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SCANNET
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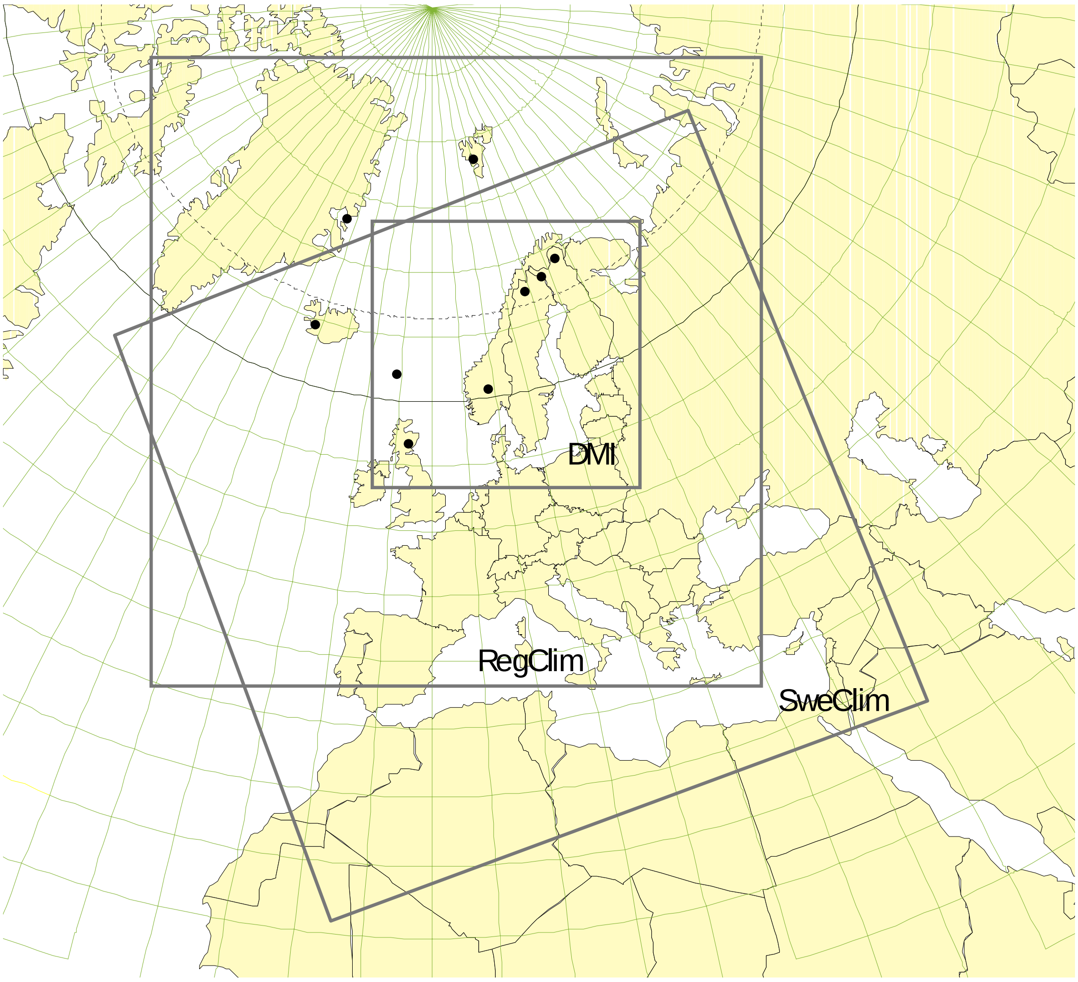
Network of Terrestrial Field
Bases

Climate Change Scenarios for the SCANNET Region



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REPORT

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Abstract

This report is mainly a review of sources for climate change assessments relevant for the SCANNET Region and presents a series of scenarios and results for the SCANNET Field Stations, besides presenting some general aspects of climate change modelling. The results presented are based both on GCM simulations and on the specific regional models covering the whole or part of the area. The regional models are the RegClim, SweClim and DMI models. With regards to local results/scenarios, the focus is on dynamic downscaling. Statistical downscaling is only discussed in general terms, as the regional application of such methods requires data and resources that are beyond the scope of this project.

The report presents a number of scenario run results without giving a single authoritative scenario. They represent a selection of possible scenarios, and the credibility or "likelihood" of the different scenarios is not discussed nor indicated. The climate change predictions/scenarios for the SCANNET region vary considerably from simulation to simulation, both between AOGCMs and RCMs, reflecting a large uncertainty at local scale.

4 keywords, Norwegian	4 keywords, English
1. Klimaendringer	1. Climate change
2. Scenarier	2. Scenarios
3. Sirkulasjonsmodeller	3. Circulation models
4. Usikkerhet	4. Uncertainty

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Network of Terrestrial Field Bases

Work Package 3

Regional Climate Change Scenarios

Climate Change Scenarios for the SCANNET Region

Frontpage illustration: Torulv Tjomsland

Preface

This report is the main output of SCANNET Work package 3, Regional Climate Change Scenarios. The results have been compiled from many sources, but the most important have been the IPCC Data Distribution Centre, the IPCC reports, the ACIA climate change scenario activities, and the work on regional downscaling carried out through the Nordic initiatives RegClim, SweClim/The Rossby Center and the Danish Climate Centre - and their collaborative effort NordEnsClim. Some of the results presented in this report will also be available on the SCANNET web site http://www.scannet.nu. As part of the work package, time series of monthly values from a series of scenario simulations representative for the SCANNET stations are stored on the SCANNET data server.

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Oslo, 28 February 2003

Contents

List of Tables

List of Figures

1. Summary

The SCANNET Field Stations span a large part of Scandinavia and the North Atlantic, from Ny-Ålesund, Svalbard at 79^o N to Banchory, Scotland at 57^o N, and from Zackenberg, Greenland and Litla-Skard, Iceland at 21^o to Kevo, Finland at 27^o E. The climate varies from temperate to high arctic, and from maritime to continental. The future climate changes to be encountered at these sites will most likely be quite different, both *per se*, and in their environmental and societal impacts. The North Atlantic is a problematic area in terms of climatic modelling - the different General Circulation Models (GCMs) show strongly varying results in the scenario runs. They also have problems in simulating the present climate in the area.

This report is mainly a review of sources for climate change assessments relevant for the region and presents a series of scenarios and results for the actual field stations, besides presenting some general aspects of climate change modelling. The results presented are based both on GCM simulations and on the specific regional models covering the whole or part of the area. The regional models are the Regclim, Sweclim and DMI models. With regards to local results/scenarios, the focus is on dynamic downscaling, *i.e*. the regional simulations from these models, using the GCMs as boundary values. The alternative, statistical downscaling, using empirical relationships between site specific historical series and circulation descriptors, is only discussed in general terms, as the regional application of such methods requires data and resources that are beyond the scope of this project.

The report presents a number of scenario run results without giving a single authoritative scenario. They represent a selection of possible scenarios, and the credibility or “likelihood” of the different scenarios is not discussed nor indicated. The range of results gives an indication of the uncertainty of climate change predictions, but does not span the full uncertainty range. In this context it should be mentioned that the Nordic regional models are based on only two GCM models and therefore do not reflect the full variability represented by all the different GCMs. However, both earlier expert judgement (mid 90ties) and recent regional models indicate the following general tendencies:

- air temperature changes of approximately 0.35-0.4 deg/decade
- about twice the temperature increase in winter as in summer
- precipitation increase of 1.5-2 percent/decade
- twice as much precipitation increase in winter /autumn as in summer.

Regarding climatic variables, the focus is on temperature and precipitation, but wind and effect on river runoff are also considered.

2. Background

2.1 SCANNET

SCANNET is a EU 5th Framework Thematic Network with the following overall objective:

> To establish a network of North European terrestrial[1] field sites which can facilitate comparative and regional environmental research activities, especially in the fields of the impacts of environmental changes on biodiversity, ecosystem function, and biological and physical resources of human use.

The specific objectives are:

- To establish a network of existing field sites, covering main environmental conditions in northern Europe, to provide improved information on the effects of spatial and temporal variation in environmental change on terrestrial and hydrological systems.
- To compile and assess existing data and information from field sites and research to address key questions: Where are ecosystems and natural resources most susceptible to changes in biodiversity, ecosystem function, resources for human use? How are these changes related to specific environmental conditions? What are the most important drivers of change? What are the consequences of change for local stakeholders? What are the main methodological and spatial constraints to improving information?
- To improve comparability and coverage of long-term observations and experiments within the network.
- To improve access and relevance of data and information on the effects of climate and other drivers of change to Global Terrestrial Observing System (GTOS), the Arctic Monitoring and Assessment Programme (AMAP), Conservation of Arctic Flora and Fauna (CAFF) and the European Environmental Agency (EEA), in addition to national organisations.

Participating institutions and sites are:

Royal Swedish Academy of Science/Abisko Scientific Research Station
Norwegian Polar Institute/Ny-Ålesund Large Scale Facility
University of Turku/Kevo Subarctic Research Institute
Natural Environmental Research Council/ Institute of
Terrestrial Ecology, Banchory Research Station
Norwegian Institute for Water Research
Danish Polar Center/Zackenberg Station
University of Helsinki/ Kilpisjärvi Biological Station
Faroes Museum of Natural History
Icelandic Institute of Natural History/Litla-Skard

The field sites and stations have been selected to cover the main range of climatic variation from Greenland (arctic), through Iceland, Faroes and Scotland (with strong ocean influence), to Svalbard (high arctic) and the Fennoscandia Peninsula (with continental effects). This initial regional focus is intended to be preliminary - if the network is successful, a widening of the geographical scope will come naturally.

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[1] Note the term terrestrial here includes aquatic environments

2.2 Important environmental parameters for SCANNET

SCANNET has its main focus on biological and ecological processes. The most important climatic parameters for evaluating impacts in this field are the primary parameters radiation, precipitation and temperature. In the arctic and alpine environment, that is central to SCANNET, snow parameters are often of vital importance – snow depth and snow pack duration. For the aquatic environment the central parameters are discharge, water temperature and ice cover duration.

For biological processes, the microclimate is more important than the general climate. There is of course co-variation between the micro- and macro-climate, but the changes may not necessarily be one to one, in particular not when dealing with changes in range and in seasonal and diurnal amplitudes. Changes in distribution of sunshine hours and frequency of temperature inversions are examples of climate variations that may have diffrent effects in a microclimatic context than in macroclimate context.

For biological processes, as for most other processes influenced by climate change, changes in extremes and frequency of critical threshold exceedances are generally more important than changes in average conditions. Generally, variables describing changes in extremes are related to changes in taverage conditions, but the relation is not linear.

Climate change scenarios provided by General Circulation Models (GCMs) and Regional Circulation Models (RCMs) are typically primary macro-climatological parameters – radiation, wind, humidity, temperature, and precipitation. The also give indications on snow cover and seasonality of river discharge, but only on a very coarse spatial resolution.

2.3 General Circulation Models and Climate Modelling

Studies of future climate change use a hierarchy of coupled ocean/atmosphere/sea-ice/land-surface models to provide indicators of global response as well as possible regional patterns of climate change.

2.3.1. GCMs and their characteristics

Atmospheric General Circulation Models (AGCMs)

Atmospheric General Circulation Models (AGCMs) consists of a three-dimensional representation of the atmosphere coupled to the land surface and cryosphere. An AGCM is similar to a model used for weather forecasting, but because it has to produce projections for decades or centuries rather than days, it uses a coarser level of detail. The AGCM has to be provided with data for sea surface temperatures and sea-ice coverage. Hence, an AGCM by itself cannot be used for climate prediction, because it cannot indicate how conditions over the ocean will change. AGCMs are useful for studying atmospheric processes, the variability of climate and its response to changes in sea-surface temperature.

AGCMs coupled to a 'slab' ocean

An AGCM coupled to a “slab” ocean has equations describing the time evolution of temperature, winds, precipitation, water vapour and pressure, coupled to a simple non-dynamic “slab” upper ocean, a layer of water usually around 50 m thick for which only temperature is calculated (a so called “mixed-layer model”) (IPCC 2001). Hence, this type of model predicts changes in sea-surface temperatures and sea-ice by treating the ocean as though it was a layer of water of constant depth.

Such air-sea coupling allows the models to include a seasonal cycle of solar radiation. The sea surface temperatures (SSTs) respond to increases in carbon dioxide (CO_2), but there is no ocean dynamical response to the changing climate. The heat transport within the ocean is specified and remains constant while the atmospheric climate changes.

This kind of model is useful for simulating what the climate would be for some fixed level of CO_2, but it cannot be used for predicting the rate of change of climate. The full depth of the ocean is not included, and the rate of change is largely determined by processes in the ocean interior. Such equilibrium (steady state) experiments provide no information on time-dependent climate change.

Atmosphere Ocean General Circulation Models (AOGCM)

Atmosphere-Ocean General Circulation Models (AOGCM) are the most complex models in use, consisting of an AGCM coupled to an OGCM. An Ocean General Circulation Model (OGCM) is a three-dimensional representation of the ocean and sea-ice.

AOGCMs can be used for the prediction of future climate, including rate of climate change. They can also be used to study the variability and physical processes of the coupled climate system. Global climate models typically have a resolution of a few hundred kilometres. Some recent AOGCM models also include the biosphere, carbon cycle and atmospheric chemistry.

In the late 1980s, the AOGCMs started to be run with slowly increasing CO_2 (“transient simulations”), and preliminary results from two such models appeared in the 1990 IPCC Assessment (IPCC 1990). Inclusion of the full ocean meant that warming at high latitudes was not as uniform as from the non-dynamic mixed-layer models. Results showed that in regions of deep ocean mixing in the North Atlantic and Southern Oceans, warming was less than at other high latitude locations (IPCC 2001).

2.3.2. Choosing a GCM for climate modelling

The ability of the GCM to simulate present day climate has often been used as criterion for choosing which GCM(s) to use as the basis for climate scenario construction, the argument being that GCMs that simulate present climate in accordance with "true values" are likely to simulate future climates more accurately. A good simulation of present day climate, however, is not a sufficient condition for accurate simulation of climate change. As an example, even a model with a poor simulation of present day climate may provide a more accurate simulation of climate change than one with a good simulation of present climate, if it contains a better representation of the dominant feedback processes that will be initiated by radiative forcing [2](IPCC 2001).

No one model can be chosen as “best”, and it is important to use results from a range of models. There will always be a role for informed but, ultimately, individual judgement when choosing GCMs for climate scenario construction. This judgement, however, should according to IPCC (2001) be made not just on empirical grounds (for example, which model’s present climate correlates best with observations), but also on the basis of understanding the reasons for good or bad model performance, especially if those reasons are important for the particular scenario application.

2.3.3. Current GCMs

Two GCMs that are of special relevance for the SCANNET project are the models used at the Hadley Centre (UK Meteorological Office) in the United Kingdom and the models used at the Max Planck Institute for Meteorology (MPI) in Germany. These models have been the basis for regional simulations of climate change in the North Atlantic region.

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[2] Radiative forcing is the long term imbalance between incoming and outgoing radiation for the atmosphere as a whole or altitude segments. Negative radiative forcing results in cooling, positive forcing leads to warming.

Other GCMs are reported and documented in the IPCC (2001), see Chapter 3.2.

Hadley Centre – HadCM

Climate projections from the Hadley Centre in the UK make use of the HadCM2 AOGCM, developed in 1994 (Johns et al. 1997), and its successor HadCM3 AOGCM, developed in 1998 (Gordon et al. 2000).

HadCM2

HadCM2 has stable and realistic control climatology, using flux adjustment, and has been used for a wide range of climate-change experiments. HadCM2 has a spatial resolution of 2.5° latitude by 3.75° longitude, giving a grid of 96 x 73 grid cells. This is equivalent to a surface resolution of about 417 km x 278 km at the Equator, reducing to 295 km x 278 km at 45 degrees of latitude (comparable to a spectral resolution of T42[3] – see below). The atmospheric component of HadCM2 has 19 levels and the ocean component 20.

HadCM3

Unlike HadCM2 the HadCM3 model does not need flux adjustment (additional "artificial" heat and freshwater fluxes at the ocean surface) to produce a good simulation. This is mainly due to the higher ocean resolution of the HadCM3. HadCM3 has been run for over a thousand years, showing little drift in its surface climate.

The spatial resolution of HadCM3 is the same as for HadCM2.

Max Planck Institute for Meteorology - ECHAM

ECHAM is a global climate model that has been developed at the Max Planck Institute for Meteorology (MPI) in **Ham**burg based on the weather forecast model **EC**MWF model, hence the model's name **ECHAM**. ECHAM GCMs have the advantage of a modular construction, which makes it easy to improve their representations of physical processes. Numerous modifications have been applied to the model at the Max Planck Institute for Meteorology and the German Climate Computing Centre (DKRZ) to make it suitable for climate forecasts, and at present it is a model of the fourth generation (ECHAM4).

The ECHAM4 model differs most sharply from its predecessor in its representation of transport and diffusion, of chemistry and radiation, and of the planetary boundary layer (PBL)[4]. The parameterisations of convection, cloud formation, and land surface characteristics also have been modified. The reference resolution is T42 (spherical harmonic representation of the processes with a scale down to 42 full cycles around the earth), but the model is set up to use resolutions in the range T21 to T106 (different triangular truncations of the expansion in spherical harmonics, corresponding to different grid point coverages of the earth's surface). Due to the harmonic representation, the actual resolution varies with latitude, increasing towards the poles. The atmosphere is represented by 19 levels.

ECHAM4/OPYC3

Climate change projections are produced with the coupled global model ECHAM4/OPYC3

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[3] The horisontal representation of spectral models is given by spherical harmonic basis functions with transformation to gaussian grids. Tk denotes a truncation of the k-th zonal wawe number. Spectral triangular 42 (T42), triangular truncation at wave number 42, gives the horisontal resolution roughly equvialent to 2.8 x 2.8 degrees latitude-longitude.

[4] The planet boundary layer is the (variable) transition and interaction zone between the surface and the free atmosphere. Typical thickness 200m to 5 km.

consisting of the ECHAM4 Atmospheric General Circulation Model and the OPYC Ocean General Circulation Model (Oberhuber 1993).

ECHAM3/LSG

The coupled global model ECHAM3/LSG consisting of the ECHAM3 Atmospheric General Circulation Model DKRZ, 1993 and the Hamburg Large Scale Geostrophic Ocean General Circulation Model (LGS) (Maier-Reimer & Mikolajewicz 1992) are also still been used for climate change scenarios.

2.4 Downscaling and regionalisation

It is widely accepted that present day GCMs are able to simulate the global large-scale state of the atmosphere in a realistic manner. However, confidence in regional climate predictions based directly on the output of the present coupled GCM simulations remains low. The spatial resolution of these models is typically a few hundred kilometres, to coarse to reproduce climate at a regional and local scale.

2.4.1. The regional climate problem

The difficulty of simulating regional climate change is evident. Local climate change is greatly influenced by local features, such as mountains, which are not well represented in global models, because of the models' coarse resolution. Other examples of regional and local scale forcing are those due to complex topography, land-use characteristics, inland bodies of water, land-ocean contrasts, atmospheric aerosols, radiatively active gases, snow, sea ice and ocean current distribution.

Furthermore, climatic variability of a region can be strongly influenced through teleconnection patterns originated by forcing anomalies in distant regions, such as in the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) phenomena.

2.4.2. Regional Scale

A definition of regional scale can be difficult, as different definitions are often implied in different contexts. Definitions can be based on geographical, political or physiographic considerations, considerations of climate homogeneity, or considerations of model resolution.

The regional scale applied by IPCC (2001) is defined as describing the range of 10^4 to 10^7 km^2. The upper end of the range (10^7 km^2) is also often referred to as sub-continental scale, and marked climatic inhomogeneity can occur within sub-continental scale regions in many areas of the globe. Weather systems occurring at scales greater than 10^7 km^2 ("planetary scale") are clearly dominated by general circulation processes and interactions. The lower end of the range (10^4 km^2) is representative of the smallest scales resolved by current regional climate models. Scales smaller than 10^4 km^2 are referred to as "local scale".

2.4.3. Derivation of regional climate change from General Circulation Model output

It is estimated that GCM results are unreliable on spatial scales shorter than about 4-8 times the spatial discretisation length in the model simulations. This corresponds to approximately 2000 - 4000 km for current GCM simulations (IPCC 2001). It is desirable to be able to make climate predictions on smaller scales than this, especially in regions where spatial gradients in the predicted climate changes may be large and in areas where orographic effects on the climate are important. Both effects are important for the SCANNET region and for SCANNET focal interests.

There are two major methods in widespread use to produce higher resolution climate scenarios:

- Dynamic downscaling - Regional climate modelling
- Statistical downscaling, often also termed empirical downscaling

2.4.4. Dynamic Downscaling - Regional Climate Models

The basic idea of regional climate modelling, or dynamical downscaling, is to use higher resolution in the area of interest to obtain regional details that the global climate model cannot achieve. The GCM provides the initial and lateral boundary conditions for driving the Regional Climate Model (RCM).

RCMs is based on the concept of limited area climate modelling. The horizontal resolution is increased up to the mesoscale over the limited area of interest. This approach allows a much more accurate description of the topography, coastlines, lakes and involves atmospheric scales from the long planetary waves to mesoscale patterns (Jones et al. 1995). Regional climate models, with a higher resolution (typically 50 km) are constructed for limited areas. They are often run for shorter periods - 20 years or so – but not limited to that. Boundary conditions saved from the global predictions are used to «drive» a nested regional climate model.

The choice of RCM resolution can modulate the effects of physical forcing and parametrisations. The description of the hydrologic cycle generally improves with increasing resolution due to the better topographical representation (Christensen et al. 1998), and the snow cover representation will be more realistic in alpine areas.

