permit, which in many cases includes upper and lower regulation limits for water levels. Often these limits include a mandatory lowering of water levels at certain set dates in spring to make room for the snowmelt flood. Temperature increases projected by climate scenarios will change the timing and magnitude of runoff. Many of the current regulation permits will no longer function properly in these changed conditions and as much as half of the regulation permits may need revision due to climate change (Silander et al., 2006).

Finnish Environment Institute's Watershed Simulation and Forecasting System (WSFS) (Vehviläinen et al., 2005) was used to simulate the impacts of climate change on hydrology. The WSFS includes a HBV-type conceptual watershed model used for operational forecasting and research purposes in Finland. The simulations were performed in several lakes in ten watersheds in different parts of Finland with an ensemble of climate scenarios for 2010–2039, 2040–2069 and 2070–2099 with a baseline period of 1971–2000. The baseline temperatures and precipitations were changed using the delta-change approach.

Different regulation practices were simulated in the WSFS by using operating rules, where certain water level at certain time of year corresponds to specific outflow. In the reference period the operating rules on average corresponded to the current regulation practices. The climate change simulations were carried out with the similar operating rules as in the reference period and additionally with modified regulation. The modified operating rules took the changed climate with shorter and wetter winters better into account and had milder and earlier lowering of water levels during winter and spring. Figure 1 shows an example from Lake Höytiäinen, where the current regulation limits are broken during spring with the modified regulation to avoid low water levels in summer.

The results show that changes of runoff cause the current regulation practices with a winter and spring lowering of water levels to function poorly on many lakes by 2040–2069. In large lakes in southern and central Finland the largest challenges in the future will be autumn and winter floods and occasional summer dryness. To adapt to these changes and to decrease the negative effects of climate change, many of the regulation practices and limits have to be changed (Fig. 1). In northern Finland the changes in seasonality are smaller, snowmelt floods remain the largest floods and the changes required in regulation practices are smaller.

The new regulation permits and limits should be flexible to function properly in a variety of conditions. Winters with large amounts of snow will still occur even in southern and central Finland especially in 2010–2039, which means that storage space for spring snowmelt floods may still be required. On the other hand, winters with low snow accumulation and large runoffs will become more common and the new regulation practices should take this into account. Decreasing and earlier spring floods and longer and warmer summers increase the risk of low water levels in summer and early autumn, and therefore the lake water levels should be high enough before summer.

The mild winters of 2006–2008 already demonstrated that in southern Finland some of the regulation permits do not function well in warmer conditions. Therefore it is important to assess the suitability of the current regulation permits and practices in future conditions to avoid situations where unsuitable regulation will aggravate problems caused by climate change.

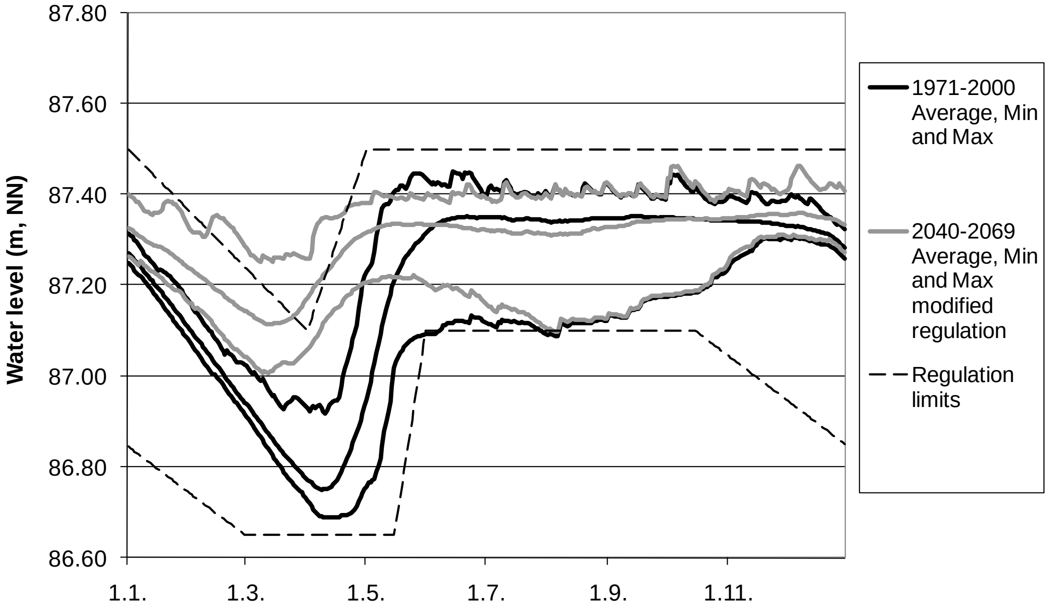

Figure 1. Average, minimum and maximum water levels in Lake Höytiäinen in eastern Finland in the reference period 1971–2000 and in 2040–2069 with the modified regulation rules. The climate scenario used is an average from 19 global climate models with A1B emission scenario.

Silander, J., Vehviläinen, B., Niemi, J., Arosilta, A., Dubrovin, T., Jormola, J., Keskisarja, V., Keto, A., Lepistö, A., Mäkinen, R., Ollila, M., Pajula, H., Pitkänen, H., Sammalkorpi, I., Suomalainen, M. and Veijalainen, N. 2006. *Climate change adaptation for hydrology and water resources.* FINADAPT Working Paper 6, Finnish Environment Institute Mimeographs 335, Helsinki.

Vehviläinen, B., Huttunen, M. and Huttunen, I., 2005. *Hydrological forecasting and real time monitoring in Finland: The watershed simulation and forecasting system (WSFS).* In: Innovation, Advances and Implementation of Flood Forecasting Technology, conference papers, Tromsø, Norway, 17–19 Oct 2005.

Veijalainen, N., Dubrovin, T., Marttunen, M. and Vehviläinen, B., In press. Climate change impacts on water resources and lake regulation in the Vuoksi watershed in Finland. Water Resources Management. DOI: 10.1007/s11269-010-9614-z, available online.

Swedish Guidelines for Design Floods for Dams in a Changing Climate

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Introduction

The simulation scheme for design flood determinations in Sweden was developed in the 1980s when it became obvious that current criteria were obsolete. The new guidelines were adopted in 1990 and a nation-wide re-evaluation programme of all major dams in the country started. In a recent new edition of the guidelines (Svensk Energi et al., 2007) it is prescribed that climate change shall also be considered in the design studies. This has led to a research project with the aim to analyse possible impacts of climate change on the design floods and to find means to account for climate change in future design studies.

A number of drainage basins and dams, relevant for the power industry and the mining industry, have been selected for the studies of climate change impacts on design floods. In these basins, floods are calculated with available regional climate scenarios for the future. Focus for the design studies in a changing climate is on the first half of the 21st century, but simulations will also be made up to the year 2100.

Results

Figure 1 shows one example of simulations for the Seitevare dam in upper River Lilla Luleälv. Shown are changes in the major components of a design simulation for high hazard dams (category I according to Swedish guidelines).

Results so far show that global warming may have great significance for dam safety, flood risks and the production of hydroelectric power in Sweden. The milder and more unstable winters in the future also means that there is a risk that spill will be released more often. This affects both dam safety and the lives of those who live along the rivers. Higher winter flows are at the same time beneficial to the production of hydroelectric power.

The results also show that there is considerable uncertainty. The difference between different climate scenarios is large when it comes to impacts on design floods. The floods can either increase or decrease depending on how changing precipitation patterns interact with new snowmelt conditions. It is therefore crucial to use more than one climate scenario in this type of studies and to take uncertainty head-on, rather than shying away from it. There is more than one answer to the question of how global warming will affect the most extreme floods in a river system.

User dialogue

The Swedish research on impacts of climate change on design floods for dams is monitored by a committee with representatives from the dam safety authority, the power industry, the mining industry and the SMHI. The task of the committee is to analyse and discuss new results and to recommend how climate change shall be accounted for in future design studies. This will have strong impact on future design of dams but also on physical planning along the shorelines in Sweden, as the same flood criteria are used for flood risk mapping.

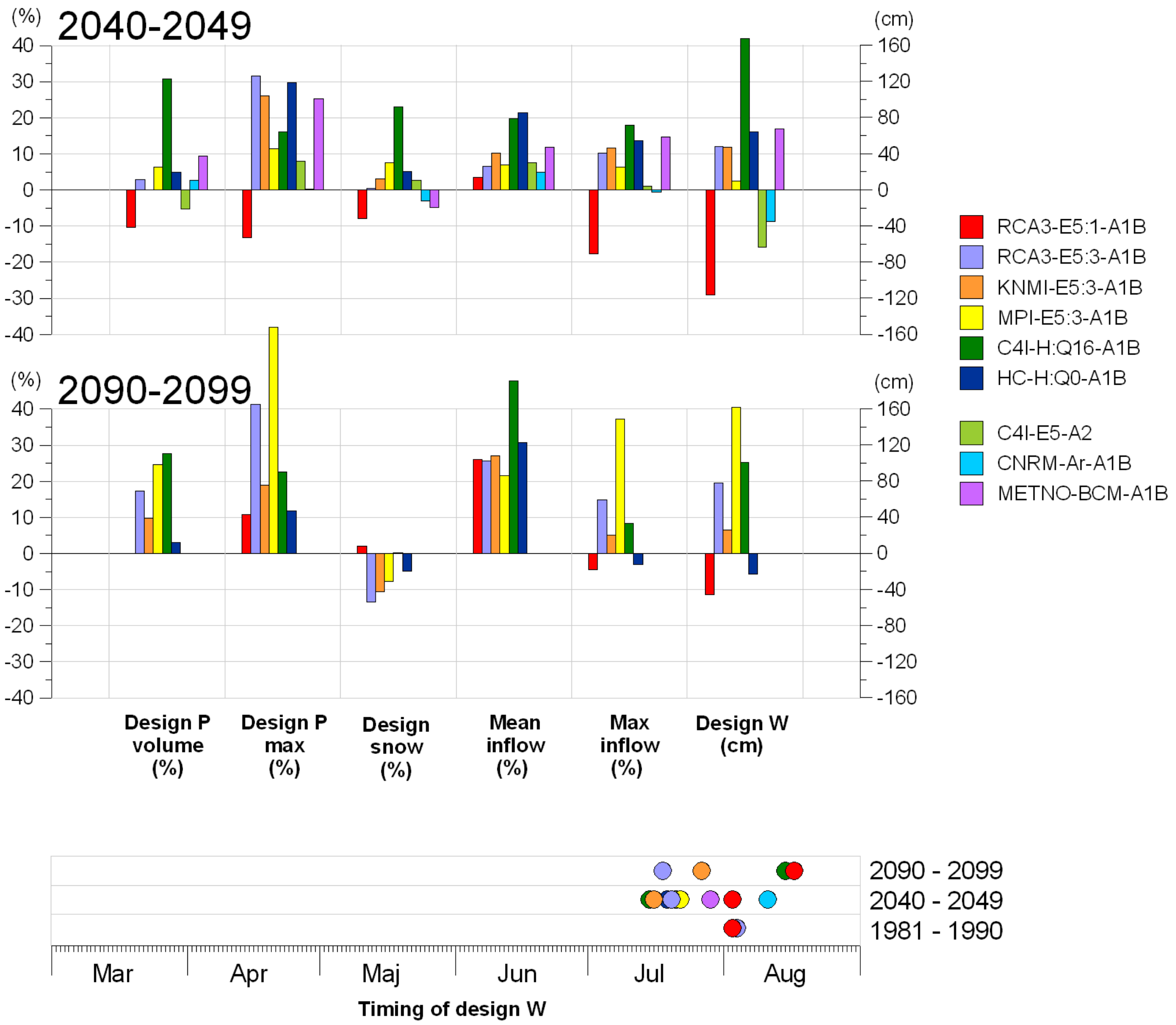

Figure 1. Changes in the main components of a design flood simulation for the Swedish high hazard dam Seitevare, based on several regional climate scenarios. *Design W* denotes change in the design level of the reservoir. The bottom graph shows how the timing of the most severe flood shifts in a changing climate (from Andréasson et al., 2009).

Acknowledgements

The Swedish research on climate change and design floods is financed by the Swedish dam safety authority (Svenska Kraftnät) and the power industry via Elforsk. The Nordic co-operation, within the CES-project, is financed by Nordic Energy Research.

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Svensk Energi, Svenska Kraftnät och SveMin (2007) Swedish Guidelines for Design Flood Determination for Dams – New edition 2007.

The impact of climate change on glaciers and glacial runoff in the Nordic countries

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Possible changes in glacier mass balance and consequent changes in glacier margins and land-ice volumes are among the most important consequences of future climate change in Iceland, Greenland and some glaciated watersheds in Scandinavia. Global sea level rise, observed since the beginning of the 20th century, is to a large extent caused by an increased flux of meltwater and icebergs from glaciers, ice caps and ice sheets. The increased flux of meltwater from land-ice has, apart from rising sea levels, potential global effects through the global ocean thermohaline circulation. It has also local effects on river and groundwater hydrology of watersheds adjacent to the glacier margins, with societal implications for many inhabited areas. Changes in glacier mass balance and glacier geometry for several ice caps and glaciers have been modelled with mass balance and dynamic models to estimate the future response of the glaciers to climate change as specified by the CES climate change scenarios. Many glaciers and ice caps are projected to essentially disappear over the next 100–200 years. Runoff from presently glaciated areas may increase on the order of 50% or more with respect to the 1961–1990 normal period in the next few decades for typical glaciated watersheds in the Nordic countries. The simulated runoff increase is in most cases not sensitive to the dynamic response of the glaciers during the initial decades of the runoff simulations, *e.g.* during most of the time period 2021–2050 covered by the CES climate scenarios, as we find that the reduction of ice volume and ice-covered area has little effect compared with a fixed ice-cover. After 30–50 years, depending on the climate scenario and the size of the glaciers in question, the results of coupled model simulations start to diverge from runoff simulated with a fixed ice-cover and after more than ~100 years the simulated glacial discharge component is crucially dependent on realistic simulation of the decreasing ice volume. The expected runoff increase may have practical implications in connection with the use of water in various sectors of society. Changes in water divides and changes in river courses may also have important consequences.

One of the goals of the CES project is to investigate the uncertainty of the climate development over the next several decades by employing many different climate change scenarios that allow the separation of a deterministic climate trend from the natural variability of the climate. Figure 1 shows simulated ice-volume and runoff changes to 2050 for the Hofsjökull ice cap in central Iceland for thirteen climate change scenarios based on both GCM and RCM simulations for the A1B emission scenario together with the temperature and precipitation changes specified by the scenarios. Before 2010 the model is forced with observed temperature and precipitation records. The same scenarios have been used to force a degree–day mass balance model for an unchanged ice-covered area and ice surface altitude distribution, a mass balance model coupled to a simple volume–area scaling glacier model and a mass balance model coupled to a dynamic ice-flow model.

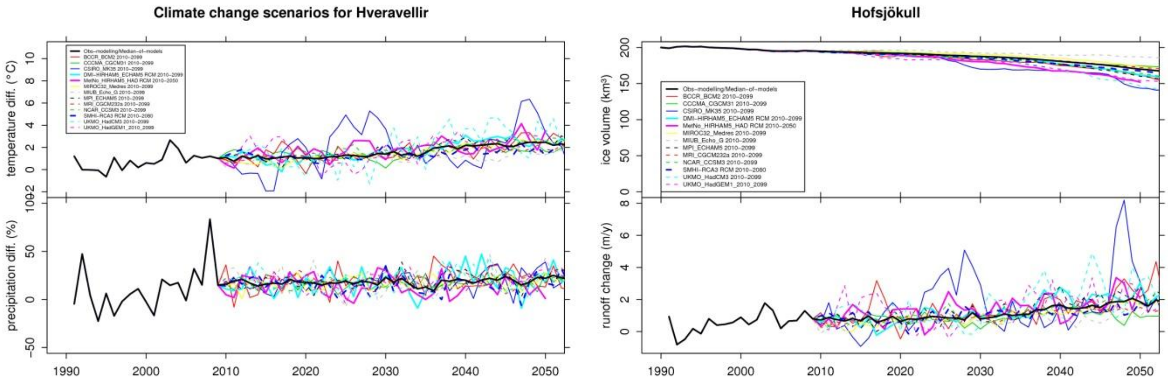

Figure 1. Climate change scenarios for Hveravellir, central Iceland, (left) and ice-volume and runoff changes for the Hofsjökull ice cap modelled with a degree–day model for a constant ice-covered area and ice surface altitude distribution (right). The solid black curves show past observations and modelling of runoff based on them and the median of the simulated future ice-volume and runoff changes. The changes are for technical reasons with respect to the period 1981–2000 but this is very similar to the CES reference period 1961–1990. One scenario (solid blue curves) shows rather large inter-annual temperature variations compared with the others.

The scenarios show considerable annual and decadal variations in temperature and precipitation which lead to substantial future variations in runoff superimposed on a rising trend and a slow reduction in ice volume. The median of the runoff changes fluctuates close to ~1 m/y after 2010 and rises to ~2 m/y near the middle of the century. In spite of the annual fluctuations, the simulated runoff changes are almost always positive and their magnitude is such that increased glacier runoff will be substantial for watersheds with only 10% glacier coverage or less. Similar modelling of the Langjökull and southern Vatnajökull ice caps in Iceland, shows that the runoff change is dependent on the altitude distribution of the glacier, the magnitude of precipitation on the ice cap and other climate characteristics.

Modelling of glaciers in Iceland and Scandinavia (with ten GCM-based A1B temperature and precipitation scenarios) for deriving projections of total ice volume changes shows that the simulated glacier response depends crucially on the employed scenarios and on the methodology used to implement them in glacier mass balance models so that ice loss by the end of the 21st century varies by an order of magnitude between scenarios. This point is reinforced by mass balance modelling of the Paakitsoq area in western Greenland using two RCM climate simulations where modelled equilibrium line altitudes differed by hundreds of metres.

Coupled mass-balance and ice-dynamic modelling or mass-balance/glacier-scaling and hydrological modelling has been carried out in the CES project for three ice caps in Iceland (Langjökull, Hofsjökull and S-Vatnajökull), three ice caps and partly glaciated catchments in Norway (Midtdalsbreen, Nigardsbreen/Nigardsbrevatn, *Fønnerdalsvatn*), two glaciers in Sweden (Storglaciären and Mårmaglaciären) and mass balance modelling for the Paakitsoq area in Greenland. The results indicate that substantial changes in ice volumes and glacier runoff may be expected in the future and that the glaciers are already considerably affected by human-induced climate changes. Glacier changes and runoff variations in the next few decades will nevertheless be much affected by natural climate variability as they have been in the past and predictability is, in addition, limited by scenario-related uncertainties.

Volume changes of the glaciers in Scandinavia and Iceland in the 21st century

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Introduction

Glacier volume changes will have direct impacts on water resources and management. In Iceland and Scandinavia glaciers cover roughly 11,000 and 3,000 km^2, respectively, and strongly influence terrestrial hydrology. The purpose of this study is to project volume changes from all glaciers in Scandinavia and Iceland until the year 2100 based on climate output from Global Climate Models (GCMs).

Methodology

First we apply an elevation-dependent mass-balance model with monthly time step to glaciers with available mass-balance. Ablation is computed for each elevation band by a degree-day model assuming different degree-day factors for snow and ice. Snow accumulation is computed from precipitation. A threshold temperature is used to discriminate snow from rain precipitation. Annual refreezing is computed from annual mean air temperature according to Woodward *et al.* (1997). The model is forced by gridded climate data: We use monthly near-surface air temperature from ERA-40 and precipitation data from the precipitation climatology by Beck et al. (2005). Due to coarse grid resolution we apply corrections to both the temperature and precipitation data. We correct for the bias in the temperature data by a „statistical lapse rate" between the ERA-40 altitude of the grid cell where the glacier is located and the highest altitude of the glacier. For precipitation we apply a precipitation correction factor. „Statistical lapse rate" and precipitation correction factor are treated as tuning factors. Bias corrected temperature and precipitation are then extrapolated across the glacier elevation bands using horizontal lapse rates which are further tuning parameters.

The model is calibrated for each glacier so that maximum agreement between modeled and observed mass-balance profiles is achieved for the years for which measurements exist. Hence, for each glacier a glacier specific set of model parameters is obtained. We assume the model parameters to vary as a function of climate variables available in the gridded climate datasets. We investigate relations between model parameters and climate variables through multiple regression analysis. The resulting relations are then used to assign model parameters to all grid cells that contain glaciers but mass balance data do not exist.

We then apply the mass balance model to each individual glacier in Iceland and Scandinavia. For Scandinavia we use data from the recently updated World Glacier Inventory (WGI-XF, Cogley, 2009). Coverage is complete for this region and we extract for each glacier location, area and if available highest and lowest elevation. For Iceland we use data from 16 ice caps from the Icelandic Inventory provided by O. Siguròsson (personal communication, 2008). Smaller mountain glaciers are assumed negligible for our regional analysis and hence neglected. Initial glacier volumes are taken from Radić and Hock (2010).

As a final step the model is run for each glacier using downscaled monthly 21st century temperature and precipitation scenarios from ten GCMs, forced by the A1B emission scenario. As the glaciers lose mass their volume, their area and hypsometry will change and affect the mass balance. We account for these changes using volume-area-length scaling (Radić et al., 2008).

Results and conclusions

In Scandinavia and Iceland the ten GCMs project temperature increases between roughly 2 and 4.5ºC by 2100. While in Scandinavia all GCMs show an increase in precipitation by the end of the 21st century, in Iceland some GCMs show an increase, others a decrease. Projected volume changes strongly differ from each other depending on the choice of the GCM. For Scandinavia two GCMs project a slight increase in volume until 2100, while all other GCMs project a decrease in volume ranging from 20 to 80% loss of initial volume.

Projected volume changes by 2100 vary from almost complete disappearance of glacier ice to no mass loss or even slight mass gain, depending on the choice of the GCM. Hence, there is a large scatter in results indicating large uncertainty in the GCM projections of air temperature and precipitation in both regions.

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Surface Mass Balance of the Greenland Ice Sheet in the Paakitsoq Area, Illulisat, West Greenland - Scenarios and Related Uncertainties

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The Paakitsoq area in West Greenland has been previously investigated with respect to its hydropower potential (Ahlstrøm et al., 2008). Within the Framework of the CES project this work is continued with special emphasis on the surface mass balance of the ice sheet. We aim on adding a range of uncertainties to the previous estimates of the hydropower potential by using more than one climate scenario and using newly available observational data for validation.

A simple glacier surface energy balance model is used to calculate the surface mass balance of the ice sheet. The model considers the most important terms of the surface energy balance and includes a simple parameterization of refreezing. For input the spatially distributed model requires fields of climate model data. A two stage validation procedure is implemented into the mass balance model: (1) Regional climate model (RCM) data (i.e. the model input) are compared to observations from weather stations as well as gridded climatologies and (2) the modelled mass balance (i.e. the model output) is compared to measured mass balance.

The mass balance model is driven from two different RCM climate scenario runs, acquired from the Danish Meteorological Institute (DMI) and from Rossby Center, Sweden (SMHI): a HIRHAM4 model run for the B2 scenario for 1950-2049 and an RCAO model run for the A1B scenario, 1970-2080). The RCM grids are of approx. 25 km and 50 km spatial resolution, respectively, and are downscaled to the resolution of the mass balance model (1 km) by means of statistical downscaling and sub-grid parameterizations.

For validation of the regional climate model (RCM) data, we use the newly available accumulation maps from Burgess et al. (2010) as well as weather station data from the GC-net and DMI. The comparison revealed differences for both RCMs.

Initial model runs for 1980 - 2000, using uncorrected RCM data, resulted in a modelled ELA of 1250 m a.s.l. (HIRHAM4) and 2050 m a.s.l. (RCAO). Observed ELA in the area is at around 1200 m a.s.l. and these results are not very promising with respect to establishing a range of uncertainty. The worse performance of RCAO has several reasons: The model is still in an experimental stage, the spatial resolution is coarser and the scenario run is a pan-arctic run whereas HIRHAM4 was applied only to Greenland. Nevertheless, based on the validation a bias correction for both RCMs was constructed. Assuming a constant bias in time, bias corrected future scenario calculations were finally performed.

