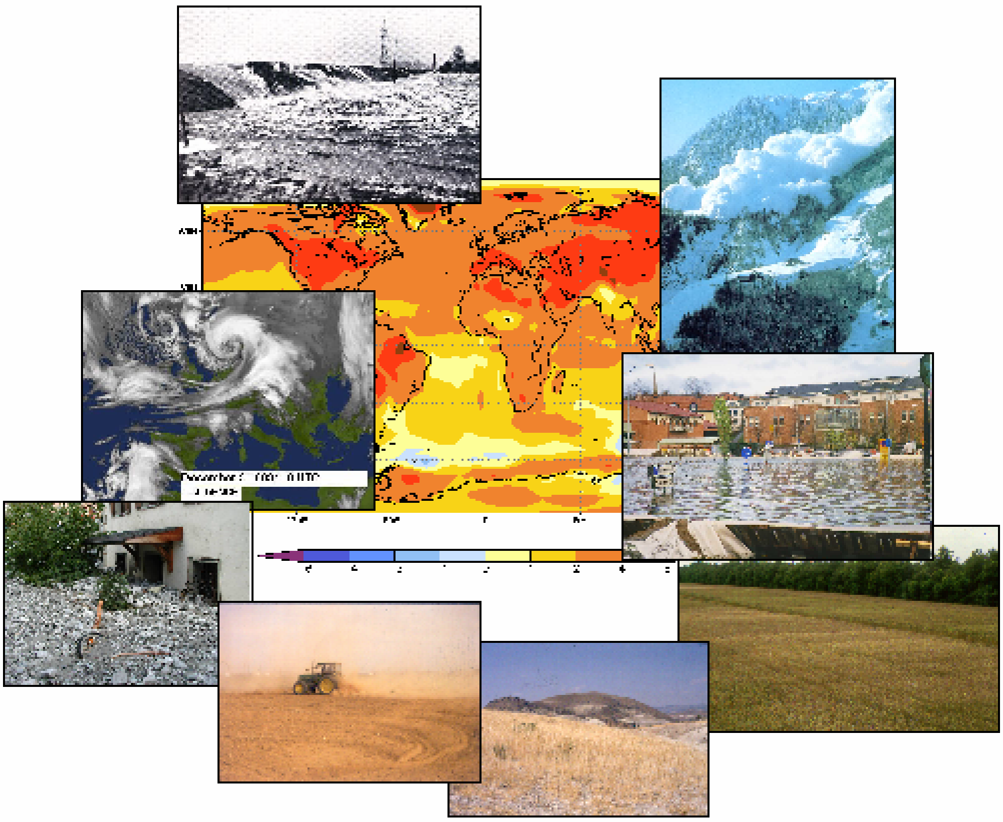
Danish Climate Centre

DMI, Ministry of Transport

PRUDENCE kick-off meeting
Snekkersten December 3-5, 2001



Jens Hesselbjerg Christensen

Report 01-8

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Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
Denmark

Phone: +45 3915 7500
Fax: +45 3927 1080

www.dmi.dk

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1. OVERALL MEETING SUMMARY

J.H. Christensen, Tim Carter, and Filippo Giorgi

Decision-makers in government, non-governmental organisations (NGOs), and industry as well as the general public need detailed information on future climate. This information is necessary to evaluate the risks associated with possible climate change due to anthropogenic emissions of greenhouse gases. Projections of future climate change already exist, but are deficient in terms of both the characterisation of their uncertainties and their regional detail. To date, the assessment of potential impacts of climate change has generally relied on projections from simple climate models or coarse resolution coupled Atmosphere-Ocean General Circulation Models (AOGCMs). The former include, at best, only a limited physical representation of the climate system. The latter are incapable of resolving processes occurring at scales of less than ~300km. This resolution limitation precludes the simulation of realistic extreme events and the detailed spatial structure of variables like temperature and precipitation over regions characterised by heterogeneous surfaces. Typical examples of such regions are mountainous areas (e.g. the Alps, Scandinavia) or coastal zones and areas surrounding inland seas (e.g. the Mediterranean and Baltic Seas).

Over the past decade, increasing attention has been devoted to the development of regional climate scenarios. In its recent Third Assessment Report (TAR), the IPCC assessed the regional climate information provided by AOGCMs and techniques used to enhance regional climate detail (Giorgi *et al*. 2001). It was noted that these techniques have been substantially improved over the last five years and have become more widely applied. They fall into three categories: high and variable resolution (atmosphere-only) AGCMs, nested regional (or limited area) climate models (RCMs), and empirical/statistical and statistical/dynamical downscaling methods. They exhibit different strengths and weaknesses and their use depends on the needs of specific applications.

A recent conference on "Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects – PRUDENCE," brought together a multidisciplinary group of approximately 60 participants from Europe and North America to initiate a new large European climate change project with the same name funded by the European Union.

In brief, the three central scientific objectives of PRUDENCE are:

1. to address and to reduce deficiencies in regional climate projections;
2. to quantify confidence and uncertainties in the predictions of future climate and its impacts by using an array of climate and impact models along with expert judgement on their performance;
3. to interpret the model results in relation to European policies for adapting to or mitigating climate change.

Climate change is expected to affect the frequency and magnitude of extreme weather events in response to higher temperatures, an intensified hydrological cycle and more vigorous atmospheric circulations. Four major limitations in previous studies of extremes have been:

1. a lack of appropriate computational resolution, which limits or even precludes the analysis of extremes;
2. an absence of long-term high resolution climate model integrations, which drastically reduces the statistical significance of any simulated changes in extremes;
3. poor co-ordination across climate modelling groups, which limits the ability to compare different studies;
4. a limited use of high-resolution model output by impact analysts, which severely restricts any evaluation of the utility of such output for impact assessment.