RCM model physics configurations are derived either from
- a pre-existing (and well tested) Limited Area Model (LAN) system with modifications suitable for climate application (Rummukainen et al. 2000) or
- implemented directly from a GCM (Christensen et al. 1996).

In the first approach, each set of parameterisations is developed and optimised for the respective model resolutions. However, this makes interpreting differences between nested model and driving GCM more difficult, as these will not result only from changes in resolution. Also, the different model physics schemes may result in inconsistencies near the boundaries (Rummukainen et al. 2000).

The second approach maximises compatibility between the models. However, physics schemes developed for coarse resolution GCMs may not be adequate for the high resolutions used in nested regional models and may, at least, require recalibration. Overall, both strategies have shown performance of similar quality (e.g., IPCC 1996).

In the context of climate change simulations, if there is no resolution dependence, the second approach may be preferable to maximise consistency between RCM and GCM responses to the radiative forcing (IPCC, 2001).

The nested regional climate modelling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution RCMs. The driving data is derived from GCMs (or analyses of observations) and can include GHG and aerosol forcing.

To date, this technique has been used only in one-way mode, i.e., with no feedback from the RCM simulation to the driving GCM. The basic strategy is, thus, to use the global model to simulate the response of the global circulation to large-scale forcings and the RCM to (a) account for sub-GCM grid scale forcings (e.g., complex topographical features and land cover inhomogeneity) in a physically-based way; and (b) enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales.

Since the IPCC (1996), much research has been done on fundamental issues concerning the nested regional modelling technique. Multi-year to multi-decadal simulations must be used for climate change studies to provide meaningful climate statistics, to identify significant systematic model errors and climate changes relative to internal model and observed climate variability, and to allow the atmospheric model to equilibrate with the land surface conditions (Christensen O.B. 1999).

Depending on the domain size and resolution, RCM simulations can be computationally demanding, which has limited the length of many experiments to date. Finally, GCM fields are not routinely stored at high temporal frequency (6-hourly or higher), as required for RCM boundary conditions, and thus careful co-ordination between global and regional modellers is needed in order to perform RCM experiments (IPCC 2001).

Surface forcing due to land, ocean and sea ice greatly affects regional climate simulation. In particular, RCM experiments do not start with equilibrium conditions and therefore the initialisation of surface variables, such as soil moisture and temperature, is important. For example, to reach equilibrium it can require a few seasons for the rooting zone (about 1 m depth) and years for the deep soils (Christensen O.B. 1999).

2.4.5. Current Regional Models for the SCANNET region

HIRHAM

The regional **HIRHAM** model consists of the **HIR**LAM Eulian gridpoint model and the EC**HAM**4 physical parameterisation routines.

The model was developed by Christensen and van Meijgaard (1992) and improved by Christensen et al. (1996). The model includes the descriptions of the physical processes (physical parameterisations) of the global model ECHAM of the Max Planck Institute for Meteorology in Hamburg (see Paragraph 2.3.3). The physical parameterisations describe radiation, cumulus convection, stratiform clouds, land surface processes, hydrology, sea ice processes, turbulent flux exchanges in the planetary boundary layer. At the lateral boundaries the model is forced by observational data analyses of wind, temperature and humidity produced by ECMWF (European Centre for Medium-Range Weather Forecasts) when run in present climate simulation mode.

At the surface the model is forced by observed sea surface temperatures and sea ice fraction. The simulations are performed at a horizontal resolution of 0.5° in latitude and longitude and 19 vertical layers with the model top at 10 hPa. The adiabatic formulation is based on the limited area model HIRLAM (Machenhauer 1988, Gustafsson 1993).

RegClim, the Norwegian regional climate project, runs several simulations of present day climate and climate scenarios based on the ECHAM4 physics package from Max Planck implemented in the parallel HIRLAM code.

Regional Climate model for the Atmosphere (RCA)

The SweClim regional climate model (RCA) is also based on the HIRLAM forecast model.
The acronym is derived from the Rossby Centre model for the Atmosphere - alternatively Regional Climate model for the Atmosphere. The Rossby Centre is the climate research centre at the Swedish Meteeorological and Hydrological Institute, SMHI, established under the Swedish Climate Research Programme SweClim.

The horisontal resolution of RCA is 44 km, with a regional coverage of 114 by 82 grid points. 19 to 24 vertical nodes are used, to an altitude of 30 km.

2.4.6. Statistical downscaling

Statistical, or empirical, downscaling is another strategy for obtaining more detailed regional and local climate scenarios. In statistical downscaling, a cross-scale statistical relationship is developed between large-scale variables of observed climate such as spatially averaged 500 hPa heights, or measure of vorticity, and local variables such as site-specific temperature and precipitation. These relationships are assumed to remain constant in the climate change context. Also, it is assumed that the predictors selected (i.e., the large-scale variables) adequately represent the climate change signal for the predictand (e.g., local-scale precipitation). The statistical relationship is used together with the change in the large-scale variables to determine the future local climate. The main limitation of the technique is that local historical data are needed for calibration, and the weakness of the method is that there is no guarantee that the relationship between the general circulation pattern and the local climate will remain unchanged under a future climate.

2.4.7. Downscaling and resolution

As mentioned above, dynamic downscaling with state of art RCMs produces result fields with a spatial resolution on the orde of ten kms. This is still an order of magnitude larger than the requirements of distributed hydrological models and landscape scale vegetation modelling, and three orders of magnitude larger than the scale needed for plot scale vegetation and snow pack modelling (~10 m). Direct coupling of RCMs to local terrestrial models is therefore seldom possible. Statistical (empirical) downscaling will in principle produce climatology representative for a point, but requires existence of historical series to calibrate against.

More problematic than the direct scale issue is the fact that the RCMs take their boundary values from the coarse grid GCMs. The effects of these coarse resolution boundary values will propagate into the RCMs, and the simulation results of the RCMs are strongly influenced by the selected GCM. This is particularly well documented by the two SweClim simulations RCA-E and RCA-H, based on two different GCMs. These simulations produce very different results, even in the centre of the region - see Chapter 4. The RegClim RCM simulations produce a temperature change field, which largely reflects the temperature change field of the driving GCM - ECHAM GDSIO. The apparent detail of the dynamic downscaling simulations can therefore be somewhat misleading, the reliability of the downscaled field is not greater than the general reliability of the forcing GCM.

2.5 Scenarios and forecasts

2.5.1. Scenarios vs forecasts

A climate change scenario is not a prediction or forecast of future climate. Rather, it is an internally consistent specification of possible climate development. Climate change scenarios are first and foremost research tools that are used to assess plausible consequences of future climate changes in the absence of reliable predictions of future climate (Sælthun et al. 1998a).

The main operational difference between a scenario and a forecast is that the scenario is a possible future outcome, without any probability connected. A prediction or forecast normally has an implicit or explicit probability statement connected. The lack of probability in the scenario formulation limits its practical applicability. In decision making, scenarios can only be used for sensitivity analysis and for checking the robustness of a decision (“what if this scenario comes true?”). A prediction, with probability and uncertainty attached, can be included in formal decision making tools like cost-benefit analysis.

Climate change scenarios for the near future will in practise often be regarded as predictions, regardless whether the publishers approve that use or not. The greenhouse gases emission scenarios (see below) do not diverge much over the next couple of decades, and the GCM climate change simulations show considerable consistence on the sub-continental scale and above. Most experts will regard the climate change scenarios as more probable future outcomes than the historical climate, which is the alternative for practical decision making.

2.5.2. Definitions

The International Panel of Climate Change (IPCC) distinguishes between a **climate scenario**, a **climate projection** and a **climate change scenario.**

Climate scenario
A climate scenario refers to a plausible future climate that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change. Such climate scenarios should represent future conditions that account for both human-induced climate change and natural climate variability (IPCC 2001).

Climate projection
A climate projection refers to a description of the response of the climate system to a scenario of greenhouse gas and aerosol emissions, as simulated by a climate model.

According to the IPCC climate projections alone can rarely provide sufficient information to estimate future impacts of climate change. Model outputs commonly have to be manipulated and combined with observed climate data to be usable as inputs to impact models.

A range of uncertainties affects projections of climate change. Uncertainty in projected climate change arises from three main sources; uncertainty in forcing scenarios, uncertainty in modelled responses to given forcing scenarios, and uncertainty due to missing or misrepresented physical processes in models.

Climate change scenario
A climate change scenario is different from a climate scenario, even though the term sometimes is used in the scientific literature to denote a plausible future climate. However, this term should strictly refer *to a representation of the difference* between some plausible future climate and the current or control climate (usually as represented in a climate model) (IPCC 2001).

A climate change scenario can be viewed as an interim step toward constructing a climate scenario. Usually a climate scenario requires combining the climate change scenario with a description of the current climate as represented by climate observations.

Baseline Climate
A climate change scenario is defined with respect to a climatological baseline, which determines a reference point for the projected climate changes.

Climate scenarios that are developed for impacts applications usually require that some estimate of climate change be combined with baseline observational climate data. Thus, the demand for more complete and sophisticated observational data sets of climate has grown in recent years. The important considerations for the baseline include the time period adopted as well as the spatial and temporal resolution of the baseline data.

IPCC have usually taken the year '1990' as the baseline year for the presentation of emissions scenarios and for calculations of future climate and sea-level change. '1990' has also been adopted by the United Nations Framework Convention on Climate Change (UN FCCC) in their definition of emissions reductions targets. Choosing a single year as a baseline is appropriate for some applications, but not for climate change studies.

Due to climate variability a single year may be unusually warm, cold, dry or wet and thus will not make a useful reference point for measuring climate change. It is more common to use the average climate over a 30-year period to define the baseline climate. A 30-year climatic average smoothes out many of the year-to-year variations in the climate. In addition, the individual 30 years of such a period captures much of the interannual and short time-scale variability of climate that may be relevant for an impact application.

The IPCC Data Distribution Centre (IPCC DDC) suggests the period 1961-90 to be used as the baseline period. This period has generally good observed data and it represents the recent climate to which many present-day human or natural systems are likely to be reasonably well adapted. The period also ends in 1990, the year adopted by many IPCC and UN FCCC applications. This period was applied as the climatological baseline for the project Climate Change and Energy Production (Sælthun et al. 1998a).

2.6 Construction of climate change scenarios

Climate change scenarios are of several different types, *e.g.* synthetic scenarios, analogue scenarios, scenarios from general circulation models (GCMs) and composite scenarios (Carter et al. 1993). This report concerns climate change scenarios based on climate models.

Such scenarios are based on climate models with future scenarios of forcing agents (e.g., greenhouse gases and aerosols) as input to make projections of possible climate changes in the future.

2.6.1. Emission scenarios

The IPCC has developed a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and fuel mix during the period 1990 to 2100. Through understanding of the global carbon cycle and of atmospheric chemistry, these emissions can be used to project atmospheric concentrations of greenhouse gases and aerosols and the perturbation of natural radiative forcing.

The six alternative IPCC scenarios (IS92a to f) were published in the 1992 Supplementary Report to the IPCC Assessment (Leggett et al. 1992). The scenarios embodied a wide array of assumptions affecting how future greenhouse gas emissions might evolve in the absence of climate policies beyond those already adopted.

The 1%/yr rate of increase of CO_2, although larger than actual CO_2 increase observed to date, is meant to account for the radiative effects of CO_2 and other trace gases in the future and is often referred to as "equivalent CO_2".

The forcing scenarios used by the DDC models do not originate directly from any coherent future view of the world. They are an arbitrary imposition of a 1% per annum growth in future greenhouse gas concentrations. In fact, the closest of the IS92 emissions scenarios to this arbitrary forcing is the IS92a scenario (IPCC (1996) calculated the equivalent per annum growth rate in concentrations for IS92a to be about 0.85% per annum). It is therefore not unreasonable to use the IS92a assumptions about population, GDP and energy technology to create the background world in which these DDC modelled climate changes might occur.

Similarly, for the ~0.5% per annum forcing scenario used by HadCM2, the IS92d assumptions would be the best to use. These data are held on the IPCC DDC web site under 'non-climatic scenarios'.

SRES Scenarios

In 1996, the IPCC began the development of a new set of emissions scenarios, effectively to update and replace the IS92 scenarios. The approved new set of scenarios is described in the IPCC Special Report on Emission Scenarios (SRES) (Nakic´enovic´ et al. 2000).

Four different narrative storylines (A1, A2, B1, B2) were developed to describe consistently the relationships between emission driving forces and their evolution and to add context for the scenario quantification. Each emission scenario represents a specific quantification of one of the four storylines, and all scenarios based on the same storyline constitute a scenario “family”.

The resulting set of forty scenarios (thirty-five of which contain data on the full range of gases required for climate modelling) cover a wide range of the main demographic, economic and technological driving forces of future greenhouse gas and sulphur emissions. None of the emission scenarios explicitly assume implementation of the UN FCCC or the emissions targets of the Kyoto Protocol. However, greenhouse gas emissions are directly affected by implementation of policies designed for a wide range of other purposes. Furthermore, government policies can, to varying degrees, influence the greenhouse gas emission drivers, and this influence is broadly reflected in the storylines and resulting scenarios.

Of the forty scenarios presented in SRES two have emerged as having particular significance. Although not referred to by IPCC in this manner, the general scientific community has come to identify the A2 scenario as the “Business as Usual” or “Worst Case” scenario and the B2 as the “Best Guess” or “Most Likely” scenario (Källén et al. 2001).

Converting the new emissions scenarios into equivalent CO_2 concentration growth curves using IPCC (1996) equations, yields the SRES A2 storyline as the best approximation for the 1% forced GCM results and the SRES B1 storyline as the best approximation for the ~0.5% forced experiments.

The SRES was approved too late for the modelling community to incorporate the final approved scenarios in their models and have the results included in the Third Assessment Report (TAR/ IPCC (2001). Thus, draft scenarios were released to climate modellers earlier to facilitate their input in the IPCC report. One marker scenario was chosen from each of four of the scenario groups based directly on the storylines, see Section 3.2.5 and Section 3.2.6.

Climate sensitivity

The term climate sensitivity refers to the steady-state increase in the global annual mean surface air temperature associated with a given global-mean radiative forcing. It is common practise to use CO_2 doubling as a benchmark for comparing GCM climate sensitivities. Thus in practise the climate sensitivity may be defined as the change in global-mean temperature that would ultimately be reached following a doubling of CO_2 concentration in the atmosphere (e.g. from 275 ppmv to 550 ppmv). The IPCC has always reported the likely range for this quantity to be between 1.5º and 4.5ºC, with a 'mid-range' estimate of 2.5ºC.

Each GCM has different climate sensitivity, depending on the representation of various feedback processes in the model, including water vapour. It is generally assumed that the climate sensitivity of a model is approximately constant over the range of forcings expected for the next century. The climate sensitivity of a model is also largely independent (±10%) of the specific combination of different forcing factors (solar, aerosols, CO2, CH4, etc.) that produce a given global-mean forcing. The range of climate sensitivities in the DDC models is from about 2.5ºC to 4.0ºC (IPCC DDC).

3. Relevant GCM runs and scenarios

3.1 IPCC 1996

The IPCC Second Assessment Report (SAR) from 1996 includes climate change scenarios based on the IS92 emission scenarios.

3.1.1. Models

The AOGCMs used as a basis for IPCC 1996 are listed in Table 1.

Table 1. Main Computing Centres and models used in IPCC 1996. From IPCC DDC[5].

Centre	Model Name
CCSR/NIES, Center for Climate Research Studies (CCSR), Japan/National Institute for Environmental Studies (NIES), Japan	CCSR/NIES
CCCma, Canadian Center for Climate Modelling and Analysis	CGCM1
CSIRO, Australia's Commonwealth Scientific and Industrial Research Organisation	CSIRO Mk2
NCAR, National Centre for Atmospheric Research, USA	NCAR1 DOE PCM
DKRZ, Deutsches Klimarechenzentrum, Germany	ECHAM3/LSG
MPI, Max-Plank Institute for Meteorology, Germany	ECHAM4/OPYC
GFDL, Geophysical Fluid Dynamics Laboratory, USA	GFDL_R15_a
GISS, Goddard Institute for Space Studies, USA	GISS2
UKMO, Hadley Centre for Climate Prediction and Research, United Kingdom Meteorological Office	HadCM2 HadCM3

Model descriptions and the IS92 Scenarios available at the IPCC DDC web site.

A description of the simple climate models used in the IPCC (1996) can be found in “An introduction to simple climate models used in the IPCC Second Assessment Report” (IPCC 1997). The report explains in general how Simple Climate Models (SCMs)[6] work, the processes that go into them and their strengths and weaknesses.

3.1.2. The key findings of the IPCC report (1996)

The key findings of the IPCC (1996) report are as follows:

- Global mean surface temperatures show increases of between 0.3 and 0.6 °C since the late 19th century.

- The global mean surface air temperature of the Earth would rise at a rate between 0.1 and 0.35°C per decade during the next decades due to increasing concentrations of CO_2 and other trace gases in the atmosphere. The transient warming rate is approximately 0.3 °C per decade for models with greenhouse gas forcing only and approximately 0.2 °C when aerosol forcing is taken into account.

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[5] http://ipcc-ddc.cru.uea.ac.uk/

[6] Simple climate models are simplified global models that attempt to reproduce the large-scale behaviour of AOGCMs. The IPCC report (1997) use the term “Simple Climate Model” (SCMs) to refer to simplified models used in the SAR to provide projections of global mean temperature and sea level change response to the IS92 emissions scenarios and CO_2 stabilisation profiles.

- In the scenarios given, the temperature change is estimated to be in the range of 1 to 4.5°C over hundred years. The estimated global climatic sensitivity is in the range 2-5 °C.

- Sea level is projected to rise by about 50 cm by 2100 (with a range of 15 cm to 95 cm), due to thermal expansion of the oceans and melting glaciers and ice sheets.

- In spite of the general agreement between the coupled models with regard to the above conclusions, there are large discrepancies between the models, especially in regional predictions of the warming. The location and amplitude of the local minima in the warming in the northern North Atlantic and the Circumpolar Ocean of the Southern Hemisphere is different in the different simulations, and local differences in the warming after 50-100 model years are higher than 2-3°C in many places. Changes in precipitation rates are believed to be much more uncertain than temperature changes, although there is some consensus among the models that precipitation rates will increase by a few percent for each degree of warming.

3.2 IPCC 2001

Since the IPCC Second Assessment Report (1996), there have been several new AOGCM climate simulations with various forcings that can provide estimates of possible future climate. Most of them are reported in “Climate Change 2001: The Scientific Basis” (IPCC 2001). This report is the first part of Climate Change 2001, the Third Assessment Report (TAR) of the IPCC.

3.2.1. Types of simulations

The simulations presented in the IPCC report (2001) fall into three categories:

- 1%/yr CO_2 increase (CMIP2) experiments
- Projections of future climate from forcing scenario experiments (IS92a)
- SRES scenario experiments

The first are integrations with idealised forcing, namely, a 1%/yr compound increase of CO_2. This 1% increase represents equivalent CO_2, which includes other greenhouse gases like methane, NO_x etc. These runs extend at least to the time of effective CO_2 doubling at year 70, and are useful for direct model intercomparisons since they use exactly the same forcing and thus are valuable to calibrate model response These experiments are collected in the Coupled Model Intercomparison Project (CMIP2) exercise[7].

The second category of AOGCM climate model simulations uses specified time-evolving future forcing where the simulations start sometime in the 19th century, and are run with estimates of observed forcing through the 20th century. That state is subsequently used to begin simulations of the future climate with estimated forcings of greenhouse gases (“G”) or with the additional contribution from the direct effect of sulphate aerosols (“GS”) according to various scenarios, such as IS92a. These simulations avoid the so called “cold start problem” present in the CMIP experiments – essentially the need for a “running-in” period which gives problems in aligning the simulations with historical and future time scale. They allow evaluation of the model climate and response to forcing changes that could be experienced over the 21st century. These experiments are assessed for the mid-21st century when most of the DDC experiments with sulphate aerosols finished. The experiments are collected in the IPCC DDC.

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[7] The Coupled Model Intercomparison Project (CMIP) collects output from global coupled ocean-atmosphere general circulation models (coupled GCMs) (CMIP1). The second phase CMIP2 continues the effort started in CMIP1, but it also includes a comparison of coupled model climate sensitivity. http://www.cmdi.llnl.gov/cmip/.

The third category are AOGCM simulations using as an initial state the end of the 20th century integrations, and then following the A2 and B2 SRES Scenarios (Nakic´enovic´ et al. 2000) forcing scenarios to the year 2100. These AOGCM simulations are assessed to quantify possible future climate change at the end of the 21st century, and also are treated as members of an ensemble to better assess and quantify consistent climate changes. A simple model is also used to provide estimates of global temperature change for the end of the 21st century from a greater number of the SRES forcing scenarios.

3.2.2. The key findings of the IPCC report (2001)

Both temperature and sea level are projected to continue to rise throughout the 21st century for all scenarios studied. According to the IPCC (2001), the average temperature in the world may be expected to rise by 1.4-5.8 °C from 1990 to 2100.

Some of the findings reconfirm results from the IPCC (1996), and this gives an increased confidence in their credibility (although agreement between models does not guarantee that those changes will occur in the real climate system):

- As the climate warms, Northern Hemisphere snow-cover and sea-ice extent decrease. The globally averaged precipitation increases.

- As the radiative forcing of the climate system changes, the land warms faster than the ocean. The cooling effect of tropospheric aerosols moderates warming both globally and locally. The surface air temperature increase is smaller in the North Atlantic and circumpolar Southern Ocean regions.