Acknowledgements: We greatly acknowledge Ralf Döscher from SMHI and Martin Stendel from DMI who made the climate model output available to us.

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The Nordic power system in 2020 – Impacts from changing climatic conditions

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Introduction

The objective of this study is to analyze the Nordic power market under changing climate conditions. The analysis is based on an assumed 2020 system configuration, that is simulated with three different climate scenarios (i.e. hydro inflow and temperature). The reference climate scenario is based on observed climatic variables from the period 1961 to 1990, whereas the remaining two scenarios are forecasted climatic variables, provided by project partners from models "met.no-HIRHAM-HadCM3-A1B" and "DMI-HIRHAM-Echam5-A1B", for the period 2021 to 2050. The simulation results show how demand, generation and transmission change, for a fixed system configuration, when climatic conditions are altered.

Methodology

The system simulations are carried out using the EMPS-model (Wolfgang, Haugstad, Mo, Gjelsvik, Wangensteen, & Doorman, 2009). EMPS simulates the optimal operation of the Nordic system and the interconnection to continental Europe. Simulations give detailed results for power production for different technologies, demand, prices and exchange between the Nordic areas and with the connected European countries.

Recently, automatic calibration has been introduced in the EMPS model, reducing the dependence on user interaction. This feature results in a more consistent response on hydropower production to climate change compared with earlier analyses.

Power system input data

The system is modeled as the current system modified with expected changes for 2020. The model contains a description of 110 thermal power plants in the Nordic countries, described by capacity and marginal cost. Marginal costs are calculated on basis of predictions for fuel- and CO2-quota prices, combined with efficiency and fuel input parameters for each individual power plant. Expected capacity development towards 2020 is based on Eurelectric"s statistics report (Eurelectric, 2009). The model includes 1108 hydropower modules with a detailed description of reservoirs, discharge and relevant constraints. Electricity prices in continental Europe are given exogenously.

Results

The predicted average annual inflow represents an increase of 10-12 % compared to reference conditions. A significant part of this increase stems from more inflow during the winter season.

Hydropower production is expected to increase with 9-10 % for the NordPool region. No prominent temporal changes have been found.

Spillage is expected to increase with 35 – 40 % for the NordPool region. We find that spillage during winter is the major component in the increase.

Reservoir handling is expected to change towards less variation in reservoir levels over the year. The main reason is that reservoirs will be less empty during late winter/early spring. See Figure 3 for an illustration of average annual inflow, reservoir handling and hydro production.

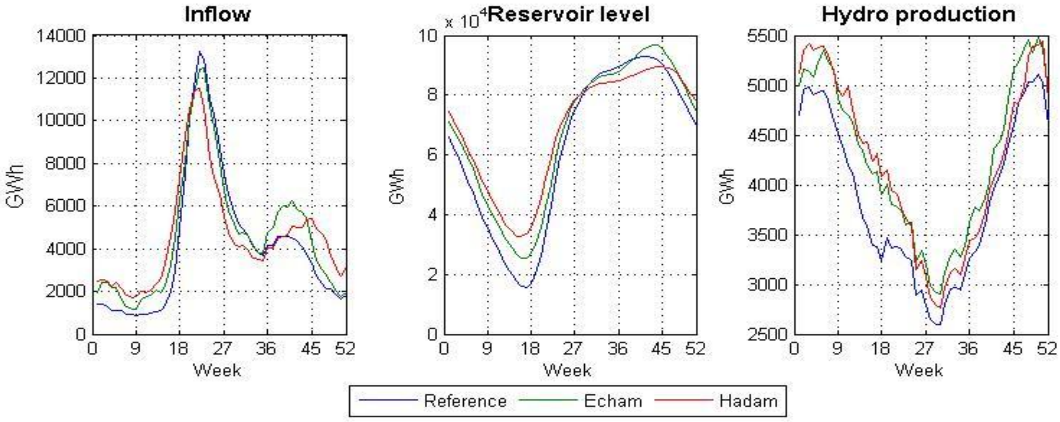

Figure 3: Average annual properties for the NordPool region, (GWh)

Annual average thermal production is expected to decrease with 7-8 % for the NordPool region. No particular seasonal pattern has been found.

Annual average demand decrease with 2 - 2.5 % for the NordPool region. The decrease is relatively stronger during winter than summer.

Electricity spot prices go down in all countries in the climatic scenarios. The reduction in Denmark is relatively small compared to the other countries, due to its strong connection to the European market and its lack of hydropower generation. The probability for high prices during late winter is reduced for all countries and the probability for long periods with low prices during summer increases.

All countries (excluding Finland) increase their net export to continental Europe. The hydro dominated systems (Norway and Sweden) also increase their net export to other NordPool countries. Total net export increases for the hydro dominated systems while Denmark and Finland reduce their total net export. All countries but Finland are net exporters in the climatic scenarios.

Due to the reduction in thermal power production, all countries contribute to a reduced total CO_2 emission in the Nordic region. The increased hydropower production stimulates more export to, and less import from Europe. This reduces European thermal power production, and leads to reduced CO_2 emissions in the European region. This type of emission reduction can be credited to the Nordic region and represents the strongest contribution to total Nordic CO_2 reductions. The annual average reduction is approximately 25 Mtonne CO_2, or 60 %, compared to the reference.

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Impacts and adaptation of the hydroelectric industry in the province of Québec, Canada

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Abstract

Hydro-Quebec, a public utility responsible for supplying electricity to its domestic customers as well as neighbouring Canadian provinces and American states, generates 97% of its energy from 59 hydroelectric power houses with a total installed capacity of 36,426 MW. The availability of this precious fuel being climate dependent, the utility is aware of the potential impacts of climate change on the resource and decided a decade ago, to undertake extensive research aimed at tackling this major issue.

It appears that the combination of warmer and consequently shorter winters and higher summer temperatures and the ensuing increases in evaporation, as well as the greater increased precipitation that will affect the region where the major portion of electricity is produced, are liable to considerably modify the quantities and the temporal distribution of water supplies to existing plants and to potential new hydroelectric developments.

Thus, we investigated the impacts of climate change on the hydrological regimes of Québec's developed watersheds in order to elaborate adequate adaptation strategies over the upcoming decades. We found that the annual water availability may increase while the intra-annual inflow pattern could vary to an extent that operating rules would have to be reassessed in order to optimize electricity generation at existing and planned power houses.

1. CLIMATE CHANGE IMPACTS

The impact analysis was initially performed using the well known "delta method", which consists of adding differences in temperature and precipitation (ratio) obtained from Climate Models (future climate) to climate observations (reference climate). We have considered 90 different climate projections (issued from different combinations of Climate Models and Greenhouse Gas scenarios from IPCC AR4). Both climate databases (observations as the reference and modified observations for time horizon 2050) were used as inputs to a global conceptual daily hydrological model to simulate actual and future hydrological regime (90 different simulations) of 94 watersheds in Québec (1,5M km^2), Canada. Given the drawbacks associated with the "delta method", we also decided to apply the "direct" and the "unbiased direct" methods (Roy et al., 2008). We felt more comfortable interpreting our results from a wide ensemble of possible hydrological regimes (3 methods and 90 climate projections). Figure 1 (a, b and c) shows maps of the expected mean runoff changes (horizon 2050) obtained from each of the 3 methods, while panel d) shows the dispersion between the 90 hydrological simulations. It appears that no significant changes are foreseen in southern Québec while surplus of water may be observed along the northern shore of the St-Lawrence River. On the other hand northern Québec may have to deal with significant runoff surplus, in the area where we produce a significant portion of our hydroelectricity. Those results are not method-sensitive insofar, as all three panels (a, b and c) show the same regional patterns. With respect to dispersion (panel d), it is interesting to note that in the area where the runoff increase signal is stronger, the dispersion between the 90 hydrological simulations is rather small.

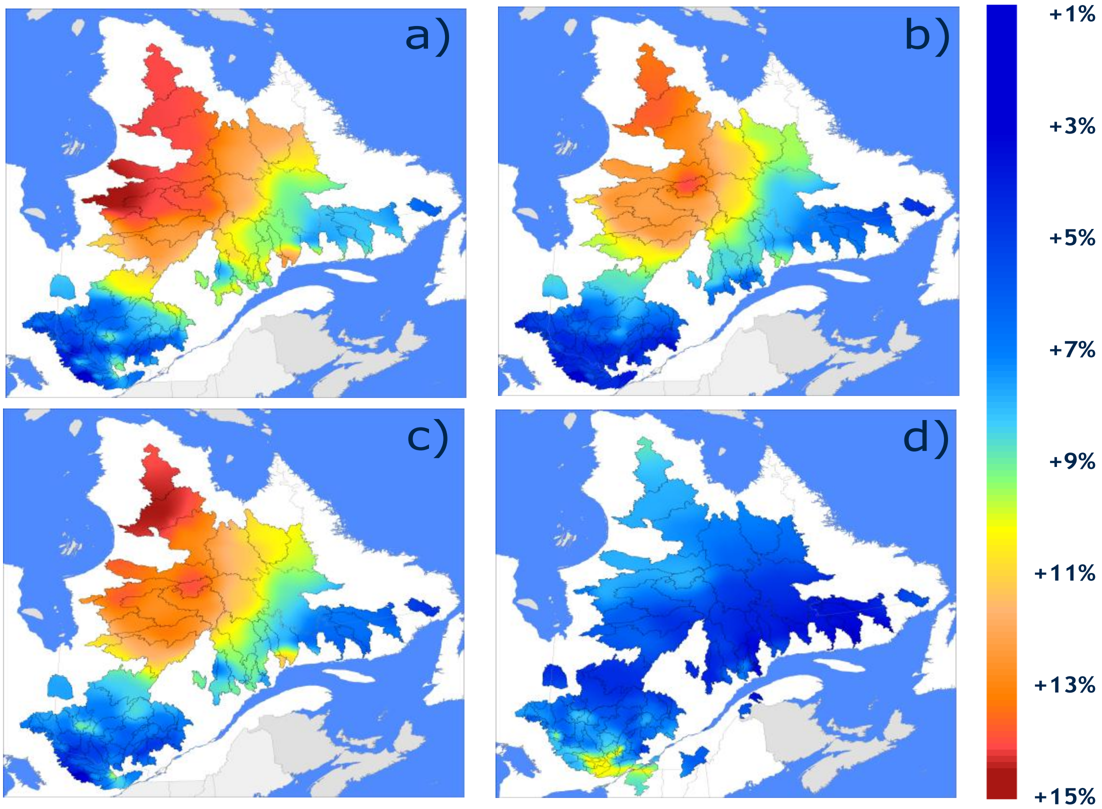

Figure 1 : Expected runoff changes [2050-actual] obtained from hydrological simulations (1 hydrological model fed by 90 climate projections), according to a) the delta method, b) the direct method, c) the direct method unbiased. Panel d) shows the dispersion between the 90 hydrological simulations.

2. THE BENEFITS OF ADAPTATION

Based on foreseen hydrological conditions (10 different future runoff conditions), we have simulated the output of power houses for the Peribonka River system, Québec, Canada i) after and ii) without adaptation of the current operating rules of the hydraulic structures (Minville et al., 2009, Pacher et al., 2009). We have shown through this experiment, that adaptation measures could lead to an increase of up to 15% in hydroelectric generation, whereas without adaptation of the operating rules, and despite the increase in water availability, output could be reduced by 14%.

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Hydropower in Iceland
Impacts and adaption in future climate

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All of the biggest hydroelectric power stations in Iceland are fed by glacial rivers. Over the last few decades some changes have been observed in both the volume and the seasonal distribution of river flows and further enhanced changes are expected in future climate. These changes will have impacts on the utilization and operation of existing power stations and should also be taken into account in the design of new ones. In order to be prepared for these changes Landsvirkjun (The National Power Company) has analyzed the operation of it‟s hydroelectric system with different expected “stationary” flow scenarios in the period 2010 to 2050.

A conceptual rainfall-runoff model is used to create five different flow scenarios which are based on perceived trends in historical measurements and prediction of future climate trends. The expected trends in future climate are derived from Nordic projects on climate, water and energy systems 2002-2010 and from IPCC reports. Temperature trends were estimated to be 0.75 °C/century in the period 1950–1975, 1.55 °C/century from 1975 to 2000 and 2.35 °C/century after 2000. Within the year these trends were seasonally distributed according to the interpretation by meteorologists of climate model results of future expected changes. With these estimated trends historical climate measurements from 1950 to 2005 were transformed into the future by adding the total change from time of measure to the target time. This way five different temperature scenario series, one for each year; 2010, 2015, 2025, 2035 and 2050 were created. Similar methods were used for precipitation and glacier area-volume-elevation curves. Using these transformed measurements as input for the runoff model the five different “stationary” flow scenarios were created.

Analysis of these scenarios show that potential energy in the total river flows to the Landsvirkjun‟s power system is expected to have increased by 20% (2.8 TWh) in 2050. The major part of this increase is explained by added runoff in glacial rivers, ranging from 27% to 84% for individual rivers. There are also differences in the seasonal flow pattern. Spring comes early causing earlier snowmelt, flow is lower in the start of the summer but in late summer glacier melt is significantly higher. Small winter floods occur more often. Changes in direct runoff and spring feed rivers is much smaller, around 5% for most rivers.

The current production system is not designed to meet these changes in runoff and will, in 2050, only be able to utilize 38% of the increment, equal to a production increase of 8.5% (1 TWh), see figure 1. This rate is low compared to the present utilization of more than 85% of the potential energy in the river flows. There are a number of reasons for this drop. Iceland has a hydro dominant system with a 30% share of geothermal energy and negligible thermal (diesel/gas) production capacity. As a result of this Landsvirkjun‟s hydroelectric stations function as base load stations with the peak load being only 15% higher than the base load. The means that the utilization of the stations is high, 6570 h/yr compared to a worldwide mean of 3854 h/yr (Energy Information Administration international statistics database, 2006). This has resulted in a design with sufficient but little additional reservoir capacity and limited extra power that will run out if flow increases as predicted.

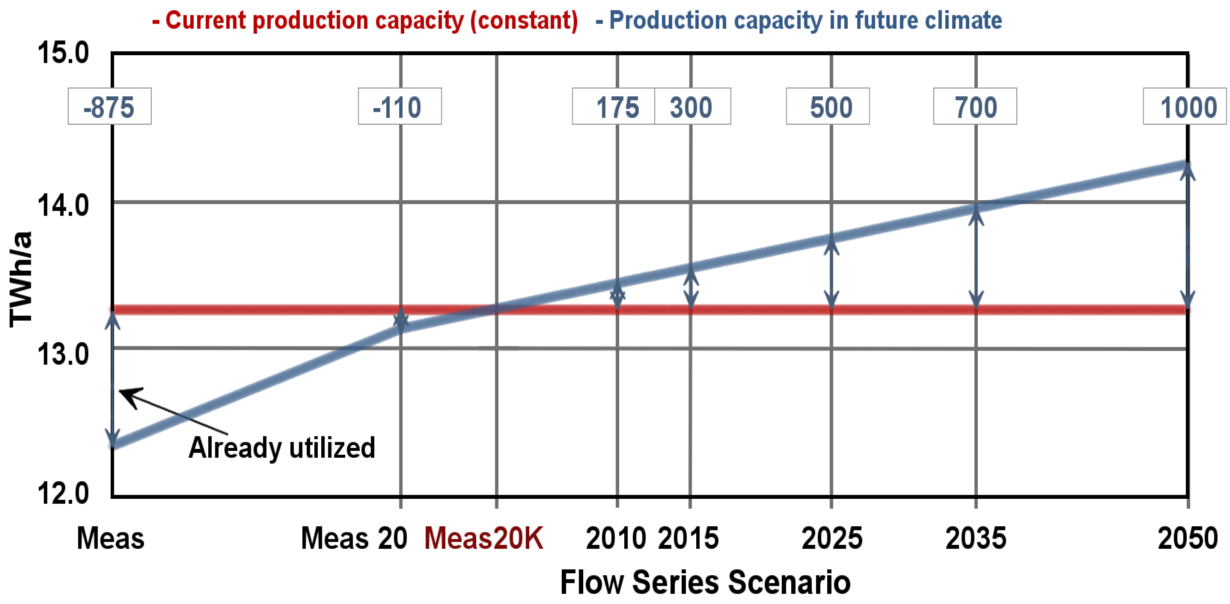

Figure 1: Possible production increase in warming climate. Meas, Meas20 and Meas20K are flow scenarios based only on historical measurements. Numbers in boxes show difference between current (Meas20K), future and past production capacity.

The results of this study are being used for more detailed analyzes on possible redesign and upgrades of current power stations and revaluation of future projects that have been proposed. Increase in production has been estimated by simulating the power system with new or altered design using these flow scenarios. The results have been used to give valuable information for taking decisions on future investments.

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Forest biomass for energy production – Potentials, management and risks under climate change

Future Climate and Renewable Energy – Impacts, Risks and Adaptation

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The EU is committed to reduce its greenhouse gas emissions by 8% and raise the share of renewable energies to 20% by 2020, which will evidently increase the utilisation of various sources of bioenergy also in Nordic and Baltic countries. A large-scale harvesting of forest biomass for energy (energy biomass) will raise the question how sustainable the energy systems based on biomass are. The production of energy biomass needs fossil energy and enhances the emission of greenhouse gases, thus negating the benefits of the production. In addition, information on the environmental effects of the energy biomass production is needed, for example, on nutrient leaching for the whole production chain, to assess the risks of the large-scale energy biomass production. Carbon and energy input calculations are, therefore, important to evaluate the contribution of forests and energy biomass in reducing emissions and storing of carbon.

In Finland, the traditional way of managing forests has been to produce timber (sawlogs and pulpwood). However, environmental concerns and climate change mitigation and adaptation strategies will set new objectives for the forest management since recovery of energy biomass timber harvesting, and carbon in the growing stocks are largely affected by management practices (e.g. thinning intensity and timing) (Alam et al., 2008). Thinning in young stands yield biomass suitable for energy, likewise provide more growing space for the remaining trees as well as accelerate the accumulation rate of carbon in the growing stocks. Sawlogs, pulpwood and energy biomass (logging residues i.e. the stem tops, branches, roots and stumps) are produced in older stands during commercial thinnings and final felling. It has been shown that undisturbed forests or elongated rotation length could store more carbon in the forest ecosystem, but this would reduce the timber production suitable for industrial purposes (Alam et al., 2008). This could also decrease the production of energy biomass due to a decreased availability of logging residues. Novel forest management systems for the production of energy biomass are needed in order to enhance the climate change mitigation in the context of energy production.

The general objective of this study was to investigate production of energy biomass along with timber, and carbon sequestration and storage in forest ecosystems in Finnish conditions. The effects of climate change and forest management on these factors were studied according to the recent climate scenarios and by changing current forest management recommendations. This approach reveals not only the production potential of energy biomass, but also facilitates to assess the holistic role of forests in climate change mitigation and fossil fuel substitution.

The study was conducted by using an ecosystem model (Sima), which simulates forest growth and development according to the implemented forest management. In addition, an emission calculation tool was developed and it was used together with Sima in assessing the carbon dioxide emissions of the management operations in the production chain, such as harvesting and transportation. The production chain was covered from plant production in nursery to the chipped biomass, pulpwood or sawlogs into the yard of power plant, pulp mill or sawmill correspondingly. The Sima model was run for 90-year period and obtained results were used as an input for the emission calculation tool. In the model, energy biomass was produced, integrated with timber, in energy biomass thinning (small-sized trees) and final fellings (logging residues, roots and stumps). Two climate scenarios (current and changing climate) were utilised with varying forest management regimes. Forest management regimes were varied by increasing initial stand densities and changing thinning regimes based on current forest management recommendations. By doing this, energy biomass and timber production as well as forest growth and carbon stocks were studied jointly with the related emissions. This kind of comprehensive assessment would help to compare energy biomass with other bioenergy sources and implicate in the forest policy of the climate change mitigation.

Table 1. Impacts of thinning and climate on energy biomass production and fossil fuel substitution potential derived at energy biomass thinning (EBT) and final felling (FF) over the simulation period in Finland. M0 represents current thinning regime.

Thinning regimes	Under current climate			Under climate change		
	EBT	FF	Total	EBT	FF	Total
(basal area thinning thresholds)	*TWh yr^{-1}			*TWh yr^{-1}		
M0 (no changes in thresholds)	8.7	40.4	49.1	17.8	67.5	85.4
M1 (15% increase in thresholds)	8.7	43.9	52.6	18.1	72.8	90.9
M2 (30% increase in thresholds)	8.4	46.4	54.8	18.4	76.4	94.8
M3 (45% increase in thresholds)	8.1	48.7	56.8	19.0	80.3	99.3

*Conversion factor: 19.23 GJ/t (energy biomass thinning) and 19.00 GJ/t (final felling) at 20% moisture content of biomass. 1 GJ = 0.2778 MWh.

The results showed that changes both in climate and thinning regimes may increase substantially the production potential of energy biomass at energy biomass thinning and final felling over the whole of Finland (Table 1). The production potential at energy biomass thinning was found to be higher in northern (above 64° N) compared to southern (below 64° N) Finland, but the case was opposite at final felling both in current and changing climate. Increased basal area thinning thresholds enhanced energy biomass production at final felling during 2040-2069 and 2070-2099 when compared with current thinning regime. Increased thinning thresholds also enhanced timber production during the period 2040-2069 and carbon stocks in the forest ecosystem over the simulation period. Simulation results also showed that increasing initial stand density enhanced the energy biomass production at energy biomass thinning regardless of climate scenarios. It was concluded that a concurrent increase in energy biomass and timber production as well as carbon stocks in either climate scenarios would be possible in Finnish forests if thinning was performed at a higher thinning thresholds level than in the current recommendation. The emission calculation for energy biomass production indicated that depending on management regimes and species-specific site type, carbon dioxide (Kg) emissions per one MWh of energy biomass could be reduced or increased up to 6% or 4%, respectively, compared with current thinning regime. Therefore, it was suggested that mitigation and adaptation in forest management and changes in forest policies need to be considered not only from the view point of the forest productivity but also the ecological sustainability related to the carbon balance of the forest production system.

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Climate change and the UK solar energy resource

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Introduction

Solar energy is the most abundant renewable energy source available on Earth. It presently counts for a very small proportion of generated energy, but growing concerns over climate change have helped stimulate a marked growth in implementation over recent years. This is set to dramatically increase as solar technologies mature and costs reduce. However, climate change will affect seasonal cloud cover and impact the available solar resource on the Earth‟s surface. This study assesses the seasonal solar resource of the UK and investigates the impact climate change could have on the resource. It uses probabilistic regional climate change scenarios released as part of the United Kingdom Climate Projections study (UKCP09).

Data and Methods

A UK solar radiation resource baseline model was developed to represent the present climate. The main data source is 30 years of historical monthly averaged sunshine duration data (Met Office 2009). All sunshine data was first converted to solar radiation using a method described by Suehrcke (2000) then averaged over the 30 year period. Figure 1 shows baseline monthly average radiation resource for summer months (June, July and August).

Validation of the conversion method (Suehrcke 2000) and the baseline model were performed by identifying UK Met Office weather stations measuring both solar radiation and sunshine duration parameters (Met Office 2006), then converting sunshine duration to solar radiation and comparing it to the actual measured solar radiation. Eighteen weather stations were found to meet these requirements and the comparisons were found to be very good. Data for locations on the baseline model where the weather stations are situated also compared well.

The UKCP09 climate change projections provide probabilistic projections for a wide range of climatic variable including „total downward surface shortwave flux‟ which is good indicator of solar resource. There are projections for seven 30 year time periods ranging from 2010 to 2099, for three future emission scenarios (low, medium and high) representing alternative climate responses to levels of future emissions, as specified in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES). The probabilistic projections give relative probability of different outcomes and are designed to capture modelling uncertainty. This study will adopt the probabilistic climate change method used by UKCP09 where the central estimate (50% probability) is followed, in brackets, by changes very likely to be exceeded and very likely not to be exceeded at (10 and 90% probability). This study focuses on output for the 2050s. It was generated by projecting the UKCP09 climate change anomalies onto the baseline solar radiation model.