These four issues are all thoroughly addressed in PRUDENCE, by using a suite of state-of-the-art high resolution global and regional climate models, ensuring that model simulations span a statistically meaningful time period (30 years), co-ordinating the project goals to address critical aspects of uncertainty, and applying impact models and impact assessment methodologies to provide the link between climate information and its application to serve the needs of society.

Climate modellers working within PRUDENCE will conduct a series of high-resolution climate change simulations for the periods 1961-1990 and 2071-2100 over Europe. The variability and level of confidence in these simulations will be characterised in terms of uncertainties in model formulations, natural/internal climate variability, and alternative scenarios of future atmospheric composition. In particular, the project will provide a quantitative assessment of the risks arising from changes in regional weather and climate over different parts of Europe by estimating future changes in extreme events (e.g. floods and windstorms) and the likelihood and magnitude of such changes. An innovative feature of the project is its intention to evaluate the performance of high-resolution model information not only through conventional climatological intercomparison, but also by inputting simulated climate data to a range of impact models and comparing the estimated impacts.

The project will also examine the uncertainties in potential impacts induced by the range of climate scenarios developed by the climate modelling groups. This will provide useful information for climate modellers on the level of accuracy in climate scenarios required by impact analysts. It may also shed new light on the robustness of conclusions obtained from recent impact assessments in Europe and offer fresh insights into the scope for adaptation and mitigation responses to climate change. Furthermore, PRUDENCE places special emphasis on the wide dissemination of information and results, both via its Web site and through the preparation of a non-technical project summary aimed at policy makers and other interested parties.

In their review of the current state of regional climate change and related impact modelling, speakers at the conference reinforced many of the findings expressed in the TAR, emphasising in particular that future research, as taken up by PRUDENCE, needs to prioritise work focusing on:

- Assessment of GCM regional attributes and climate change simulations.
- Systematic comparisons of the relative strengths and weaknesses of different techniques to derive regional climate information.
- Intercomparison of RCM simulations across a range of models and across different realisations of the same experiment with individual models.
- Assessment of the uncertainties attributable to RCM simulations driven by different AOGCM simulations.
- Intensified efforts in the evaluation of variability (daily to inter-annual) and extreme events both in GCMs and RCMs, and comparison between the two.
- A systematic evaluation of uncertainties in regional climate information derived from multiple sources.
- Enhanced methods of applying climate model simulations in the assessment of the potential impacts of anthropogenic climate change.
- Improved representation of uncertainties in future impacts, whether attributable to uncertainties in climate scenarios, uncertainties in non-climate scenarios or uncertainties in impact estimation.

A key objective of this first PRUDENCE meeting was to identify gaps in knowledge and potential bottlenecks, which might hinder the progress of the project. Two of the important issues to emerge were:

- The design of an effective suite of intercomparison studies by both climate modellers and impact assessors.
- Agreement on and development of standard protocols for transferring and applying climate model information for impact assessment.

PRUDENCE is an interdisciplinary project, comprising, among others, climate modellers, ecologists, economists, agronomists, hydrologists and geographers. In addition, the external advisory board of the project includes a number of representatives from industry and other economic sectors having a strong interest in the potential impacts of future climate change. This mixture of interests should provide a stimulating environment for policy-relevant and innovative research.

PRUDENCE is a three-year project that runs until 2004. It is co-ordinated by Dr. J.H. Christensen of the Danish Meteorological Institute - one of the authors of this article - and formally comprises 21 research groups from 9 European countries. Encouragingly, several additional groups within Europe as well as elsewhere have already expressed their interest in contributing to the project. Therefore, it has been decided to operate ‘an open door policy’, such that, to the extent possible, the project would share model data and analysis among a wider community, including groups outside Europe. This policy is also reflected in the list of participants at the conference.

The conference on “Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects – PRUDENCE,” was held on December 3 – 5, 2001, in Snekkersten, Denmark.

Additional information is available from http://www.dmi.dk/f+u/klima/prudence/index.html.

1.1 Reference

Giorgi, F., B.C. Hewitson, J.H. Christensen, M. Hulme, H. von Storch, P.H. Whetton, R.G. Jones, L.O. Mearns, and C.B. Fu (2001): Regional climate information - evaluation and projections. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge and New York, pp. 581-638.

1.2 Project start

PRUDENCE was formally accepted by the European Commission as contract No. EVK2-2001-00156, which was signed on 29 October 2001. The project accordingly started officially on 1 November 2001. The present document presents the minutes of the first meeting by the entire PRUDENCE consortium, which took place during 3 – 5 December, 2001 at the conference hotel

Scanticon Comwell Helsingør,
Nørrevej 80, DK 3070 Snekkersten, Denmark
tel: +45 4922 0333,
fax: +45 4922 0399

hotel.helsingor@comwell.com

www.comwell.com.