- The general pattern of precipitation changes is:
    - increase in the tropical areas, particularly over ocean
    - decrease in most of the sub-tropics
    - Moderate precipitation increases in high latitudes.

- The signal-to-noise ratio (from the multi-model ensemble) is less for precipitation than for surface air temperature.

- An increase in mean temperatures leads to more frequent extreme high temperatures and less frequent extreme low temperatures. Night-time low temperatures in many regions increase more than daytime highs, thus reducing the diurnal temperature range. Decreased daily variability of temperature in winter and increased variability in summer in Northern Hemisphere mid-latitude areas.

- There is a general drying of the mid-continental areas during summer in terms of decreases in soil moisture, and this is ascribed to a combination of increased temperature and potential evaporation not being balanced by precipitation. Intensity of precipitation events increases.

The IPCC (2001) includes some new methodological improvements since the previous IPCC report:

- There are several more model projections for a given scenario, and more scenarios. The greater number of model simulations allows for better to quantify patterns of climate change for a given forcing and develop a measure of consistency among the models.

- Including the direct effect of sulphate aerosols according to an IS92a type estimate reduces global mean mid-21st century warming. The indirect effect, not included in most AOGCM experiments to date, is acknowledged to be uncertain.

- The geographic details of various forcing patterns are less important than differences among the models' responses for the scenarios considered here. This is the case for the global mean as well as for patterns of climate response. Thus, the choice of model and the choice of scenario are both important.

3.2.3. IPCC 2001 models

The IPCC (2001) results are based on a large number of models and simulations. The main centres and models are listed in
Table **2**. Details on the simulations are given in Annex A.

Table 2. Main Computing Centres and models used in IPCC 2001.

Centre	**Model Name**
CERFACS, European Centre for Research and Advanced Training in Scientific Computation, France	ARPEGE/OPA2
BMRC, Bureau of Meteorology Research Centre, Australia	BMRCa
CCSR/NIES, Center for Climate Research Studies (CCSR), Japan/ National Institute for Environmental Studies (NIES), Japan	CCSR/NIES CCSR/NIES2
CCCma, Canadian Center for Climate Modelling and Analysis	CGCM1 CGCM2
CSIRO, Australia's Commonwealth Scientific and Industrial Research Organisation	CSIRO Mk2
NCAR, National Centre for Atmospheric Research, USA	CSM 1.0 CSM 1.3 DOE PCM
DKRZ, Deutsches Klimarechenzentrum, Germany	ECHAM3/LSG
MPI, Max-Plank Institute for Meteorology, Germany	ECHAM4/OPYC
GFDL, Geophysical Fluid Dynamics Laboratory, USA	GFDL_R15_a GFDL_R15_b GFDL_R30_c
GISS, Goddard Institute for Space Studies, USA	GISS2
IAP/LASG, Institute of Atmospheric Physics (IAP), China / State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics, China	GOALS
UKMO, Hadley Centre for Climate Prediction and Research / United Kingdom Meteorological Office	HadCM2 HadCM3
IPSL/LMD, Institut Pierre Simon Laplace (IPSL), France / Laboratoire de Météorologie Dynamique (LMD), France	IPSL-CM2
MRI, Meteorological Research Institute, Japan	MRI1 MRI2

3.2.4. The Coupled Model Intercomparison Project

The Coupled Model Intercomparison Project (CMIP), started in 1995, collects output from global coupled ocean-atmosphere general circulation models (coupled GCMs). CMIP has archived output from both constant forcing ("control run") and perturbed (1%/yr increasing atmospheric CO_2) simulations.

CMIP includes output from 29 AOGCMs worldwide, with roughly half of them using flux adjustment (additional "artificial" heat and freshwater fluxes at the ocean surface). In models with heat flux corrections, the surface temperature is influenced less by the specifications of CO_2 concentration and solar constant than is the case for models without such flux corrections. Also, the radiative forcing perturbation is determined primarily by the logarithm of the ratio of transient-to-control CO_2 concentrations, rather than by the control concentration alone (Meehl et al. 2001).

The second phase of the Coupled Model Intercomparison Project (CMIP2) is an intercomparison of standard, idealised climate change experiments with coupled atmosphere-ocean general circulation models, including a comparison of coupled model climate sensitivity. 19 of the models have been used to perform idealised 1%/yr CO_2-increase climate change experiments suitable for direct intercomparison (CMPI2) and have been analysed in IPCC (2001). Roughly half that number have also been used in more detailed scenario experiments with time evolutions of forcings including at least CO_2 and sulphate aerosols for 20th and 21st century climate. Since there are some differences in the climate changes simulated by various models even if the same forcing scenario is used, the models are compared to assess the uncertainties in the responses lists the models used in the CMIP analysis. . A new phase of CMIP, CMIP2+, extends the database to include all output originally archived during model runs. Table 3 lists the models used in the CMIP analysis.

Initial intercomparison exercises involve the calculation of inter-model mean and standard deviation from the transient experiments to provide an indication of the spread of coupled model climate sensitivity. Each experiment consists of an 0-year control run with constant “present-day” CO_2 and of an 80-year greenhouse run with gradually increasing (1%/yr compounded) CO_2.

The simulations performed with and without the direct sulphate effect (GS and G, respectively) with the same model are more similar to each other than to the other models (Table 4). This indicates that the individual response characteristics of the various models are dominating the response pattern rather than differences in the forcing. With greater CO_2 forcing, the simulated patterns are more highly correlated in the G simulations than in the GS.

The biggest difference between the CMIP2 G and GS experiments is the regional moderating of the warming mainly over industrialised areas in GS where the negative forcing from sulphate aerosols is greatest at mid-21st century. This regional effect was noted in the IPCC report (1996) for only two models, but IPCC (2001) shows this is a consistent response across the greater number of more recent models. The GS experiments only include the direct effect of sulphate aerosols, but two model studies have included the direct and indirect effect of sulphate aerosols and show roughly the same pattern (Meehl et al. 1996, Roeckner et al. 1999).

Table 3. Models tested in the CMIP Project

	Model Version *	**CMIP/1 Runs ****	**CMIP/2 Runs ****	**Flux Correction *****	**Archived Control Run length [yr]**	**Control Run CO_2 [ppmv]**	**Solar Constant [W/m^2]**	**CMPI Comments**
1	BMRC1	•		None	150	330	1365	No standard devs. or ocean data
2	BMRC2		•	Heat, water, scf, SW radn.	80	330	1365	
3	CCCMA	•	•	Heat, water	150	330	1370	
4	CCSR	•	•	Heat, water	200	345	1365	
5	CERFACS1	•		None	40	353	1370	
6	CERFACS2		•	None	80	353	1370	
7	COLA1	•		None	50	345	1365	
8	COLA2	•		None	191	345	1365	Long transient
9	CSIRO	•	•	Heat, water, momentum	100	330	1367	
10	DOE PCM		•	None	300	355	1367	
11	ECHAM1+LSG	•		Heat, water, momentum	960			Temperature time-series data only
12	ECHAM3+LSG**	•	•	Heat, water, momentum	1000	345	1365	No flux-correction field
13	ECHAM4+OPYC3	•	•	Heat, water (annual mean)	240	353	1365	
14	GFDL_R15_a	•	•	Heat, water	1000	300	1353.5	
15	GFDL_R30_c		•	Heat, water	300	360	1365	
16	GISS (Miller)	•		None	89			
17	GISS (Russell)	•	•	None	98	315	1367	No decadal standard deviations or barotropic stream functions
18	IAP/LASG1			Sea scf salinity restored to obs	50	345	1367.04	
19	IAP/LASG2		•	Heat, water, momentum	80	345	1367.04	
20	LMD/IPSL1	•		None	24	320	1367	No decadal standard Deviations
21	LMD/IPSL2		•	None	80	320	1367	
22	MRI1	•		Heat, water	100	345	1365	No ocean heat transport data available
23	MRI2		•	Heat, water	80	345	1365	
24	NCAR (CSM)	•	•	None	300	355	1367	
25	NRL1		•	Sea ice prescribed to obs	36	355		
26	NRL2		•	Heat,water (annual mean)	3			Perturbed run is 80 years
27	UKMO (HadCM2)	•	•	Heat, water	1085		1365	
28	UKMO (HadCM3)		•	None	400	322.6 (equiv.-CO_2)	1365	
29	YONU		•	Sea ice prescribed to obs	80			

* More information about the models and Key References are presented at the CMPI website: http://www-pcmdi.llnl.gov/cmip/. The IPCC TAR (2001) also gives further details on selected features of CMIP models.

**CMIP/1 runs are control experiments with seasonal-mean climatological output data. CMIP/2 runs are paired control and perturbed (1%-per-year increasing carbon dioxide) experiments with annual-mean climatological output data. When both CMIP/1 and CMIP/2 runs are marked for a model, essentially the same model version has been used to produce both the CMIP/1 control run and the paired CMIP/2 runs. In other cases, a given model version produced only the CMIP/1 or only the CMIP/2 runs.

*** Additional "artificial" heat and freshwater fluxes at the ocean surface. In models with heat flux corrections, the surface temperature is influenced less by the specifications of CO_2 concentration and solar constant than is the case for models without such flux corrections. Also, the radiative forcing perturbation is determined primarily by the logarithm of the ratio of transient-to-control CO_2 concentrations, rather than by the control concentration *per se*.

Table 4. The pattern correlation of temperature and precipitation change for the years (2021 to 2050) relative to the years (1961 to 1990) for the simulations in the IPCC DDC.
Above the diagonal: G experiments, below the diagonal: GS experiments. The diagonal is the correlation between G and GS patterns from the same model. From IPCC (2001).

Temperature	CGC M1	CCSR/NIES	CSIRO Mk2	ECHAM3 / LSG	GFDL_R15_a	HadCM2	HadCM3	ECHAM4 / OPYC	DOE PCM
CGCM1	**0.96**	0.74	0.65	0.47	0.65	0.72	0.67	0.65	0.31
CCSR/NIES	0.75	**0.97**	0.77	0.45	0.72	0.77	0.73	0.80	0.49
CSIRO Mk2	0.61	0.71	**0.96**	0.40	0.75	0.72	0.67	0.75	0.63
ECHAM3/LSG	0.58	0.50	0.44	**0.46**	0.40	0.53	0.60	0.53	0.35
GFDL_R1_a	0.65	0.76	0.69	0.42	**0.73**	0.58	0.61	0.69	0.55
HadCM2	0.65	0.69	0.59	0.52	0.50	**0.85**	0.79	0.79	0.43
HadCM3	0.60	0.65	0.60	0.49	0.47	0.63	**0.90**	0.75	0.47
ECHAM4/OPYC	0.67	0.78	0.66	0.37	0.71	0.61	0.69	**0.89**	0.41
DOE PCM	0.30	0.38	0.63	0.24	0.36	0.40	0.44	0.37	**0.91**

Precipitation	CGC M1	CCSR/NIES	CSIRO MK2	ECHAM3 / LSG	GFDL_R15_a	HADCM2	HADCM3	ECHAM4 / OPYC	DOE PCM
CGCM1	**0.88**	0.14	0.08	0.05	0.05	0.23	-0.16	-0.03	0.02
CCSR/NIES	0.14	**0.91**	0.13	0.21	0.34	0.36	0.29	0.33	0.18
CSIRO Mk2	0.15	0.14	**0.73**	0.13	0.29	0.32	0.31	0.07	0.11
ECHAM3/LSG	0.20	0.23	0.13	**0.39**	0.28	0.19	0.11	0.11	0.29
GFDL_R15_a	0.18	0.20	0.28	0.28	**0.41**	0.28	0.20	0.22	0.21
HadCM2	0.34	0.34	0.23	0.37	0.24	**0.73**	0.19	0.24	0.17
HadCM3	-0.20	0.06	0.31	-0.05	0.11	-0.01	**0.81**	0.25	0.09
ECHAM4/OPYC	0.13	0.30	0.09	0.07	0.04	0.23	0.20	**0.79**	0.01
DOE PCM	0.02	0.08	0.12	-0.09	0.06	0.13	-0.06	-0.07	**0.43**

3.2.5. Scenarios based on SRES emission scenarios

Since the AOGCM SRES results discussed in IPCC (2001) are based on draft marker SRES[8] scenarios, notice should be taken to differences that would result from the use of the final SRES scenarios. Studies show that the final scenarios for the three SRES scenarios A1B, A2 and B2 give temperature changes that are slightly smaller than those of the preliminary emission scenarios (Smith et al. 2001).

The main difference is a change in the standardised values for 1990 through 2000, which are common to all these scenarios. This results in higher forcing early in the period. There are further small differences in net forcing, but they decrease until, by 2100, differences in temperature change in the

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[8] "Draft marker scenarios" are the IPCC term for the preliminary SRES emission scenarios used in the IPCC report (2001). The final emission scenarios were not ready when the IPCC (2001) work started.

two versions of these scenarios are only 1 to 2%. For the B1 scenario, however, temperature changes are significantly lower in the final version. The difference is almost 20% in 2100, as a result of generally lower emissions across the whole range of greenhouse gases.

The SRES A2 and B2 integrations show a similar pattern of temperature change as the CMIP2 G experiments. The positive radiative forcing from greenhouse gases overwhelms the sulphate aerosol forcing at the end of the 21st century in A2 and B2 compared to the GS experiments at mid-21st century, thus they are more similar to the G simulations. The amplitude of the climate change patterns is weaker for the B2 than for the A2 simulations at the end of the 21st century.

3.2.6. Climate change scenarios

CMPI2 projections

The doubling of CO_2 in the CMIP2 experiments takes place in 70 years. During this time, the global mean warming in the 19 experiments varies from 1.1 to 3.1°C, with a mean value of 1.75°C (Figure 1). This rate of warming is very similar to the warming projected by the IPCC (2001) for the B2 emission scenario. The latter amounts to about 2.5°C between 2000 and 2100, as averaged over the seven models used by IPCC (reported in IPCC DCC). The increase in CO_2 in the IPCC B2 scenario is much below 1% per year, however, the warming in the B2 scenario is enhanced by projected increases in other greenhouse gases and reduced sulphur emissions.

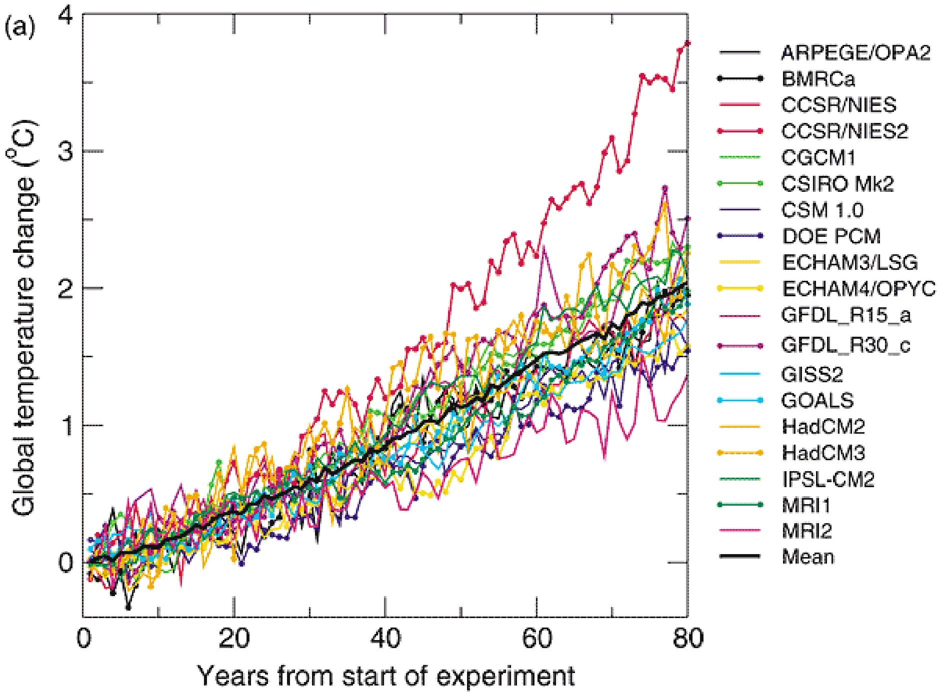

Figure 1. The time evolution of the globally averaged temperature change relative to the control run of the CMIP2 simulations. (Unit: deg C). Data from IPCC (2001).

Projections of future climate from forcing scenario experiments (IS92a)

These experiments include changes in greenhouse gases plus the direct effect of sulphate aerosol using IS92a type forcing (see Paragraph 2.6.1).

The temperature change for the 30-year average 2021 to 2050 compared with 1961 to 1990 is +1.3°C, with a range of +0.8 to +1.7°C, as opposed to +1.6°C, with a range of +1.0 to +2.1°C, for greenhouse gases only.

The experiments including sulphate aerosols show a smaller temperature rise compared to experiments without sulphate aerosols due to the negative radiative forcing of these aerosols. Further, in these simulations CO_2 would double around year 2060. Thus, for the averaging period being considered, years 2021 to 2050, the models are still short of the CO_2 doubling point seen in the idealised 1%/yr CO_2 increase simulations.

The globally averaged precipitation response for 2021 to 2050 for greenhouse gases plus sulphates is +1.5% with a range of +0.5 to +3.3% as opposed to +2.3% with a range of +0.9 to +4.4% for greenhouse gases only.

Marker scenario experiments (SRES)
Only the draft marker SRES scenarios A2 and B2 have been integrated with more than one AOGCM in IPCC (2001). Also, some new versions of models have been used in CMPI2 to run the A2 and B2 scenarios that have not had time to be fully evaluated by the IPCC (2001).

The IPCC report (2001) therefore present results from all the model simulations and consider them all as possible realisations of future climate change. However, their ranges are not directly comparable to the simple model results (see Section 3.2.1 and Footnote 6) also presented in the report (range: 1.4 to 5.8°C), because in the simple model analysis seven somewhat different versions of the nine models have been considered.

Further, for the AOGCMs the temperature changes are evaluated for an average of years 2071 to 2100 compared with 1961 to 1990, while the simple model results are differences of the year 2100 minus 1990. The average temperature response from nine AOGCMs, using the SRES A2 for the 30-year average 2071 to 2100 relative to 1961 to 1990, is +3.0°C, with a range of +1.3 to +4.5°C, while using the SRES B2 scenarios it amounts to +2.2°C, with a range of +0.9 to +3.4°C.

The B2 scenario produces a smaller warming which is consistent with its lower positive radiative forcing at the end of the 21st century. For the 30-year average 2021 to 2050 using the A2 scenario, the globally averaged surface air temperature increase compared with 1961 to 1990 is +1.1°C, with a range of +0.5 to +1.4°C, while using the SRES B2 scenarios it amounts to +1.2°C with a range of +0.5 to +1.7°C. The values for the SRES scenarios for the mid-21st century are lower than for the IS92a scenarios for the corresponding period due to differences in the forcing.

The average precipitation response using the SRES A2 forcing for the 30-year average 2071 to 2100 compared with 1961 to 1990 is an increase of 3.9% with a range of 1.3 to 6.8%, while using the SRES B2 scenarios it amounts to an increase of 3.3% with a range of 1.2 to 6.1%. The lower precipitation increase values for the B2 scenario are consistent with less globally averaged warming for that scenario at the end of the 21st century compared with A2.

For the 30-year average 2021 to 2050 the globally averaged precipitation increases 1.2% for the A2 scenario, and 1.6% for B2 which is again consistent with the slightly greater global warming in B2 for mid-21st century compared with A2.

3.3 IPCC results accessibility

Currently, model results from seven different modelling groups are available in the IPCC database, IPCC Data Distribution Centre (IPCC-DDC)[9] (Table 5).

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[9] http://ipcc-ddc.cru.uea.ac.uk/

Table 5. Available IPCC-DDC SRES scenario runs

CENTER	ACRONYM	MODEL	SRES SCENARIO RUNS			
Max Planck Institut für Meteorologie	MPI	ECHAM4/OPYC3		A2		B2
Hadley Centre for Climate Prediction and Research	HCCPR	HADCM3		A2		B2
Australia's Commonwealth Scientific and Industrial Research Organisation	CSIRO	CSIRO-Mk2	A1	A2	B1	B2
National Centre for Atmospheric Research	NCAR	NCAR-CSM		A2		
		NCAR-PCM		A2		B2
Geophysical Fluid Dynamics Laboratory	GFDL	R30		A2		B2
Canadian Center for Climate Modelling and Analysis	CCCma	CGCM2		A2		B2
Center for Climate Research Studies (CCSR) National Institute for Environmental Studies (NIES)	CCSR / NIES	CCSR/NIES AGCM + CCSR OGCM	A1	A2	B1	B2

Also available on the IPCC DCC web site are results from GCM-runs based on the IPCC- IS92a (or similar) emission scenarios.

Neither the IS92 nor the SRES emissions scenarios available from the IPCC DDC, nor any of the forcing scenarios used by GCM experiments, include the effect of the Kyoto Protocol on future emissions or radiative forcing. Climate change scenarios obtained from the IPCC DDC should therefore be regarded as 'non-interventionist' scenarios.

4. Relevant runs and scenarios for the SCANNET region

4.1 Scenarios from General Circulation Models (GCMs)

4.1.1. Spatial Scale of Scenarios

As discussed in Chapter 2, the spatial scale of the GCM (order of 300 km^2) is so large that they only can describe variation on the sub-continental scale. Local variations due to topography and local impacts of circulation changes can not be depicted. Downscaling methods, dynamic or empirical are necessary for description of local effects.