Results

All ranges have been examined and one is presented here. By the 2050s, under a „medium emissions‟ scenario, summer months (Figure 1) show solar radiation increases of up to 7.9% (-0.2% to 18.1%) in the south west, these reduce further north with decreases of up to -2.9% (-10.8% to 1.8%) in the north of Scotland. Winter months show a reduction throughout the UK with extremes of -7.6% (-25.2% to 10.1%) in mid west Scotland. This shows that most parts of southern UK will get sunnier and benefit from increased solar energy resource in summer, while the relatively poor resources in the north will decrease slightly. All regions in winter will have increased cloud cover and slightly reduced solar energy resource. The UK will see an overall annual increase of 2.6% (-1.1% to 6.5%), which is positive news for the viability of solar technologies, particularly in southern regions and would correlate well with increased use of air cooling systems due to the increased temperatures. However, the resource will be more seasonally variable and regional resource differences will be further reinforced.

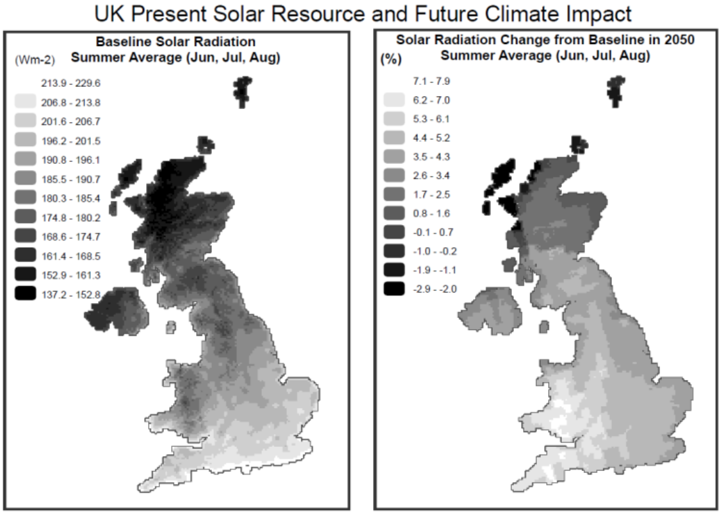

Figure 4. Present UK average solar radiation resource for summer months (jun, jul, aug) and a future climate change projection for the 2050‟s.

Conclusion

Accurate estimations of mean monthly solar radiation resource have been generated from mean monthly sunshine duration measurement data using a method described by Suehrcke(2000). A baseline model of present climate UK solar radiation has been developed and validated. UKCP09 climate change projections have been used to show climate change impact in percent change relative from baseline.

Acknowledgements

© Crown Copyright 2009. The UK Climate Projections data have been made available by the Department for Environment, Food and Rural Affairs (Defra) and Department for Energy and Climate Change (DECC) under licence from the Met Office, Newcastle University, University of East Anglia and Proudman Oceanographic Laboratory . These organisations accept no responsibility for any inaccuracies or omissions in the data, nor for any loss or damage directly or indirectly caused to any person or body by reason of, or arising out of, any use of this data.

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Climate policy uncertainty and investment risk - Evidence from small hydropower plants

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In the coming years, the world will need more electric power from renewable resources. Norway is well positioned to contribute with additional capacity. However, climate policy uncertainty represents a risk for investor so that even profitable investments in renewable capacity may be postponed. This claim is supported by reference to recent contributions in real option theory and illustrated by actual data from 225 small hydro power concession grants.

Decisions on whether and when to invest in new capacity will depend on uncertainty with respect to future cash flows generated by the renewable electricity projects. One source of uncertainty is climate policy. The uncertainty may be with respect to the future level of fluctuating market prices on climate policy instruments like CO2 emission quotas or green certificates. Or, the uncertainty may be with respect to the future climate policy itself. For instance, what will happen when the Kyoto protocol expires in 2012?

Real option theory can be used to translate climate policy uncertainty into investment risk. A license to build a wind power farm or a small hydropower plant is a real option, where the investor has the right, but not the obligation, to pay the investment cost to get the cash flow of the project. Faced with a risky irreversible decision, investors will value the opportunity to gain additional information about likely future conditions affecting the project. This could mean delaying investments until uncertainty has been partly resolved.

There is a new and growing literature on the use of real option theory to predict investor‟s responses to both energy market and climate policy uncertainty. Fuss et al. (2008) find that policy-driven uncertainty such as uncertainty in the total CO2 quota levels postpones investment in emission-reducing technologies. Fleten and Ringen (2009) derive predictions regarding the amount of renewable capacity in Norway under a joint Swedish-Norwegian electricity certificate scheme. Faced with stochastic electricity and certificate prices, the investors will value the option to wait and postpone otherwise profitable investments.

An interesting question is whether investors faced with climate policy uncertainty behave according to the real option theory. The authors shed some light on this issue by examining 225 concessions to hydro power plants given in the period 2001-2009 in Norway. These data were provided from NVE, and in a MSc thesis Wenngren (2009) used these data to derive optimal investment decisions according to real option theory assuming stochastic electricity prices.

Using this data set, the authors test the validity of the option value investment rule derived by Wenngren (2009) against the traditional net present value investment rule. While a traditional discounted cash flow investment rule is: invest now if the discounted revenues exceed the discounted costs, an option value investment rule would be: invest now only if the discounted revenues exceed the discounted cost by a margin sufficient to overcome the value of waiting:

$$(1)\ NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} - I \geq T$$

where NPV is the net present value of the project, CF_t is the net cash flow generated by the investment at time t, r is the required rate of return, I is the investment and T is the value of waiting.

The examination shows that although all the 225 power plants were expected to give a positive net present value at the time when the concession were given, only 74 were built by March 2009. The real option model derived by Wenngren (2009) predicted that 195 were profitable according to his real option model. Thus, although the Wenngren‟s option model does not fully explain investor‟s behavior, it does a better job than the traditional net present value model. Further research will require better data as to when the investment decision were made. It will also require a better modeling of not only electricity price but also climate policy uncertainty.

Knowledge on how investors respond to uncertainty with respect to the impact of existing climate policy or with respect to the future climate policy itself may help authorities to design tailored policies to achieve its targets for renewable electricity. It may also illustrate the social benefits of committing to long-term stable policies which reduces investors‟ risk.

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Climate change and UK electricity network capacity

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The current-carrying capacity (ampacity) of overhead conductors within the electricity network is limited by the thermal properties of their constituent materials. At the limit of a line‟s design capacity (or thermal rating), exceeding a pre-defined temperature will result in sag – where the line may become too close to the ground – or loss of strength. Current flowing through a line causes a heat gain, known as „joule heating‟. Radiative and convective cooling effects counteract some of the heat gain but in instances of higher ambient temperature, less cooling will occur and thus allowable levels of current will be more limited.

Generally in the UK, the thermal ratings of conductors are calculated by network operators as „static‟ long-term properties, assuming typical mean seasonal temperatures of 20°C in summer, 2°C in winter and 9°C in autumn and spring (ENA, 1986), and often using conservative estimates of the other contributing factors such as wind speed (IEEE, 2007). However, climate change models indicate rises in mean temperature in all seasons, which will reduce the current assumed ratings. Alongside this, as the penetration of renewable energy increases, particularly on low voltage networks, the networks will be more likely to need to carry larger currents. This combination of warming and greater loads could present a capacity problem for network operators.

The United Kingdom Climate Projections 2009 (UKCP09)[i] provide the most high resolution and up-to-date probabilistic modelling of climate change in the UK. UKCP09 provides projections for 30 year time periods from 2010 to 2099 under three future emission scenarios (low, medium and high). In order to carry out a basic analysis of how temperature change – as projected by UKCP09 – could affect conductor ratings in the UK area, a subset of data containing the changes in mean summer and winter temperatures for a selection of future time periods and probability levels under the „medium‟ emissions scenario were extracted. Using the IEEE Standard (2007), the thermal rating of a common type of conductor („lynx‟) was calculated under current summer and winter temperatures as well as under future scenarios in which current temperatures were increased by the changes described by UKCP09. The results indicate that by the 2050s, in the case of a temperature increase at the 90% probability level, the average thermal rating of a lynx conductor decreases by up to 4.5% in the worst-affected region. A change at the 10% probability level results in a decrease of between 1 and 2% in rating. The winter temperature changes are, in general, smaller than those in summer and so the resulting decreases in conductor rating are proportionately less.

Taking this analysis a step further, it is clear that the worst case scenario for network operators will occur under conditions of maximum seasonal temperatures and may vary over the UK regions. By calculating the thermal rating of this hypothetical conductor based on current gridded (25km) long-term average summer maximum (rather than mean) temperatures [ii]over the whole area and comparing these to ratings calculated from temperatures perturbed by the future projected changes (on the same 25km grid), the spatial variability of the worst case scenarios can be analysed.

The decreases for the 2050s at the 10% probability level are between 0.5 and 1.5% from the baseline, but under the „worst‟ scenario for this time period (90% probability), as shown inFigure 1, the rating shows significant drops. In percentage terms, the changes in rating range from around a 3.5% decrease in the northern part of the country to a 7.5% decrease in the southernmost regions. As the southern half of the UK already experiences higher peak summer temperatures, it follows that the lowest ratings are seen in this region. The UKCP09 model projects greater temperature rises in the south, further increasing the difference between maximum temperatures in the two regions, and consequently giving rise to greater differences in thermal ratings over the country.

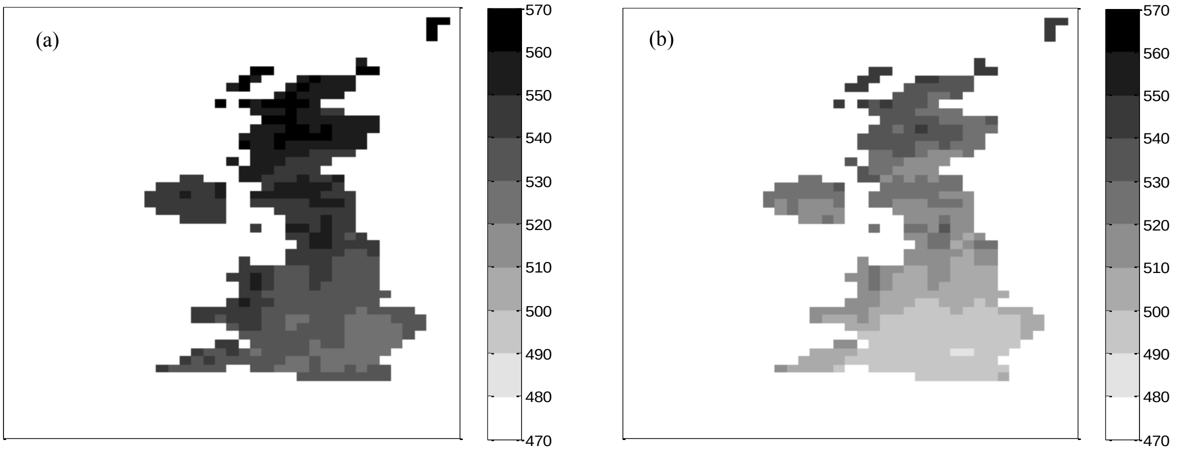

Figure 1: Ratings calculated at maximum summer temperature for (a) the baseline period and (b) 2050s @ 90% probability level (Amperes)

From the analysis of the mean changes, the summer season is clearly more vulnerable to thermal limitations due to the higher temperatures experienced. The point of greatest concern is the change in the summer maximum temperature, particularly in the southern half of the UK. The connections for renewable generation tend to be considered more likely in northern areas where resources are greater, and there is somewhat less vulnerability to thermal capacity constraints here. However, a further consideration is the possibility of increased electricity demand in periods of hot weather (Parkpoom & Harrison, 2008). This will be more probable in southern areas due to higher temperatures, and potentially more severe due to a higher population density in the south. Network operators may need to consider using dynamic real-time calculation of line ratings taking local weather variables into account, rather than using seasonal averages, which may allow for some mitigation of the possible problems.

References

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Parkpoom, S, Harrison, G.P. 2008. 'Analyzing the Impact of Climate Change on Future Electricity Demand in Thailand', *IEEE Trans. Power Systems*, **23** (3), 1441-1448.

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[i] © Crown Copyright 2009. The UK Climate Projections (UKCP09) have been made available by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Climate Change (DECC) under licence from the Met Office, UK Climate Impacts Programme, British Atmospheric Data Centre, Newcastle University, University of East Anglia, Environment Agency, Tyndall Centre and Proudman Oceanographic Laboratory. These organisations give no warranties, express or implied, as to the accuracy of the UKCP09 and do not accept any liability for loss or damage, which may arise from reliance upon the UKCP09 and any use of the UKCP09 is undertaken entirely at the users risk.

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Using the CES risk assessment framework in the distribution sector

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Climate change poses a significant risk for existing infrastructure for transmitting and distributing power in the Nordic region. Increased extremes in weather conditions are predicted. These may place new and greater demands on ensuring security of power supply in the Nordic region. Recognising and identifying risks associated with changes in weather patterns is an important step towards planning of new infrastructure investments and mitigating potential damage to existing transmission and distribution infrastructure in the power sector.

VTT of Finland developed a risk assessment tool aimed at identifying climate change risks for power generators. The goal of this analysis was to further develop VTT"s risk management tool in order that it could be applicable and accessible for power distribution companies as well. The tool is intended to act as a first step in developing a strategy for identifying and acting on potential risks associated with climate change. The tool does not aim to be exhaustive nor a template for professional risk managers, but rather a tool for laymen as a first step in initiating a response to climate risks.

Two case studies were used in order to identify the risks for distribution companies in a changing climate and further develop the risk management tool to encompass the requirements of grid operators. Both case studies were Danish distribution companies, one in western and southern Zealand and one on the west coast of Jutland. The case studies were carried out in brainstorming sessions with members of the distribution companies" management. The case studies were carried out consecutively. Alterations to the risk management tool from the first case study were carried over to the second for further development and input.

Both case studies suggested that the risk management tool would be more user-friendly if expected changes to weather patterns were included as climate was not an area of competence for distribution companies. It was also suggested that the risk management tool also include standard adaptation measures to climate risk. This was proposed due to the uniform nature of electricity distribution compared to the generation sector where technologies can vary greatly from power plant to power plant. A list of standard responses would allow distribution companies to use the risk management tool as a benchmark.

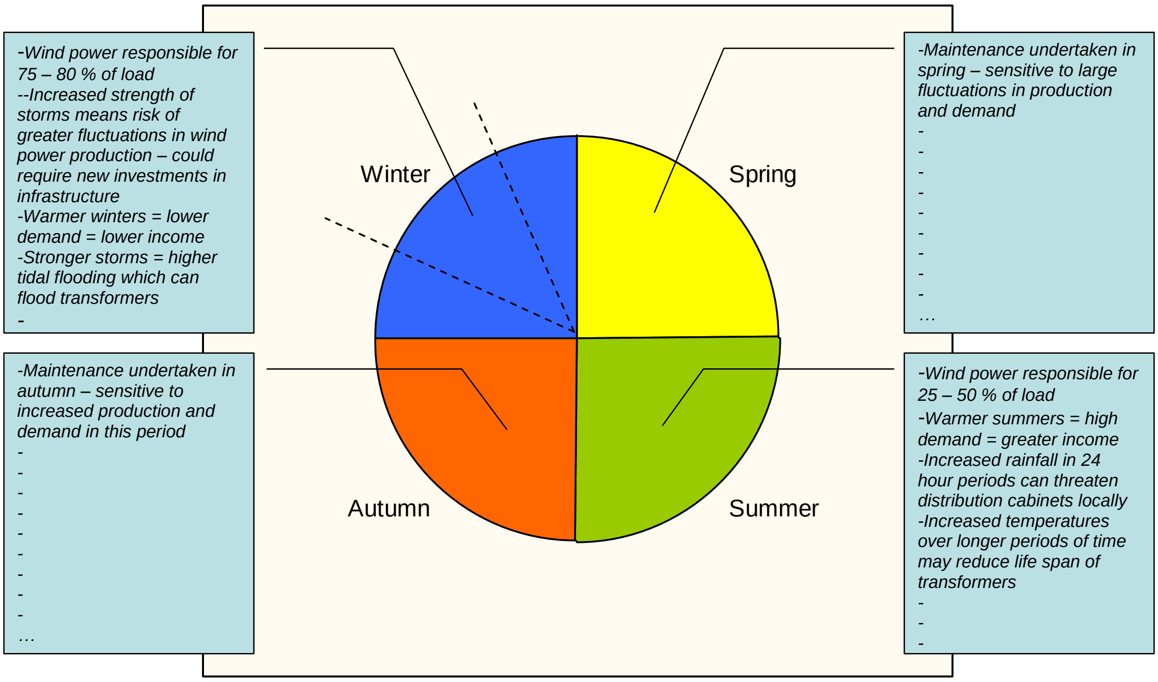
The brainstorming sessions revealed that both distribution companies felt that the grid was already well prepared for most of the risks presented by climate change. This was mostly due to the Danish policy of replacing overhead lines with underground cables, which greatly reduces many weather related risks. The major risk at present for distribution was the flooding of distribution boxes due to increased downpours or tidal surges due to stronger storms. Adaptation measures were already in place for these issues in the form of elevated distribution boxes in areas prone to flooding. Increased corrosion of transformers due to salt spray being blown further in land was also identified as a new and serious problem due to changing weather patterns.

Both case studies identified climate policy as a major risk factor for distribution companies. Increased deployment of distributed generation, generally in the form of wind turbines, was putting an increased pressure on existing infrastructure. Both case studies said that their distribution grids were no longer dimensioned according to demand, but rather according to production from distributed generation. Increasing wind speeds, the occurrence of stronger, more frequent storms and further expansion of wind turbine deployment could place pressure on existing infrastructure.

Growing interest and political backing in substituting natural gas and oil with heat pumps and the use of electric cars were identified as a potential risk factor. For historical reasons the grid in Denmark was generally not dimensioned at the lowest level to supply households with electricity for heating purposes. If levels of demand for electric heating and electric cars were to increase new investments would be necessary.

If temperatures increase then the demand for electricity will fall. In Denmark approximately 22 MW of load is temperature dependant[1]. If demand is reduced, but distributed generation increases then distribution costs per customer may become more expensive. This could jeopardise the economics of many distributors in Denmark.

The seasonal clock for the risk management tool, shown in figure 1 below shows the major concerns for one of the case studies.



-Wind power responsible for 75 – 80 % of load
--Increased strength of storms means risk of greater fluctuations in wind power production – could require new investments in infrastructure
-Warmer winters = lower demand = lower income
-Stronger storms = higher tidal flooding which can flood transformers
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-Maintenance undertaken in spring – sensitive to large fluctuations in production and demand
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-Maintenance undertaken in autumn – sensitive to increased production and demand in this period
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-Wind power responsible for 25 – 50 % of load
-Warmer summers = high demand = greater income
-Increased rainfall in 24 hour periods can threaten distribution cabinets locally
-Increased temperatures over longer periods of time may reduce life span of transformers
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Figure 1: Example of a completed annual clock

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[1] Togeby, M. *Coincidence factors in Nordic electricity demand*. 2007. Copenhagen

Case study – Using the CES risk assessment framework in the biomass and wind power sectors

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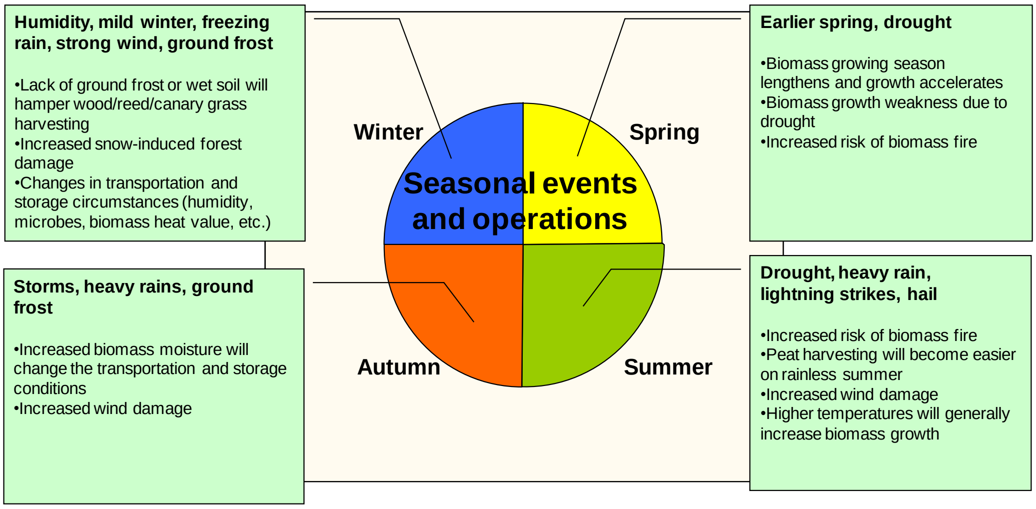
According to recent studies, climate change is expected to transform the environmental conditions associated with biomass and wind power production in the Nordic countries. It has been assumed that the climate especially in Finland will become significantly warmer during this century. Precipitation is also expected to increase, although more slowly, and wintertime temperature and precipitation changes should be higher than changes in the summer. At the same time, the thermal growing season is predicted to lengthen by 1-1.5 months (Jylhä *et al.* 2009) and a few percent increase is anticipated in the annual average wind speed during the coming decades ("Finnish Wind Atlas" website). These changes may in some cases be beneficial; for instance, higher temperature and greater precipitation may increase biomass growth. Although a variety of impacts on local power production are expected to be observed, the entire energy sector must adapt to climate change. To support future investment decisions, it is essential for power companies to take heed of the anticipated environmental changes and, in doing so, develop climate change adaptation strategies for each individual power plant.

During the CES project, VTT developed a new risk assessment framework for power plants, which allows the integration of climate scenarios by applying approaches based on technical risk assessment traditions. The risk assessment framework is designed to assist power plants plan their future by identifying and prioritising the risks and possible opportunities associated with climate change. The suggested risk/opportunity analysis could thus result in concrete proposals for the improvement of the technical or operational performance of power plants (Molarius *et al*. 2010).

In order to help create a common understanding of the possible future developments, the risk assessment framework is best carried out in qualitative brainstorming-based sessions (Molarius *et al*. 2010). During the sessions the risks/opportunities associated with climate change are examined mainly from two perspectives: how risks/opportunities are connected to the power plants' functions, and how they occur seasonally (Figure 1).

Some future challenges for biomass-based power production are related to the expected increase in precipitation. For instance, a shorter period of ground frost might hamper biomass harvesting and transportation, which may also subsequently endanger a power plant's fuel supply. At the same time, those dealing with the storage aspect of the biomass might focus on the avoidance of harmful moisture-based contamination or quality deviation, as the power plant‟s combustion process efficiency is rather dependent on the moisture of fuel components.

Because the biomass-based fuel components supply reliability and storage capacity were seen as being more vulnerable in the future, better preparation is needed. In lieu of the changed circumstances, the biomass storage capacity and locations could be defined based on the climate change information and identified risks. An uninterrupted fuel supply was especially important in one case-study because the biomass power plant being scrutinised produced district heat for the entire municipal area, which contained the provincial hospital services, nursing home, etc.



Humidity, mild winter, freezing rain, strong wind, ground frost

- Lack of ground frost or wet soil will hamper wood/reed/canary grass harvesting
- Increased snow-induced forest damage
- Changes in transportation and storage circumstances (humidity, microbes, biomass heat value, etc.)