2. SYNOPSIS

The 1st meeting of the PRUDENCE project was held with the aim to activate the interactions between the involved partners and interested parties and identify issues which required action in order for the project to progress smoothly according to the description-of-work (DoW) document associated with the EU contract. This was accomplished by having the partners give scientific presentations highlighting the main activities relevant for PRUDENCE at their home institution in combination with a set of keynote presentations. For more details, see the meeting agenda and the abstract compilation below. As the PRUDENCE project intends to keep an 'open door' policy, a number of external participants were also present at the meeting, and several contributed with a scientific presentation. The total number of participants was 58. The full list of participants is provided in the back of this report

During the meeting, a total of three breakout sessions were scheduled with the aim that any outstanding issues in the seven work packages could be identified, and strategies to resolve these could be established. Three break-out groups were formed dealing with WP1 & WP2, WP3 – WP5, and WP6, respectively. Issues with respect to WP7 were dealt with in plenary during the last session on the last day of the meeting. During the second meeting day, a special break-out session dealt with practical issues relating to the exchange and handling of model data. Separate minutes from the breakout groups are provided elsewhere in this report.

According to the DoW a PRUDENCE steering committee should be established in order to assist the co-ordinator in managing the project. Likewise, an external advisory board should be established, with members identified and agreed upon by the steering committee. During the first evening of the kick-off meeting the steering committee had its first meeting, subsequently followed by a meeting with the external board. Short summaries of these separate meetings are provided elsewhere in this document. The steering committee consists of the WP leaders, identified in the DoW and is enlarged by a few additional PIs notified by the co-ordinator. The steering committee formed has the following members:

Jens H. Christensen, DMI
Ole B. Christensen, DMI
Daniela Jacob, MPIM
Richard Jones, Hadley Centre
Markku Rummukainen, SMHI
Filippo Giorgi, ICTP
Jørgen E. Olesen, DIAS
Kirsten Halsnæs, RISØ
Tim Carter, FEI
Jean Palutikof, UEA

During their first meeting the committee agreed to have as members of the external board:

One person representing the MICE project – here Jean Palutikof
One person representing STARDEX project – here Torben Schmith
Gerhard Berz (absent) from Munich Re (Germany)
Jean-Yves Caneill from Électricité de France (France)
Gunner Hovsenius from Elsforsk (Sweden)
Trond Iversen (substituted by Jan Erik Haugen) from RegClim (Norway)
Manfred Lange from University of Münster (Germany)
Axel Michaelowa from Hamburg Institute of International Economics (Germany)
Ib Troen from DG-XII (EU commission)

In addition, it was agreed to try to have one additional member from outside Europe, with general expertise in climate change related issues (see details in Section from 1st EAG meeting).

3. SCIENTIFIC STEERING GROUP AND EXTERNAL ADVISORY GROUP MEETINGS

The management of PRUDENCE will broadly follow the Project Management methodology of the PRINCE (Projects IN a Controlled Environment) system widely used in government and industry.

A Scientific Steering Group (SSG) consisting of senior scientists from most of the contracting organisations will fulfil the role of the Project Board. A Project Manager (Dr. Ole B. Christensen) has been assigned to the PRUDENCE project to assist the Project Co-ordinator in maintaining the control on the various phases of the project. The leaders of the seven research Work Packages will fulfil the role of the Project Assurance Team, plus other experts co-opted as required. At this stage the SSG is formed of:

Jens H. Christensen, Co-ordinator and WP7
Ole B. Christensen, Project Manager
Daniela Jacob, WP1
Richard Jones, WP2
Markku Rummukainen, WP3
Jørgen E. Olesen, WP4
David Stephenson (unable to attend the meeting), WP5
Kirsten Halsnæs (here replaced by Jean-Charles Hourcade), WP6
Tim Carter,
Filippo Giorgi,
Jean Palutikof.

3.1 1st SSG meeting

On the evening of December 3rd, the PRUDENCE SSG convened for the first time. The agenda was relatively modest with only 3 items:

1. Defining the tasks of the SC
2. Reporting issues
3. Communication

Ad 1.) The project co-ordinator welcomed the members of the SSG and expressed his hopes and wishes for the role of the SSG. The main aim for this group should be to enable an efficient way to communicate key problems and developments within and between the individual WPs, as well as to make such information available to the co-ordinator as early as possible. Therefore, the WP task leaders should also be responsible for capturing the essentials from the break-out sessions scheduled under the main meeting agenda and duly report this to the co-ordinator in a meeting summary.

It was pointed out that as one of its first activities, the SSG should agree upon an External Advisory Group (EAG). This group would include representatives from the user community of the PRUDENCE final products as well as special interests groups. A total of five externals have indicated their strong interest in the development of PRUDENCE. They have very different expertise in climate change related issues and also represent broadly the European Union geographical extent. However, some of these individuals have not been able to follow PRUDENCE in detail and therefore a couple of additional persons have been contacted by the co-ordinator.

PRUDENCE recognises the existence of other EC RTD projects with related objectives. Therefore PRUDENCE will exchange knowledge and advances with the climate change impacts project “Modelling the Impact of Climate Extremes (MICE)” and co-ordinate its efforts in analysing extremes from the high-resolution model simulations with similar efforts using statistical down-scaling techniques in the project “Statistical and regional dynamical downscaling of extremes for European regions (STARDEX)”. Including participants from these two projects in EAG will strengthen this.

Finally, a close and direct contact with the EC has been considered essential for advancing the project and one participant from DG-XII has been envisaged to participate in the EAG meetings.

Given these circumstances, the SSG agreed upon the following EAG:

One person representing the MICE project – Jean Palutikof (UEA)
One person representing the STARDEX project – Phil Jones / Clare Goodess (UEA)
here represented by Torben Schmith (DMI)
Gerhard Berz (unable to attend the meeting) from Munich Re (Germany)
Jean-Yves Caneill from Électricité de France (France)
Gunner Hovsenius from Elsforsk (Sweden)
Trond Iversen (substituted by Jan Erik Haugen) from RegClim (Norway)
Manfred Lange from University of Münster (Germany)
Axel Michaelowa from Hamburg Institute of International Economics (Germany)
Ib Troen from DG-XII (EU commission)

The EAG was scheduled for a meeting immediately after the meeting in the SGG.