4.1.2. Temporal Variability

The climate change information most commonly taken from climate modelling experiments comprises mean monthly, seasonal, or annual changes in variables of importance to impact assessments. Changes in climate will, however, also involve changes in variability as well as mean conditions. The inter-annual variability in climate scenarios constructed from mean changes in climate is most commonly inherited from the baseline climate, not from the climate change experiment (IPCC, 2001). However, changes in variability could be very important to most areas of impact assessment. The most obvious way in which variability changes affect resource systems is through the effect of variability change on the frequency of extreme events.

Changes in standard deviation have a proportionately greater effect than changes in means on changes in the frequency of extremes. For instance, the frequency factor formulation of the Gumbel (Extreme Value Distribution II), calculates an extreme event with 100-year return period (annual exceedance probability 0.01) as:

$$q(100) = q_m + 3.14\, s_q$$

where q_m is the mean value of annual extremes and s_q their standard deviation. For the 100-year return period fractile, the weight on the standard deviation increases to 5.

From a climate scenario point of view, however, it is the relative size of the change in the mean versus standard deviation of a variable that determines the final relative contribution of these statistical moments to a change in extremes. The construction of scenarios incorporating extremes is discussed in IPCC (2001).

4.1.3. Results

Currently available coupled ocean-atmosphere simulations indicate that the rate of CO_2-induced warming might be similar or somewhat lower than a global average of approximately 0.2-0.3°C per decade in Iceland, in southern Greenland and along the west coast of Norway and Denmark. The warming in other parts of the Nordic countries could, on the other hand, be somewhat higher than the global average, *i.e.* more in line with other areas in the latitude range of the Nordic countries. The GFDL results indicate that the warming in the northern North Atlantic and in Scandinavia will not be as seasonally dependent as elsewhere in the latitude range of the Nordic countries, *i.e.* the warming will be similar for both summer and winter. Very little can be said about precipitation changes directly on the basis of the output of the coupled GCMs, except that it is likely that precipitation will increase, perhaps by the order of 5% for each degree of warming in the latitude range of the Nordic countries (Sælthun et al. 1998b).

The Arctic is recognised as the area of the world where climate change is likely to be largest, and is also an area where natural variability has always been large. Current climate models predict a greater warming for the Arctic than for the rest of the globe (Källén et al. 2001).

Although current AOGCMs differ significantly with respect to both the magnitude and distribution of future changes, they can still guide our understanding of what may happen in the Arctic in the coming decades. On average, the models indicate a 2 to 6 ºC warming of the Arctic by the year 2070, with considerable uncertainty around these estimates and large model-to-model differences. Although many emission assumptions exist for the future, the range of projected Arctic temperature responses is similar to the range of responses observed due to model-to-model differences.

As referred to in Section 2.2, IPCC (2001) compared A2 and B2 based simulations for the time span 1961-1990 to 2070-2100, i.e. 110 years with the nine AOGCMs CGCM1, CCSR/NIES, CSIRO Mk2, ECHAM3/LSG, GFDL_R15_a, HadCM2, HadCM3, ECHAM4/OPYC, DOE PCM. This comparison was done on a regional scale, to identify common trends and check the consistency between the models. The B2 results are reproduced in Figure 2 (temperature) and Figure 3 (precipitation). The results are interpreted regionally. For results to be regarded as consistent, it is required that seven of nine simulations show the same tendencies regionally. As can be seen, both the North Europe region (NEU) and Greenland region (GRL) show temperature increases much greater than average warming for the winter season and greater than average for the summer. However, if we go into more detail, we see that the SCANNET field stations mostly are in areas of moderate warming, except Ny-Ålesund, Kilpisjärvi and Kevo. For more detailed scenarios, see Chapter 5.

The precipitation results show small increases – small in winter and zero in summer for NEU, and small increases both for summer and winter for GRL.

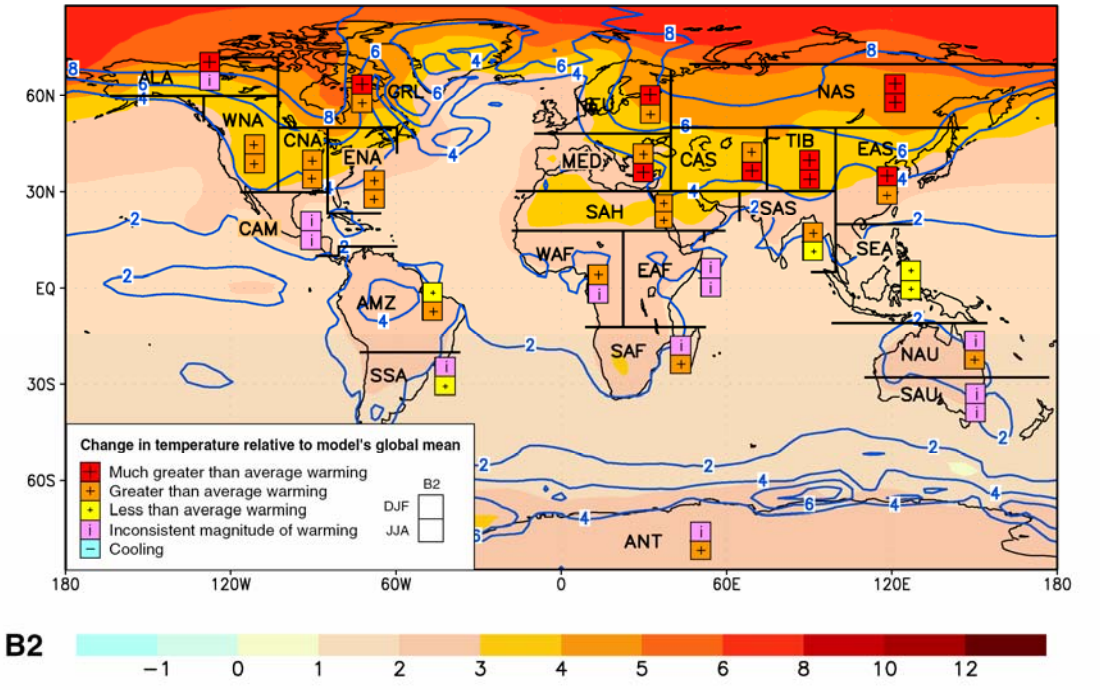

Figure 2. Temperature changes in deg C over 110 years, based on nine AOGCMs and B2 emission scenario. Data from IPCC (2001).

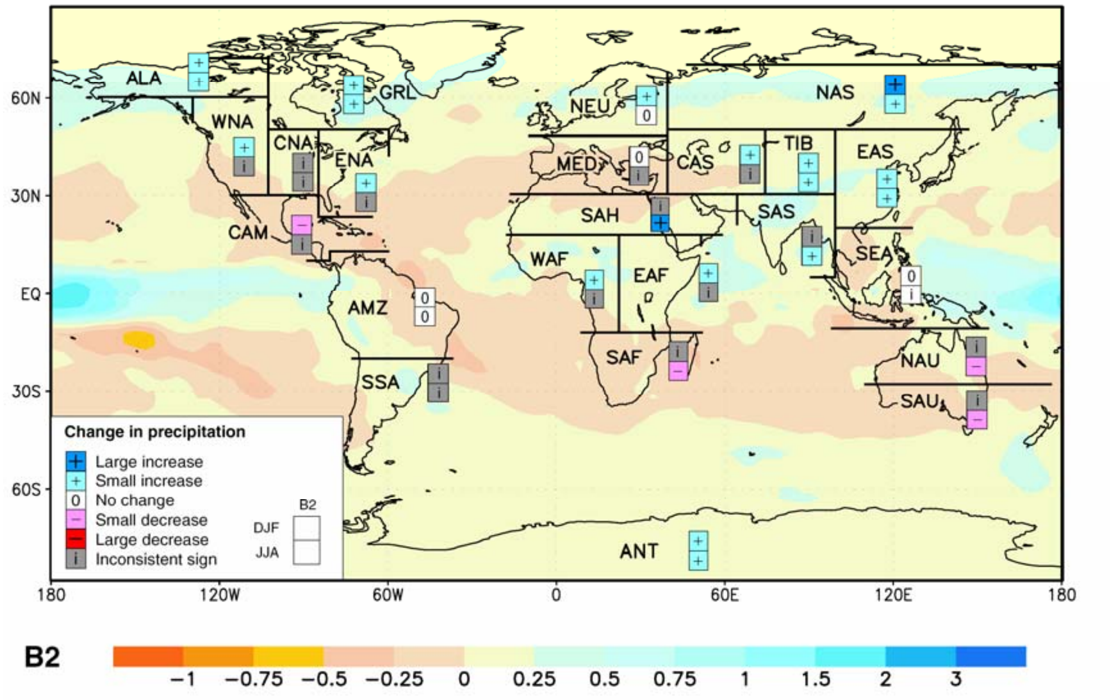

Figure 3. Precipitation changes in mm/day over 110 years, based on nine AOGCMs and B2 emission scenario. Data from IPCC (2001).

General
According to Räisänen (Källén et al. 2001) the model-to-model differences in climate change result partly from differences in model characteristics, and partly from natural variability ("noise") in the simulations. When using a method detailed in Räisänen (Räisänen, 2001), the latter factor is only likely to explain 10–20% of the differences in seasonal and annual temperature changes. However, it explains a more substantial part of the differences in the changes of precipitation and, in particular, sea level pressure.

4.2 The Arctic Climate Impact Assessment (ACIA)

The Arctic Climate Impact Assessment (ACIA) is a four-year international project of the Arctic Council (AC) and the International Arctic Science Committee (IASC), to evaluate and synthesise knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences in the Arctic. It started officially in the third quarter of 2000 and is expected to be completed by the third quarter of 2004. In agreement with IPCCs approach, appropriate emission scenarios are assumed and AOGCMs are used to project the resultant changes to the physical environment.

4.2.1. The region

The ACIA project examines changes in four arctic sub-regions. Region 1 covering the Arctic Europe East Greenland, Northern Atlantic, Northern Russia is of the most relevance for the SCANNET project per se. Region 2 covers Siberia, Region 3 covers Chukota, the Bering Sea, Alaska and the West Arctic Canada. Region 4 covers north-eastern Canada, the Labrador Seas, the Davis Strait and West Greenland. See Figure 4.

The southern limit for the sub-regions is not defined but coincides roughly with the Arctic Monitoring and Assessment Programme (AMAP) "definition" of the Arctic. Because of the difficulty of defining the Arctic in a way that is relevant for all areas of science, AMAP does not define the Arctic but gives a guideline about the core area to be covered by the AMAP assessment.

In the North Atlantic, the southern boundary follows 62°N, and includes the Faroe Islands. To the west, the Labrador and Greenland Seas are included in the AMAP area. In the Bering Sea area, the southern boundary is the Aleutian chain. Hudson Bay and the White Sea are considered part of the Arctic for the purposes of the assessment. In the terrestrial environment, the southern boundary in each country is determined by that country, but should lie between the Arctic Circle and 60°N.

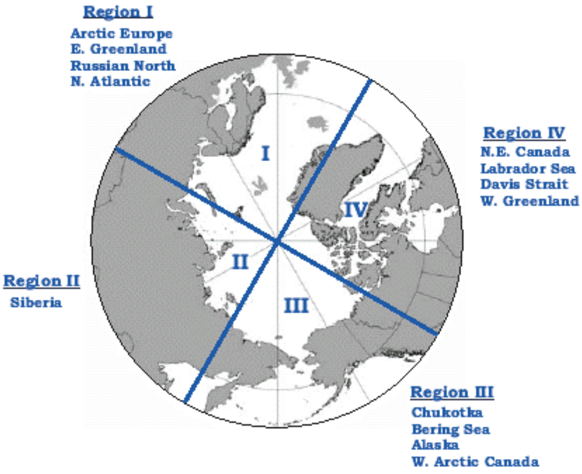

Figure 4. ACIA regions. From ACIA Scenario Site[10]

4.2.2. Models

While it is recognised that some models may be more appropriate for Arctic use, it is currently difficult to establish criteria determining which AOGCMs should or should not be used. As a starting point, the ACIA group has decided to follow the selection of models made by IPCC in their climate scenario database.

The following models are included in the ACIA project:
- Canadian Climate Centre GCM (CCC)
- NCAR Climate System Model (CSM)
- Geophysical Fluid Dynamics Laboratory GCM (GFDL)
- Hadley Climate Centre GCM 3 (HadCM3)
- European Centre, Hamburg GCM (ECHAM)

4.2.3. Downscaling

For some small regions of the Arctic, a considerably finer grid-scale (e.g. 50 m by 50 m) is needed to assess terrestrial impacts, such as impacts to vegetation and infrastructure. This scale is obtained by statistical downscaling from global or preferably regional models. Areas of long-term ecological monitoring, as near Abisko, Toolik Lake and Svalbard, would benefit from such efforts.

A number of regional models exist for specific areas of the Arctic, but there is currently no working coupled ocean-ice-atmosphere regional model for the Arctic as a whole. This lack was recognised by ACIA as a serious gap in the projects' current ability to assess climate change impacts in the Arctic. Thus, several groups would like to work on developing an appropriate model and may get support for this work in the future.

4.2.4. Emission scenarios

No new emission scenarios are developed in the ACIA-project. The scenarios developed by CMIP2 (a 1%/yr increase of CO_2) and IPCC (IS92 and SRES) are considered useful for assessing model-to-model differences. To stay co-ordinated with the current IPCC efforts, the ACIA group has agreed to work from IPCC SRES scenario B2.

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[10] http://faldo.atmos.uiuc.edu/ACIA/

4.2.5. Time Slices

The time slices for special consideration in the ACIA-project will be centred around 2020, 2050 and 2080. These horizons are also being given special attention by IPCC.

Results from models will have to be examined for some number of years around these times to represent average values as well as the characteristic variability. Characterising the changes in extreme events will require using historical data and daily model output in addition to the monthly output typically archived. A record length of ten to thirty years will be examined for each time slice.

4.2.6. Climate change simulations

A number of simulations are stored on the ACIA web server. Details are given in Table 6.

Table 6. B2 scenarios available at ACIA server

Model	Monthly data	Daily data
HadCM3 GCM	150 years (1950 - 2099)	130 year (1970 - 2099)
Echam GCM	111 years (1990 - 2100)	1980 – 2000, 2010 – 2030, 2040 – 2060, 2070 – 2090
CCC GCM	126 years (1975 - 2100)	Control simulation : 1975 – 1995 Transient simulation : 2011 – 2030, 2041 – 2060, 2071 - 2090
NCAR-CSM GCM	control simulation : 1980 - 1999 transient simulation : 2000 – 2099	Control simulation : 1980 – 1999 Transient simulation : 2000 - 2099
GFDL GCM	monthly : 1965 - 2104	Control simulation : 50 years Transient simulation : 2010 – 2029, 2040 – 2059, 2070 - 2089

4.2.7. Results

Räisänen (in Källén et al. 2001) presents results from the CMPI2 experiments for the Arctic region:

> *The magnitude of variability in the control runs appears in many respects reasonable, but it varies a lot between the different models, and almost all models overestimate temperature variability on low-latitude land areas. The gradual doubling of CO_2 leads in most models to a decrease in temperature variability in the winter half-year in the extratropical Northern Hemisphere and in the high-latitude Southern Ocean. Over land in low latitudes and in northern midlatitudes in summer, a slight tendency towards increased temperature variability occurs.*
>
> *The standard deviation of monthly precipitation increases, on the average, where the mean precipitation increases, but even in some areas where the mean precipitation decreases slightly. The coefficient of variation of precipitation also shows a tendency to increase in most areas, especially where the mean precipitation decreases. The changes in variability, however, are less similar between the 19 experiments than the changes in mean temperature and precipitation, at least partly because they have a much lower signal-to-noise ratio. Also, the changes in the standard deviation of monthly temperature are generally much smaller than the time mean warming, which suggests that future changes in the extremes of interannual temperature variability will be largely determined by the latter.*

Annual Temperature

With a doubling of CO_2, the models generally show a larger increase in annual mean temperature over the Arctic than anywhere else in the world. On the average, the warming amounts to 3.4°C (double the global mean) for the whole area north of 60°N, with even larger warming over the high Arctic.

The scatter among the individual models is substantial (1.5°C to 7.6°C) in the 60°–90°N area mean, although 17 of the 19 models are within 2.2–3.9°C. The model-to-model differences at the sub-Arctic level are even larger, with some models predicting the greatest warming over the Russian part of the Arctic and others over the high Arctic or over the Canadian part of the Arctic.

In a few cases, patches of local cooling actually occur over the Atlantic sector. Despite this, the standard deviation among the 19 experiments is typically only about a half of the 19-model mean warming. Thus, although the absolute scatter is large, the relative agreement may still be regarded as reasonably good according to Räisänen (Källén et al. 2001).

Seasonal Temperature

The models generally predict a strong seasonal cycle in the changes in temperature, with the greatest changes in autumn and winter and the smallest change in summer. In the high Arctic, the 19-model mean warming reaches 7–8°C in autumn and winter but only 1°C in summer.

Precipitation

On the average the 19 models included in CMPI2 simulate about a 20% increase in annual precipitation over the high Arctic and about a 11% increase for the whole area 60°–90°N. The largest increases are projected for autumn and winter and the smallest for summer.

To a greater extent than with the results for temperature, the scatter among the individual experiments is large. The sub-regional patterns of change are noisy and vary strongly among the 19 experiments, from local decreases to increases exceeding 50% in some cases. The local model-to-model standard deviation is generally of similar magnitude with the 19-model mean precipitation increase. Estimating changes in land surface wetness or moisture availability will require considering changes in evapotranspiration as well as precipitation.

Arctic sea ice

There is increasing evidence that there is a decline in the extent and thickness of Arctic sea ice in the summer that appears to be connected with the observed recent Arctic warming. It is not known whether these changes reflect anthropogenic warming transmitted either from the atmosphere or the ocean or whether they mostly reflect a major mode of multi-decadal variability (IPCC 2001).

What does seem clear is that the changes in Arctic sea ice are significant, and there is a positive feedback that could be triggered by declines in sea-ice extent through changes in the planetary albedo. If the Arctic shifted from being a bright summer object to a less bright summer object, then this would be an important positive feedback on a warming pattern.

In addition to these recently available observations, there have been several models (CIRO, DOE PCM, NCAR CSM) that have improved their sea ice representation since the IPCC report (1996). These improvements include simulation of open water within the ice pack, snow cover upon the ice, and sea ice dynamics. The incorporation of sophisticated sea ice components in climate models provides a framework for testing and calibrating these models with observations

New field programmes are under way with the explicit goal of improving the accuracy of model simulations of sea ice and polar climate. In order to improve model representations and validation, it will be essential to enhance the observations over the Arctic including ocean, atmosphere, and sea ice state variables. This will help provide more reliable projections for a region of the world where significant changes are expected.

4.2.8. Accessibility of the ACIA data and results

Summary of archive contents for selected models, time series plots and event frequencies for selected models and summary fields for selected variables and models are presented at the ACIA Scenario Sites:
http://zubov.atmos.uiuc.edu/ACIA
http://faldo.atmos.uiuc.edu/ACIA/

4.3 Existing local and regional scenarios

Regional climate modelling is presently pursued by three modelling groups in the Nordic countries. At the Norwegian Meteorological Institute (DNMI) regional modelling is being done in the nationally co-ordinated RegClim-project (Haugen et al. 1999). Similarly the activity at the Rossby Centre at the Swedish Meteorological and Hydrological Institute (SMHI) takes place as a part of the national SweClim program (Räisänen et al. 1999). At the Danish Meteorological Institute (DMI) such modelling has been an activity for quite some years (Christensen et al. 1997, Christensen et al. 1998, Tackle et al. 1999) and it is presently organised at the Danish Climate Centre (DDC).

4.3.1. RegClim - Regional Climate Development Under Global Warming

The main objective of the Norwegian project, RegClim (Regional Climate Development Under Global Warming), is to assess the regional impact of global climate change for Northern Europe and bordering seas by developing climate scenarios.

A second aspect of the project is to quantify uncertainties in these estimates, with special focus on the regional processes. This includes processes determining sea-surface-temperature (SST) and sea ice cover in the Nordic Seas, and processes related to radiatively active atmospheric contaminants with a regional distribution (direct and indirect aerosol effects, and tropospheric ozone).

The project started in June 1997 and ended in December 2002, and has been funded by the Norwegian Research Council. The main participants are the Norwegian Meteorological Institute, the Institute of Marine Research, the Nansen Environmental and Remote Sensing Center, the Geophysical Institute at the University of Bergen, the Department of Geophysics at the University of Oslo and the Norwegian Institute for Air Research. Much of the results are published in the electronic journal Cicerone[11]: A popular presentation of the main results was published in November 2002, and is avilable in pdf-format on the project web-site. The project is followed up by Klimprog, also financed by the Norwegian Research Council, and is becoming an integrated part of the Norwegian climate research programme.

The region
The region covered is shown in Figure 5. It covers all SCANNET sites.

Downscaling
RegClim includes both dynamical downscaling and empirical downscaling.
Dynamical downscaling in RegClim has so far been concentrated upon using the GSDIO[12] run from Max Planck Institute to force the regional atmospheric climate model HIRHAM, the HIRLAM model

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[11] http://www.cicero.uio.no/cicerone/

[12] A transient integration including greenhouse gases as well as direct and indirect sulphur aerosol forcing and ozone.

with ECHAM4 physic, as described in previous reports by Bjørge & Haugen (1998) and Haugen et al. (1999).

Two time slices each consisting of 20 years have been run; the control run corresponding to present climate and a scenario run corresponding to a doubling of the atmospheric CO_2 content, i.e. corresponding to year 2050 (Førland et al. 2000).