Earlier spring, drought

- Biomass growing season lengthens and growth accelerates
- Biomass growth weakness due to drought
- Increased risk of biomass fire

Storms, heavy rains, ground frost

- Increased biomass moisture will change the transportation and storage conditions
- Increased wind damage

Drought, heavy rain, lightning strikes, hail

- Increased risk of biomass fire
- Peat harvesting will become easier on rainless summer
- Increased wind damage
- Higher temperatures will generally increase biomass growth

Figure 1. An example of the risks/opportunities seasonal examination.

An essential part of the wind power study material includes the recently published nation-wide Finnish Wind Atlas. The atlas contains the average monthly and annual values of wind speed and associated potential power production estimates ("Finnish Wind Atlas" website). Frozen power plant structures could result in a significant decline in power production, and increased weather extremes can exacerbate the freezing damage to the power plant infrastructure. Alternatively, higher wintertime temperatures and a shorter ice season would probably boost power production and reduce wintertime power interruptions.

Climate change is expected to increase the variance in the weather conditions and the observed extremes, and thus impact on power production. The risk assessment framework was seen to generate the best feedback when used in conjunction with local environmental knowledge. Climate scenarios can provide the basic structure for an examination, but the knowledge of the locals (e.g. powerplant's operating personnel) is key for translating the modelling results in practice.

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An updated gridded precipitation data set for Iceland

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Spatially distributed precipitation estimates are needed in hydrological and glaciological modelling and in regional climate analyses. In Iceland, the rain gauge network is rather sparse and unevenly distributed, especially in the highlands and in complex terrain, because these locations are difficult to access and the presence of several large glaciers prevents the deployment of conventional precipitation gauges. Under such conditions, gridding precipitation with spatial interpolation methods is difficult.

An alternative approach based on the use of a linear theory of orographic precipitation (Smith and Barstad, 2004) has recently been used to construct a gridded daily precipitation data set with 1 km horizontal resolution for the period 1958−2006 (Crochet et. al. 2007; Jóhannesson et. al. 2007). The model combines airflow dynamics and cloud microphysics to simulate airflow over topography and to calculate the condensation and production of hydrometeors resulting from terrain-forced vertical velocities. The input parameters of the model are background precipitation, upstream average wind speed and direction, surface temperature and humidity, moist Brunt-Väisälä frequency and hydrometeor formation and fallout times. The model was forced with large-scale atmospheric variables taken from the European Centre for Medium range Weather Forecasts (ECMWF) re-analysis (ERA-40) from 1958 to 2001 and available analysis from 2002 to 2006. Several input parameters, namely the moist Brunt-Väisälä frequency and hydrometeors formation and fallout times were defined once for all by statistical optimization, after comparison between model simulations and rain gauge and glaciological data. This gridded precipitation data set is being used in hydrological and glaciological studies within the CES project and in other studies.

The present work explores whether several refinements in the methodology and parameterization may further improve the overall quality of these precipitation estimates at various temporal scales. In particular, using this model without a priori knowledge of the hydrometeor formation and fallout times could extend its applications, such as for dynamical downscaling of climate scenarios for instance. The proposed refinements are as follows; The first refinement consists of running the model over several sub-domains to better represent the spatial variability of ambient atmospheric conditions; The second refinement involves the calculation of the depletion of water vapour flux downwind, when the model is applied to a succession of mountains; The third refinement consists of estimating the moist Brunt-Väisälä frequency and the hydrometeors formation and fallout times at each time step according to ambient conditions; The fourth refinement is the introduction of a local humidity factor to better define the limits of application of the model when unsaturated conditions prevail.

So far, the results obtained for a 7-year period (1994−2000) indicate that the refinements lead to precipitation estimates of similar quality in average, and sometimes better than previously with a statistical optimization of the moist Brunt-Väisälä frequency and the hydrometeors formation and fallout times. However, simulated precipitation is sensitive to the calculation of input parameters and adjustments in some of the parameterization schemes were necessary to obtain these results. The robustness of these refinements still needs to be verified over a longer period. As an example, Figure 1 presents a verification of winter accumulated precipitation against mass-balance measurements made on Vatnajökull glacier (SE Iceland) and Hofsjökull glacier (central Iceland) between October 1995 and April 1996. As can be seen, the resulting precipitation estimates are in agreement with the observations but some discrepancies can be observed at the lowest points on the glaciers, mainly downwind, both because of the presence of snow drifting and the difficulty to correctly simulate lee-drying.

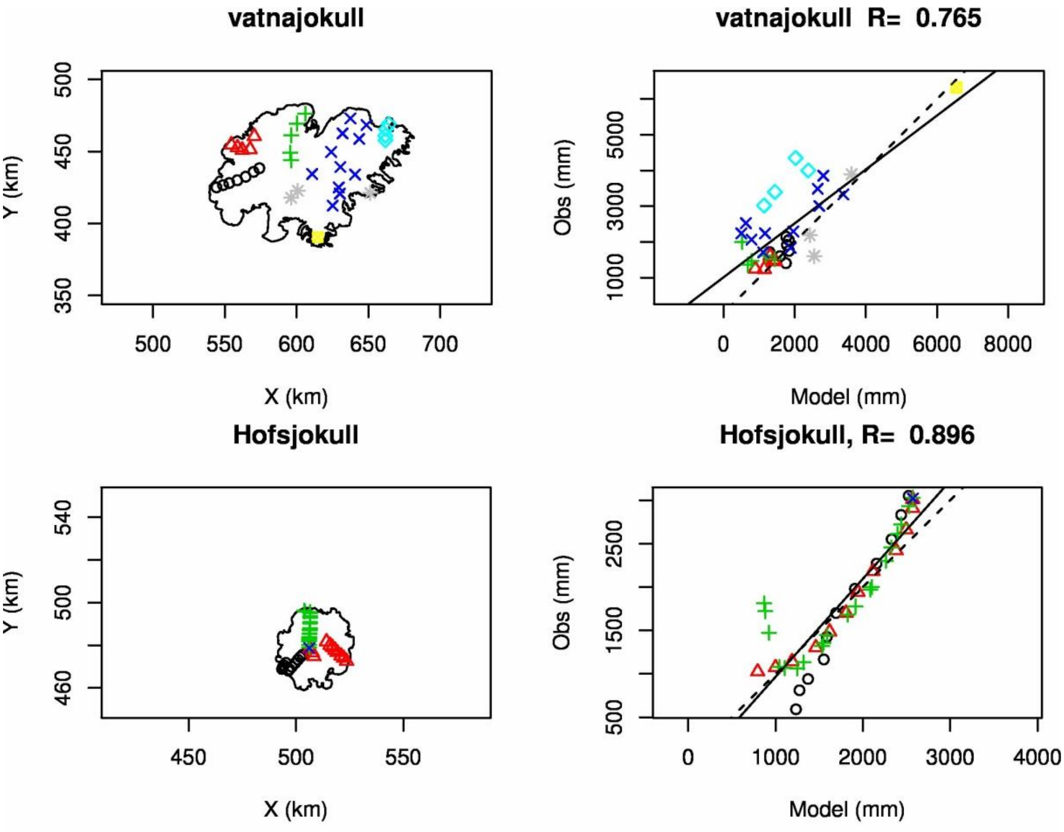

Figure 1: Winter precipitation on Vatnajökull glacier (top) and Hofsjökull glacier (bottom) between October 1995 and April 1996.

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Studies of cyclic behaviour of the air temperature, precipitation and water runoff time series in the Baltic states

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The analysis of the cyclic behaviour of the time series (river flows, precipitation and air temperature data) in the Baltic States is the essential part of data analysis in hydrology.
The Caterpillar-SSA technique was used for this studying. Caterpillar-SSA (Singular Spectrum Analysis) is a powerful model-free method of decomposition of a series into a sum of a small number of interpretable components such as slow varying trend, oscillatory components and “structureless” noise. The basic Caterpillar-SSA algorithm for analysing one-dimensional time series consists of:
-transformation of the one-dimensional time series to the trajectory matrix by means of a delay procedure (this gives the name to the whole technique);
- singular value decomposition of the trajectory matrix;
- reconstruction of the original time series based on a number of selected eigenvectors.

This decomposition initialises forecasting procedures for both the original time series and its components. Figure 1 shows the reconsracted water runoff time series of the Amata River nearby Melturi and it‟s forecast to 2030.

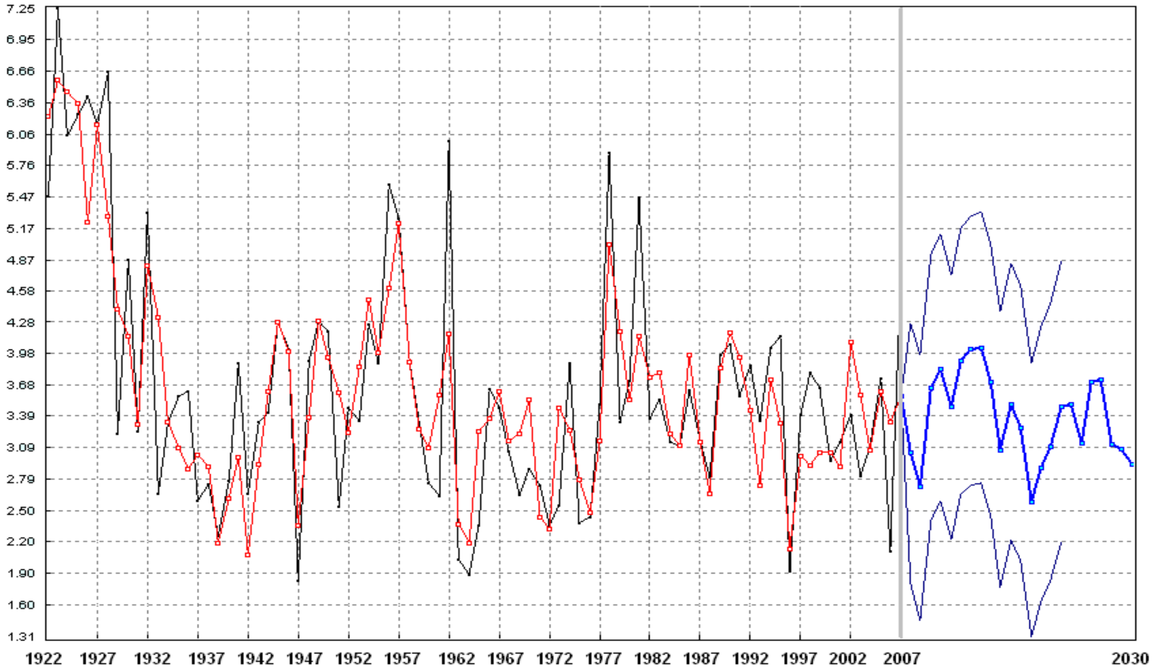

Figure 1. Water runoff of Amata River (black line – initial time series, red line – reconstracted time series, blue line – forecast, dark blue lines – 95% confidens intervals)

The time series of the air temperature, precipitation were analysed in all Baltic States for the period of 1925-2007 and the water runoff for the period 1922-2007.

Main periodicity of 28-years has been considered for the water runoff of rivers in the Baltic regions. The cycles of 3-, 4-, 5- and 6-years were determined too. The similar small cycles were found in the time series of precipitation and air temperature. Evidently these cycles and the small cycles of water runoff are interconnected.

Multidimensional „Caterpillar“-SSA method gives a good solution of the problem to find the simultaneous common components of all 3 series: temperature, precipitation and water runoff and to forecast data. Multidimensional analysis and the short-term forecast were made for seven water runoff data series and the weighed precipitation and temperature data series within the same water basins.

Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
Water runoff						
Jonova	*1961*	*2030*	*70*	-2.32	*	-0.500
Kuldiga	*1961*	*2030*	*70*	2.71	**	0.345
Melturi	*1961*	*2030*	*70*	2.03	*	0.008
Mezotne	*1961*	*2030*	*70*	2.08	*	0.163
Narva	*1961*	*2030*	*70*	4.59	***	2.731
Parnu	*1961*	*2030*	*70*	4.73	***	0.373
Jekabp	*1961*	*2030*	*70*	3.54	***	2.396
Precipitation						
Jonova	*1961*	*2030*	*70*	-0.71		-0.396
Kuldiga	*1961*	*2030*	*70*	0.47		0.305
Melturi	*1961*	*2030*	*70*	-0.45		-0.289
Mezotne	*1961*	*2030*	*70*	-0.71		-0.393
Narva	*1961*	*2030*	*70*	0.83		0.546
Parnu	*1961*	*2030*	*70*	3.34	***	2.517
Jekabp	*1961*	*2030*	*70*	-0.79		-0.514
Temperature						
Jonova	1961	2030	70	0.54		0.0035
Kuldiga	1961	2030	70	1.27		0.0079
Melturi	1961	2030	70	1.20		0.0088
Mezotne	1961	2030	70	1.41		0.0093
Narva	1961	2030	70	0.05		0.0006
Parnu	1961	2030	70	0.47		0.0034
Jekabp	1961	2030	70	1.08		0.0084

Table 1. Data series trend statistic results.

The Mann-Kendall test was used for the trend analysis of the data series of water runoff, precipitation and air temperature data as well for the period 1961-2030. Table 1 shows the trend statistic results.

Temporal Variation of Spring Flood in Rivers of the Baltic States

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Under current climate change conditions, extreme flood events become an increasingly threating hazard in terms of risk and damage potential. Therefore, forecasting and managing floods is the key issue of protection systems. However, forecasts still include some level of uncertainty. The uncertainty maybe controlled and managed if good hydrological data and statistical analysis is used for prediction of lood hazards for a long time period. Fortunately, Baltic states have a long time series hydrological data that make it possible to estimate flood frequency and their tendency for the last 80 years. Snow melting and ice jams result in the rise of water level in the upstream. Spring flood is a very significant hydrological phase of rivers in Baltic states. Last several years were marked by floods wave with multipple peaks that created additional difficulties in managing floods.

In this research, the timing of spring flood in rivers of the Baltic States is statistically analysed. The Mann-Kendall test and the nonparametric Sen‟s method (Helsel and Hirsch, 2002) for the magnitude of the trend were used to detect trends in time series for different periods. The main parameters such as flood duration and frequency, runoff volume, runoff peak, and its time of spring flood are evaluated for all the Baltic countries. The assessment of spring flood parameters was done for three different periods (1923–2007, 1941–2007 and 1961–2007). Maximum spring water discharges with the date of its observation from 69 hydrometric measurement stations were used for this analysis. There are three common hydrological regions in all Baltic states based on the annual runoff distribution: marine, transitional and continental. The regions in this research were more appropriate to spring floods regionalisation, it allows to estimate floods for ungauged catchments using an index flood method. Lakes, forests and soil type and of the basins have the biggest impact on the volume and duration of floods. These elements regulate the runoff, decreasing the maximum discharges and flood height and prolonging runoff duration. Despite of significant differences in area covered by the wetlands in all Baltic countries (from 8% in Lithuania to 40% in Estonia) this factor impact on the flood parameters is minor.

The spring flood maximum discharge has decreased (Figure 1) and its fluctuation from year to year has decreased as well. Trends were negative significant and weakly significant only for the 1923-2007 and 1941-2007 periods. The period of 1961-2007 had the same negative tendency, but trends were not significant. It could indicate that spring flood maximum discharges are becoming more stable in Estonia with a more uniform shape of hydrograph within a year. There were no maximum discharges over 5% probability observed during the last 50 years.

Dates of spring flood peaks were moved to earlier times in a year. However, for the periods 1941-2007 and 1961-2007 spring flood changes were insignificant with a more stable distribution. The tendencies of maximum discharge timing are similar in all Baltic states (Meilutytė-Barauskienė and Kovalenkovienė, 2007, Klavins et al., 2002). Everywhere trends are definitely negative, i. e.maximum discharges are observed earlier and earlier (because of warmer winters). The contribution fraction of spring season runoff to the annual runoff has decreased by 3% -5% on the average. All these changes could be caused by increasing ambient temperature and precipitation in the last decades.

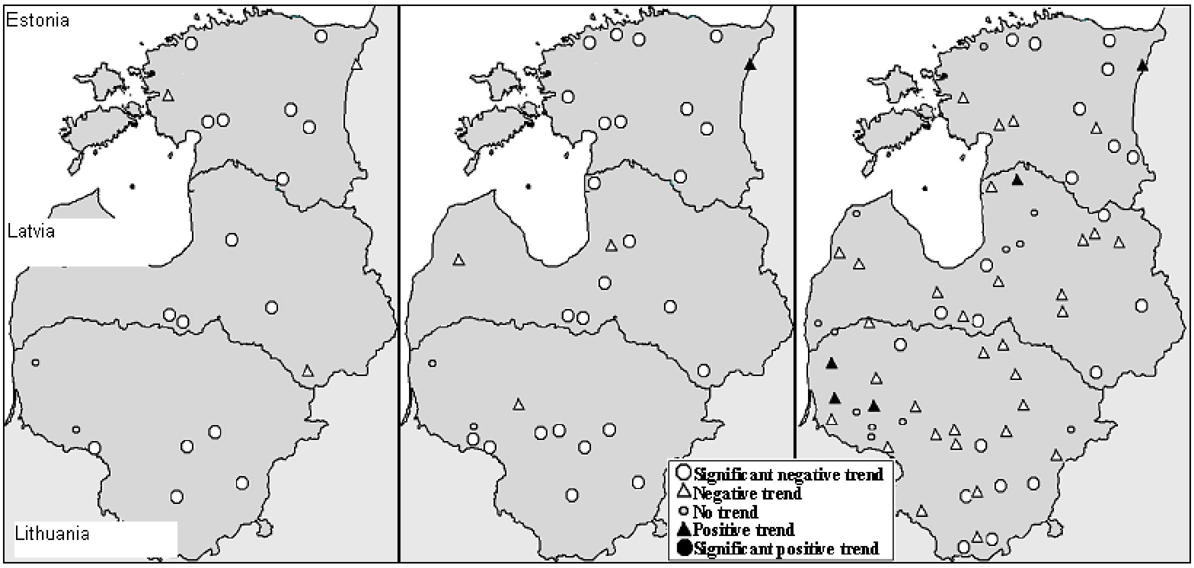

Figure 1. Trends in spring flood maximum discharge for the periods 1923-2007 (left), 1941-2007 (middle) and 1961-2007 (right)

On the one hand, decrease in spring runoff is good for the designing and construction of road bridges and culverts whose cost will decrease. A more evenly distributed river flow throughout a year will lead to a profitable situation for the hydropower industry; it is also good for water level regulation against floods and droughts. However, on the other hand, the earlier and shortened spring and the longer low flow period after spring may deteriorate water quality and have a negative impact on aquatic habitats. Thus, all these changes should be taken into account for an optimal management of water resources to prevent possible risks and to ensure the sustainability of water ecosystems.

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Long term variability and projection of shifts in the streamflow at selected catchments in Norwegian rivers induced by climate change

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Abstract

Observed time series of the streamflow in Norwegian rivers tend to cluster in periods of wet and dry years in annual as well as seasonal values. The clustering is linked to shifts in the dominating atmospheric circulation and the topography and exposure of each catchment to the trajectories of incoming fronts. The observed variability is mostly linked to natural variability although anthropogenic climate change may have played a part in the recent years. Based on transient simulation of temperature and precipitation, daily series have been established for a number of catchments for the period 1952-2099. These series are based on simulation of daily temperature and precipitation based on the ECHAM5 model driven by emission scenario A1b. Five long term data series have been selected in different regions of Norway with long series of observed streamflow, with little or no modification because of hydropower development as shown in Table 1.

Table 1 lists the series which are included in this study.

Station	**Region**	**River**	**Observed**		**Projected**	
			from	**to**	**from**	**To**
Atnasjø	**East**	**Glomma**	**1917**	**2009**	**1952**	**2099**
Flaksvatn	**South**	**Tovdalselv**	**1899**	**2009**	**1952**	**2099**
Bulken	**West**	**Vosso**	**1892**	**2009**	**1952**	**2099**
Høggås bru	**Mid**	**Stjørdalselv**	**1912**	**2009**	**1952**	**2099**
Øvrevatn	**North**	**Salangselv**	**1913**	**2009**	**1952**	**2099**

The observed series include a period of wet and cool years in the 1920s, a warm and wet period in the 1930‟s and again since the late 1980s and a cool and partly dry period in the 1960s to the early 1980s. The statistical properties of the observed and projected streamflow data are examined for a number of wet and dry time slots to explore if the observed clustering of streamflow is present in the climate change projections both in terms of annual and seasonal means and the occurrence and magnitudes of extremes.

Figure 1 gives an example of long term variability of the annual streamflow at Atnasjø expressed as the percentage of the mean value 1961-1990 and of the projected data of the same reference period. The results of the analysis will be presented in a poster.

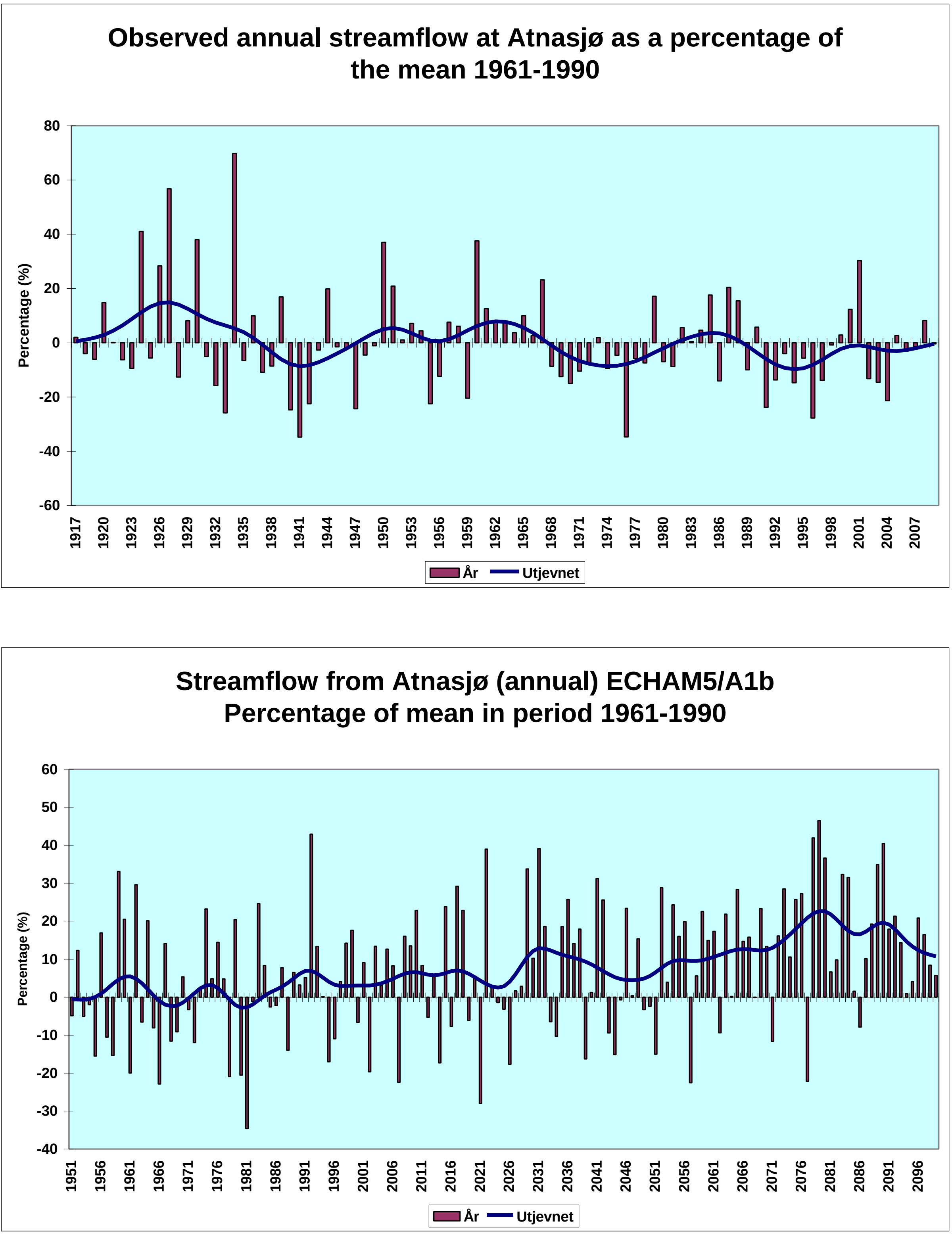

Figure 1. Observed annual streamflow at Atnasjø 1917-2009 (upper) and projected annual streamflow at Atnasjø 1951-2099 (lower).