It was furthermore agreed to try to have one additional international expert associated with PRUDENCE. Dr. Peter Whetton from CSIRO in Australia was mentioned by several of the SSG members as a very qualified potential candidate. He has contributed to several of the chapters in the TAR from IPCC both in WG-I and

WG-II. The co-ordinator agreed to contact him regarding this issue. In case new meetings in the EAG cannot be arranged in connection with general meetings where Dr. Whetton is present, it should be clarified whether money from the co-ordinator’s special meeting budget can legally be spent on inviting non-EU persons.

Ad 2.) It was agreed that the SSG should make meeting minutes public. Moreover, it was envisaged that the SSG or smaller fractions of it could be expected to have a need for more frequent meetings than would be possible in connection with the plenary PRUDENCE meetings expected to take place once per year.

Ad 3.) The SSG agreed to correspond with the rest of the consortium through the means of an electronic Newsletter, which will be issued by the co-ordinator on a regular basis (app. one issue every 3rd month). The first Newsletter will report on the kick-off meeting.

3.2 1st EAG meeting

The EAG met with the SSG when this group had finished its own business. The proposed agenda was identical to that of the SSG.

1. Defining the tasks of the EAG
2. Reporting issues
3. Communication

Ad 1.) The project co-ordinator welcomed the members of the EAG and expressed his hopes and wishes for the role of the group. The main aim should be to enable an efficient way to communicate general project-related issues to a wider audience. Moreover, the EAG is meant to keep a 'critical' eye on the developments within the project and stimulate the consortium to take up new ideas within the framework of the project.

The members of EAG all expressed their interest in the PRUDENCE project but also their concerns regarding some of the specific formulations in the DoW, which forms the backbone of the work to be carried out within the project. Obviously, at this stage the specific formulations have all been accepted by the EC and there is limited scope for any modifications. However, it is essential that PRUDENCE will convey any relevant information from its findings as correctly as possible to the various European decision makers, for whom these may prove to be relevant.

The representatives from the two other EU RTD projects – STARDEX and MICE - each gave a brief summary of their projects (see below).

It is envisaged that the EAG will be more active once the project have results that are relevant to a wider community.

Ad 2.) No specific recommendations were made for the communication within the EAG or between this body and the rest of the consortium. It was therefore proposed that the co-ordinator gives a brief summary of the EAG meetings to the entire PRUDENCE consortium.

In case of more critical decisions or recommendations being made by the EAG, the co-ordinator can decide to keep this information within the PRUDENCE consortium and hence not necessarily inform the public from the very beginning, but keep this as confidential information with restricted access.

Ad 3.) No specific decision was made. But following the agreement by the SSG to correspond with the rest of the consortium through the means of the electronic PRUDENCE Newsletter, seems as an appropriate option.

The link with the other EC RTD projects mentioned should be further strengthened. Therefore, it was decided that the co-ordinator should meet jointly with the MICE and STARDEX co-ordinators as convenient but not too far in the future. A definite date was not decided at the meeting, but after the kick-off meeting, 22 February 2002 has been identified as suitable for all.

3.3 STARDEX Project Summary

Problems to be solved

The climate of the 21st century is likely to be significantly different from that of the 20th because of anthropogenically-induced climate change. The Kyoto protocol and future initiatives, together with actions taken by the EU, are expected to reduce the impacts of the changes, but significant changes will still occur. These changes will be perceived by European citizens mostly through increases in some types of extreme weather. STARDEX aims to provide scenarios of expected changes in the frequency and intensity of extreme events (such as heavy precipitation and resultant flooding and high temperatures) which are likely to have an impact on human lives and activities and on the environment. Climate change scenarios, particularly those for extremes, are needed for all aspects of future design (e.g., water resources, agriculture, irrigation, storm and land drainage, road, railway and building design and other sectors such as tourism) where the weather and climate are key determinants of everyday life. In all these aspects there is a clear European-wide need for more reliable, high-resolution scenarios of extremes. STARDEX will not be making predictions, but providing information on the likely changes in extremes. If work of this kind is not undertaken, future designs will not be able to incorporate the latest information about changes in extreme climate in the future.

Scientific objectives and approach

STARDEX will achieve its aims by a rigorous and systematic intercomparison of the three main downscaling methods (statistical, dynamical and statistical-dynamical) that are used to construct scenarios of extremes at the time and space scales where they are most needed. STARDEX will identify the more robust downscaling techniques and apply them to provide reliable and plausible future scenarios of temperature and precipitation-based extremes for selected European regions for the 2071-2100 timeframe. The extreme scenarios will incorporate three forms of uncertainty related to the specific downscaling method, different future emission paths and inter- and intra-model variability. To achieve these aims, STARDEX will develop standard observed and climate model data sets and a diagnostic software tool for calculating a standard set of extreme statistics across Europe. Two of the major climate models in Europe (HadCM3 and ECHAM4/OPYC) will be extensively validated, with the particular emphasis on extremes. The intercomparison of downscaling methods will take place using observed climate data from the second half of the 20th century.