The GSDIO integration with the MPI ECHAM4/OPYC3 has been used as a basis for downscaling of future climate in Norway and on Svalbard. Climate scenarios based on the dynamical downscaling are reported by Bjørge et al. (2000) and Hansen-Bauer & Førland (Hanssen-Bauer and Forland, 2001). The results are obtained using a regional climate model with resolution ½ degree (50 km).

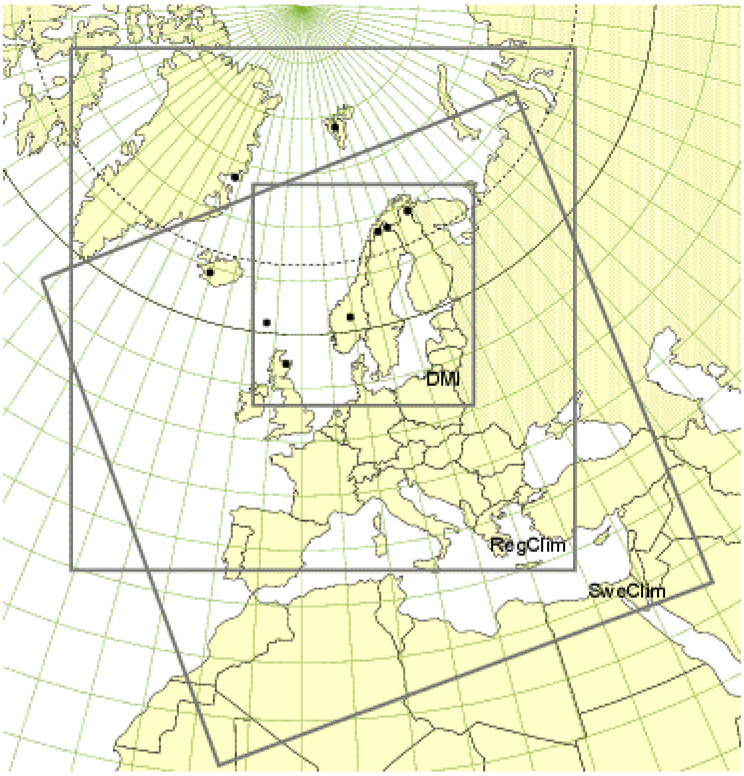


Figure 5. Regions covered by the RegClim, SWECLIM and DMI RCM simulations. The stippled line shows the Arctic Circle, indicating the southernmost border of the ACIA project, which lies between the Arctic Circle and 60° N (also shown). The SCANNET field sites are marked on the map.

Results from dynamical downscaling

Taken from Hanssen-Bauer & Førland (2001):

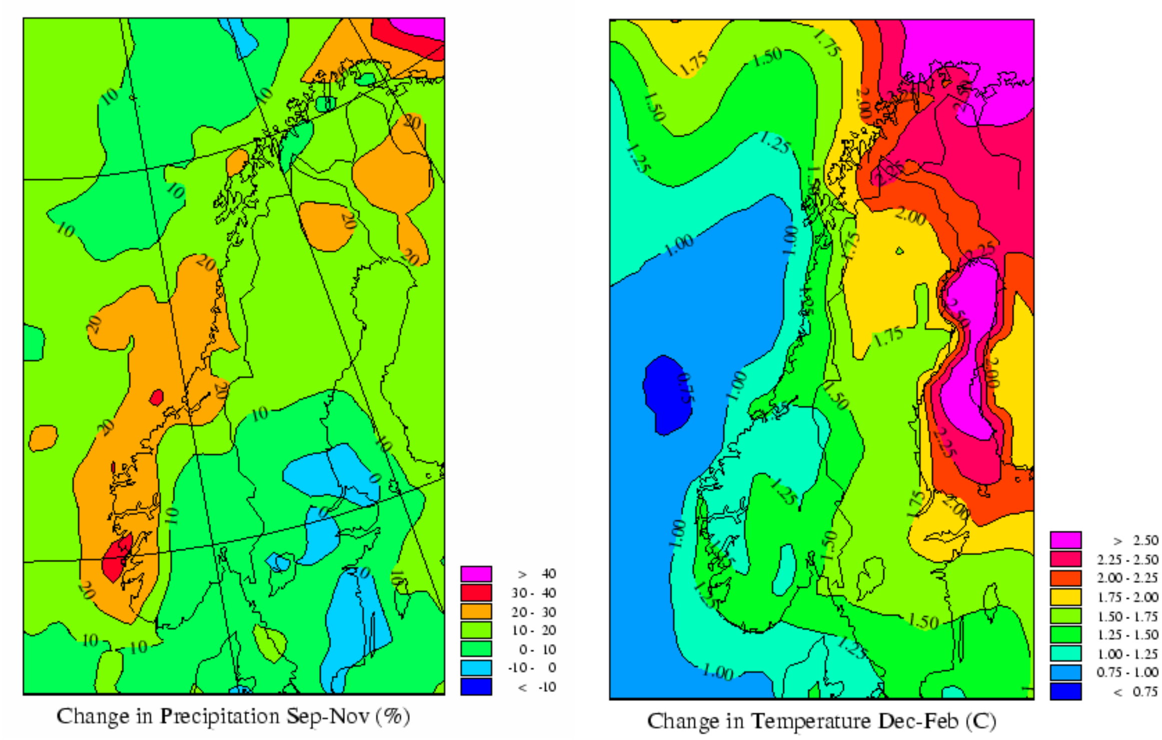
> *The GSDIO-integration gives during the period 1871-1990 a fairly realistic temperature climate over Norway and Svalbard. The wind field shows in average a too weak westerly component over Norway. There is still an agreement between model and observations concerning the strengthening of the westerlies over Norway during the period 1961-1990 relatively to earlier 30-year periods. There is a reasonable agreement between model and observations concerning the connection between the sea level pressure field and temperature field, especially during winter.*
>
> *Established connections between the sea level pressure field and temperature in Norway indicate that 1/3 to 2/3 of the expected warming during winter can be explained directly be the changes in the SLP-field, which mainly is a strengthening of the westerlies.*

Examples of the details obtained by using dynamic downscaling are shown in Figure 6.

Temperature

The experiments show a mean annual temperature increase varying between 0.2-0.5ºC/decade in mainland Norway as and 0.8ºC/decade at Svalbard. The warming is largest in continental areas and in the Arctic. Further, the increase in temperature will be largest for the winter season and smallest for the summer.

It should be noted that the Arctic is a region where one can not expect to gain much from dynamical downscaling using the atmospheric model alone (Førland et al. 2000).



Change in Precipitation Sep-Nov (%)

Change in Temperature Dec-Feb (C)

Figure 6. Simulated precipitation and temperature, RegClim. Projected change during the next 50 years for winter temperature (2-meters) and autumn precipitation. From DNMI[13].

Dynamical downscaling shows its strengths where local forcing such as topography, land sea contrasts and interaction with the underlying surface are important. Large differences between present climate (control) and scenario are found in the Arctic and are related to a strong reduction of the sea ice coverage.

Precipitation

An increased precipitation was also found over the whole region (10% as an average) but significantly more upwind of the major mountain ranges (western coast of Norway) where it amounted to a 30% increase in autumn as a maximum.

Wind

Average wind speed shows a moderate increase most places in the winter, with largest increase in the central Norwegian mountains, the West Norwegian Coast and the Barents Sea. However in general the increase is marginal, 0 to 1% per decade. See Figure 7.

Empirical Downscaling

Benestad (1999) conducted a pilot study on future local climate scenarios, based on empirical downscaling of transient climate change integration from Max-Planck-Institute (MPI). A number of

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[13] http://www.met.no

test results based on various predictor fields gave diverging results, ranging from cooling to warming, and sensitivity experiments indicated a great deal of uncertainty associated with the downscaling itself. Some of uncertainty was attributed to the mismatch between simulated and observed spatial climate structures.
A method involving common empirical orthogonal functions (common EOFs) was suggested to overcome some of the problems. Benestad (2000) proposed a new empirical downscaling approach based on common EOFs that aims to reduce the uncertainty level.

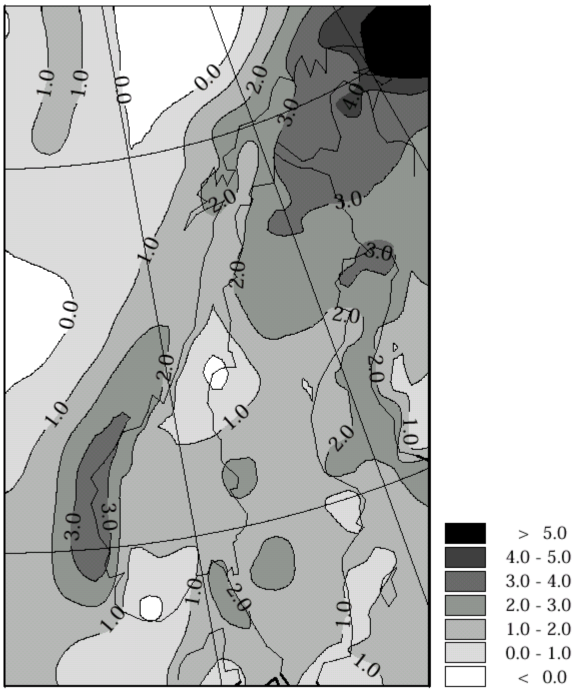

Figure 7. Increase in average wind speed for Scandinavia, over 50 years. From Haugen & Nordeng (2001).

A number of experiments with empirical downscaling of temperature and precipitation scenarios for various Norwegian locations indicate that empirical downscaling is associated with uncertainties due to sampling fluctuations, model shortcomings, and the linear assumption. The advantage of using empirical models is that they are cheap to use and allow fast and easy assessment of uncertainty by repeating the projection with different model settings (e.g., different data sets, predictor domain, record length, and linear optimisation method). The common EOF method gives an indication of how well the GCM reproduces the observed climatic features, and relies on the assumption that these features only change in strength or occurrence in the future. The empirical methods are likely to fail if a global warming introduces new climate patterns.

More results can be found in Benestad & Førland (2000).

Climate data archive
A number of different gridded data have been compiled for use as predictors in the construction of empirical models. The data sets were partly compiled from internet sites and partly by special requests to relevant institutions. The public, historical gridded data sets (monthly values) for sea level pressure (SLP) and temperature in the North Atlantic region have been extended back to 1873 by use of advanced statistical analysis (Benestad and Førland 2000). A description and evaluation of the historical data sets is published by Benestad (1998) and a survey of the data sets are given at the DNMI RegClim website (in Norwegian mostly).

Web sites:
http://www.nilu.no/RegClim
http://projects.dnmi.no/~RegClim

4.3.2. SweClim - The Swedish Regional Climate Modelling Program

The climate change scenarios within SweClim are produced by the Rossby Centre regional atmospheric climate model, which performs downscaling from different global climate scenarios on a time horizon of 50 to 100 years in the future. The regional modelling makes it possible to obtain higher spatial resolution and to include treatment of the Scandinavian Mountains and regional water bodies, such as the Baltic Sea and the Nordic lakes.

The regional climate model (RCA) simulations used up to now for water resources scenarios have a horizontal resolution of ~ 88 km and ~ 44 km. The two global models used so far are the HadCM2 from the Hadley centre in Reading and the ECHAM4 of the Max Planck Institute of Meteorology in Hamburg.

The region
The region covered is shown in Figure 5. Of the SCANNET sites, Zackenberg and Ny-Ålesund falls outside the area covered, while Litla-Skard is close to the margin.

Downscaling
The latest SweClim regional simulations are presented in Räisänen et al. (2000). These are regional climate scenarios for Northern Europe run on 44 km resolution with the RCA1 model system. Two simulations have been carried out, one based on the HadCM2 control and transient GHG simulations at the Hadley Centre (Johns et al. 1997). The other simulation is based on ECHAM4/OPYC3 transient GHG-run at the Max-Planck-Institute for Meteorology in Hamburg (Roeckner et al. 1996, Oberhuber 1993).

In both cases, two 10-year time slices are run. In the HadCM2 case, one of the time slices is from a control integration of the GCM and the other from one of its transient GHG-integrations, separated by a 150% increase in equivalent CO_2. In the ECHAM4 case, both time slices are from its transient GHG-run, separated by a 100% increase in equivalent CO_2.

Temperature
The global mean temperature change in both of the forcing GCMs is almost the same, 2.6ºC. In the RCM simulations, the land area mean temperature changes are 3.4ºC (when forced by HadCM2) and 4.0ºC (when forced by ECHAM4). These are only slightly (0.07ºC and 0.03ºC) below those for the same area from the GCMs.

Results from the SweClim project clearly showed that an ocean and sea ice model of the Baltic Sea were necessary to achieve reasonable temperatures in northern Sweden and Finland (Räisänen et al. 1999).

Precipitation
The patterns of precipitation change are also broadly similar between the simulations, with the largest relative increases over the Nordic region, especially northern Scandinavia, and the smallest relative increases over central and southern Europe. In the ECHAM4 case, in particular, precipitation actually decreases in the latter parts.

Water resources
In SweClim, the regional simulations are further interpreted using hydrological modelling. This provides water resources scenarios covering hydropower potential, dam safety, flood risk estimation and water quality issues. Changes in precipitation and temperature are extracted from the RCA model and transferred to off-line hydrological simulations with the HBV model for a number of selected test basins in Sweden. Two different methods for the estimation of future evapotranspiration have been used in the hydrological model.

The water resources scenarios have so far mainly included the analysis of changes to snow pack, soil moisture content, groundwater recharge and river runoff. Changes in runoff totals and runoff regimes have been analysed as well as extreme values by frequency analyses of floods.

The SweClim study includes the impact on the annual cycle of runoff of eight different water resources scenarios. A general tendency is the shift in runoff regime towards decreasing spring flows and increasing flows during the rest of the year. In southern Sweden, however, the scenarios indicate a decrease of low flows during summer and give diverging results for autumn and winter. Generally, the spread of the scenario curves is larger towards the south of the country.

The use of ensembles of differently structured scenarios shows a possible range in the water resources scenarios and illustrates the uncertainties involved in this type of impact studies. The interface between the regional scenarios and the hydrological model is to be further developed by SweClim to allow for accounting for possible changes in variability and extremes, in addition to changes in the mean climate.

4.3.3. Danish Meteorological Institute (DMI) Scenarios

DMI has applied the HIRHAM4 model (Christensen et al. 1996) as an RCM in several contexts and configurations. A European experiment covers broadly the same region as the RegClim simulation (see Figure 8), with a resolution of approximately 56 km. A Scandinavian setup covers the region shown in Figures 5 and 8, with a resolution of 18 km. This is the simulation used in the NordEnsClim comparative study (see below). There is also a setup for the Russian Tundra, used in the EU TUNDRA study. This is centered on 55 °E, 67 °N. It covers an area with extent approximately 1600 km north-south and 2000 km east-west, with a resolution of approximately 16 km. The forcing GCM in these studies is ECHAM4 (Christensen J.H. & Christensen O.B 2000).

TUNDRA simulations
DMI has applied the HIRHAM4 model (Christensen et al. 1996) over the Arctic part of European Russia at a horizontal resolution of 16 km. The work is part of an EU project called TUNDRA[14], where the main objective is to obtain net fluxes for carbon and freshwater from a specific Arctic catchment area in European Russia under base-case and global change scenarios. Here, the results from the HIRHAM simulations will be used as input to base-case climate studies.

In order to provide the present-day model climate, a simulation using 15 years of boundary data from the European Centre for Medium Range Weather Prediction (ECMWF) re-analyses project has been performed. The model has for practical reasons been set up for a larger region than that required by the investigation. More about the TUNDRA experiment and the simulation found in Christensen J.H. (1999).

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[14] Tundra Degradation in the Russian Arctic

4.3.4. NordEnsClim - The Nordic Ensemble of Climate Scenarios

Since the regionalisation of global climate scenarios already done in the different Nordic groups covers considerably overlapping areas, it is natural to join forces and compare and possibly synthesise the results. This is the first goal of the co-operative effort named ‘NordEnsClim’ - Nordic Ensemble of Climate Scenarios (Räisänen et al. 2000, Christensen J.H. et al. 2001).

The comparison includes four climate change experiments, each consisting of a control run (representing present or pre-industrial climate) and a scenario run (some future climate). Driving global model data are taken from the MPI ECHAM4 (Roeckner et al. 1996) or from the Hadley Centre HadCM2 (Johns et al. 1997) experiments.

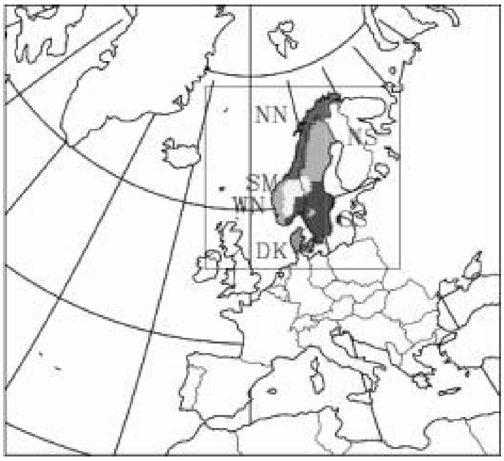

Figure 8. The regions covered by the DMI European and Scandinavian simulations. Christensen J.H. & Christensen O.B. (2000).

Table 7. The four NordEnsClim regional climate change experiments. From Räisenen et al. (2000).

	DMI	**DNMI/REGCLIM**	**RCA-E**	**RCA-H**
Regional model	HIRHAM4 (18 km)	HIRHAM4 (55 km)	RCA1 (44 km)	RCA1 (44 km)
Driving GCM	ECHAM4	ECHAM4	ECHAM4	HadCM2
Forcing scenario	GHG	GSDIO (GHG, sulphates, Tropospheric O_3	GHG	GHG
Control period	“pre-industrial” (9 yr)	1980-1999 (20 yr)	1980’s (10 yr)	“pre-industrial” (10 yr)
Scenario period	2070’s (8 yr)	2030-2049 (20 yr)	2070’s (10 yr)	2040’s (10 yr)
Global warming	3.4ºC	0.9ºC	2.65ºC	2.60ºC
G.W. 1990-2050	1.7ºC	1.1ºC	1.7ºC	1.73ºC
Scaling coeff.	0.5	1.2	0.65	0.67

RegClim has so far been using the MPI GSDIO run to force the regional climate model, the results have been compared with those from the SweClim project, using results from the Hadley Centre to see what impact the use of different GCMs might have on climate change scenarios. The experiments that have been conducted have great differences concerning resolution, model selection and so forth.

As seen from Table 7 the experiments differ in a number of respects:
1. They have been conducted with three versions of two regional climate models (RCMs).
2. They use boundary data from two general circulation models (GCMs), ECHAM4 and HadCM2.
3. Three of them include only the forcing due to increases in well-mixed greenhouse gases (occasionally represented in terms of equivalent CO_2), but one (DNMI) also sulphate aerosol effects and changes in tropospheric O_3.
4. The control and the scenario periods vary widely. In addition, these periods are in most cases at most 10 years long, which makes the noise associated with internal variability a major issue.

The DNMI experiment is longer, but the climate change signal (at least as measured by the global mean warming in the driving GCM) is also substantially weaker in this experiment than in the others. The RCA-H and RegClim are the experiments that differ the most in result.

Results

In Table 8, from Räisänen et al. (2000), the climate change results have been adjusted to a common period (1990 to 2050). When interpreting the information, it should be kept in mind that the three of the simulations use the same GCM forcing simulations, ECHAM4.

4.3.5. RESMoNA - Regional Earth System Modelling Network for the Arctic

Another co-operative effort by the Nordic climate modelling centres, very relevant to SCANNET, is Regional Earth System Modelling Network for the Arctic (RESMoNA). It is a three-year project (2001-2003) funded by the Nordic Arctic Research Programme (under the Nordic Council of Ministers). The participants are the Nordic meteorological institutes, with the Danish Meteorological Institute as co-ordinator. The objectives of the project are very ambitious, and point beyond the three-year project period:

- *Co-ordinate Nordic modelling efforts on regional climate aspects within the Nordic countries, Greenland and in the rest of the Arctic.*
- *Improve and further develop regional climate prediction models for the Arctic and Nordic region. The evaluation will focus on the treatment of physical processes related to clouds and precipitation, large-scale atmospheric dynamics, surface energy balance and soil processes, ocean-atmosphere interactions and interaction with sea ice. The physical parameterizations of the state-of-the-art RCMs; HIRHAM and RCA will be evaluated and used as a background for further development.*
- *Evaluate coupled regional models of the atmosphere, land, lakes, sea ice and ocean, so that the ability of the coupled models to correctly simulate feedback processes can be assessed and a common Nordic model platform established.*
- *Consider atmospheric and land-surface interactions in atmosphere-only models, as well as processes determining sea-surface temperatures and sea-ice cover in the Nordic Sea and the Arctic Ocean in ocean-se- ice models, eventually, coupled regional atmosphere-ocean-sea ice models.*
- *To provide the scientific basis for applying RCM results to integrated impact studies of climate change in the Nordic countries and Greenland. The impact community in the Nordic countries has very little awareness of the Nordic climate modelling community, therefore this effort will increase and stimulate the contact between the two communities. This includes providing more detailed climate simulations as well as targeting specific model output products for applications such as fisheries, agriculture, forestry, transportation, hydro-electric power industries and mineral extraction. Furthermore, severe damages caused by flooding and storms have noticeable societal impacts, which need specific treatment at the regional scale. An important group of end users of our results should be the scientific community engaged in Arctic climate impact assessments.*

Table 8. Climate change scenarios for the four NorEnsClim simulations, for the period 1990 to 2050, and for the Nordic land area (Denmark, Norway, Sweden and Finland, excluding Svalbard, Greenland and Faroe Islands). From Räisänen et al. (2000).