Norwegian regional runoff series

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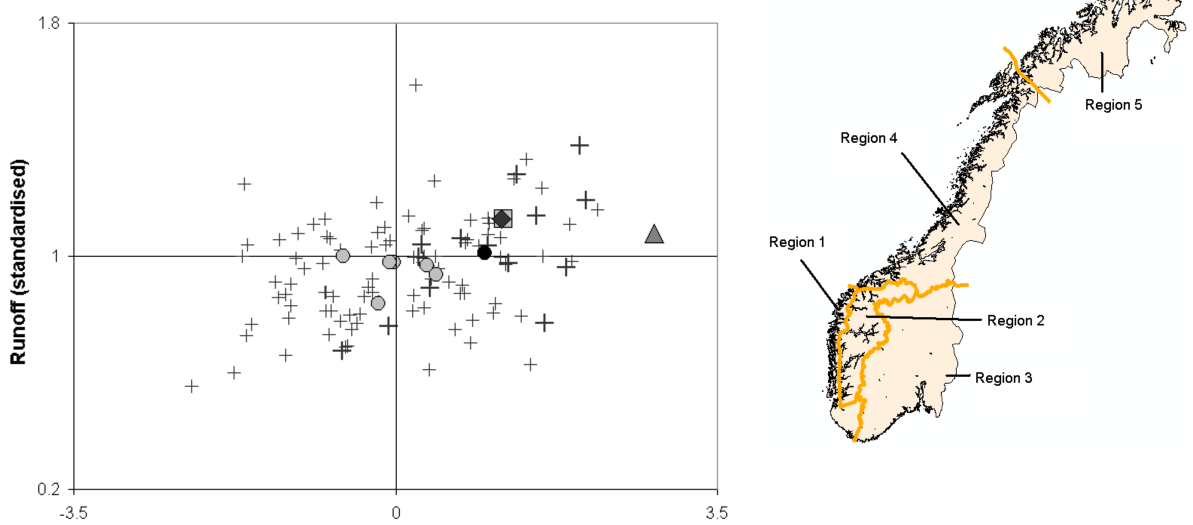
The hydropower industry within Norway is sensitive to long-term variations in runoff, and climate change could have significant consequences for hydropower production. The objective of this paper is to: (i) identify homogeneous regions of long-term runoff from historical series, (ii) provide an overview of relationships between observed regional runoff, temperature and precipitation, and (iii) consider potential future changes in runoff, temperature and precipitation on a regional basis.

Annual runoff data from 82 gauging stations for the period 1897 to 2009 were used for the analysis. Each station series was standardised by dividing annual values by the station mean for the period 1961-90. To identify runoff regions, cluster and correlation analyses were used to group stations with similar temporal behaviour, in addition to knowledge of catchment boundaries and the existing hydropower regions. Five runoff regions were delimited (Figure 1), and regional series were calculated. Each regional series is the mean of the standardised series for the stations in each region. The number of series used in calculating the regional mean at each time step varies as the record length available for each station differs. Norway was originally divided into 13 runoff regions in order to describe the variability of runoff (Førland *et al.*, 2000), but fewer regions are identified herein to facilitate application of the series for water resource planning, such as in relation to the existing hydropower regions.

Temperature and precipitation regional series are available for Norway. Six temperature and 13 precipitation regions have been identified and are described by Førland *et al.*, (2000). There are some broad similarities between the boundaries of the runoff, temperature and precipitation regions, but differences also exist. The calculation of regional series based on annual data is the same for precipitation as for runoff, but the procedure used to standardise temperature data is different. Each temperature series was standardised by subtracting the mean for the period 1961-90 and dividing by the standard deviation. To facilitate comparison of the regional series, the temperature and precipitation series were recalculated for the five runoff regions by area weighting each of the temperature and precipitation series. The correlation between regional precipitation and runoff was found to be stronger than that between regional temperature and runoff (e.g. Figure 1). All regions show relatively high temperatures within the more recent period (1990-2003). Precipitation and runoff for individual years within this more recent period were more variable, but higher values were observed in all regions to differing extents, compared with the 1961-90 reference period.

Potential future changes in temperature, precipitation and runoff were investigated using projections based on three ENSEMBLES scenarios (ECHAM5/DMI-HIRHAM5, HadCM3Qref/Met.no-HIRHAM and BCM/SMHI-RCA3). Temperature and precipitation projections from these regional climate models were downscaled using an empirical adjustment method (Engen-Skaugen, 2007), and used to simulate future runoff using the HBV hydrological model for 115 catchments. Differences exist between the catchments used to derive the observed and projection regional series due to data availability. The same procedure was followed for the calculation of the projection regional series, as for the observed regional series. Differences exist both between the results based on the three different GCM/RCM combinations and between regions. However, all regions show a tendency towards higher annual temperatures, precipitation and runoff in the period 2021-50, compared with the 1961-90 reference period (Figure 1 shows the results for Region 1). Higher relative temperatures are projected based the HadCM3Qref/Met.no-HIRHAM scenario compared to the ECHAM5/DMI-HIRHAM5 and BCM/SMHI-RCA3 scenarios. The mean standardised projected temperature for the years 2021-50 are for all regions and scenarios greater than the mean 15-year temperatures calculated from the observed regional series. A similar pattern is observed for precipitation and runoff, with the exception of Region 4 for precipitation and Regions 4 and 5 for runoff.


(a) Temperature and runoff

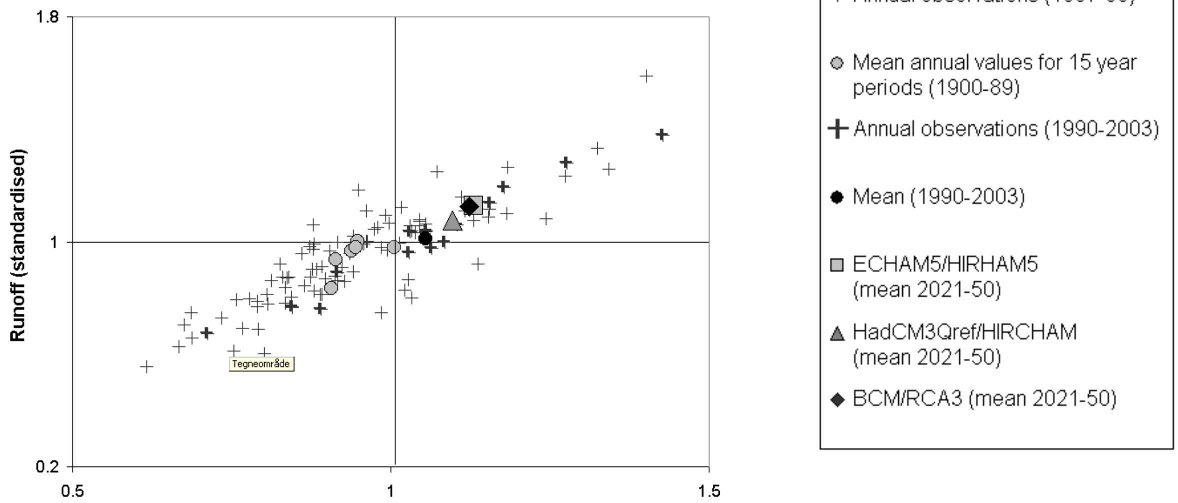

(b) Precipitation and runoff

Figure 1. Standardised annual observed temperature, precipitation and runoff, and future projections for Region 1.

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21st century changes in the Nordic climate: Uncertainties derived from an ensemble of regional climate model simulations

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Seasonal mean temperature, precipitation and wind speed over the Nordic region are analysed in an ensemble of 16 regional climate model (RCM) simulations for 1961-2100. To construct the ensemble we have used the Rossby Centre RCM with boundary conditions from seven global climate models (GCMs) under four emission scenarios. Most of the simulations were downscaling experiments of GCMs forced by the emission scenario SRES A1B (Nakićenović and Swart, 2000). One of the GCMs was run three times under A1B differing only in initial conditions. The Rossby Centre ensemble and the more large-scale European climate change signal has earlier been documented by Kjellström et al. (2010). The ensemble is used to; i) evaluate the simulated Nordic climate against observed climatologies for 1961-1990, ii) assess future climate change and iii) illustrate uncertainties in future climate change related to natural variability, boundary conditions and emissions.

The results indicate that biases in temperature and precipitation in the 1961-1990 period are strongly related to errors in the large-scale circulation in the GCMs (not shown). A general feature of many simulations is a too mild wintertime climate in much of Europe in connection to a too strong zonal circulation on average. However, there are also GCMs that does not show this bias pattern in the large-scale circulation and there are others that show a too zonal situation in central Europe and yet too cold conditions in northern Scandinavia. Possible reasons for some of the more local biases include erroneous sea surface temperatures and/or sea-ice conditions.

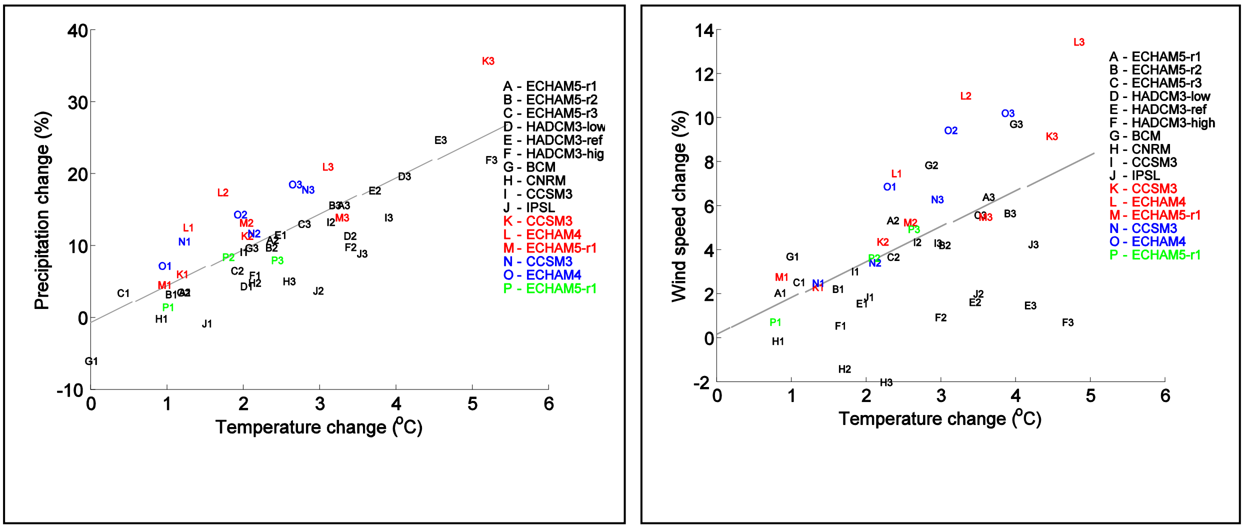

Figure 1. Change in annual mean precipitation (left) and wind speed (right) versus T_{2m} over all land grid points covering Iceland (left) and all ocean grid points covering the Baltic Sea (right) relative to 1961-1990. The letters indicate which driving GCM that has been used. The numbers for which time period the change is calculated: (1) 2011-2040, (2) 2041-2070 and (3) 2071-2100. Colours indicate emission scenarios (A2-red, A1B-black, B2-blue, B1-green). The grey line is a least-square fit to the data.

In terms of climate change the ensemble shows that statistically significant increases in temperature are seen for all of the Nordic region already in the next decades, particularly in winter as exemplified for Iceland in Figure 1. Precipitation increases in northern Europe and most so in winter (Fig. 1). Wind speed changes are generally small in the area albeit areas of simulated increase in wind speed are found in the northern seas in some but not all models (Fig. 1). The results in Fig. 1 reveals that uncertainty largely depend on choice of GCM. This strong dependency is related to their representation of changes in the large-scale circulation. The uncertainty related to forcing (i.e. emission scenario) is most important by the end of the century while natural variability sometimes dominates the uncertainty on local to regional scales in the nearest few decades.

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Acknowledgements

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Characteristics of Wintertime North Atlantic Cyclones in ERA-40 Reanalyses and IPCC 20th Century Control Runs

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The short-term as well as seasonal weather conditions in Northwest Europe strongly depend on the location and intensity of dominant low-pressure centres over the North Atlantic, especially during winter, when these storm systems are most intense. In this study, the spatial distribution of wintertime North Atlantic cyclones during the second half of the 20th Century is analysed, based on ERA-40 reanalyses, as well as the control runs of those general circulation models (GCMs), that were used by the Intergovernmental Panel on Climate Change (IPCC) for their Forth Assessment Report. The reanalyses cover the winter seasons from 1958 to 2002. However, comparisons with the GCM runs are restricted to the years of 1958 – 98, which is the longest period that it is covered by all GCM control runs as well as the reanalysis project.

Dominant cyclone centres are defined here as local closed minima in monthly averaged fields of mean sea level pressure, with values of at least 4 hPa below the average air pressure over the ocean surface, within the study domain between -80 – 60ºE and 40 – 80ºN.

Significant differences occur from one year to the next. However, in the northern North Atlantic, average low-pressure centres during the winter months from December through February in the ERA-40 reanalyses tend to cluster in a region extending from the northern part of the Norwegian Sea into the Barents Sea, as well as in two regions southwest of Iceland: the Irminger Sea, associated with northward moving cyclones passing east of southern Greenland, and the Labrador Sea, associated with cyclones passing Greenland to the west and moving north into Davis Strait (Dacre and Gray, 2009).

In the reanalyses, the distribution of dominant wintertime low-pressure centres is limited by the sea ice edge, which is likely due to the larger surface heat flux and its promotion of cyclone development and intensification over the ice-free ocean (e.g., Dierer and Schlünzen, 2005). This is also true in the IPCC control runs. However, for the majority of GCMs, there is more extensive sea ice cover over the Barents Sea compared with the reanalyses, and correspondingly a reduced northward spread of dominant cyclone centres. The northward shift of storm tracks over the North Atlantic predicted by some of the IPCC models for the 21st Century may therefore be the result of sea ice reduction in the northern part of the ocean, in addition to a warming-induced northward shift of the midlatitude baroclinic zone as proposed by Yin (2005). The simulated shifting storm tracks would then be the result of the initial model cold bias and excessive warming, rather than a reflection of real climate trends.

As shown in Figure 1, according to the reanalyses, there are well defined differences in composite mean surface wind speed for prevailing cyclones in different regions. Most notable are the strong westerly winds to the west of the British Isles, as well as the strong northerly winds along the eastern coast of Greenland in the presence of a dominant wintertime low-pressure centre over the Norwegian Sea, compared with the weak winds associated with prevailing cyclones over the Labrador Sea.

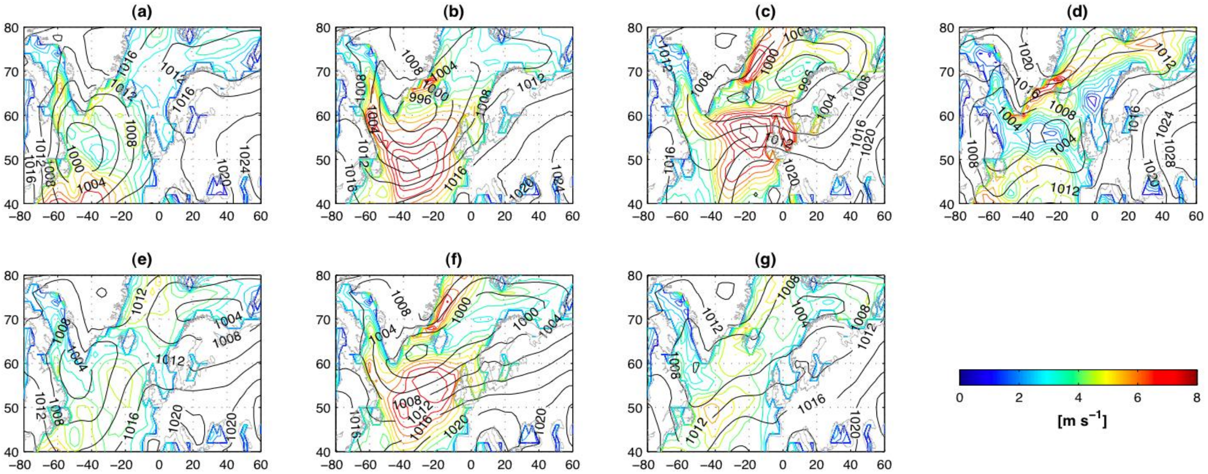

Figure 1: *ERA-40 composite fields of mean sea level air pressure (black contours) and surface wind speed (coloured contours) for wintertime (DJF) dominant cyclone centres during the 1958 – 2002 period, located in different regions: (a) Labrador Sea, (b) Irminger Sea, (c) Norwegian / Barents Sea, (d) Labrador and Irminger Sea, (e) Labrador and Norwegian / Barents Sea, (f) Irminger and Norwegian / Barents Sea, and (g) Labrador, Irminger, and Norwegian / Barents Sea.*

These differences in surface wind speed have immediate implications for the average sea state and sea ice transport. Less pronounced are differences in boundary-layer temperatures below 850 hPa for different surface air pressure distributions. However, the lowest 1000 – 850 hPa layer thickness north of Iceland is associated with prevailing cyclones over the Labrador Sea. As the dominant low-pressure centre shifts north, the increased southerly flow and warm advection over the eastern North Atlantic increases mean boundary-layer thickness there.

Regarding the thermodynamic properties of low-pressure centres below 850 hPa, based on the reanalyses and GCM runs, the warmest cyclones on average are those over the Irminger Sea. Those are also associated with the highest sea surface temperatures, as well as the largest anomalies of central pressure (with values down to -25 hPa in the reanalyses) compared with the regional average within the study domain.

Changes from one year to the next of central pressure values within the 1958 – 98 period are large, both in the reanalyses and GCM runs, without any clear indications of long-term trends. However, in the reanalyses, there is an overall small decrease in central pressure of the northern cyclones, which is not reflected in any of the GCM runs. No such trend is found for the southern cyclones.

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Surface Air Temperature and Total Precipitation Trends for Iceland in the 21st Century

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The general circulation model (GCM) runs used by the Intergovernmental Panel on Climate Change (IPCC) for their Forth Assessment Report (IPCC, 2007) predict that annual and regional mean surface air temperatures (SAT) over Iceland will increase during the 21st Century at a rate that is slightly below the global average. However, the reliability of these results may be compromised by the low spatial resolution of the GCM fields.

To determine the impact and potential benefits of a higher spatial resolution, we examine the trends in SAT and total precipitation over Iceland for a subset of the IPCC GCMs, as well as for three regional climate models (RCMs). The smaller ensemble of GCMs was determined as those ten models, that performed best for SAT during the 1958 – 98 control period compared with the ERA-40 reanalyses (Uppala et al., 2005), whereby the control period was chosen such that it is covered by all GCM runs and the reanalyses. The RCMs are those that were recommended following the CES staff meeting in Copenhagen in May 2009, namely the SMHI-RCA3, MetNo-HIRHAM5, and DMI-HIRHAM5. For both, the GCM runs as well as the driving models for the RCM runs, the IPCC A1B emissions scenario was used. The domain chosen for regional averages ranges between 10 – 28ºW, and 62 – 68ºN, covering Iceland as the only land mass.

In the GCM ensemble mean field of SAT, the terrain of Iceland is recognised only by a weak wave pattern imposed on the larger-scale northwest to southeast gradient, resulting in about 2 K lower mean annual SAT over the island, when compared with the surrounding ocean. By contrast, mean SAT fields in the RCM simulations show spatial patterns that are directly related to their respective model terrain, whereby the rate of change of SAT with ground elevation follows a well defined seasonal cycle, that is consistent with past long-term surface station records (Björnsson et al., 2007). Impacts of the terrain on linear trends of ensemble mean SAT during the first half of the 21st Century are small, with a warming rate of 0.30 K per decade over the ocean, and 0.32 K per decade over land. For comparison, the corresponding projected linear rates of SAT increase per decade over the first half of the 21st Century are 0.17 K and 0.20 K based on the SMHI-RCA3, 0.24 K and 0.32 K based on the MetNo-HIRHAM5, and 0.40 K and 0.44 K based on the DMI-HIRHAM5 over the ocean and land, respectively. The average warming rates in the RCM runs are 0.27 K per decade over the ocean, and 0.33 K per decade over the land. While these average values are close to the GCM ensemble means, especially over land, there are considerable differences between the RCM simulations. The higher spatial resolution of RCMs allows a more detailed analysis of linear SAT trends as a function of terrain elevation (see Figure 1). In the SMHI-RCA3 and MetNo-HIRHAM5 runs, SAT trends increase with height up to about 1 km. By contrast, in the DMI-HIRHAM5, warming rates over the ocean and at low elevations are significantly higher, but decrease with height.

Taking into account GCM and RCM runs, average linear trends of total precipitation are 0.8 % of the 1961 – 90 mean value per decade, or 2.5 % per degree warming.

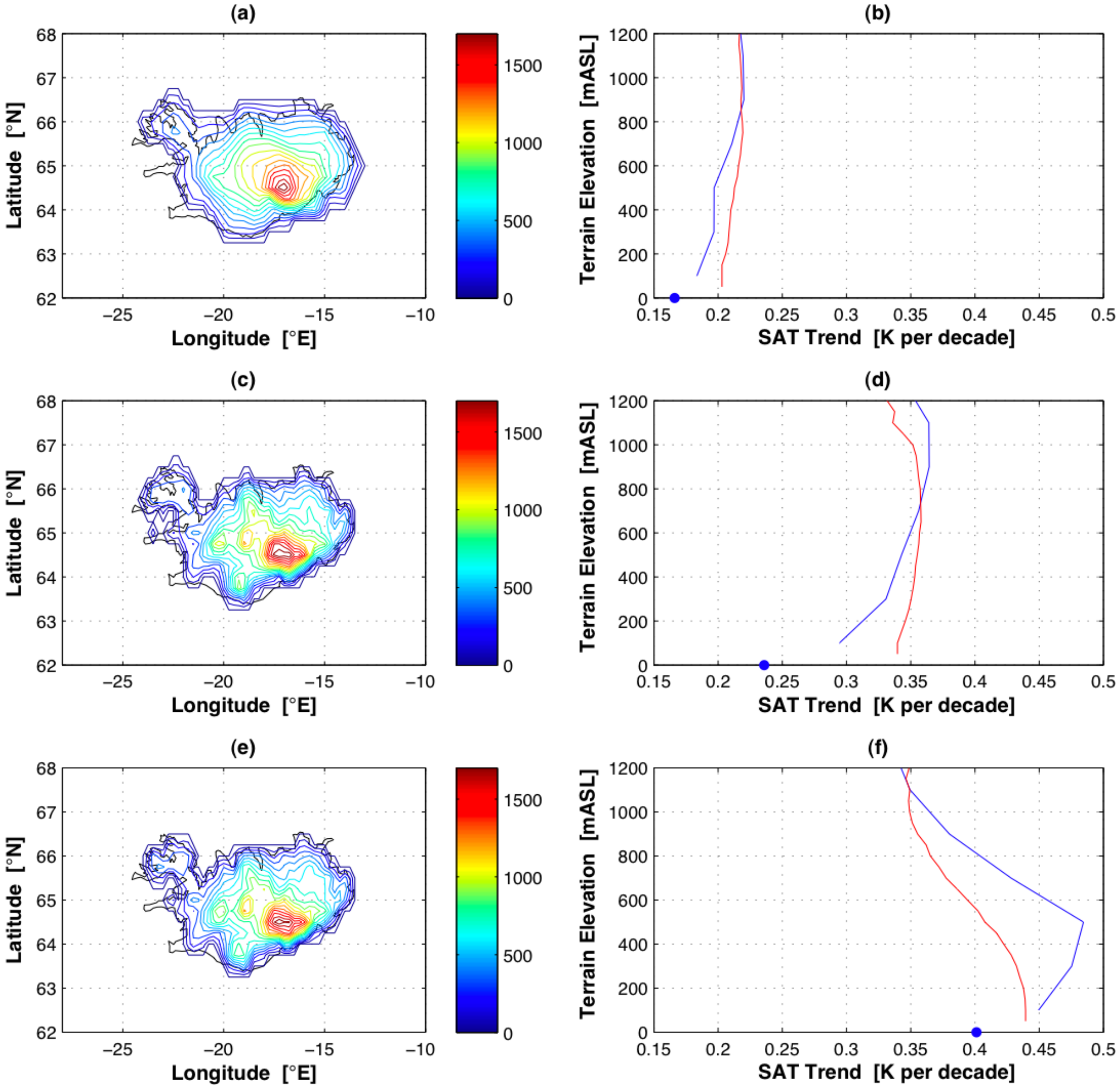

Figure 1: Dependence of 2004 - 50 linear surface air temperature trends on terrain elevation in (b) the SMHI-RCA3, (d) the MetNo-HIRHAM5, and (f) the DMI-HIRHAM5, together with the corresponding model orographies in (a), (c), and (e), respectively (the actual coast line is indicated in black). The blue dots indicate mean trend values over the ocean within the domains shown on the left. The solid blue lines indicate mean trend values at the corresponding elevation, whereas the red lines show mean trend values at or above the corresponding elevation.