Finally, recent extremes across Europe will be analysed. What were their causes and impacts? Was anthropogenic climate change a factor? What can be learned from the recent past? The analysis of the recent past will bring together representatives from the reinsurance industry and the climate modelling and climate impact communities in an expert advisory panel.

Expected impacts

The impacts of STARDEX will be improved methodologies for the development of scenarios of extremes, with recommendations as to which are best for different regions across Europe and for different variables. The various sectors listed above will be able to find off-the-shelf scenarios of extremes relevant to their business, incorporating all the various uncertainties. The scenarios will be used for many aspects of design (e.g., modification of dam design criteria, agricultural potential and alteration to insurance premiums) where extremes of weather are crucial determinants. The results will be made available through standard methods of scientific publications and reports, conferences and the World-wide Web.

3.4 MICE Project Summary

Problems to be solved

It is widely accepted that climate change due to global warming will have substantial impacts on the natural environment, and on human activities. Furthermore, it is increasingly recognized that changes in the severity and frequency of extreme events, such as windstorm and flood, are likely to be more important than changes in the average climate. MICE seeks to identify the likely changes in the occurrence of extremes of rainfall, temperature and windstorm in Europe due to global warming, using information from climate models as a basis, and to study the impacts of these changes for selected impact categories: agriculture (Mediterranean drought), commercial forestry and natural forest ecosystems (windstorm, flood and fire), energy use (temperature extremes), tourism (heat stress in the Mediterranean, changes in the snow pack) and civil protection/insurance (windstorm and flood). Throughout the project, a continuing dialogue with stakeholders and end-users will be maintained.

Scientific objectives and approach

The information on future changes in extreme events will be taken from climate models. The first objective is therefore to evaluate the ability of such models to successfully reproduce the occurrence of extremes at the required spatial and temporal scales. This will be done by comparison with observations (station and gridded). Second, the model output will be analysed with respect to future changes in the occurrence of extremes. Statistical analyses will determine changes in (a) the return periods of extremes, (b) the joint probability of extremes (combinations of damaging events such as windstorm followed by heavy rain), (c) the sequential behaviour of extremes (whether events are well-separated or clustered) and (d) the spatial patterns of extreme event occurrence across Europe. The range of uncertainty in model predictions will be explored by analysing changes in model experiments with different spatial resolutions and forcing scenarios. The third objective is to determine the impacts of the predicted changes in extremes occurrence on selected activity sectors. For some activities, good quantitative impacts models already exist and will be utilized (e.g., forest fire and windthrow models). For others, such as energy use and agriculture, the relationships with climate are well understood, and models exist, but may have to be adapted for the particular case of extremes. For categories such as tourism, models exist only for the physical part of the system, e.g., modelling snow depth, such that in addition an expert-judgement-based approach will be adopted.

Expected impacts

MICE will develop techniques to analyse changes in the occurrence of extreme events in climate models due to global warming, taking into account the uncertainties inherent in model predictions. These changes will be used, together with a suite of impacts models to be developed during the project, to study the implications for impacts categories ranging from natural forest ecosystems through to tourism. End-users will provide advice throughout the duration of MICE, and will be informed of the results through a number of impact-specific and general workshops to be held in the final year, and through a summary of the final report dedicated specifically to their needs. MICE will provide end-users with a suite of techniques with which to study changes in climate extremes, and the potential impacts of these changes. These tools can be used to explore sensitivities and vulnerabilities to such changes in sectors as diverse as forestry and tourism.

4. BREAK OUT GROUP REPORTS

4.1 WP 1 and 2:

Rapporteur: Daniela Jacob

High Resolution GCM Simulations

It has been confirmed that all runs mentioned in the Description of Work document tables (DoW) on the PRUDENCE home page will be carried out, although ECHAM4.5/T106 will most likely be used instead of ECHAM5, as this model does not yet seems to be well suited for high resolution. Furthermore, it was decided that all participating GCMs will use monthly data for aerosols, SST and sea ice distribution based on the Hadley Center coupled model runs.

Regional model domains

Maximum overlap of all domains is planned:

7 models (6 + Dutch Meteorological Institute (KNMI) although without PRUDENCE funding) include the Baltic Sea catchment (deliverables for WP3) – 2 include the Mediterranean Basin and surrounding catchment (a few additional models have a substantial part of the Mediterranean Basin included). All will cover the Rhine catchment (deliverables for WP3).

The group urged the modeling groups to provide the project manager with detailed information about their domains, to be hosted at the PRUDENCE homepages.

Input data to drive the regional models

All driving data will come from the high resolution Hadley Centre global atmosphere model on a 6 hourly time interval. However, the prognostic variables in the atmosphere and the surface fields are available on 150 km horizontal resolution only within the boundary zone of the Hadley center regional model. These data have been used to carry out the RCM runs at the Hadley center. Atmospheric data outside the boundary zone are available on 300 km (every other grid point without smoothing), surface fields on 150 km. A list of archived data can be found on the PRUDENCE homepage. Tapes with the boundary data will be send around soon. It was agreed that the aerosol forcing coming from the driving model will be include in the regional models following their own possibilities (e.g. albedo changes).

A couple of issues was raised which suggested that a discussion amongst the modelers about how to identify and homogenize the treatment of aerosols, SSTs and sea-ice (in Baltic Sea) and the interpolation of Theta_l, the prognostic variable respresenting temperature in the Hadley Centre models. Email discussions were envisaged to take place in the upcoming months on these issues.

Output data from regional model simulations

A proposed list from the Hadley Centre RCM circulated, to define the need from the impact modeling communities. The list is now hosted at the PRUDENCE homepage. This should cover variables as well as time intervals. It needs to be defined before the runs will be started. Data from all GCM runs are also available for impact studies.