	DMI	**REGCLIM**	**RCA-E**	**RCA-H**	**mean**
T2 (deg C)	2.1	1.6	2.5	2.4	2.2
TRANGE (deg C)	-0.24	-0.31	-0.33	-0.53	-0.35
P (%)	10	10	10	13	11
P (%)	10	10	10	13	11
E (%)	4	5	4	4	4
NP0 (days/yr)	-0.5	-3.5	4.6	4.3	1.2
NP10 (days/yr)	5.2	4.2	4.5	5.1	4.7

Parameters: T2: surface temperature; TRANGE: diurnal temperature range; P: precipitation; E: Evaporation, NP0: Number of days with no precipitation; NP10: Number of days with heavy precipitation (<10 mm).

5. Climate Change Scenarios for SCANNET Field Sites

5.1 Selected scenarios

The following information is mainly based on published maps of climate change scenarios, and adjusted to the common time horisons 2020, 2050 and 2080 (the ACIA time slices) by linear interpolation. Baseline is 1990. To reflect the large uncertainty, the resolution in the change per ten years have been limited to 0.1 °C for temperature and 1% for precipitation.

5.1.1. Temperature

AOGCMs

Table 9 to Table 12 show approximate AOGCM results. The Canadian CCCma and American NCAR-CSM models have a regional pattern that is very different from the European models ECHAM4-GSDIO and HadCm runs. The latter show a large temperature increase close to the present sea-ice limit, especially on Svalbard – this is not present in the two other runs. The results for the period 1990-2080 are summarised in Figure 9.

Table 9. AOGCM ECHAM4-GSDIO simulations, based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990	0,3	0,9	1,8	2,7
Liltla-skard, Iceland	1990	0,1	0,3	0,6	0,9
Sornfelli, Faeroe	1990	0,1	0,3	0,6	0,9
Banchory, Scotland	1990	0,2	0,6	1,2	1,8
Dovre, Central Norway	1990	0,2	0,6	1,2	1,8
Ny Ålesund, Svalbard	1990	0,7	2,1	4,2	6,3
Abisko, Swedish Lapland	1990	0,4	1,2	2,4	3,6
Kilpisjärvi, NW Finnish Lapland	1990	0,4	1,2	2,4	3,6
Kevo, NE Finnish Lapland	1990	0,5	1,5	3	4,5

Table 10. AOGCM HADcm simulations, based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990	0,4	1,2	2,4	3,6
Liltla-skard, Iceland	1990	0	0	0	0
Sornfelli, Faeroe	1990	0,1	0,3	0,6	1,2
Banchory, Scotland	1990	0,2	0,4	0,8	1,6
Dovre, Central Norway	1990	0,3	0,9	1,8	2,7
Ny Ålesund, Svalbard	1990	0,8	2,4	4,8	7,2
Abisko, Swedish Lapland	1990	0,5	1,5	3	4,5
Kilpisjärvi, NW Finnish Lapland	1990	0,5	1,5	3	4,5
Kevo, NE Finnish Lapland	1990	0,6	1,8	3,6	5,4

Table 11. AOGCM CCCma simulations, based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990	0,3	0,9	1,8	2,7
Liltla-skard, Iceland	1990	0,2	0,6	1,2	1,8
Sornfelli, Faeroe	1990	0,2	0,6	1,2	1,8
Banchory, Scotland	1990	0,1	0,3	0,6	0,9
Dovre, Central Norway	1990	0,2	0,6	1,2	1,8
Ny Ålesund, Svalbard	1990	0,3	0,9	1,8	2,7
Abisko, Swedish Lapland	1990	0,3	0,9	1,8	2,7
Kilpisjärvi, NW Finnish Lapland	1990	0,3	0,9	1,8	2,7
Kevo, NE Finnish Lapland	1990	0,3	0,9	1,8	2,7

Table 12. AOGCM NCAR-CSM simulations, based on based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990	0,4	1,2	2,4	3,6
Liltla-skard, Iceland	1990	0,6	1,8	3,6	5,4
Sornfelli, Faeroe	1990	0,1	0,3	0,6	0,9
Banchory, Scotland	1990	0	0	0	0
Dovre, Central Norway	1990	0,2	0,6	1,2	1,8
Ny Ålesund, Svalbard	1990	0,3	0,9	1,8	2,7
Abisko, Swedish Lapland	1990	0,4	1,2	2,4	3,6
Kilpisjärvi, NW Finnish Lapland	1990	0,4	1,2	2,4	3,6
Kevo, NE Finnish Lapland	1990	0,5	1,5	3	4,5

RCM runs

Table 13 to Table 16 show results from the simulations used in the NordEnsClim comparison. Only RegClim cover all the SCANNET Stations. RegClim shows a smaller temperature increase than the other NordEnsClim simulations. Generally, these simulations show a quite flat temperature change field in Scandinavia. Figure 10 summarises the variation over the period 1990 to 2050.

Table 13. RegClim simulations, based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990	0,4	1,2	2,4	3,6
Liltla-skard, Iceland	1990	0,3	0,9	1,8	2,7
Sornfelli, Faeroe	1990	0,2	0,6	1,2	1,8
Banchory, Scotland	1990	0,2	0,6	1,2	1,8
Dovre, Central Norway	1990	0,2	0,6	1,2	1,8
Ny Ålesund, Svalbard	1990	0,6	1,8	3,6	5,2
Abisko, Swedish Lapland	1990	0,3	0,9	1,8	2,7
Kilpisjärvi, NW Finnish Lapland	1990	0,3	0,9	1,8	2,7
Kevo, NE Finnish Lapland	1990	0,4	1,2	2,4	3,6

Table 14. DMI simulations (DCC), based on Räisänen et al (2000).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	0,3	0,9	1,8	2,7
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	0,4	1,2	2,4	3,6
Kilpisjärvi, NW Finnish Lapland	1990	0,4	1,2	2,4	3,6
Kevo, NE Finnish Lapland	1990	0,4	1,2	2,4	3,6

Table 15. RCA-E simulations, based on Räisänen et al. (2000).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	0,4	1,2	2,4	3,6
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	0,4	1,2	2,4	3,6
Kilpisjärvi, NW Finnish Lapland	1990	0,4	1,2	2,4	3,6
Kevo, NE Finnish Lapland	1990	0,4	1,2	2,4	3,6

Table 16. RCA-H simulations, based on Räisänen et al. (2000).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	0,4	1,2	2,4	3,6
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	0,4	1,2	2,4	3,6
Kilpisjärvi, NW Finnish Lapland	1990	0,4	1,2	2,4	3,6
Kevo, NE Finnish Lapland	1990	0,4	1,2	2,4	3,6

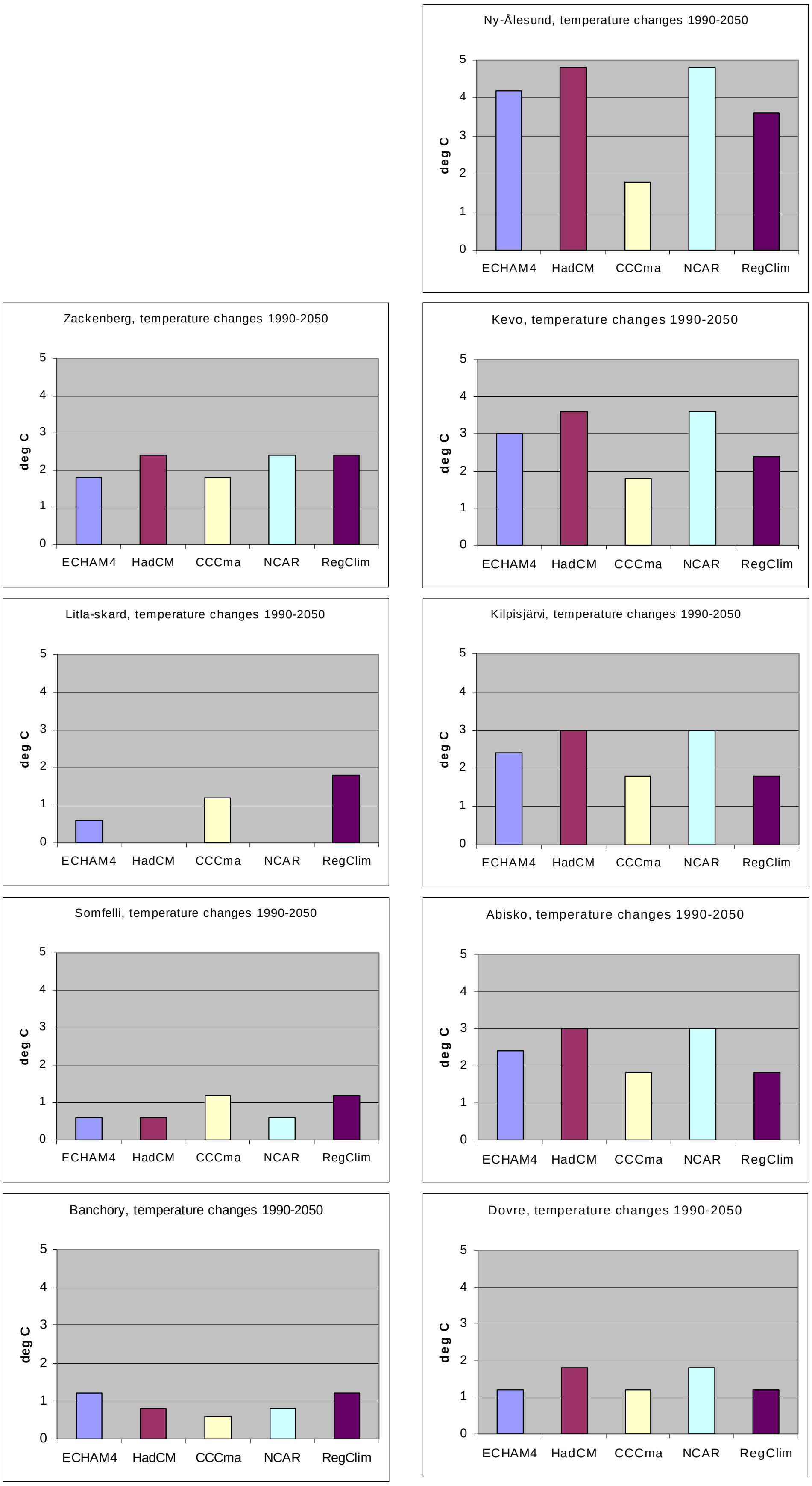

Figure 9. A selection of temperature change scenarios at SCANNET stations

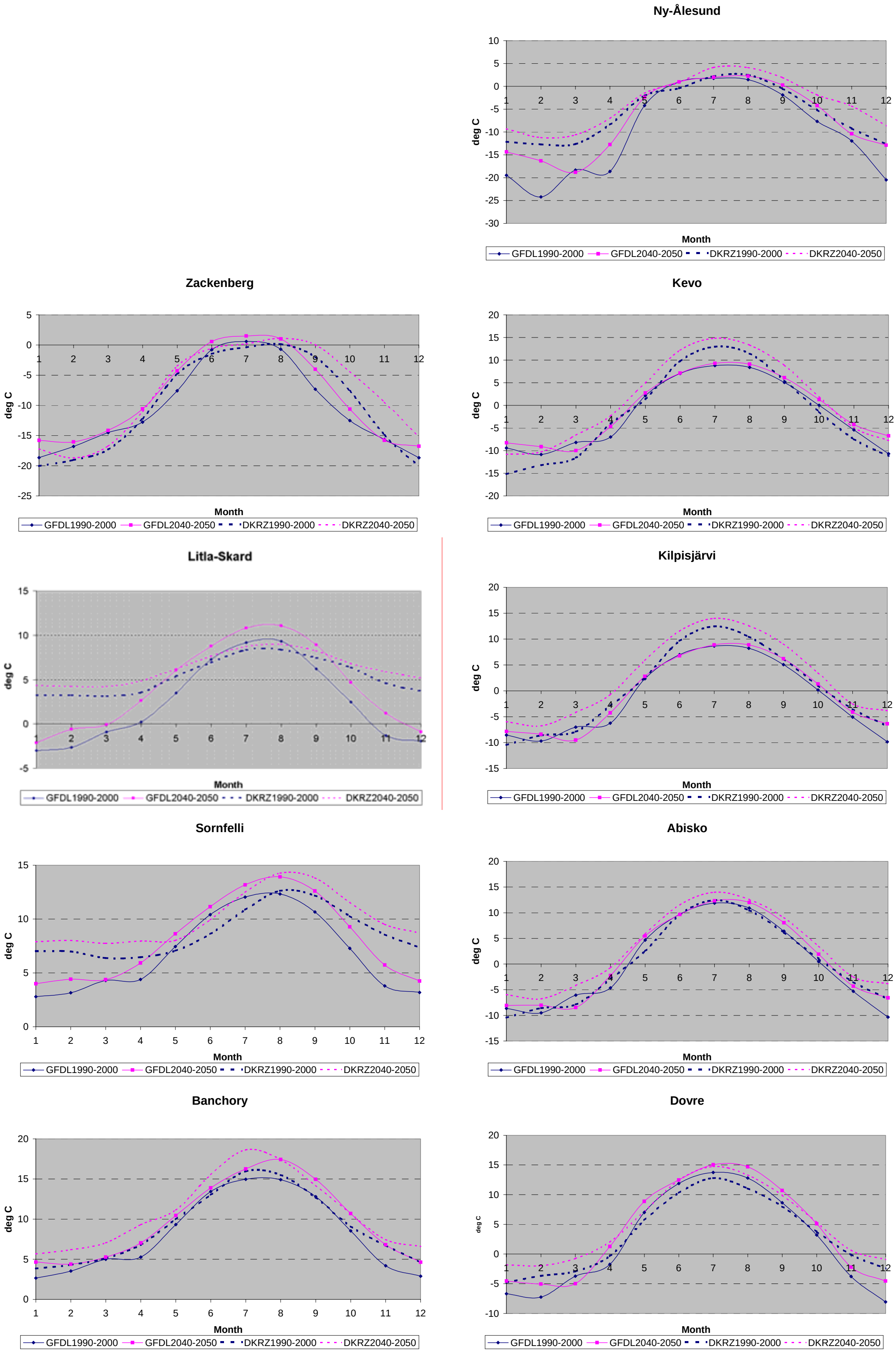

Figure 10. Seasonal temperature variations, GFDL and DKRZ (ECHAM4) models. Time slices 1990-1999 and 2040-2049.

Seasonal variation

The seasonal variations of temperature is illustrated in Figure 10, which shows the results of two AOGCM models, GFDL and ECHAM4 (DKRZ). The simulations are based on the B2 scenario. The results are referred to the SCANNET stations, as the closest grid point is used. It should be noted that the grid distance is 2 to 3 degrees, and that, due to different resolutions, the results from different models do not refer to the same geographical location, only the closest location to a SCANNET station. These data are examples of the scenario time series uploaded to the SCANNET data server.

The graphs displayed refer to the time slices 1990-1999 and 2040-2049, and are averaged over the 10 years. It should be kept in mind that a 10-year average has significant statistical variation.

The NordEnsClim collaborative effort has collected and compared seasonal variations from the Nordic regional simulations. The results for surface temperature (2 m, T2) are reproduced in Figure 11, from Christensen et al. (2001). The dotted line is the ensemble average. All four models show the same pattern, about twice as high increase in temperature in winter as in summer. These results apply to the NordEnsClim region, Fennoscandia and Denmark, but the pattern is probably applicable to most SCANNET sites. It is, however, possible that stations close to the sea ice may have a deviating pattern.

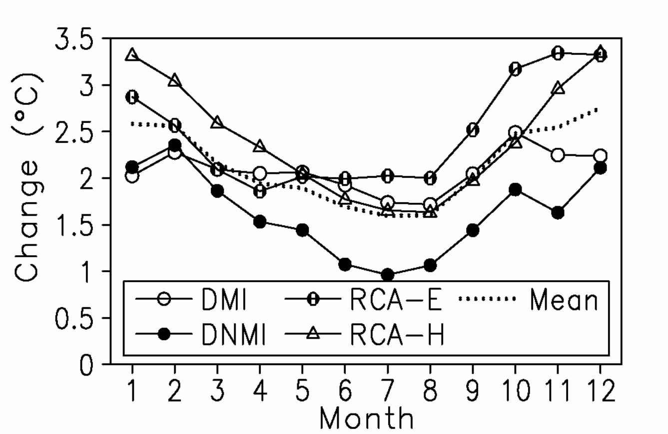

Figure 11. NordEnsClim scenarios for seasonal variations of temperature change (deg C) 1990 to 2050, from Christensen et al. (2001).

Christensen et al. (2001) also includes simulations of change in diurnal temperature range, Figure 12. The models all indicate reduced temperature variations, particularly in winter. The 95% confidence limits are indicated with light shading - the reduced range in winter is significant at this level.

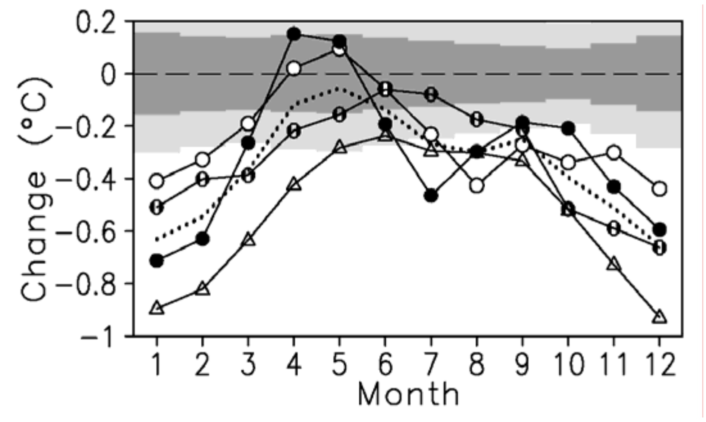

Figure 12. NordEnsClim scenarios for seasonal variation of change in diurnal temperature range (°C) 1990 to 2050, from Christensen et al. (2001). Same legend for models as in Figure 11.

Ground temperature

Changes in ground temperature are generally of greater importance when it comes to biological effects, than the air temperature. Ground temperature is not studied explicitly in most scenario runs or downscaling exercises, but it could be addressed by empirical downscaling where sufficient observation data exists for calibrating the downscaling relationships. One of the most important drivers for changes in ground temperature and ground temperature range is change in cloudiness. More cloud cover reduces the diurnal temperature range. The NordEnsClim results give some indications that this can be a likely result: the number of precipitation days in general increases, and the diurnal range of the air surface temperature decreases - as a consistent result. However, the decrease is less in summer than in winter.

5.1.2. Precipitation

RCM results

Table 17 to Table 20 present results from the NordEnsClim simulations.

Table 17. RegClim (DNMI) simulations, based on Førland et al. (2002).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	1	3	9	12
Ny Ålesund, Svalbard	1990	3	9	18	27
Abisko, Swedish Lapland	1990	2	6	12	18
Kilpisjärvi, NW Finnish Lapland	1990	2	6	12	18
Kevo, NE Finnish Lapland	1990	2	6	12	18

Table 18. DMI simulations, based on Räisänen et al. (2000).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	2	6	12	18
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	2	6	12	18
Kilpisjärvi, NW Finnish Lapland	1990	2	6	12	18
Kevo, NE Finnish Lapland	1990	2	6	12	18

Table 19. RCA-E simulations, based on Räisänen et al. (2000).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	2	6	12	18
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	3	9	18	27
Kilpisjärvi, NW Finnish Lapland	1990	2	6	12	18
Kevo, NE Finnish Lapland	1990	2	6	12	18

Table 20. RCA-H simulations, based on Räisänen et al. (2000).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990				
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre, Central Norway	1990	2	6	12	18
Ny Ålesund, Svalbard	1990				
Abisko, Swedish Lapland	1990	3	9	18	27
Kilpisjärvi, NW Finnish Lapland	1990	4	12	24	36
Kevo, NE Finnish Lapland	1990	4	12	24	36

Seasonal variations

The NordEnsClim seasonal variations for precipitation for the period 1990-2050 are reproduced in Figure 13, from Christensen et al. (2001). The dotted line is the ensemble average. The scatter between the models is larger for precipitation than for temperature, but all four models agree on a maximum increase in autumn. The light shaded zones indicate the 95% confidence limits.

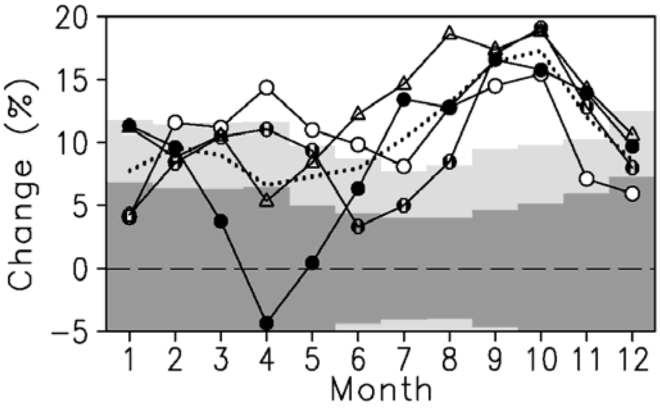

Figure 13. NordEnsClim scenarios for seasonal variation of change in precipitation (%) 1990 to 2050, from Christensen et al. (2001). Same legend for models as in Figure 11.

5.1.3. Runoff and snow cover

The spatial resolution of current global climate models, 200 to 300 km, is too coarse to simulate the impact of global change on most individual river basins, or to represent well the inhomogeneous and non-linear hydrological processes. Verification of the transport models will require budgets of water and other biogeochemical constituents for large basins of the world. This requires ground-based meteorology in tandem with remotely-sensed data for a series of variables, including information on precipitation, soils, land cover, surface radiation, vegetation canopy, topography, floodplain extent, and inundation.