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Probabilistic projections of temperature and precipitation change for the period 2021-2050

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Projections of climate change are affected by several sources of uncertainty. In long-term projections extending towards the end of this century and beyond, a large part of the uncertainty is associated with the uncertain evolution of anthropogenic greenhouse gas emissions and the resulting external forcing of the climate system. During the first half of the 21st century, however, the differences among emission scenarios are still relatively small. In this timeframe, the uncertainty in climate change mainly arises from two sources: differences among climate models in their response to anthropogenic forcing, and natural climate variability that may either reinforce or oppose the anthropogenic changes.

We have derived probabilistic projections of temperature and precipitation change in Europe from the baseline period 1961-1990 to the period 2021-2050, taking into account natural climate variability and modelling uncertainty. The projections are built on the results of 19 global climate models participating in the CMIP3 intercomparison (Meehl et al., 2007), but 13 high-resolution (25 km grid size) regional climate simulations from the ENSEMBLES (van der Linden and Mitchell, 2009) database (including many conducted within CES) are used to refine their regional details. Further details are provided in Räisänen and Ruokolainen (2009).

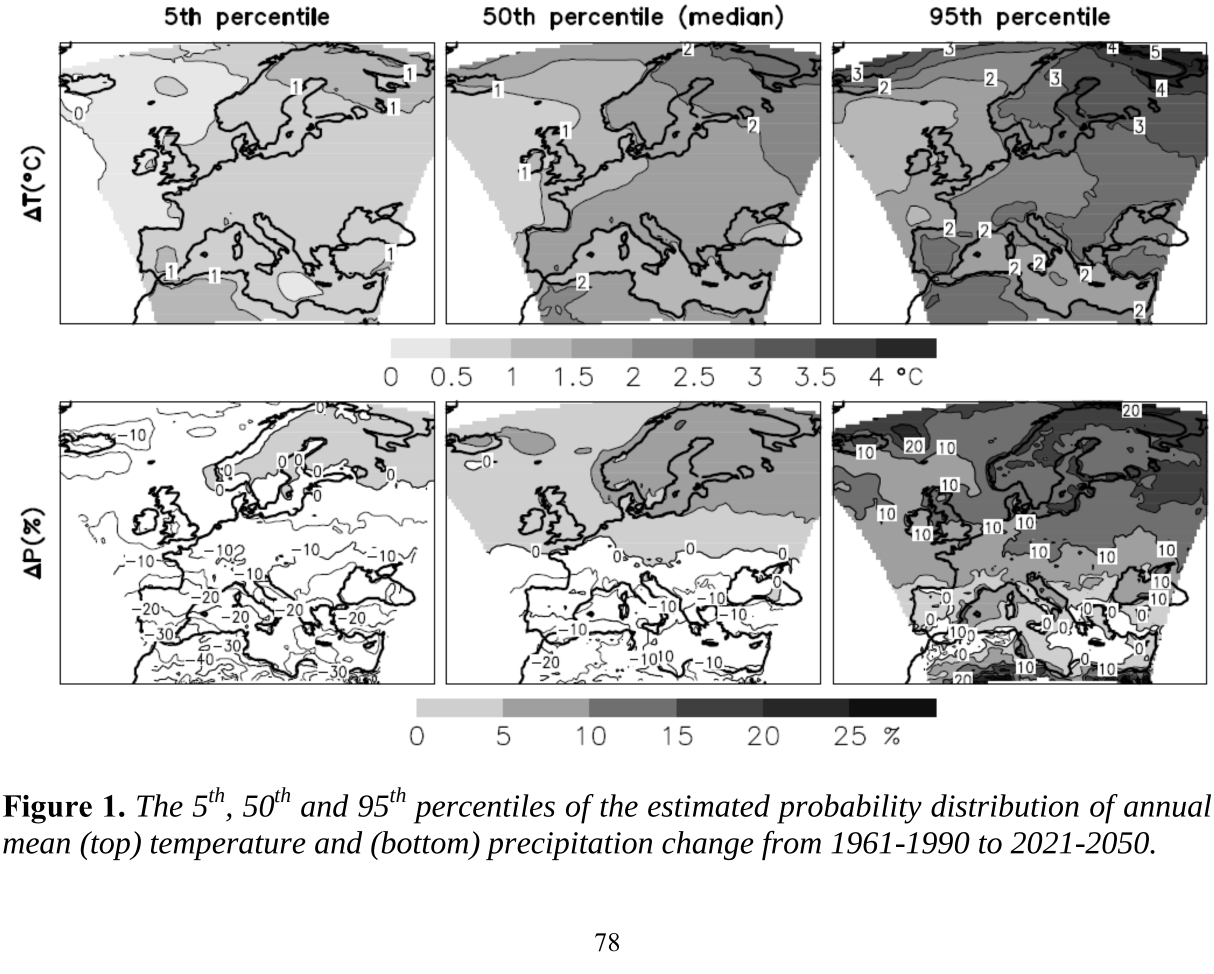

Figure 1. *The 5th, 50th and 95th percentiles of the estimated probability distribution of annual mean (top) temperature and (bottom) precipitation change from 1961-1990 to 2021-2050.*

As the best estimate, the analysis suggests an annual mean warming of about 1.5ºC in Iceland, Denmark, and the west coast of Norway (Fig. 1, top middle). In northeastern Fennoscandia, a best-estimate warming of 2-2.5ºC is projected. The best-estimate annual mean precipitation change is within 5-10% in most of the Nordic area (Fig. 1, bottom middle). The changes vary with season, with the largest increases in temperature and (in most of the Nordic area) precipitation projected for winter (not shown).

Although there is substantial uncertainty in the magnitude of the change, the sign of the 30-year annual mean temperature change appears to be nearly certain. The 5th percentile of the calculated distribution is positive in the whole Nordic area (although near zero in Iceland), indicating that the probability of cooling is less than 5% (Fig. 1, top left). Conversely, the 95th percentile of the distribution suggests a 5% chance that the warming will exceed 2ºC at the west coast of Norway and 3.5ºC in Finnish Lapland (Fig. 1, top right).

Changes in precipitation are more uncertain than those in temperature (Fig. 1, bottom), partly because the signal-to-noise ratio between the greenhouse-gas-induced change and natural variability is lower for precipitation than temperature. For the 30-year annual means in 2021-2050, the 5th percentile of the change is close to zero in most of the Nordic area, whereas the 95th percentile varies around 15%. The uncertainty ranges for changes in seasonal mean precipitation are wider (not shown).

The probabilistic projections derived with our method are quite similar to those obtained directly from global climate models. The inclusion of data from regional climate models adds credible small-scale detail to the projections, in particular near land-sea boundaries and in areas of high orography, but this systematic effect is generally small compared with the total uncertainty in future climate change.

The results discussed here relate to changes in 30-year mean climate, not to the weather conditions in individual years. Thus, for example, some individual cold winters and cool summers will still most likely occur in the next few decades, although increasingly seldom with time.

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Projected effects of climate change on the hydrology of Norway
Future Climate and Renewable Energy – Impacts, Risks and Adaptation

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About 98 % of the electricity production in Norway is based on hydropower. Climate change can lead to changes in the amount and seasonality of runoff, and thus affect the hydropower production. The Norwegian Meteorological Institute and the Norwegian Water Resources and Energy Directorate have determined projections of meteorological and hydrological processes in Norway for the periods 2021-2050 and 2071-2100. A range of projections of climate change impacts on the hydrology of Norway have been estimated based on results from several emission scenarios and global climate models. Dynamical downscaling using a regional climate model and adjustment of regional climate model results to correct for bias compared to meteorological observations have been performed (Engen-Skaugen, 2007). This procedure resulted in several projections of climate change for the 21st century. The climate change projections were used for driving a spatially distributed version of the HBV hydrological model, yielding an ensemble of climate change impacts on water resources in Norway. Present conditions were determined through control runs with the hydrological model using observed meteorological data and climate model results.

Present and future conditions for hydrological state variables and fluxes are presented as time series and maps showing 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. The different climate change projections are consistent regarding whether an increase or a decrease in runoff and other hydrological processes occur, but the magnitudes of the changes differ between the projections and periods. Moderate changes in annual runoff are expected, with a decline in some regions for some scenarios and periods. Significant changes in the seasonal distribution of runoff are expected; increase almost everywhere in the winter, increase in mountainous basins in southern Norway and in basins in northern Norway in the spring, a moderate decline in central and south-eastern Norway and in coastal basins in western Norway in the spring. Decrease will occur almost everywhere in the summer, while autumn runoff will increase in most basins. Runoff changes in Norway are strongly linked to changes in the 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. These results are caused by the combined effects of higher temperature and more precipitation in the winter in the scenario climate. Reduced snow cover leads to smaller snow melt floods, while increased precipitation where a larger proportion falls as rain will increase rain floods, and possibly also combined snow melt and rain floods (Beldring et al., 2008).

Figure 1 presents percentage change in seasonal runoff from 1981-2100 to 2031-2050 based on emission scenario IS92a, global climate model ECHAM4/OPYC3, regional climate model HIRHAM and hydrological model HBV.

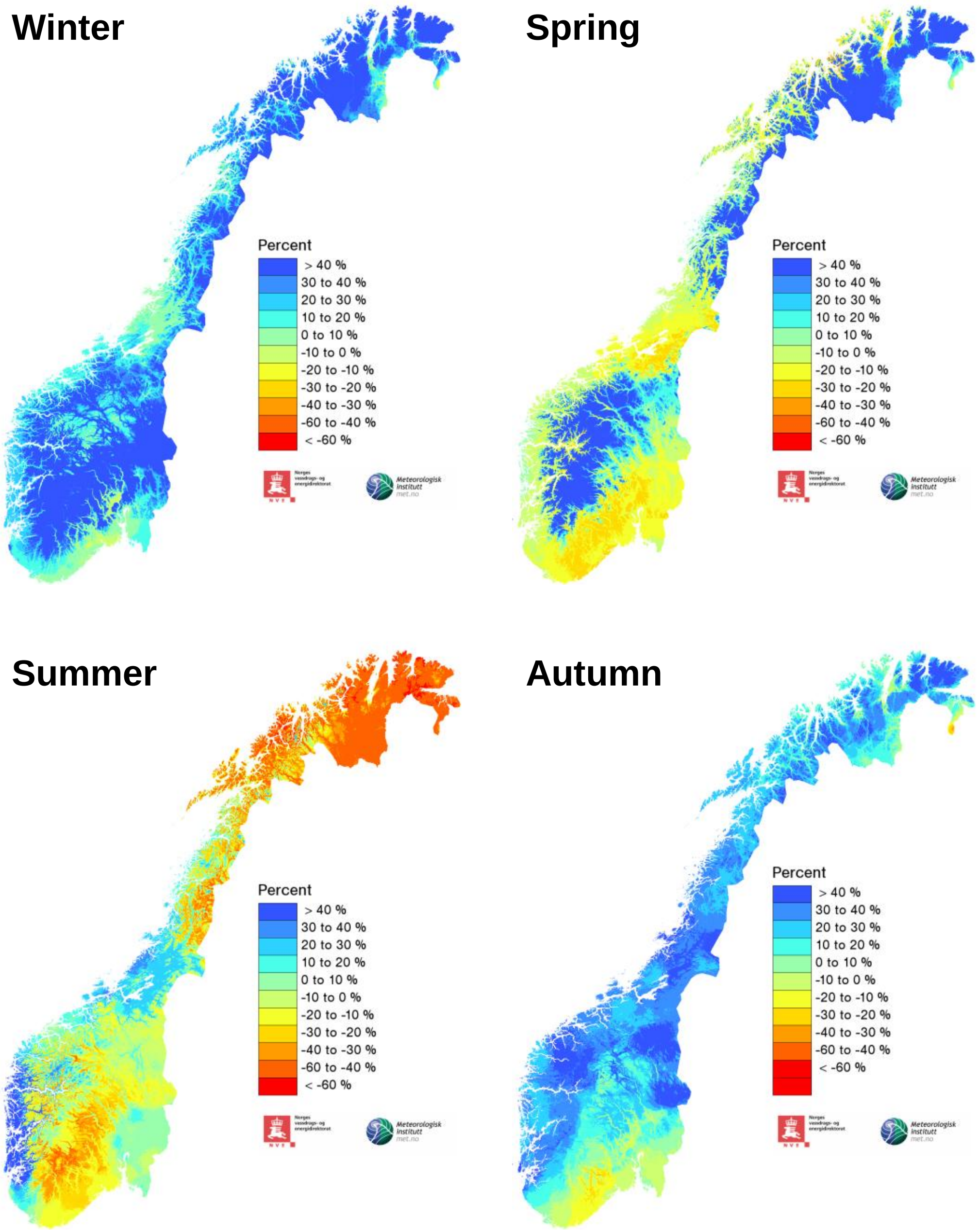

Figure 1. Percentage change in seasonal runoff from 1981-2100 to 2031-2050 based on emission scenario IS92a, global climate model ECHAM4/OPYC3, regional climate model HIRHAM and hydrological model HBV. Top left: Winter (Dec., Jan., Feb.). Top right: Spring (Mar., Apr., May). Bottom left: Summer (Jun., Jul., Aug.). Bottom right: Autumn (Sep., Oct., Nov.).

Beldring, S., Engen-Skaugen, T., Førland, E.J. and Roald, L.A. 2008. Climate change impacts on hydrological processes in Norway based on two methods for transferring regional climate model results to meteorological station sites. *Tellus* 60A, 439–450. DOI: 10.1111/j.1600-0870.2008.00306.x.

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Modelling the Scottish hydropower resource

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Introduction

Scotland has a long history of exploiting its hydropower potential and, with aggressive targets for renewable energy set by the Scottish Government, interest in this resource is resurgent. Little research has been conducted to investigate the potential climate impacts upon the resource, however. Climatologies developed by the United Kingdom Meteorological Office (UKMO; Hollis et al, 2004) for the standard periods 1961-1990 and 1971-2000 show an interdecadal reduction in days of the year with lying snow. Snowmelt plays an important role in the operation of Scottish hydro schemes, effectively providing additional storage capacity, smoothing out winter/spring runoff allowing improved capacity factors.

Method

To allow a more complete study of the temporal distribution of the resource, including recent climate impacts upon snowfall and snowmelt, a grid based distributed deterministic rainfall-runoff model has been applied Scotland-wide to simulate daily average river flows. The model makes use of both historic gridded daily rain gauge and temperature data to allow snowfall and snowmelt to be modelled. Called the "Grid-to-Grid Model" or G2G, the model was developed by CEH Wallingford (Bell V.A. et al, 2007) to make use of gridded meteorological and GIS based datasets. As the model is designed to make distributed flow predictions it is well suited for use in a hydropower resource assessment.

The model was forced using a daily gridded rainfall dataset derived from gauged rainfall data (UKMO, 2007) covering Scotland for the period 1960-2005 and an elevation weighted daily gridded temperature derived from a dataset produced by the ENSEMBLES project. Gridded monthly evapotranspiration was computed using the Penman Monteith method based upon gridded UKMO data made available by the UK Climate Projections (UKCP09) project. An elevation corrected snowmelt model utilising a water budget and degree day method was used to model snowfall and melt.

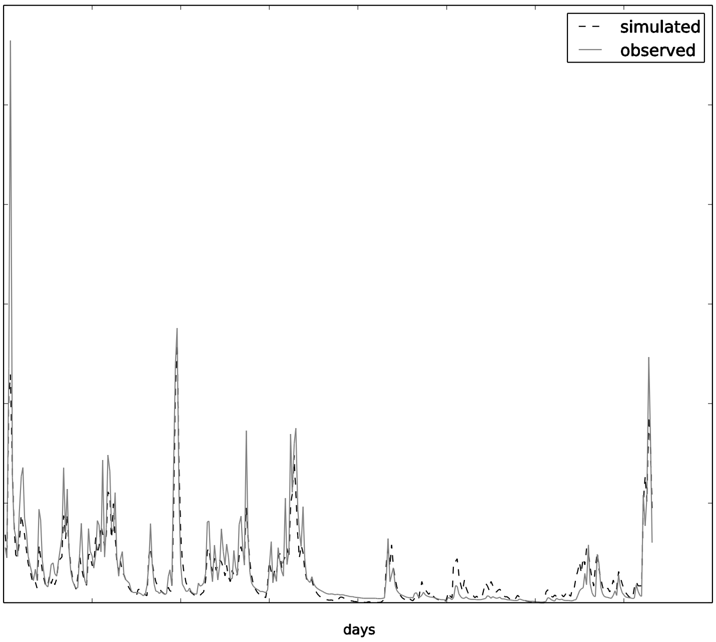

Figure 1 Simulated daily average hydrograph for Girvan catchment over year 1982

The model was implemented in optimised C++ code allowing a high resolution grid size of 250m. This high resolution has made it possible to produce long-term simulated hydrographs (see figure 1) and flow duration curves at frequent intervals for the vast majority of reaches in Scotland‟s river network.

Results

Catchments were modelled with and without the snowmelt model, it was found that when included, overall model performance for upland catchments with significant annual snowcover was greatly improved, giving confidence in the snowmelt model‟s ability to represent both volumes and timing of snowfall and snowmelt.

To enable the model to be used country-wide and effectively simulate ungauged catchments the model was calibrated over multiple catchments to produce a single set of parameters. Six geographically dispersed catchments were chosen, and optimised parameter settings found using the mean goodness of fit across the catchments as an objective function.

Future Work

The development of a high resolution distributed hydrological model with a country wide calibration will allow an analysis of the temporal variance of the resource from season to season and year to year, including interdecadal changes to snowmelt patterns as identified by the UKMO. Future work will focus upon developing a multi-parameter „hydro-search algorithm‟ which will use the simulated hydrographs and derived flow duration curves as input in conjunction with a suitable elevation model.

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Acknowledgments

We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://www.ensembleeu.org) and the data providers in the ECA&D project (http://eca.knmi.nl).

Importance of groundwater modelling in hydrological modelling in Iceland and implementation of the groundwater module in the hydrological model WASIM for two water sheds in Iceland

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Large areas of Iceland are covered with postglacial lava fields. These young lava fields are porous and with high hydrological conductivity. Underground flow through tectonical faults and fissure swarms is also important in some locations. The high hydraulic conductivity of both the lava fields and the fissure swarms make groundwater flow an important part of the runoff from many areas. In total approximately 20% of runoff in Iceland originates from groundwater.

A runoff map was made for Iceland for the period 1961–1990 (Jónsdóttir, 2008). In that work groundwater was omitted and effects of groundwater flowing across watershed boundaries was simulated by scaling the precipitation for each watershed. On watersheds where part of the precipitated water leaves the watershed as groundwater, precipitation was scaled down but on watersheds where groundwater flow from other watersheds emerges as spring flow, precipitation was scaled up. To account for the damping and smoothing effects of groundwater reservoirs damping and time factors in surface runoff and interflow were increased to many times the normal values. These approximations are simple and give satisfactory results for total runoff but for many other parameters such as snow storage, maximum winter snow and thereby total amount of spring melt, these approximations are not acceptable.

On watersheds where groundwater plays an important role, the above approximation leads to model parameters describing surface runoff and interflow that are very different from those that can be deduced from the unit hydrograph for these watersheds. This implies that physical description of some processes is compromised for better overall calibration performance. As proper modelling of physical processes is preferable for modelling of the hydrological regime under different conditions this is a particularly drawback for future scenario modelling for example.

To overcome these shortcomings the groundwater module of the hydrological model WaSiM will be used in future modelling in Iceland at the IMO. Comparisons of calculations for two watersheds, one in northern Iceland and one in the north-eastern part of the country, with and without the groundwater module indicate that better results are obtained by using the groundwater module although it requires considerable more time in preperation and calibration.

Table 1. *Recession constants for the surface runoff (k_D) and interflow (k_I) estimated by two different methods and results with and without groundwater module.*

	k_D (optimized) [hours]	**k_D (from hydrograph) [hours]**	**k_I (optimized) [hours]**	**k_I (from hydrograph) [hours]**	**R^2**	**R^2_{log}**	**ME [%]**	**RMSE [m^3/s]**
Northern Iceland								
With g.w. module	50	20–50	150	120–240	0.74	0.79	0.2	3.27
Without g.w. module	81	20–50	5000	120–240	0.70	0.70	-2.0	3.77
North-eastern Iceland								
With g.w. module	50	35–80	300	150–350	0.55	0.64	1.4	1.57
Without g.w. module	100	35–80	2000	150–350	0.43	0.18	-11.2	2.56

For both watersheds performance was found to improve according both to the Nash–Sutcliffe criterion calculated on stream flow and Nash-Sutcliffe criterion calculated on the logarithm transformed stream flow, i.e. performances were improved both for flood events and peaks and for low flows as shown in Table 1. The representation of inter annual variability was also found to improve by the activation of the groundwater module.

Jónsdóttir, J. F. 2008. A runoff map based on numerically simulated precipitation and a projection of future runoff in Iceland. *Hydrological Sciences Journal*, **53**(1), 100–111.

The effect of climate change on runoff from two watersheds in Iceland

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To investigate the effect of climate change on the hydrological regime in Iceland, future projections of river discharge were made for two watersheds with the WASIM hydrological model. The projections were made for the period 2021–2050 and compared with the reference period 1961–1990. The runoff projections are based on thirteen different climate scenarios (Nawri and Björnsson, 2010; Jóhannesson, 2010), ten derived from GCM model runs prepared in connection with the IPCC 2007 report and three based on RCM downscalings recommended by the CES climate scenario group (Kjellström, 2010).

The watersheds have different hydrological properties and climate characteristics. One is located close to the coast in the north-eastern part of Iceland while the other is located in the northern part of the central highland. The watershed in the central highland has 10% glacier coverage. In order to preserve the internal consistency of the meteorological input data for the hydrological simulations, a year with temperature and precipitation records close to the baseline period of the climate change scenarios was chosen as a basis for the simulations. Monthly differences in temperature and precipitation with respect to the baseline were then used to model future discharge. The simulations were both run for the current glacier extent and altitude distribution by coupling the WASIM model to a simple glacier-scaling model which simulated future changes in ice covered area and ice thickness. Changes in glacier geometry were not found to have much effect on discharge during the period 2021–2050 but became increasingly important in the second half of the 21st century.