Analyses of results

Each group will analyze their model runs according to a common strategy on a precisely defined grid (The one half by one half degree Climate Research Unit grid will be adopted) in the file format IEEE-Binary files in service format (as was also used in MERCURE project). At first the inter-comparison follows the MERCURE strategy for surface fields budgets. In addition the following fields will be saved on a monthly basis:

Top of the atmosphere outgoing long wave radiation and shortwave radiation, Temperature at 50 hPa, Geopotential at 500 hPa, Temperature at 850 hPa, clear sky radiation (solar as well as longwave).

A suggestion was made to start an email discussion on how to analyze the variability within a month and on which addition fields need to be stored. The PRUDENCE homepages should host the outcome.

Pilot study to link RCM results to impact model

All RCM groups have or will soon finalize a 15 years long run using ERA15 data as driving fields for 1979 to 1993. A validation against observation is or will be done by each group. These data will be provided to the PRUDENCE consortium to test the link between RCM output and the impact models as well as to test the performance of the impact models for today’s climate conditions

4.2 WP 3, 4 and 5:

Rapporteur: René Laprise

The discussions within this group are summarized below:

Data needs and delivery schedule to impact community:

The DoW says that data should be fully available at month 24.

It is desirable to have some sample data before, in order to test software and ascertain hat the "right" data is saved/used.

Domain of interest:

AGCM data should be available at their full resolution (e.g. 150 km) for the whole of Europe, including Scandinavia and southern Mediterranean regions.

50-km RCMs' domain should "ideally" also cover Scandinavia and southern Mediterranean regions, keeping in mind that the safe region is smaller than the computational domain (some edge effects extend beyond the sponge zone).

Frequency and format of data archival:

For low time resolution (e.g. monthly):

Distribute from a common site (e.g. DMI)
Individual model data interpolated onto a common grid
Simple UNIX-compressed ASCII-type format

For high time resolution (e.g. 6-hourly or daily):

Available from original centre where data was produced
Available on original model grid (to avoid unphysical results of interpolation)
Native (packed) format, with unpacking software made available to users

An issue of concern is whether AGCMs' data as frequently archived as RCMs' ones? The immediate answer seems to be yes. At least it is strongly desirable.

A wish was expressed for a common data interchange and basic certification of data, much in the way of PIRCS at Iowa State University and AMIP at Lawrence Livermore National Laboratories. The project manager should take this up.

Specific questions for the near future

Would it be possible to archive specialised fields from AGCMs and RCMs, e.g. "Biological" potential evapo-transpiration could be saved as a time integral, cumulative quantity. The alternative is to calculate snap-shot samples of this quantity diagnostically, from the high time resolution archived fields.

Biological/ecological/hydrological modellers need to know the precise $CO_2(t)$ concentration corresponding to the equivalent GHG scenario used in climate models simulations.

A discussion was initiated amongst impact scientists about the relative merits of two alternative approaches to physical modelling, depending upon what is used for recent past (current, 1xCO2) climate: either 1960-1990 model simulations or observations for the same period. Similarly the altered climate may be taken in one of two ways: either 2070-2100 model simulations directly or observations of 1960-1990 modified by the DELTA from model simulation between 2070-2100 and 1960-1990.

Model data are available at high time resolution (e.g. daily) while observations are only available as monthly means for some fields. Impact models have often been calibrated (tuned) on observations, and they are sometimes extremely sensitive to even minute variations of environmental parameters.

There is no unique way to apply the DELTA approach: for temperature the DELTA can be added, while for precipitation it may be preferable to multiply observations by the ratio of the model differences. Shouldn't the changes in variability also be taken into account? This is not trivial for non-Gaussian fields.

4.3 WP 6:

Rapporteur: Kirsten Halsnæs

In accordance with the description of WP6, the participants from SMASH-CIRED and Risø (contractors 14 and 19) decided on the approach and work plan for the coming 9 months outlined below.

The main activity under WP6 in the given period of time will be the development of an operational approach for the work under WP 6. The output of this process will be a work report providing a discussion of the climate and physical impact information that is required for economic and policy analysis at the national and regional sector level (deliverable D6A1).

The following issues will be included:

- Identification of key issues to be addressed
- Development of a framework for translating physical impacts into damages (main responsibility of contractor 19)
- Development of a framework for assessing the socio-economic impacts of the damages at the national and regional level (main responsibility of contractor 14)

- Identification of possible case-studies, e.g. assessment of impacts on demographic trends, sector specific impacts such as interrelations between wind power and hydropower in the energy sector, and changes in agricultural productivity.
- Assessment of scenarios that can be used to represent socio-economic development trends in Europe as a basis for climate change policy analysis.
- Assessment of the information needed from the other PRUDENCE participants for the development of a comprehensive list of indicators for the assessment of the socio-economic aspects of climate change impacts at the regional level

The participants from SMASH-CIRED and Risø plan a meeting in May 2002 to co-ordinate the efforts and prepare the work report D6A1 to be submitted to the project group.