Runoff scenarios were established for 28 catchments in the Nordic countries and Greenland in the Nordic Council of Minister study “Climate Change and Energy production”. As part of this study, a Nordic expert group (Jóhannesson et al. 1995a) established climate change scenarios based on a comparison of available AOGCM runs. The scenarios were given as change per decade, precipitation and temperature, summer and winter. They are summarised in the same form as the newer scenarios in

Table 21 and Table 22. Comparing these scenarios to the later scenarios from NordEnsClim and the AOGCMs reveals no significant systematic differences.

Seasonal variation profile was established both for temperature and precipitation. The summer temperature increase for central Scandinavia was set to 0.25 °C, and winter increase to 0.55 °C. This is very close to the NordEnsClim ensemble mean.

Table 21. Nordic expert group temperature scenarios, based on Jóhannesson et al. (1995a).

	Baseline	2000	2020	2050	2080
Field stations		deg C	deg C	deg C	deg C
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990	0.3	0.9	1.8	2.7
Sornfelli, Faeroe	1990	0.3	0.9	1.8	2.7
Banchory, Scotland	1990				
Dovre, Central Norway	1990	0.4	1.2	2.4	3.6
Ny Ålesund, Svalbard	1990	0.5	1.5	3	4.5
Abisko, Swedish Lapland	1990	0.5	1.5	3	4.5
Kilpisjärvi, NW Finnish Lapland	1990	0.5	1.5	3	4.5
Kevo, NE Finnish Lapland	1990	0.5	1.5	3	4.5

Table 22. Nordic expert precipitation scenarios, based on Jóhannesson et al. (1995a).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, Iceland	1990	1.5	4.5	9	13.5
Sornfelli, Faeroe	1990	1.5	4.5	9	13.5
Banchory, Scotland	1990				
Dovre, Central Norway	1990	1.5	4.5	9	13.5
Ny Ålesund, Svalbard	1990	1.5	4.5	9	13.5
Abisko, Swedish Lapland	1990	1.5	4.5	9	13.5
Kilpisjärvi, NW Finnish Lapland	1990	1.5	4.5	9	13.5
Kevo, NE Finnish Lapland	1990	1.5	4.5	9	13.5

The hydrological HBV runoff model was used for computing the runoff scenarios. The model was analysed and improved in some respects to be suitable for this purpose. This included re-evaluation of the procedures for snow modelling, interception and evapotranspiration. In short, these changes are:

- Introduction of a one-parameter lognormal snow depth distribution function.
- Explicit representation of interception of precipitation on vegetation - including snow. The interception varies seasonally, depending on vegetation type.
- A temperature index based evapotranspiration alorithn, with seasonal variation of efficiency, has been introduced.
- A somple lake temperature, lake ice and lake evaporation estimation method is included.
- Direct representation of climate change parameters (seasonal change in temperature (°C) and precipitation (%)

A glacier model, the MBT model (Mass Balance of Temperate glaciers), was also developed for this project (Jóhannesson et al. 1995b).

Due to the large uncertainty in the precipitation scenarios, alternative simulations without any increase in precipitation were also carried out (Sælthun et al. 1998a). The modelling of evapotranspiration and its sensitivity to climate change proved to be the most uncertain part of the hydrological model, as diverging results were obtained by different parameterisations.

The results of the runoff simulations show great regional variations. Total runoff volumes after 100 years increase by up to 20% in the wettest areas (western Norway) and drop by about 20% in the dry areas with large evapotranspiration (southern Sweden).

Table 23. Runoff changes in rivers close to SCANNET sites, based on Sælthun et al. (1998a).

	Baseline	2000	2020	2050	2080
Field stations		%	%	%	%
Zackenberg, East Greenland	1990				
Liltla-skard, (Blandá, non-glaciated)	1990	0.5	2	4	6
Sornfelli, Faeroe	1990				
Banchory, Scotland	1990				
Dovre (Otta)	1990	1	4	8	12
Ny Ålesund (Bayelva, non-glaciated)	1990	2	6	12	18
Ny Ålesund (Bayelva, glaciated)	1990	15	45		
Abisko (Suorva)	1990	1	3	6	9
Kilpisjärvi (Alta)	1990	0	0	-1	-2
Kevo (Kummaniva)	1990	0.5	2	4	6

Catchments with significant glaciers show a stronger increase in runoff, up to 75% in a catchment in Iceland. The effects of climate change on runoff regimes (seasonal variability) prove to be very strong, even dramatic in some areas. Generally the winters become less stable, and the pronounced snowmelt peak in runoff is replaced by more evenly distributed runoff during winter in many areas. Using the temperature *and* precipitation change scenarios, the runoff changes simulated are given in Table 23. The results from the river closest (in hydrological/climatological regime) to the actual field station is used. Summaries of the changes over 100 years (seasonal runoff, snow cover, soil moisture content, runoff duration, flood frequency and annual runoff) are given in Figure 14 to Figure 19 (from Sælthun et al 1998a). These should only be considered as indicative results.

Hydrological simulations of this type also calculate changes in snow cover duration. Snow cover duration is a function of winter precipitation and autumn and spring temperature. Higher temperature has the double effect of reducing the amount of precipitation falling as snow and of increasing snow melt. In most climate change scenarios, the temperature increase is accompanied by increased winter precipitation, to some extent offsetting the effect of increased temperature (Figure 13). In these simulations, the snow cover in the mountain catchments typically melted away six weeks earlier than present in the +100 year scenario. The maximum amount of snow is also dramatically reduced, increasing the probability for winters with little or no snow cover. The reduced snow cover makes the overall effects on soil frost more difficult to predict.

In the mountain areas with high precipitation located in maritime climatic regimes, there is a possibility that an increased winter precipitation will compensate for the increase in temperature, to the degree that the period of snow cover could increase. In this case, biological and ecological effects of climate change in these areas would be radically different from the effects expected in the continental alpine areas.

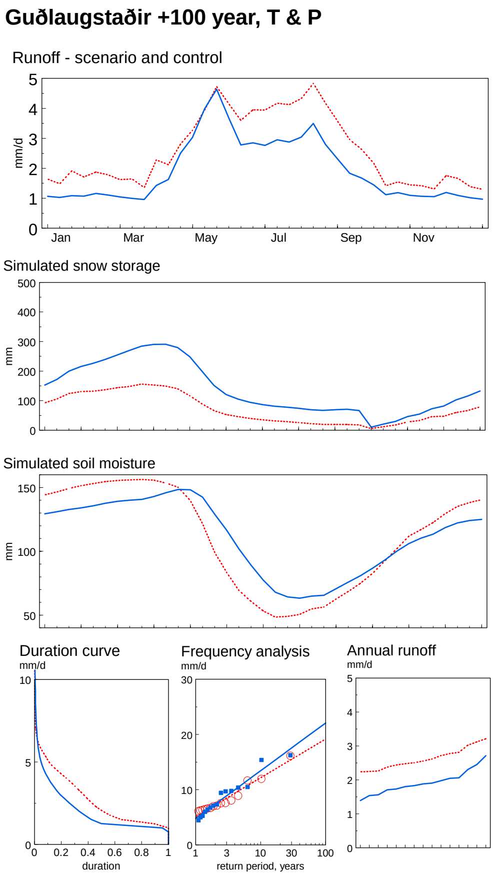

Figure 14. Hydrological simulations for Guðlaugstadir in Blanda. Blue solid lines: simulated near present (1960-1990), red dotted lines: +100 years. The simulations are not representative for Litla-Skarð, as Blanda has 15% glacier coverage and is in another climatic region in Iceland.

Top graph: Seasonal variation of runoff, mm/day
Second: Snow storage, in mm water equivalent
Third: Soil moisture, mm
Bottom row (all in mm/day):
  Left: Duration curve
  Middle: Frequency analysis of annual floods
  Right: Annual runoff ranked

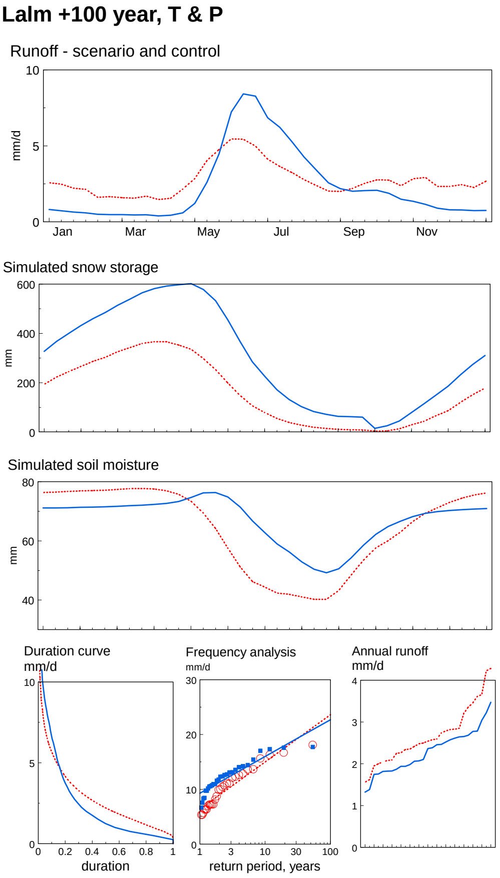

Figure 15. Simulations for Lalm in Otta river (part of Glomma catchment). Indicative for Dovre.

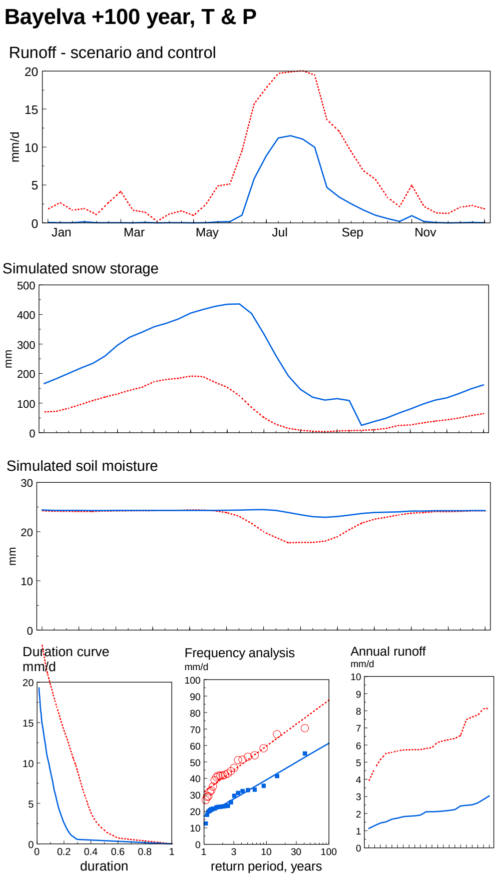

Figure 16. Hydrological simulations for Bayelva near Ny-Ålesund, Svalbard.

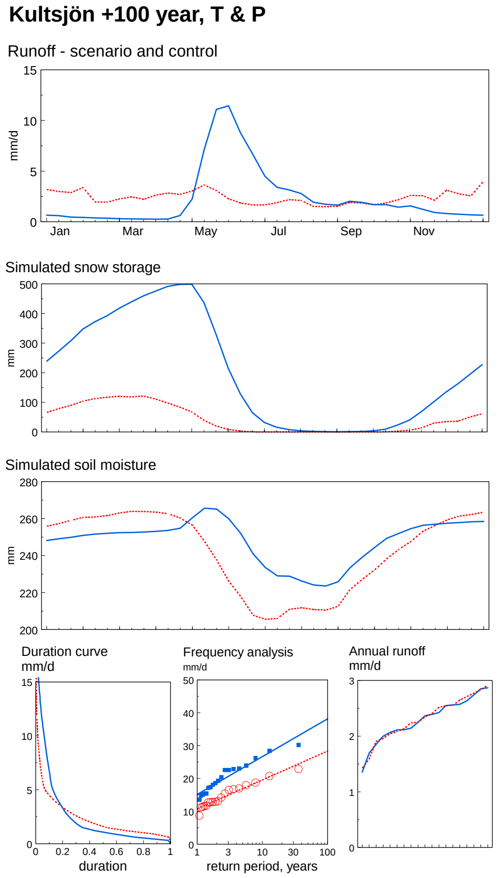

Figure 17. Simulations for Kultsjön in the Ångerman river headwaters. Indicative for Abisko.

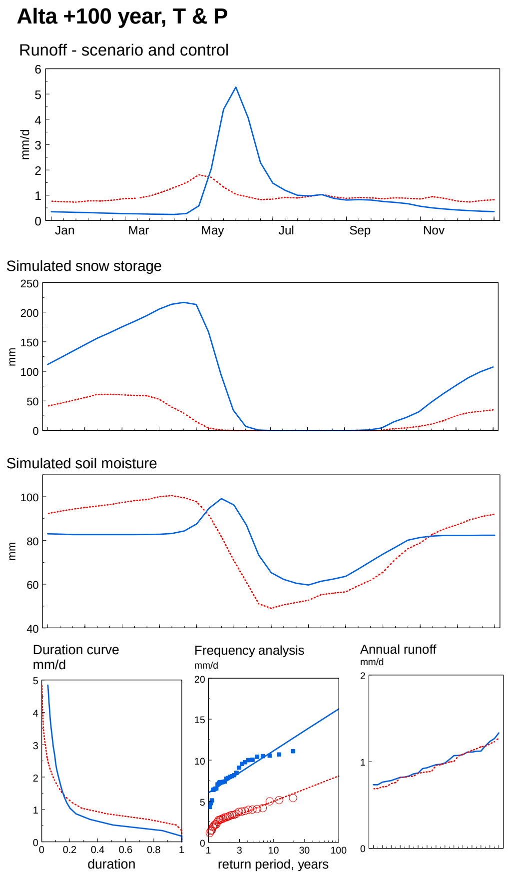

Figure 18. Hydrological simulations for Masi in Alta river. Indicative for Kilpisjärvi.

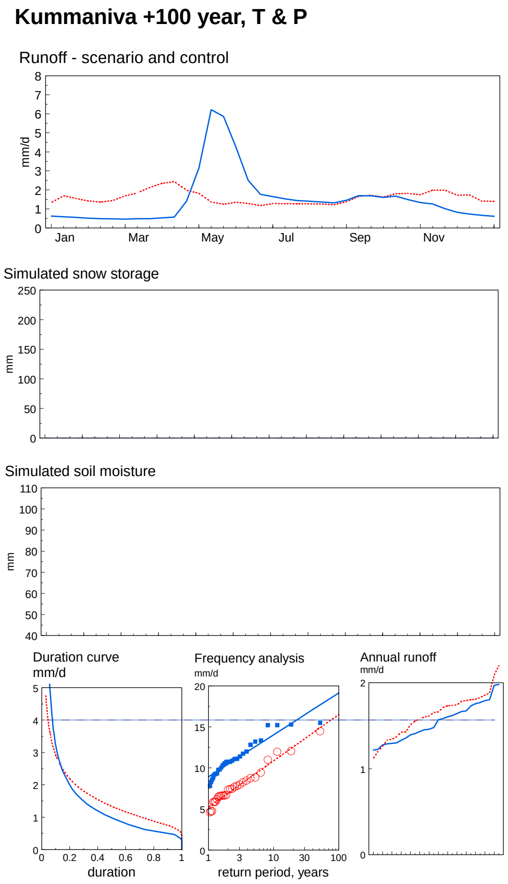

Figure 19. Simulations for Kummaniva in the Kemijoki river. Indicative for Kevo.

6. Conclusions and recommendations

The climate change predictions/scenarios for the SCANNET Region vary considerably from simulation to simulation, both between AOGCMs and RCMs, reflecting a large uncertainty at local scale. However, the regional ensemble averages, as reflected by the Nordic expert group scenarios from the mid-nineties (Jóhannesson et al. 1995a) and the NordEnsClim comparisons of the latest Nordic RCM (Räisänen et al. 2001) runs show surprisingly consistent results. Both studies indicate

- air temperature changes of approximately 0.35-0.4 deg/decade
- a temperature increase in winter about twice as high as in summer
- precipitation increase of 1.5-2 percent/decade
- a precipitation increase in winter (Jóhannesson et al. 1995a)/autumn (Räisänen et al. 2000) about twice as high as in summer.

Concerning regional variations, there seems to be a general tendency to predict higher temperature increase in the northern part of the region than in the southern, and particularly in areas close to the (retreating) sea ice. On precipitation, most results from RCMs and the Nordic expert group show a larger increase in Western parts of Norway than in most other areas.

A consistent result between the RCMs in NordEnsClim is the reduction in diurnal temperature range and an increase in the number of days with heavy precipitation (more than 10-mm precipitation).

There seems to be a tendency towards increased wind velocity, but only moderate changes.

Simulations with hydrological models show strong reduction in snow cover depth and snow cover season. Accordingly, spring flood is reduced. For the sites that today have seasonal snow cover, this consequence of a climatic change will have a large effect on terrestrial and aquatic ecology. For the sites that today only has intermittent snow cover (Litla-skard, Sornfelli and Banchory), this will of course be of less consequence.

In the mountain areas with high precipitation located in maritime climatic regimes, there is a possibility that an increased winter precipitation will compensate for the increase in temperature, to the degree that the period of snow cover could increase. In this case, biological and ecological effects of climate change in these areas would be radically different from the effects expected in the continental alpine areas.

The effect on ground temperature and frost, which are essential elements in the ground microclimate, cannot be deducted directly from these results. The consistent reduction in diurnal temperature range is an interesting result in this context. This, together with the increase in number of precipitation days, give some indication that the diurnal ground temperature range may be reduced, but the model simulations need to be studied more closely to get a better understanding of these changes.

Although downscaled results are available for most parts of the region, these should be used with some care, as the apparent spatial detail displayed by these results is not necessarily an indication of the accuracy of the predictions. One should also be careful in interpreting consistent results from different RCMs based on the same forcing AOGCM, or consistent regional patterns of the RCM and the forcing AOGCM as evidence of predictive power. Such results are not independent.

Due to the high activity in regional climate change research in the Nordic countries, the SCANNET Region is in general well covered with downscaled scenarios. This report has focused on results from dynamic downscaling. At the moment, the NordEnsClim synthesis provides the best basis for providing spatially consistent regional scenarios. For studies where such scenarios are needed for the SCANNET Region, the ensemble mean of the seasonal change profiles provided by NordEnsClim is a good starting point. It is important to realise that variation displayed by the underlying individual simulations does not extend the full uncertainty in the future climate, as a limited selection of underlying emission scenarios is used, and only a couple of independent GCM simulations. As the activity in climate research remains high, the near future will hopefully provide more independent simulations of the future climate of the region.

Statistical (empirical) downscaling is an attractive toolbox of methods for site-specific research, but such scenarios should be worked out in close co-operation with experts from the climatological research centres. It is important to be aware of the need for historical "training" data in empirical downscaling. Unfortunately, the volume of data sets describing microclimate and other relevant parameters relevant for assessing biological and ecological effects of climate change is low and the observation periods short. In addition, these data sets are generally not easily available. This touches the core activity of SCANNET - to assist in making these valuable data sets more easily available for the research community.

References

Benestad, R.E. (1998) Description and Evaluation of the Predictor Data sets used for Statistical Downscaling in the RegClim. 24. 1-32. Oslo, Norway: DNMI.

Benestad (1999) Evaluation of the common EOF approach in linear Empirical Downscaling of Future ECHAM4/OPYC3 GSDIO Climate Scenarios, DNMI, Klima, 35/99.

Benestad, R.E. and Førland, E. (2000) Local Climate scenarios for Norway based on MPI's ECHAM/OPYC3, a new DNMI data analysis, and the common EOF method. *RegClim General Technical Report* **4.**

Bjørge, D. and Haugen, J.E., (1998) Simulation of present-day climate in HIRLAM using 'perfect' boundaries. *RegClim General Technical Report* **1** NILU, Norway.

Bjørge, D., Haugen, J.E. and Nordeng, T.E. (2000) Future Climate in Norway. Dynamical downscaling experiments within the RegClim project. 103 edn, Oslo, Norway.: DNMI. IBSN: 0332-9879.

Haugen, J.E., Bjørge, D. and Nordeng, T.E., (1999) HIRHAM simulation with high NAO-index MPI bounday data, present-day and scenario climate. *RegClim General Technical Report* **2**. NILU, Norway.

Carter, T., Holopainen, E. and Kanninen, M. (1993) Techniques for developing regional climatic scenarios for Finland. Carter, T., Holopainen, E. and Kanninen, M., (Eds.) 2/93. 1-63. Helsinki: Academy of Finland. ISBN: 951-37-1282-6.

Christensen J.H., Christensen, O.B., Loucks, D.P., van Meijgaard, E. and Botzet, M. (1996) The HIRHAM4 regional atmospheric climate model. 96-4 edn, Copenhagen, Denmark: Danish Meterological Institute.

Christensen J.H. (1999) Modelling the regional climate in the European north- The permafrost regions as simulated with HIRHAM4. 2. NILU.

Christensen J.H. and Christensen, O.B. (2000) Dynamical downscaling results from DMI. *RegClim General Technical Report* **4** edn, NILU.

Christensen J.H., Räisänen, J., Iversen, T., Bjørge, D., Christensen, O.B. and Rummukainen, M. (2001) A synthesis of regional climate change simulations- A Scandinavian perspective. *Geophys.Res.Lett.* **28**, 1003-1006.

Christensen, O.B. (1999) Relaxation of soil variables in a regional climate model. *Tellus-Series A - Dynamic Meteorology and Oceanography* 51, 674-685.