The mean discharge seasonality for scenario runs are shown in Figure 1 for both watersheds and compared with the period 1961–1990 and the more recent period 2000–2009. Snow storage has a dominating effect on the discharge seasonality for both watersheds at present and snowmelt spring floods are the largest floods of the year. This is predicted to change for the glacier-covered watershed as runoff from the glacier will increase substantially due to increased snow and ice melting. This leads to a late summer discharge maximum caused by increased glacier runoff. The magnitude of spring floods is on the other hand predicted to decrease and they will appear earlier in the year, in Mars–April instead of May–June. The discharge peaks caused by snowmelt and glacier melt will therefore become more distinct and appear as two separate maxima. Winter flow is also predicted to increase. For the non-glacier covered watershed, the most important change is that the snowmelt generated spring/summer discharge peak largely disappears and is replaced with a more evenly distributed seasonal discharge with much higher winter discharge values and lower discharge during the fall.

The total annual discharge is greatly increased for the glacier-covered watershed as runoff from the glacier is, depending on scenario, estimated to become 65% to 167% higher than the 1961–1990 average.

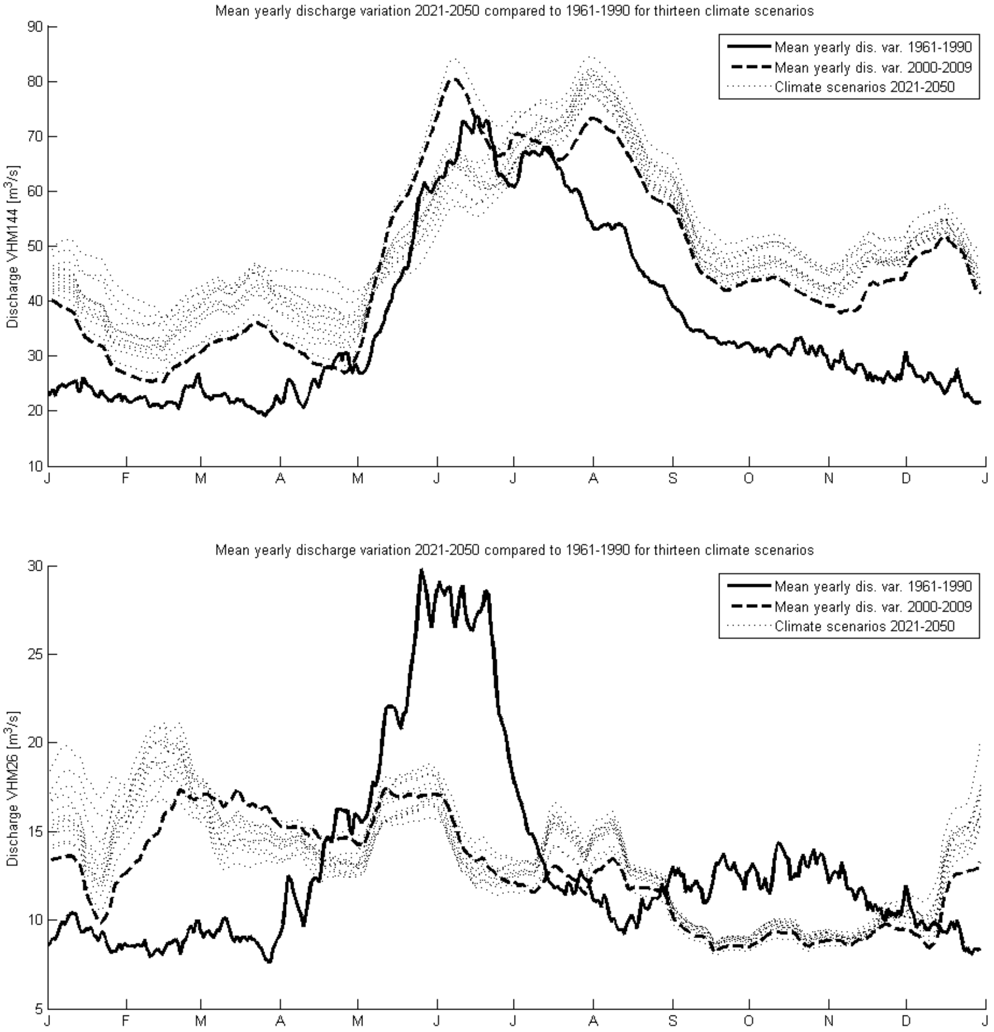

Figure 1. Seasonal discharge variations for a glacier covered watershed (Vestari-Jökulsá, VHM 144) and non-glacier covered watershed (Sandá, VHM26).

It is interesting to note that a large part of the predicted discharge changes between the periods 1961–1990 and 2021–2020 have already taken place for both watersheds as clearly shown by the curves depicting the mean discharge variation of the period 2000–2009 in Figure 1.

Jóhannesson, T. 2010. Sviðsmynd um loftslagsbreytingar á Íslandi fyrir jökla- og vatnafræðilega líkanreikninga í CES og LOKs verkefnunum. (Climate change scenarios for Iceland for glaciological and hydrological modelling in the CES and LOKS projects). Icelandic Meteorological Office, Memo ÚR-TóJ-2010-02.

Kjellström, E. 2010. Deliverable 4.3: Report on user dialogue and analysis of regional climate scenarios for northern Europe. The CES-project, technical report, final version delivered 15 April 2010.

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The effect of climate change on runoff from a partly glaciated river basin simulated with a coupled glacier-scaling-hydrological model

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Changes in river runoff due to climate change have been simulated for several partly glaciated watersheds and ice caps in Iceland and Norway with a coupled glacier-scaling–hydrological or –mass balance model. Most hydrological models effectively assume an inexhaustible reservoir of ice with an unchanged altitude distribution for partly glaciated watersheds. This leads to an unrealistic contribution of meltwater from glaciated areas in long integration periods for a warming climate. More realistically, runoff modelling of such water basins needs to take into account the limited ice volume stored in the glaciers, the reduction in ice-covered area and the progressive lowering of the ice surface that are associated with a reduction in ice volume. The glacier-scaling model simulates annual changes in ice volume from an integration of the specific mass balance computed by the hydrological or mass balance model over the hydrological year. The model represents the ice-covered areas as groups of glaciers with similar dynamic characteristics such as response time and uses volume–area scaling to simulate area changes from ice volume changes calculated from the integrated mass balance for each group. This makes the model suitable for simple runoff modelling of drainage basins with several glaciers without detailed mass balance and dynamic modelling of each glacier. The model has been coupled to the current versions of the Swiss WaSiM and the Norwegian HBV hydrological models and to the MBT degree–day glacier mass balance model.

Changes in mass balance are the driving factor of glacier changes in climate change simulations. If the datum glacier is initially comparatively close to a steady state, changes in the ice flux gradient will be small to begin with because they are caused by accumulated changes in the glacier geometry over time. Mass balance changes will then initially be balanced by corresponding local changes in ice thickness to first approximation since the ice flux will approximately balance the steady state mass balance. The ice flux maintains a “baseline” flow of ice from the accumulation area to the ablation area until significant changes in the glacier geometry have accumulated. Since mass balance changes need time to bring about sufficient changes in ice geometry to alter the ice flow, one may initially assume that changes in the geometry of the glacier do not matter in runoff calculations so that the same values for the glaciated areaand its altitude distribution may be used. This is the current implementation of glaciated areas in the WaSIM and HBV models. Negative mass balance perturbations in climate change runs are typically on the order of –1 m/y so that over a period of a few or several decades, the ice surface may be lowered by several tens of metres. A lowering of that magnitude will start to affect the airtemperature over the glacier and leads to an intensification ofsurface melting through the mass-balance–elevation feedback. This effect might initially be taken into account by a local lowering of the ice surface, corresponding to the negative mass balance perturbation, without consideration of ice flow dynamics. Local lowering of the glacier surface does, however, not take the retreat of the ice margin and the corresponding reduction in ice-covered area into account. With some delay with respect to the ice volume reduction, the ice margin will start to retreat, which leads to a reduction in ice-covered area and runoff from the glacier. This effect counteracts the mass-balance–elevation feedback and brings about an approximately exponential decay of ice volume towards a new steady state of the glacier in the case of a “moderate” step change in climate. These effects may both be taken into account to first approximation by employing empirical power-law relationships between total ice volume and ice-covered area that have been validated for many regions of the world.

Figure 1 shows the results of the glacier–scaling model coupled to the HBV hydrological model for the Nigardsbrevatn and Fønnerdalsvatn watersheds in Norway, which are both partly glaciated, for the three recommended CES climate change scenarios. The results for both watersheds show the effect of the positive glacier mass balances in the 1990s in western Norway which were due to above normal precipitation. According to two of the climate change scenarios, high precipitation values counteract higher temperatures for the Fønnerdalsvatn watershed so that ice volumes there do not start to decay until around 2040. The third scenario for Fønnerdalsvatn and all three scenarios for Nigardsbreen show ice volumes starting to decay in the period 2000–2010.

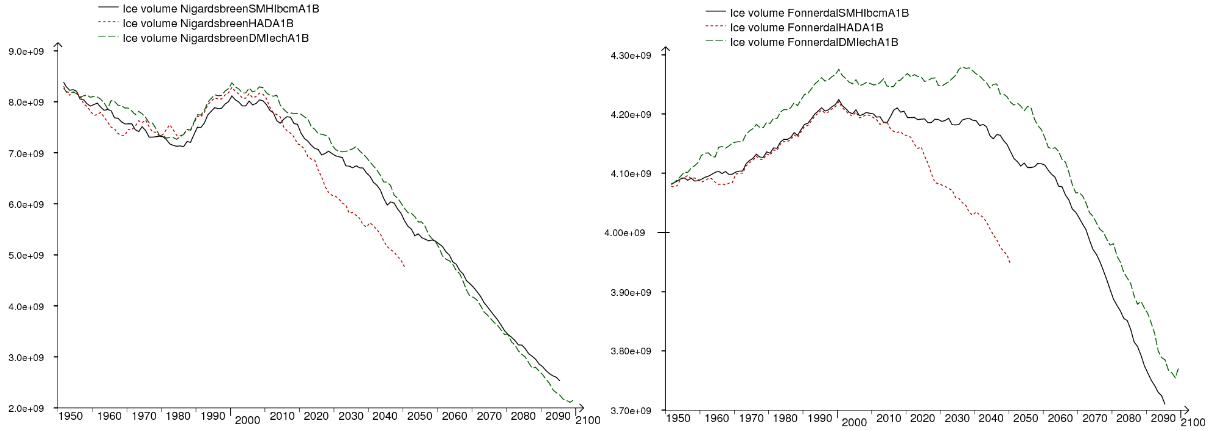

Figure 1. Changes in total ice volume for the Nigardsbrevatn and Fønnerdalsvatn watersheds in Norway simulated with a glacier-scaling model coupled to the HBV hydrological model for three RCM/GCM climate simulations based on the A1B emission scenario (ECHAM5/DMI-HIRHAM, HadCM3/MetNo-HIRHAM, BCM/SMHI-RCA3).

Comparison of simulations with a glacier scaling model and a dynamic ice flow model, on the one hand, with models with a fixed glacier geometry, on the other hand, for glaciers in Iceland show that the reduction of ice volume and ice-covered area has little effect compared with a fixed ice-cover during the initial decades of the runoff simulations. After 30–50 years, depending on the climate scenario and the size of the glaciers in question, the results of the coupled model start to diverge from runoff simulated with a fixed ice-cover and after more than ~100 years the simulated glacial discharge component is crucially dependent on realistic simulation of the decreasing ice volume within the watersheds.

A coupled mass-balance and ice-flow model for Midtdalsbreen; projection of glacier length based on climate scenarios (CES)

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Midtdalsbreen, central southern Norway is an outlet glacier on the northeastern margin of Hardangerjøkulen (Fig. 1b, c). Hardangerjøkulen is situated between the wet maritime environment on the Atlantic coast and the dry continental environment further to the east. As a result, the ice cap is particularly sensitive to climate shifts and changes in circulation pattern. Midtdalsbreen covers an area of about 6.6 km^2. The glacier descends from the glacier plateau at 1860 m a.s.l. to 1380 m a.s.l and its length is about 4.7 km. At Midtdalsbreen, detailed knowledge about glacier geometry and ice flow exists for the present glacier.

A coupled dynamic/mass balance model for Midtdalsbreen has been developed in order to estimate the response of the glaciers to past, present and future climate changes. The mass-balance model (degree-day model) computes glacier mass balance as a function of altitude based on observations of temperature and precipitation at a meteorological station. The coupled dynamic/mass-balance model computes the length and volume change of the glaciers with time. The models have been calibrated using existing front positions (glacier geometry), mass balance data (proxy) and measured climate data.

The models is forced by climate scenarios defined in CES (*Climate and Energy Systems* project) that are have been development for the purpose of outlining the hydrological consequences of future climate change. Transient simulations were carried out based on four sets of future climate scenarios were established; S1, a continuation of the observed 1961-2005 climate over the next 95 year (until 2100); S2, S3 and S4, representing climate downscaled from Atmospheric-Ocean General Circulation Models. The climate input variables for S1 use observed data from meteorological stations for the period 1961-2005. The observed data is projected/repeated until 2100 we therefore imposed no change in the climate until 2100.

Scenarios S2, S3 and S4 were obtained from CES project. Here a summary will be given. Three different Atmospheric-Ocean General Circulation Models (GCMs) has been used the ECHAM5, HadCM3 and Bergen Climate Model (BCM). The GCMs are run using the emission scenarios A1b. Since the spatial resolutions of the general circulation models are low downscaling is necessary to obtain reliable estimates of the climate specific regions. Results from AOGCMs have been downscaled with the regional climate model (RCM). Three different RCM has been used DMI-HIRHAM (using the ECHAM5), met.no-HIRHAM (using the HadCM3) and SMHI-RCA3 (using the BCM) which give the scenarios S2, S3 and S4 respectively. The RCM have spatial resolution of 25 × 25 km^2. Since monthly or daily values of temperature and precipitation at station are needed as input of the mass-balance model the RCM data was dynamically downscaled to meteorological stations sites using a method developed by Engen-Skaugen (2007).

We calculated the static mass-balance sensitivity for Midtdalsbreen using scenarios S2. The static sensitivity ignores time-dependent retreat or advance of the terminus, changes in geometry of the glacier. The change in the specific mass balance of Midtdalsbreen as a result of the increased temperature, assuming none change in glacier geometry, is -0.91 m w.e. a^{-1}

°C^{-1}. The same procedure can also be used to investigate the sensitivity to precipitation changes. We found that a 30% decrease in precipitation has roughly the same effect as a 1K warming giving -0.03 m w.e. a^{-1} %$^{-1}$. A cooling of 1K without precipitation changes is predicted to lead to a fall by ELA about 125 m. Our result is in agreement with previous modelling studies from southern Norway e.g.(Jóhannesson and others, 1995).

In the numerical experiments with the glacier model the ice geometry was initiated with the 1961 topography. By forcing the model with the climate scenarios described above (S1, S2, S3 and S4), we calculate the future evolution of Midtdalsbreen until 2100. The model shows a retreat of snout of Midtdalsbreen between 200 m and 4700 m, depending on the scenarios applied. With the S1 scenario which gives a slightly negative mass balance for the present glacier, the glacier does not reached a steady state after 95 years (2100). The glacier continuously loses mass, and the volume reduction between 1995 and 2100 is about 22 %.

For scenarios S2-S4 the model results show retreat rate until 2050 of about -17 m a^{-1}. Thus the reaction of the glacier is rather moderate in this period. From 2050 the retreat rate increases as the length variations of the glacier is largely affected by the geometry of the ice mass and its underlying bedrock topography. The fast retreat after about 2060 to 2080 are a result of the modelled glacier separates into two part and only the upper part is remains in the model domain (Fig. 1). The retreat rates are most likely overestimated.

For the scenarios used glacier will retreat and the volume of the glaciers is predicted to decrease by approximately 15% to 64 % (depending on scenarios) over the next 43 years, and the glacier essentially disappear during the next 100 to 150 years for the warmer scenarios.

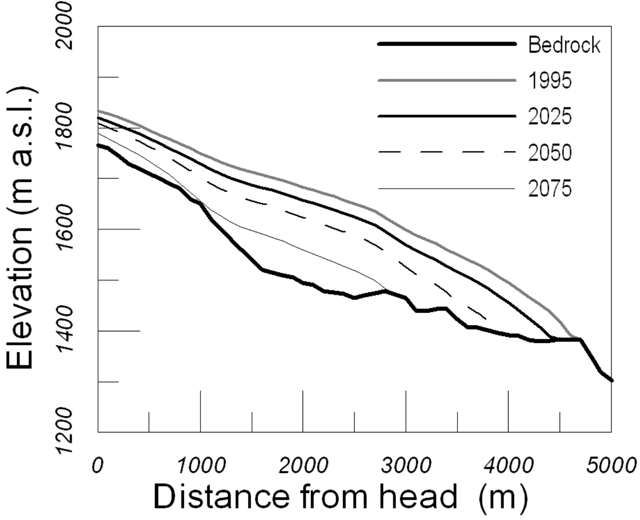

Fig. 1. The surface elevation of Midtdalsbreen observed in 1995 and simulated for the future based on S3 scenarios.

Jóhannesson, T., Sigurdsson, O., Laumann, T. and Kennett, M., 1995. Degree-day glacier mass-balance modelling with applications to glaciers in Iceland, Norway and Greenland. *Journal of Glaciology*, 41(138), 345-358.

Engen-Skaugen, T., 2007. Refinement of dynamically downscaled precipitation and temperature scenarios. *Climate Change*, 84, 365-382 doi:310.1007/s10584-10007-19251-10586.

Monitoring changes in glacial hydrology in Iceland

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Ice caps and glaciers cover about 10% of the surface area of Iceland and receive 20% of the precipitation that falls on the country. The mass balance of the major ice caps in the central highlands has been negative since 1995 and the termini of outlet glaciers have typically been retreating by 20–50 m each year in this period. Modelling of future changes of the main ice caps based on climate projections for Iceland in the 21st century predicts continuing retreat and steady increase in glacial runoff, that needs to be taken into account in the future development of the capacity of reservoirs, tunnels and waterways of hydropower plants in Iceland. Moreover, changes in subglacial water courses and in river courses in front of the receding glaciers need to be monitored and predicted to the extent possible.

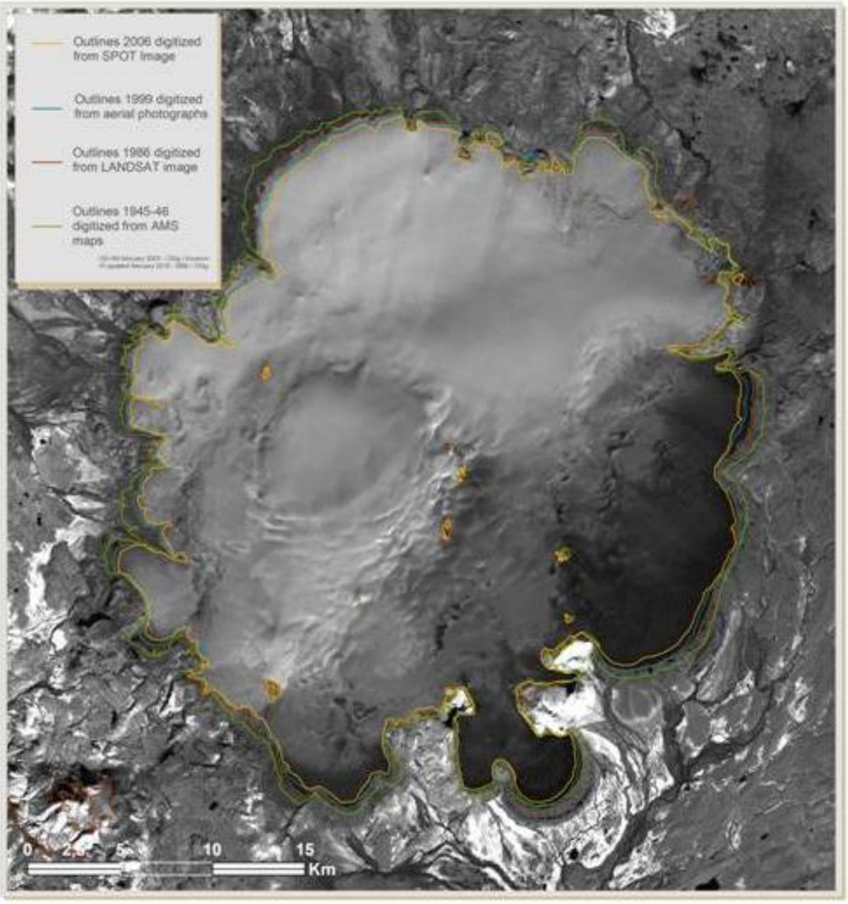

Fig. 1 – The Hofsjökull ice cap, Central Iceland, lies between elevations of 610 m and 1790 m a.s.l. The area of the ice cap is presently about 860 km^2, the average thickness is 215 m and the maximum thickness is 750 m. Variations in the position of the ice-cap margin have been

recorded since the 1930s and the mass balance has been measured annually since 1988. The river Þjórsá originates in the SE-part of Hofsjökull and Blanda in the NW-part.

This poster presentation gives an overview of recent changes in the extent of major ice caps in Iceland, with focus on:

1. Analysis of recent marginal variations of the Hofsjökull ice cap, Central Iceland, based on satellite images, maps and direct observations at the ice-cap margin. Special focus is on those parts of Hofsjökull that deliver meltwater to rivers harnessed for hydropower production. Figure 1 shows the outlines of the ice cap at different times in the period 1946–2006.

2. Recent changes at the front of the Skeiðarárjökull outlet glacier, S-Vatnajökull. The Skeiðará river, which was one of the major impediments to travel in Southern Iceland since the time of settlement until it was bridged in 1974, stopped flowing in its course during the summer of 2009. The river waters now flow westwards along the glacier margin where they enter a different river course.

Impacts of climate change on the Norwegian Energy System towards 2050

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The overall aim of the project is to identify the effects of climate change on the Norwegian energy system towards 2050. It is analysed how changes in renewable resources and end use demand due to climate change influence the entire energy system.

Ten existing climate experiments, based on a set of five global climate models and six emission scenarios, provided by the Norwegian Meteorological Institute, cover a range of possible future climate scenarios. The experiments are downscaled to central and Northern Europe by using the HIRAM atmospheric climate model. In each experiment, there are two simulations; a control period representing present climate scenarios and a scenario period representing a possible future climate (adjusted around 2045). In this project, the data is interpolated to 20 geographical locations to study the temperature, solar radiation and wind characteristics distribution over the entire country. The selected locations for analysis of precipitation are analysed by the Norwegian Water Resources and Energy Directorate (NVE) in another ongoing project.

Temperature, solar radiation and wind data is converted into monthly average values. Based on the climate data analysed it is concluded that climate change will not change the potential for wind power significantly. For most locations, months and models analysed, the temperature increases 1 - 4 °C from the control to the scenario period. The increase is higher during the winter and at northern or inland locations. In July and August the temperature difference between the control and the scenario period is relative small.

A simplified method to analyse the effects of climate change on the energy use for space heating is the heating degree days (HDD) method. This method is used with all the analysed climate experiments. With a base temperature at 17 °C the heat demand decreases between 9 and 13 % in the residential sector.

The effect of climate change on the heating and cooling demand in various residential and commercial buildings at seven different locations in Norway is studied with the SolDat model developed by the University of Oslo. The calculations are based on one of the ten climate experiments; the ECHAM model with the IS92a emission scenario. Based on the SolDat calculations the change in the Norwegian heating and cooling demand is derived by weighing the seven locations by a population share. New health, office, trade and multi family buildings have the largest reduction with 17 % and old education, hotel, and single family buildings have the smallest reduction with 13 %. The climate impact is assumed to have a linear trend. The heating demand is reduced with 4 and 10 TWh and the cooling demand is increased with 0.3 and 0.4 TWh in 2030 and 2050 respectively.

The effect on climate change on useful water inflow is analysed by NVE. Changes in the hydro power resources are investigated on a regional and a national level. Climate change gives an overall wetter climate, but with drier summers. The useful hydro inflow is increases between 6 and 14 % to 2045 for the four analysed climate experiments. Based on the ECHAM model with the IS92a emission scenario the Norwegian hydro resources increase with 13 and 23 TWh in 2030 and 2050 respectively.