4.4 Data group:

Rapporteur: Ole B. Christensen

A list was compiled for impact group data needs for DAILY data. More requirements are excepted from ETH, GKSS, and DLR

Required fields:

- T_2m (K)
- Precipitation (mm/day)
- Total cloudiness (Fraction)
- Evapotranspiration (mm/day)
- Snow water equivalent (mm)
- Total runoff (mm/d)
- Soil moisture (mm)
- Surface pressure (hPa)
- MSLP (hPa)
- T_2m_max (K)
- T_2m_min (K)
- 10-m wind speed (m/s)
- 10-m daily max wind speed (m/s)
- Sea ice thickness (m)
- 2m specific humidity (kg/kg)
- Net and downward SW and LW radiation (W/m2) (positive downwards)

Optional fields:

- 2m relative humidity (Fraction)
- Potential evaporation (mm/d)

These data should be delivered on the native RCM grid. Otherwise interpolation will probably have to be applied several times, hence damping data too much.

Practicalities:

The present preliminary plans are as follows with possible future corrections:

Monthly mean data of various kinds, including at least the fields mentioned above, will be available for ftp from the web site at the DMI. They will be interpolated to the CRU 0.5x0.5 degree grid, which is a regular lat/lon grid between -31.75 and 65.75 longitude, 25.25 and 80.75 latitude, i.e. 196X112=21952 points; the CRU data are only on 12499 points containing land. Previously, DMI has only used the 100x80 subgrid [W,E,S,N]=[-14.75,34.75,35.25,74.75].

It remains to be decided exactly which fields are needed. Daily data requirements consist of 19-21 fields as listed above. A 30-y experiment will consequently give a volume of the order of 10GB for this kind of data. A check of a netCDF file at the DMI, with an estimate of 19 fields in DMI's native 110x104 resolution is 9.393.144.760 bytes, i.e., 8.75 GB. This is actually a tiny bit more than two DVDs; it might be possible to compress the data, i.e., deliver .nc.gz or .nc.zip.

At the DMI, there is equipment to burn DVDs. This will be done in netCDF format with data descriptors making the data importable into e.g. Grads.

Note that it was agreed in this meeting, which followed the WP3-5 meeting summarized above, to deliver data in netCDF format and not in compressed ASCII.

Outstanding issues:

NetCDF may follow several standards (COARDS etc.).We need to agree on one. I (OBC) will collect relevant information.

It was discussed wether some groups would have to enlarge their domains in order to accommodate the impacts groups? At present most areas (ICTP is still missing) have been posted on the PRUDENCE www site. No conclusion is likely to be reached on this topic and it seems acceptable that each group will work according to their own expectations.

Which fields should be stored as monthly means for impact model use (CRU grid)? There are several options for data format wrt. monthly means:

- DMI stores the data in several formats for ftp (NetCDF, compressed ASCII, ...)
- We install on-the-fly filters that will convert things to a number of formats

We supply conversion routines (fortran?) to the users -Jan-Erik Haugen, DNMI agreed to come up with some.

5. OUTLOOK

The break-out groups identified a number of outstanding issues and proposed ways to deal with most them. The PRUDENCE home page established and maintained by the project manager Ole B. Christensen will serve as a vehicle to keep the dialog between the partners up to date. The home page URL is http://www.dmi.dk/f+u/klima/prudence/index.html. The reports from the break-out sessions will at this stage serve as a set of working documents for the co-ordinator as well as the WP leaders during the next three to six month. Before the summer period, it is important that all the outstanding issues are taken care of, and the co-ordinator and the project manager will monitor them. In collaboration with the WP leaders decisions will be made on how to proceed, and these decisions will be made available via the Newsletter and the PRUDENCE homepage to the entire consortium.

The co-ordinator informed the participant that a brief summary of the scientific meeting would possibly be accepted for publication in the journal EOS, Transactions, American Geophysical Union. This was based on discussions with one of the editors of the journal. This summary is also provided in this volume.

5.1 Next meetings:

A considerable effort was made to identify possible plenary progress meetings for the following years. It was agreed to have the second PRUDENCE meeting held back-to-back with the SECOND ICTP CONFERENCE ON DETECTION AND MODELING OF REGIONAL CLIMATE CHANGE, organised by: F. Giorgi and R. Jones (see http://www.ictp.trieste.it/www_users/calendar/cal2002.html).

taking place **30 September - 4 October, 2002, at ICTP in Trieste, Italy**. The ICTP is a full partner of the PRUDENCE consortium. It was agreed by the organisers to have the last 2.5 days of the conference dedicated to PRUDENCE, with 4 October completely dedicated to technical and management-related issues, with an option to use part of 5 October as well. Likewise, business meetings can be arranged in parallel with the scientific presentations as well as during evenings. The program of the conference would be set up in a way such that a smooth transition from the general theme to specific PRUDENCE presentations will be natural. Besides, it is expected that many of the regional climate modellers and several of the impact modellers within PRUDENCE would like to be present during the entire conference.

Two years from now a larger PRUDENCE meeting is envisaged. By then many results from the project should be ready or in the pipeline. Thus, a first scientific assessment of the research results obtained can be made. Prof. Martin Beniston (also a member of the PRUDENCE consortium) has regularly arranged workshops in Wengen, Switzerland with climate related topics (see e.g. http://www.unifr.ch/geoscience/geographie/EVENTS/Wengen/02/Wengen2002.html).

He proposed to host the 3rd PRUDENCE meeting in 2003 in Wengen and to keep the meeting open to external participants as it has also been the case for this kick-off meeting. It was agreed to follow that idea, and to aim for a full one-week PRUDENCE workshop in **September 2003, at Hotel Regina, Wengen, Switzerland**.

The final PRUDENCE meeting was addressed very loosely. Prof. Manuel Castro will investigate the possibility to host the meeting in Toledo, Spain 3–4 months prior to the end of the project, so that some time to adjust the project will remain after that.