DKRZ (1993) The ECHAM3 Atmospheric General Circulation Model. Deutche Klimarechenzentrum, M., (Ed.) 6 edn, Hamburg: Deutche Klimarechenzentrum Modelbetreuungsgruppe. http://www.dkrz.de/ipcc/ddc/html/DKRZ/echam3lsg.html.

Førland, E.J., Benestad, R.E., Hanssen-Bauer, I., Iden, K.A. and Tveito, O.E. (2000) Local climate scenarios for Norway based on empirical downscaling. *RegClim General Technical Report* 5.

Førland, E.J., Hanssen-Bauer, I. and Haugen, J.E. (2002) Climate Scenarios for the Norwegian Arctic (in Norwegian). Presented at the Second Norwegian ACIA

Workshop: Climate Change and Concequences for infrastructure in Norway, 10-11 January 2002. http://acia.npolar.no/Dokumenter/ScenarierTerrestrisk(1).pdf.

Gordon, C., Cooper, C., Senior, C.A., Banks, H.T., Gregory, J.M., Johns, T.C., Mitchell, J.F.B. and Wood, R.A. (2000) The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Clim.Dyn.* **16**, 147-168.

Gustafsson, N. (1993) HIRLAM 2 Final Report. Norrköping, Sweeden. http://www.knmi.nl/hirlam/TechReports/.

Hanssen-Bauer, I. and Førland, E. (2001) Verification and analysis of climate simulation of temperature and pressure fields over Norway and Svalbard. *Climate Research* **16**, 225-235.

Haugen, J.E and Nordeng, T.E. (2001) Endret vindmønster i et fremtidig norsk klima? (Changed wind pattern in a future Norwegian Climate?) Cicerone (RegClim), 2001 (2): pp.28-31. In Norwegian

IPCC (1990) *Climate Change. The IPCC Scientific Assessment*, ISBN 0-521-40360 Cambridge University Press.

IPCC (1996) *Climate Change 1995. Impacts, Adaptions and Mitigation of Climate Change: Scientific-Technical Analyses*, Cambridge: Cambridge University Press.

IPCC (1997) An introduction to simple climate models used in the IPCC Second Assessment Report. Houghton, J.T., Filho, L.G.M., Griggs, D.J. and Maskell, K., (Eds.) 2 edn, 1-51. Intergovermental Panel on Climate Change. ISBN: 92-9169-101-1.

IPCC (2001) Climate *Change 2001. The Scientific Basis*, http://www.ipcc.ch.

Jóhannesson, T., Jónsson, T., Källén, E. & Kaas, E. (1995a) Climate Change Scenarios for the Nordic Countries. *Clim. Res.* 5(3)181-195.

Jóhannesson, T., Sigurðsson, O., Laumann, T. & Kennet, M. (1995b) Degree-day mass balance modelling with the application to glaciers in Iceland, Norway, and Greenland. *J. Glac.,* 41(138)345-358.

Johns, T.C., Carnell, R.E., Crossley, J.F., Gregory, J.M., Mitchell, J.F.B., Senior, C.A., Tett, S.F.B. and Wood, R.A. (1997) The second Hadley Centre coupled atmosphere-ocean GCM: model description, spinup and validation. *Clim.Dyn.* **13**, 103-134.

Jones, R.G., Murphy, J.M. and Noguer, M. (1995) Simulation of Climate Change over Europe using a nested regional model. Part I: Assessment of control climate including sensitivity to location of lateral bounderies. *Q.J.R.Meteorol.Soc.* **121**, 1413-1449.

Källén, E., Kattsov, V., Walsh, J. and Weatherhead, E.e. (2001) Report from the Artic Climate Impact Assessment Modelling and Scenario Workshop, Stockholm, Sweden, January 2001. ACIA Secretariate, Fairbanks. http://www.acia.uaf.edu.

Machenhauer, B. (1988) HIRLAM Final Report. Copenhagen, Denmark.

Maier-Reimer, E. and Mikolajewicz, U. (1992) The Hamburg Large Scale Geostropic Ocean General Circulation Model Cycle 1. Deutche Klimarechenzentrum, M., (Ed.) 2 edn, Hamburg: Deutche Klimarechenzentrum, Modelbetreuungsgruppe.

Meehl, G.A., Washington, W.M., Erickson III, D.J., Briegleb, B.P. and Jaumann, P.J. (1996) Climate change from increased CO_2 and direct and indirect effects of sulphate aerosols. *Geophys.Res.Lett.* **23**, 3755-3758.

Meehl, G.A., Boer, G.J., Covey, C., Latif, M. and Stouffer, R.J. (2001) The Coupled Model Intercomparison (CMIP). *Bull.Am.Met.Soc.* **81**, 313-318.

Nakic´enovic´, N., Almaco, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rover, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Raihi, K., Roehrl, A., Rogner H-H, Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N. and Dadi, Z. (2000) *IPCC Special Report on Emissions Scenarios*, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Oberhuber, J.M. (1993) Simulation of the Atlantic circulation with a coupled sea-ice-mixed layer-isopycnical general circulation model. Part I: model description. *J.Phys.Oceanogr.* **23**, 808-829.

Räisänen, J., Bjørge, D., Christensen J.H., Christensen, O.B., Iversen, T. and Rummukainen, M. (2000) Comparison of the NordEnsClim regional climate change simulations. *RegClim General Technical Report* **4**

Räisänen, J., Rummukainen, M., Ullerstig, A., Bringfelt, B., Hansson, U. and Willén, U. (1999) The first Rossby Centre regional climate scenario – Dynamical downscaling of CO_2-induced climate change in the HadCM2 GCM. *Reports Meteorology and Climatology No. 85,* SMHI, SE-60176 Norrköping, Sweden, 56 pp

Räisänen, J. (2001) CO2-induced climate change in CMIP2 experiments: quantification of agreement and role of internal variability. *J.Climate* **14**, 2088-2104.

Roeckner, E., Bengtsson, L., Feichther, J., Lelieveld, J. and Rodhe, H. (1999) Transient climate change with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycler. *J.Climate* **12**, 3004-3032.

Rummukainen, M. (2000) The SweClim regional climate modeling program; recent developments. *RegClim General Technical Report* **4**.

Sælthun, N.R., Aittoniemi, P., Bergström, S., Einarsson, K., Jóhannesson, T., Lindström, G., Ohlsson, P.-E., Thomsen, T., Vehviläinen, B. and Aamodt, K.O. (1998a) Climate Change Impacts on Runoff and Hydropower in the Nordic Countries. Final report from the project "Climate Change and Energy Production". 1998:552. 1-170. Copenhagen: Nordic Council of Ministers. ISBN: 92-893-0212-7.

Sælthun, N.R., Aittoniemi, P., Bergström, S., Einarsson, K., Jóhannesson, T., Lindström, G., Ohlsson, P.-E., Thomsen, T., Vehviläinen, B. and Aamodt, K.O. (1998b) Climate Change Impacts on Runoff and Hydropower - A Regional Study for the Nordic Countries. In: Lemmelä, R. and Helenius, N., (Eds.) *Proceeding of the International Conference on Climate and Water, Espoo, Finland 17-20 Aug 1998,* pp. 1495-1504. Helsinki: Helsinki University of Technology].

Smith, S.J., Wigley, T.M.L., Nakic´enovic´, N. and Raper, S.C.B. (2001) Climate implications of greenhouse gas emisson scenarios. *Technological Forecasting and Scocial Change* **65**, 195-204.

Acronyms

AC	Arctic Council
ACIA	The Arctic Climate Impact Assessment
AGCM	Atmosphere General Circulation Model
AMAP	The Arctic Monitoring and Assessment Programme
AO	Arctic Oscillation
AOGCM	Atmosphere-Ocean General Circulation Model
ARPEGE/OPA	Action de Recherche Petite Echelle Grande Echelle/Océan Parallélisé
BMRC	Bureau of Meteorology Research Centre (Australia)
CAFF	Conservation of Arctic Flora and Fauna
CCC(ma)	Canadian Centre for Climate (Modelling and Analysis) (Canada)
CCSR	Centre for Climate Research Studies (Japan)
CERFACS	European Centre for Research and Advanced Training in Scientific Computation (France)
CMIP	Coupled Model Intercomparison Project
COLA	Centre for Ocean-Land-Atmosphere Studies (USA)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSM	Climate System Model
DCC	Danish Climate Centre
DKRZ	Deutsche KlimaRechenZentrum (Germany)
DMI	Danish Meteorological Institute
DOE PCM	Department of Energy Parallel Climate Model (USA)
ECHAM	European Center /MI (Hamburg) AGCM
ECMWF	European Centre for Medium-range Weather Forecasting
EEA	European Environmental Agency
G	Forcings by greenhouse gases
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHS	Greenhouse gases
GISS	Goddard Institute for Space Studies (USA)
GOALS	Global Ocean-Atmosphere-Land System
GS	G + sulphate aerosols
GSDIO	A transient integration including greenhouse gases as well as direct and indirect sulphur aerosol forcing and ozone.
GSIO	G + sulphate aerosols + ozone

GTOS	Global Terrestrial Observing System
HadCM	Hadley Centre Coupled Model
HIRHAM	HIRLAM + ECHAM
HIRLAM	High resolution Local Area Model
IAP	Institute of Atmospheric Physics (China)
IASC	International Arctic Science Committee
IPCC	The Intergovernmental Panel on Climate Change
IPCC DDC	IPCC Data Distribution Centre
IPSL-CM	Institut Pierre Simon Laplace/Coupled Atmosphere-Ocean-Vegetation Model
IS92	IPCC Emission Scenarios defined in IPCC (1992)
LAM	Local Area Model
LASG	State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics (China)
LMD	Laboratoire de Météorologie Dynamique (France)
ML	Mixed Layer
MPI	MPI, Max-Plank Institute for Meteorology, Germany
MRI	Meteorological Research Institute (Japan)
NCAR	National Centre for Atmospheric Research (USA)
NIES	National Institute for Environmental Studies
NordEnsClim	Nordic Ensemble of Climate Scenarios - co-operation between SweClim, RegClim and DCC
NRL	Naval Research Laboratory (USA)
RCA	The SweClim Regional Climate Model
RCM	Regional Climate Model
RegClim	Regional Climate Development Under Global Warming
SCANNET	Scandinavian/North European Network of Terrestrial Field Bases
SCM	Simple Climate Model
SLP	Sea Level Pressure
SRES	IPCC Special Report on Emissions Scenarios (2000)
SST	Sea Surface Temperature
SweClim	Swedish Climate Research Programme
TCR	Transient Climate Response
UKMO	United Kingdom Met Office (UK)
YONU	Yonsei University (Korea)

Important links

ACIA	http://www.acia.uaf.edu/ http://acia.npolar.no/
ACIA Scenario site	http://faldo.atmos.uiuc.edu/ACIA/
Arctic Monitoring and Assessment Programme (AMAP)	http://www.amap.no/
Arctic Regional Climate Model Inter-comparison Project (ARC-MIP)	http://cires.colorado.edu/lynch/arcmip/
Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO)	http://www.csiro.au
Center for Climate Research Studies (CCSR), Japan	http://www.ccsr.u-tokyo.ac.jp/
Coupled Model Intercomparison Project (CMPI)	http://www-pcmdi.llnl.gov/cmip/
Danish Meterological Institute (DMI)	http://www.dmi.dk/
Deutsches Klimarechenzentrum (DKRZ)	http://www.dkrz.de/
DNMI	http://www.met.no
EuroClim	http://euroclim.nr.no
Hadley Centre for Climate Prediction and Research	http://www.met-office.gov.uk/research/hadleycentre/
HIRHAM	http://www.awi-bremerhaven.de/www-pot/hirham/
HIRLAM Forcast Model	http://www.knmi.nl/hirlam/
IPCC	http://www.ipcc.ch/
IPCC Data Distribution Centre (IPCC-DDC	http://ipcc-ddc.cru.uea.ac.uk
Max Planck Institute for Meteorology	http://www.mpimet.mpg.de/
National Centre for Atmospheric Research (NCAR), USA	http://www.ncar.ucar.edu/
National Institute for Environmental Studies (NIES), Japan	http://www.nies.go.jp/

Program for Climate Model Diagnosis and Intercomparison (PCMDI)	http://www-pcmdi.llnl.gov/
RegClim	http://www.nilu.no/regclim http://projects.dnmi.no/~regclim
SCANNET	http://www.SCANNET.nu
SMHI	http://www.smhi.se/
TUNDRA	http://www.urova.fi/home/arktinen/tundra/tundra.htm

Annex A. Models referred to by IPCC 2001

Model Name and centre	**Scenario name**	**Scenario description**	**No of Simulations**	**Length of simulation (or starting and final year)**	**Transient Climate Response (TCR)**	**Equilibrium climate sensitivity**	**Effective climate sensitivity**
ARPEGE/OPA2 ***CERFACS***	CMIP2	1% CO_2	1	80	1.64		
BMRCa ***BMRC***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	2	60		2.2	
	CMIP2	1% CO_2	1	100	1.63		
CCSR/NIES ***CCSR/NIES***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	40		3.6	
	CMIP2	1% CO_2	1	80	1.8		
	G	Historical equivalent CO_2 to 1990 then 1% CO_2 (approx. IS92a)	1	1890-2099			
	GS	As G but including direct effect of sulphate aerosols	1	1890-2099			
	GS2	1% CO_2 +direct effect of sulphate aerosols but with explicit representation	1	1890-2099			
CCSR/NIES2 ***CSR/NIES***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	40		5.1	
	CMIP2	1% CO_2	1	80	3.1		11.6
	A1	SRES A1 scenario	1	1890-2100			
	A2	SRES A2 scenario	1	1890-2100			
	B1	SRES B1 scenario	1	1890-2100			
	B2	SRES B2 scenario	1	1890-2100			
CGCM1 ***CCCma***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	30		3.5	
	CMIP2	1% CO_2	1	80	1.96		3.6
	G	Historical equivalent CO_2 to 1990 then 1% CO_2 (approx. IS92a)	1	1900-2100			
	GS	As G but including direct effect of sulphate aerosols	3	1900-2100			
	GS2050	As GS but all forcings stabilised in year 2050	1	1000 after stability			
	GS2100	As GS but all forcings stabilised in year 2100	1	1000 after stability			
CGCM2 ***CCCma***	GS	As G but including direct effect of sulphate aerosols	3	1900-2100			
	A2	SRES A2 scenario	3	1990-2100			
	B2	SRES B2 scenario	1	1990-2100			

CSIRO Mk2 ***CSIRO***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	60		4.3	
	CMIP2	1% CO_2	1	80	2.00		3.7
	G	Historical equivalent CO_2 to 1990 then 1% CO_2 (approx. IS92a)	1	1881-2100			
	G2080	As G but forcing stabilised at 2080 (3x initial CO_2)	1	700 after stability			
	GS	As G +direct effect of sulphate aerosols	1	1881-2100			
	A2	SRES A2 scenario	1	1990-2100			
	B2	SRES B2 scenario	1	1990-2100			
CSM 1.0 ***NCAR***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	50		2.1	
	CMIP2	1% CO_2	1	80	15707,00		1.9
CSM 1.3 ***NCAR***	GS	Historical GHGs +direct effect of sulph- CO_2 + direct effect of sulphate aerosols including effects of pollution control policies ate aerosols to 1990 then BAU	1	1870-2100			
	GS2150	Historical GHGs +direct effect of except WRE550 scenario for CO_2 until it reaches 550 ppm in 2150 sulphate to aerosols to 1990 then as GS	1	1870-2100			
	A1	SRES A1 scenario	1	1870-2100			
	A2	SRES A2 scenario	1	1870-2100			
	B2	SRES B2 scenario	1	1870-2100			
	CMIP2	1% CO_2	1	100	1.58		2.2
ECHAM3/LSG ***DKRZ***	G	Historical equiv CO_2 to 1990 then 1% CO_2 (approx. IS92a)	1	1881-2085			
	G2050	As G but forcing stabilised at 2050 (2x initial CO_2)	1	850 after stability			
	G2110	As G but forcing stabilised at 2110 (4x initial CO_2)	2	850 after stability			
	GS	As G + direct effect of sulphate aerosols	2	1881-2050			
	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	60		3.2	
ECHAM4/OPYC **MPI**	CMIP2	1% CO_2	1	80	1.4		2.6
	G	Historical GHGs to 1990 then IS92a	1	1860-2099			
	GS	As G +direct effect of sulphate aerosol interactively calculated	1	1860-2049			
	GSIO	As GS +indirect effect of sulphate aerosol +ozone	1	1860-2049			
	A2	SRES A2 scenario	1	1990-2100			
	B2	SRES B2 scenario	1	1990-2100			

GFDL_R15_a ***GFDL***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	2	40		3.7 (3.9[a]**)**	
	CMIP2	1% CO_2	2	80	42036,00		4.2
	CMIP270	As CMIP2 but forcing stabilised at year 70 (2x initial CO 2)	1	4000		(4.5)[b]	
	CMIP2140	As CMIP2 but forcing stabilised at year 140 (4 x initial CO_2)	1	5000			
	G	Historical equivalent CO_2 to 1990 then 1% CO 2 (approximate IS92a)	1	1766-2065			
	GS	As G + direct effect of sulphate aerosols	2	1766-2065			
GFDL_R15_b ***GFDL***	CMIP2	1% CO_2	1	80			
	GS	Historical equivalent CO_2 to 1990 then 1% CO_2 (approximate IS92a) + direct effect of sulphate aerosols	3	1766-2065			
GFDL_R30_c ***GFDL***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	40		3.4	
	CMIP2	1% CO_2	2	80	1.96		
	CMIP270	As CMIP2 but forcing stabilised at year 70 (2 x initial CO_2)	1	140 after stability			
	CMIP2140	As CMIP2 but forcing stabilised at year 140 (4 x initial CO_2)	1	160 after stability			
	GS	1% CO (approximate IS92a) + direct effect of sulphate aerosols Historical equivalent CO_2 to 1990 then	9	1866-2090			
	A2	SRES A2 scenario	1	1960-2090			
	B2	SRES B2 scenario	1	1960-2090			
GISS2 ***GISS***	ML	Equilibrium 2xCO_2 in mixed-layer experiment	1	40		3.1	
	CMIP2	1% CO_2	1	80	1.45		
GOALS ***IAP/LASG***	CMIP2	1% CO_2	1	80	1.65		
HadCM2 ***UKMO***	ML	Equilibrium 2 xCO_2 in mixed-layer experiment	1	40		4.1	
	CMIP2	1% CO_2	1	80	1.7		2.5
	CMIP270	As CMIP2 but forcing stabilised at year 70 (2 x initial CO_2)	1	900 after stability			
	G	Historical equivalent CO_2 to 1990 then 1% CO_2 (approximate IS92a)	4	1881-2085			
	G2150	As G but all forcings stabilised in year 2150	1	110 after stability			
	GS	As G + direct effect of sulphate aerosols	4	1860-2100			

HadCM3 ***UKMO***	ML	Equilibrium 2xCO$_2$ in mixed-layer experiment	1	30		3.3	
	CMIP2	1% CO$_2$	1	80	1.96		3.0
	G	Historical GHGs to 1990 then IS95a	1	1860-2100			
	GSIO	As G + direct and indirect effect of sulphate aerosols + ozone changes	1	1860-2100			
	A2	SRES A2 scenario	1	1990-2100			
	B2	SRES B2 scenario	1	1990-2100			
IPSL-CM2 ***IPSL/LMD***	ML	Equilibrium 2xCO$_2$ in mixed-layer experiment	1	25		3.6	
	CMIP2	1% CO$_2$	1	140	35065,00		
	CMIP270	As CMIP2 but forcing stabilised at year 70 (2 x initial CO$_2$)	1	50 after stability			
	CMIP2140	As CMIP2 but forcing stabilised at year 140 (4 x initial CO$_2$)	1	60 after stability			
MRI1 [f] ***MRI***	ML	Equilibrium 2xCO$_2$ in mixed-layer experiment	1	60		4.8	
	CMIP2	1% CO$_2$	1	150	1.6		2.5
	CMIP2S	As CMIP2 + direct effect of sulphate aerosols	1	100			
MRI2 ***MRI***	ML	Equilibrium 2xCO$_2$ in mixed-layer experiment	1	50		**2.0**	
	CMIP2	1% CO$_2$	1	150	1.1		1.5
	G	Historical equivalent CO$_2$ to 1990 then 1% CO$_2$ (approx IS92a)	1	1900-2100			
	GS	As G + explicit representation of direct effect of sulphate aerosols	1	1900-2100			
	A2	SRES A2 scenario	1	1900-2100			
	B2	SRES B2 scenario	1	1900-2100			
DOE PCM ***NCAR***	ML	in mixed-layer exp. Equilibrium 2xCO$_2$	1	50		2.1	
	CMIP2	1% CO$_2$	5	80	1.22		1.7
	G	Historical GHGs +direct effect of sulph- CO$_2$ + direct effect of sulphate aerosols includ-ing effects of pollution control policies ate aerosols to 1990 then BAU		1870-2100			
	GS	Historical GHGs +direct effect of except WRE550 scenario for CO$_2$ until it reaches 550 ppm in 2150 sulphate to aerosols to 1990 then as GS	5	1870-2100			
	GS2150	Historical GHGs to 1990 then as GS except WRE550 scenario for CO$_2$ until it reaches 550 ppm in 2150.	5	1870-2100			
	A2	SRES A2 scenario	1	1870-2100			
	B2	SRES B2 scenario	1	1870-2100			

From IPCC (2001)

a The equilibrium climate sensitivity if the control SSTs from the coupled model are used.

b The equilibrium climate sensitivity calculated from the coupled model.