Climate impact on the resources and on the end use demand is implemented in the Norwegian MARKAL model. MARKAL is a linear programming tool, a bottom-up model with a detailed representation of the energy sector of the economy. The model consists of a detailed description of the energy system, both technically and economically, with resources, energy carriers, conversion technologies, and energy demand. Available resources (hydro, wind, bio etc.) and the end use demand are given exogenously in the model.

The MARKAL analyses show that with climate change the share of the electricity production from hydro power increase and the share of electricity production from new renewable technologies like offshore wind and ocean power decrease. In addition the climate change postpone the time when offshore wind and ocean power become competitive in the electricity production marked. The Norwegian electricity export potential increase with climate change but investments in new export cables depend on the future electricity price. If the gas and export electricity price both increase with 1.4% per year, there will be no new export cables, given the modelled costs, but with an assumption of 2.8 % increased electricity price per year (and 1.4% for gas), there will be investments in new cables and 4 TWh more electricity is exported in 2050. A decrease in heat demand influences the energy consumption and heating technologies used in the residential and commercial sector. All technologies except energy efficiency measures are reduced. Electricity is most significantly reduced mainly due to a cut in the use of direct electric heating.

A stochastic programming approach will give near term solutions taken into account the uncertainty of the future climate change. The results can for example show what the profitable investments in new electricity export cables and wind power are in the near future (towards 2030) taken into account the uncertainties of the future climate. There is not much experience with stochastic modelling of hydro resources in MARKAL and as far as we know it has not been done before. This has led to some modelling challenges that have not yet been solved. Consequently we do not have any results from the stochastic analysis yet.

A limitation with the current methodology is that the Norwegian emissions are not linked to the climate model data. Hence, increases in greenhouse gas emissions (GHG) increase the temperature level and reduce the heating demand. Less demand can results in less use of fossil fuel based heating technology and less use of fossil fuels reduces the GHG emissions and lowers the temperature increase. However for a small country like Norway a linkage between the energy model and global climate model is not crucial because the Norwegian emissions contribute to a minor part of the global emissions.

Acknowledgements
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Sensitivity of thermal power generation to climate change

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Introduction

Climate change will have a wide range of impacts on the electricity industry affecting generation, transmission and demand. One specific effect will be that higher temperatures will tend to reduce the efficiency of thermal power stations, of particular interest in the United Kingdom (UK) given its overwhelming reliance on thermal technologies. Heat engine performance is fundamentally driven by the temperatures of the hot source and the cold sink to which heat is rejected. The Carnot efficiency is the maximum attainable efficiency. Whilst small increases in ambient temperature have a modest impact on Carnot efficiency, since real thermodynamic cycles are inherently less efficient, there is potential for power stations to show greater sensitivity to changes in ambient conditions driven by climate change. A reduction in air density could also affect the operation of CCGT stations. With gas turbines designed to operate with constant volumetric airflow, the reduced density causes the mass flow to fall, consequently reducing the power of the gas turbine and the amount of heat generated in the heat recovery boiler (Kehlhofer *et al.*, 1999).

Plant models

Three different power stations were modeled in this study: Torness nuclear power station in East Lothian, Longannet coal-fired power station in Fife, and Rye House combined cycle gas turbine (CCGT) station in Hertfordshire. The results presented here are focused on the Rye House CCGT plant. Opened in 1993 by Scottish Power it has a capacity of 715 MW. The station possesses three 155 MW Siemens gas turbines capable of burning gas at 39 m^3/s. The hot exhaust gases from the gas turbines feed their own heat recovery boiler and produce superheated steam which drives a 250 MW Siemens turbine generator. The station is cooled by an air-cooled condenser. A thermodynamic model of the station has been created and used to analyze the effects of changes in ambient temperature on power and energy output.

UKCP09 Scenarios

This analysis uses the climate change projections, UKCP09 [1], published in 2009. These projections were created from ensemble runs of a number of climate models and provide information on common climate variables for seven thirty-year time periods from 2010 – 2099 under a range of greenhouse gas emissions levels. Because a number of models were used to derive the projections, a probability distribution is available for many of the variables under a specific time period/emissions scenario. The spatial resolution of the output from the UKCP09 model is 25km. To aid interpretation, for the CCGT plant which takes air temperature as input, three emissions scenarios of „low", „med" and „high" are shown here for three time periods: 2020s, 2050s and 2080s. While 2080 is well outside the planning range for power systems it has been included for completeness. Three probability levels have been discussed for each scenario in order to consider the range of possible outcomes: 10%, 50% and 90%.

Results

The mean air temperature changes applicable to the Rye House CCGT were taken for the closest grid cell. These changes were applied on a monthly mean basis to a baseline calculated from observed temperature data interpolated onto the same 25km grid as the projections[2]. The UKCP09 scenarios imply annual average air temperature rises of between 1-4ºC by the 2050s under medium emissions. This masks some more significant seasonal differences, with summer and autumn largely showing greater changes than winter and spring. The impact of this on power generation at the Rye House CCGT plant has been modelled and the changes in monthly mean power output calculated. The percentage changes for the 2050s under medium emissions appear to be worse in summer months, the maximum change being a drop of just over 3% in August at the 90% level. Additionally, the number of hours in each month have been used to derive the theoretical energy output for the year under the different scenarios – this assumes the station is running continuously as baseload – which gives some insight into the potential economic impacts that could be felt by the operators. The changes in annual energy output are shown for 2020s/‟low‟, 2050s/‟med‟ and 2080s/‟high‟ scenarios at 10%, 50% and 90% probability in Figure 1. Examining the 2050s/‟med‟ scenario, this reveals a very likely drop in annual energy output of 1%, with a 10% chance that it could be as much as 2.3%.

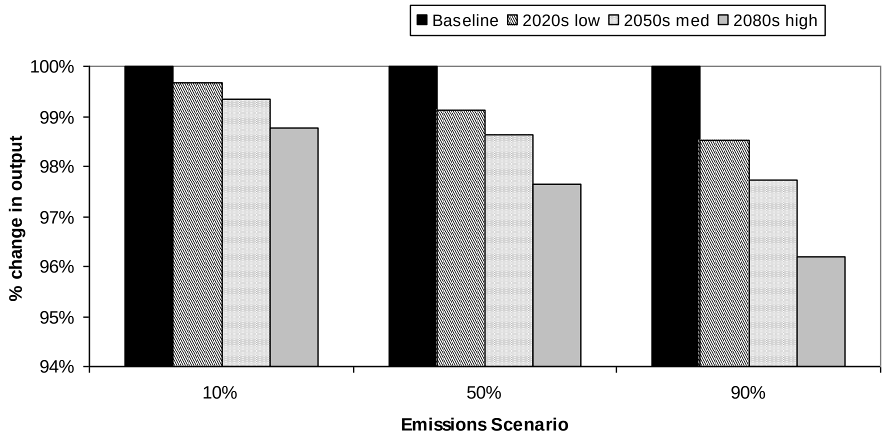

Figure 1: Change in annual energy output for range of time/emissions/probability scenarios (%)

Discussion

The changes projected by this model are not large in magnitude, but have the potential to cause disruption in cases of peak load, particularly when combined with a possible shift to in the demand peak to summer months. The fact that the reduction in power appears to be worst in summer could prove to have a significant impact. The economic consequences of the calculated drop in yearly energy output are difficult to judge without consideration of other circumstances, but again, the seasonal impacts could be amplified.

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[1] © Crown Copyright 2009. The UK Climate Projections (UKCP09) have been made available by the Department for Environment, Food and Rural Affairs (Defra) and the Department of Climate Change (DECC) under licence from the Met Office, UK Climate Impacts Programme, British Atmospheric Data Centre, Newcastle University, University of East Anglia, Environment Agency, Tyndall Centre and Proudman Oceanographic Laboratory. These organisations give no warranties, express or implied, as to the accuracy of the UKCP09 and do not accept any liability for loss or damage, which may arise from reliance upon the UKCP09 and any use of the UKCP09 is undertaken entirely at the users risk.

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Impact of a changing climate on power production in the Nordic region

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This paper presents an analysis of how climate change may influence electricity generation in the Nordic region during 2020-2050. Climate scenarios developed by IPCC and ENSEMBLES indicate increased precipitation in the Nordic region in the future. The Nordic electricity system is dominated by hydropower and changes in precipitation will strongly influence future investments in power production. Political targets related to climate change will channel investments towards CO_2-neutral generation capacity and lower final demand. Global warming will also reduce space heating demand and, thus, electricity used for heating.

The objective of this analysis is to determine how changes in precipitation and political targets for greenhouse gas mitigation may influence future investments in generation capacity in the Nordic region. The analysis is based on three hypotheses;

i. the current definition of a wet year in the Nordic power system will represent a normal year from 2020[1]
ii. there will be greater fluctuations in weather patterns in the future with extreme climate events, such as drought, occurring more often than in the past
iii. power production in the Nordic region must be fossil fuel free by 2050.

The Balmorel electricity market model was used for the analysis. Balmorel is a partial equilibrium model that assumes perfect competition in the electricity and combined heat and power sectors. The model optimises investments in generating capacity subject to technology and policy constraints to meet end-user demand, which is assumed to be inelastic. The model consists of a number of electricity regions divided by transmission bottlenecks. Balance of supply, demand and net exports are maintained in each region. The model minimises costs at full foresight to obtain optimal operation including generation for specific or aggregated plants, consumption of fuels, emissions, losses, international transmission etc.[2]

To analyse the effects of changes in precipitation and the phasing out of fossil fuels in the power sector, the three hypotheses were incorporated in the Balmorel model as constraints and two scenarios with different demand levels were developed. More frequent occurrences of extreme weather conditions were represented in the model by four drought years; 2021, 2031, 2041 and 2049. It was assumed that a drought year is the same as a current day dry year and will occur approximately once a decade. The inclusion of drought years provides an indication of the investments required in a system optimised for higher levels of precipitation, but with increased risk of extreme climate events.

Input data are based on the assumption that all EU and national policy goals for reduced energy use and CO_2 emissions and integration of renewables have been achieved. Demand data, fuel prices and technology data for the model are based on the most recent projections

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[1] Currently a wet year is defined as having at least 12 % more precipitation than in a normal year.
[2] For more information on Balmorel please refer to www.balmorel.com.
[3] Currently a dry year occurs when precipitation is a maximum of 88 % of a normal year.

from the Danish Energy Agency and ENTSO-E[4]. For years without projections, demand is extrapolated at the latest available rate of change.

The results for scenario A are shown in figure 1. Nuclear capacity and available biogas supplies are used throughout the period. Hydro capacity increases by 1.000 MW from 2020 to 2050. Most new hydro investments occur in Norway. CCS is introduced at large scale in 2040 and reduces natural-gas use substantially during normal years. There is considerable biomass expansion in the 2040s to achieve fossil free power production. It is not always profitable to replace decommissioned wind turbines until electricity generation must be completely decarbonised in 2050. In drought years, increased biomass and natural gas generation substitutes the shortfall in hydropower production, which results in higher electricity prices. The average price difference between 2020 and 2021 is 11%. Prices in drought years are from 2030 onwards 30-60% higher than in normal years. Prices in normal years remain stable from 2030-2040, but increase from 2040-2050 due to the phasing out of fossil fuels.

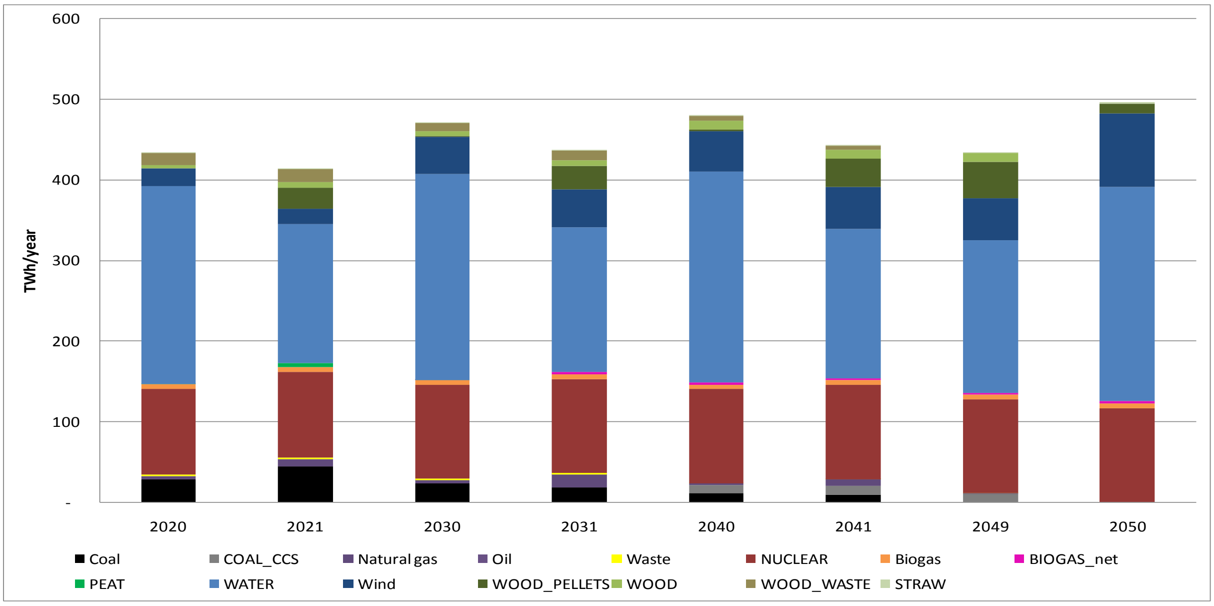

Figure 1: Electricity generation mix for normal and drought years in the Nordic region

A low demand scenario was developed with 10 % reduction in electricity consumption in all countries from 2020 to 2050. Besides this a 40 % reduction in demand for electric heating in Norway and Sweden due to improved insulation and switching to heat pumps was included by 2050. The resulting demand in 2050 is 730 TWh instead of the 840 TWh in scenario A. Wind power capacity is 50% smaller and biomass generation capacity 30 % smaller. The lower demand results in electricity prices that are 30 % lower in 2050. Prices in other normal years are also lower due to hydro and nuclear power covering a larger portion of demand. In the drought years 2021 and 2031 the electricity price is much less than in scenario A as the need for generation from natural gas is more than 60 % less and investments in new biomass plants are much smaller. Drought years in 2041 and 2049 have slightly lower prices than in scenario A as biomass is used instead of coal.

A fossil fuel free power system optimised to higher levels of precipitation will experience markedly higher prices in drought years. The impact of drought years can be reduced substantially if ambitious energy efficiency initiatives are implemented.

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Impacts of climate change on the heating and cooling demand of Norwegian buildings

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A complete assessment of the impact of climate change on the future renewable energy resources should also include the study of the energy demand side. Major renewable energy resources (solar, wind, wave energy) have discontinuous availability, are difficult to store or are produced at the end-user level. Hence the interplay between renewable energy supply and demand, which may both fluctuate in time, is an important issue.

After transport and industry the energy demand in Norwegian buildings related to heating and cooling is the third largest contribution – a demand which is strongly correlated to climate parameters as ambient temperature, solar radiation, wind, etc. The aim of the present work is to identify the effects of climate change towards 2050 on the heating and cooling demand in Norwegian buildings. The latter are calculated with suitable time steps so that the correlation to time-, seasonal- and geographical energy and power production capacities can be assessed (Fidje et al., 2010).

The climate data used in the present study are based on the NorACIA-Regional Climate Model, which was run with input data from MPIs global climate model ECHAM4 T42, and with the emission scenario IS92a (IPCC, 2001). The choice of emission scenario is not essential for projections up to year 2050 because for this period there are relatively small discrepancies in global warming between the various SRES emission scenarios. The calculations were performed with a spatial resolution of 25x25 km^2 for the period 1981 – 2050, and to study the changes throughout this period, two time slices 1981–2010 (control period) and 2021–2050 (scenario period) were compared. The calculations are done with a time-step of a few minutes, but results are just stored for 24 hours and provide the input parameters for the present simulation study.

For seven selected geographic locations in Norway the parameters ambient temperature (*t2*) and the downward surface short-wave radiation (*sradsd*) from the climate data were used as input for a study with the simulation program SolDat v.12.2.0 (SolDat, 2009). Although SolDat cannot read-in the series of climate data directly, it reproduces ambient temperature profiles and the global solar irradiation for a defined geographic location with desired time step based on the Monte-Carlo algorithm and only few parameters deduced from the climate response experiment (*t2* and *sradsd).* SolDat calculates -among others- the net heating and cooling demand of buildings and passive gains correlated to local climate and geographic location.

Five major Norwegian cities were chosen as geographical location for the present study, Oslo, Kristiansand, Bergen, Trondheim, Tromsø, further one central mountain climate (Trysil) and one northern inland climate (Karasjok). Seven different building types with different thermal insulation standard, building size, orientation of windows and internal gains (according to NS3031:2007) were defined: Single- and multi-family houses, institutional buildings (offices, hotels, schools and hospitals) and commercial buildings (shopping centres. etc.). It is further assumed that the present building stock consists of existing houses with technical standard according to TEK 87 and new-built houses with technical standard according to TEK 07.

Considering major Norwegian cities, the largest reduction of the net heating demand due to climate change is found for new office- and health- and multi-family buildings (14% - 18%) and the smallest for old single-family houses, educational and hotel buildings (12% - 13%). These figures are based on an increase of the average annual ambient temperature of 1.2 K - 1.5 K.

The climate change-induced variation of downward surface short-wave radiation is small (±2%) for all locations except Bergen (-14%) and Trondheim (-10%). However passive gains due to solar radiation through windows represents a non-negligible contribution to the heat balance of buildings, in particular for buildings with south-facing windows. Passive gains in single- and multi-family houses account for 13% -16% of the total heat balance at latitudes below 61° and 8% - 14% at latitudes larger than 63°. But the climate-induced changes of the passive gains are small and their relative share varies with ±2%.

The SolDat study included also the effect of climate change on the net cooling demand in Norwegian buildings. Net cooling demands of considerable size were found only for the locations Oslo and Kristiansand based on the present climate data. Relative to the net heating demand, the net cooling demand is largest for new multi-family houses, office-, hospital and trade buildings, and increases due to climate change from 5% - 6% to 10% - 12%.

The results of the present study, which investigated the climate change induced consumption of energy in different buildings for seven geographic locations, were used as input for an extended study by Fidje et al. (2010), which analyses the impacts on the entire Norwegian energy system. Although SolDat has originally been developed for a different application, the modified version 12.2.0 is a suitable tool to investigate the effect of climate change on the heating and cooling demand in buildings.

Acknowledgements - The present work has been funded by the Research Council of Norway with co-financing from the Norwegian Water Resources and Energy Directorate (NVE).

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Climatic zones in Europe as a dissemination tool of climate change information

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A major challenge for raising awareness of climate change and motivating active mitigation and adaptation measures is the dissemination of scientific information in terms that are understandable to the layman, i.e., anyone without scientific training, including many decision-makers. An introduction to world climatic zones is included in the syllabus for geography in basic and secondary education in many countries. Besides, everyone has a sense of the climate type of the region where they live or have visited. This suggests that maps illustrating the projected future shifts of the climatic zones might help to make the regional impacts of global climate change more easily imaginable. However, if the maps are interpreted incorrectly, the attempt to strengthen people's knowledge about global change by this means is likely to fail.

We have two objectives in this paper: first, to construct scenarios for the migration of climatic zones in Europe and second, to consider the use of climatic zones from the point of view of visualizing climate change information. For the first objective, we make use of simulations performed with regional climate models (RCMs) operated in the CES project at 25km spatial resolution, with boundary conditions from three different global climate models (GCMs). The following experiments were considered: HIRHAM5(DMI) downscaling ECHAM5 member 3; HIRHAM(Met.No) downscaling HadCM3, and RCA3(SMHI) downscaling BCM.

In order to assess the future climatic zones, the projected changes in 30-year averages of monthly mean temperature and precipitation were combined with the observational E-OBS dataset (version 3.0; Haylock et al. 2008), applying the delta method. In addition to inter-comprisons between individual model simulations, the results are compared to outcomes from studies by Castro et al. (2007), Gao and Giorgi (2008), and Jylhä et al. (2010). The first of these three papers was based on the PRUDENCE set of RCM simulations, the second on a single RCM (the ICTP RegCM) and the latter on global CMIP3 climate model data.

The current distribution of the main climatic zones, based on the E-OBS dataset for temperature and precipitation, is shown in Figure 1. Based on the model projections, major changes in the climatic zones will take place, particularly in north-eastern Europe, in the Iberian Peninsula, around the Black Sea, and in the Alps. During the next few decades, regions assigned to either the tundra (ET) or boreal (Df, Ds) climates are projected to shrink, while the temperate (Cf, Cs) and dry climate (BW, BS) zones will expand. The projected changes, in terms of relocation and coverage, are in accord with the observed trends during the past fifty years.

As to the second goal of this paper, we discuss findings of a web-based questionnaire survey in Finland (Jylhä et al., 2010). The survey indicated that the information regarding the migrating climatic zones as disseminated by maps was generally interpreted correctly. The percentage of correct answers to 13 checkbox questions in the survey was 86% on average, ranging from 65 to 93% among the questions. The maps were regarded as an effective tool to visualize projections of climate change by 81% of the respondents. The educational background of the respondents and their level of prior knowledge about climate change were less influential than the process of answering, i.e., whether or not the respondent had utilized the maps when replying to the questions. This suggests that the use of the charts notably helped the viewers to find the correct answers. It may thus be concluded that maps showing projected temporal evolutions of the climatic zones appeared to be an easily-comprehensible means for dissemination of climate change information.

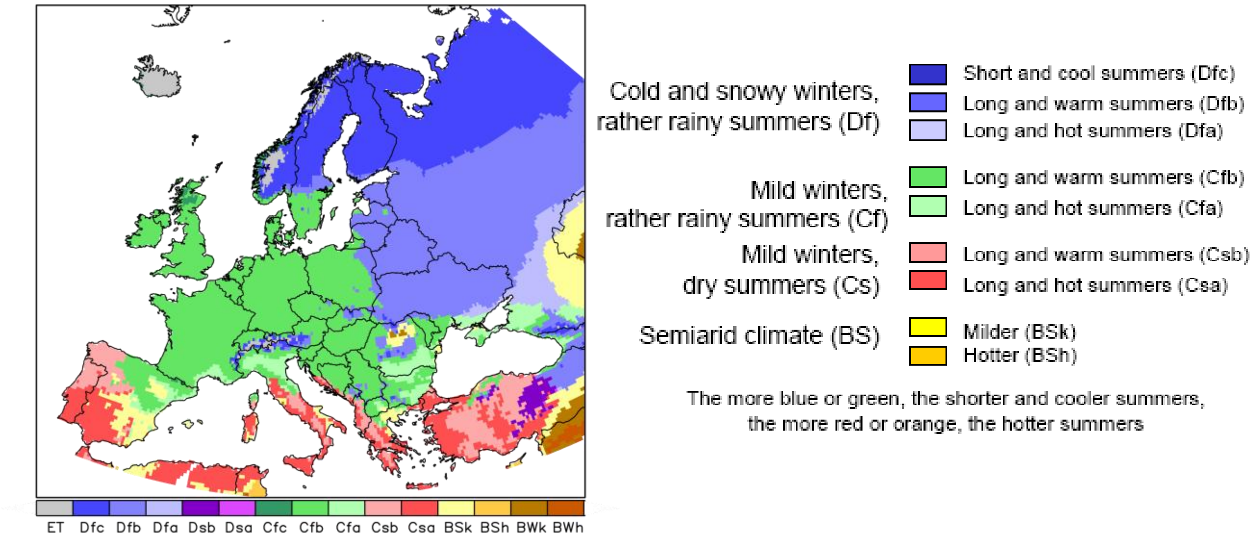

Fig. 1 Köppen climate zones deduced from observations for the period 1971-2000.

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