6. WORKSHOP AGENDA

Sunday 2 December

20.30 Icebreaker.

The Danish Climate Centre are pleased to invite PRUDENCE participants to a small informal gathering at the Comwell Helsingør conference centre, offering a glass of wine, a beer or soft drinks.

Monday 3 December

9:00 Welcome *Jens Hesselbjerg Christensen*

Introducing PRUDENCE participation

Regional information from climate models *(chair: Michel Déqué)*

9:15 Emerging patterns of simulated regional climate changes for the 21st century: Regional information from coupled OAGCMs *(Filippo Giorgi, ICTP)*

9:45 Regional information from high-resolution atmospheric global climate modelling *(Richard Jones, Hadley Centre)*

10:15 Regional climate models: The nesting approach *(Jens Hesselbjerg Christensen, DMI)*

10:45 Coffee break

Summary of modelling activities by partners *(chair: Franco Molteni)*

11:00 Regional climate and climate change modelling over Scandinavia *(Ole Bøssing Christensen & Jens Hesselbjerg Christensen, DMI)*

11:30 European impact of an IPCC-B2 scenario simulated by a global variable resolution model. *(Michel Déqué, Météo France)*

11:50 European Climate Change: Model Experiments and Initial Results *(Dave Rowell et al., Hadley Centre)*

12:10 Physical processes affecting the seasonal and inter-annual variations of the European water cycle *(Vidale et al., ETH)*

12:25	Lunch	

Summary of modelling activities continued *(chair: Dieter Heimann)*

13:30	ICTP and CINECA activities for PRUDENCE	*(Filippo Giorgi, ICTP & Susanna Corti, CINECA)*
13:50	PRUDENCE-related regional climate modelling at the SMHI/Rossby Centre	*(Rummukainen et al., SMHI)*
14:05	Contributions to PRUDENCE by UniCM	*(Manuel Castro & Alberto Arribas, UniCM)*

Non PRUDENCE presentations *(chair: Eigil Kaas)*

14:20	Results from a Big-Brother Little-Brother Experiment	*(Daniel Caya, UQAM, Canada)*
14:35	KNMI activities related to PRUDENCE	*(Aad van Ulden, KNMI)*
14:50	Intensive precipitation as simulated in a high resolution GCM model	*(Wilhelm May, DMI)*
15:05	Summary of report submitted to WGNE/WGCM by the RCM panel	*(Rene Laprise, UQAM, Canada)*
15:20	Coffee break	

Break out sessions

15:35	Defining break out task groups	
	WP1 + WP2	*Headed by: Hadley and MPI*
	WP3 + WP4 + WP5	*Headed by: SMHI, DIAS, UniReading*
	WP6	*Headed by: Risø*
15:40	The groups will meet in separate rooms with separate agendas (to be established from the leading PI, see '3.2 List of work packages' in DoW). The overall objective will be to identify gaps in information flow and data needs, and identify how these can be amended. Reference persons for cross WP issues must be identified.	
17:00	Meeting adjourned	
18:45	Steering committee meeting	
20.00	PRUDENCE external advisory board meeting	

Tuesday 4 December

Bridging the gaps; plenary session *(chair: Jens Hesselbjerg Christensen)*

9:00	Reports from break out sessions and general discussion	
10:30	Coffee break	

Climate change scenarios

(chair: Maria Ines Minguez-Tudela)

9:00	Reports from break out sessions and general discussion	
10:30	Coffee break	
10:45	Developing and applying scenarios	*(Timothy Carter, FEI)*
11:15	Assessing damages: Is 2% of GDP losses a relevant information?	*(Jean-Charles Hourcade & Philippe Ambrosi, SMASH CIRED)*
11:45	Regional Climate Change Impacts in the EU Socio-economic Issues and Policy Implications	*(Kirsten Halsnæs, Risø)*
12:15	Lunch	

Introducing PRUDENCE participation II

Summary of impacts modelling *(chair: Martin Sykes)*

13:30	Assessing the uncertainties in Impact-relevant changes in climate and weather: seasonal means and daily extremes in Europe	*(Kirsti Jylhä & Heikki Tuomenvirta, FMI)*
13:45	Assessing Climate-related uncertainties in Future Natural Resource Potential in Europe	*(Timothy Carter and Stefan Fronzek, FEI)*
14:00	Uncertainties of impact assessments	*(Maria Ines Minguez-Tudela et al., UniPM)*
14:15	DIAS contribution to PRUDENCE	*(Jørgen E. Olesen et al., DIAS)*
15:00	Coffee break	

Break out sessions

15:15	Discussion of further needs for developments in the task groups.	

Summaries continued *(chair: Tim Carter)*

16:00	Shifts in extreme climatic events and	*(Martin Beniston & Stephane Goyette, UniFribourg)*

	implications for severe impacts	
16:15	Modelling activities at GKSS	*(Burkhardt Rockel & Katja Woth, GKSS)*
16:30	Modelling climate impacts on forest landscapes and ecosystem processes using the LPJ modelling framework.	*(Martin T. Sykes & Pablo Morales, UniLund)*
16:45	Climate Extremes in the Mediterranean in a Warmer World	*(Jean Palutikof, CRU)*
17:00	ETH	
17:15	MPI	
17:30	Modeling climate change impacts on hydrology at SMHI/Rossby Centre: a starting point for PRUDENCE	*(Phil Graham et al., SMHI)*

Non PRUDENCE presentation

17:45	PIRCS (Project to Intercompare Regional Climate Models)	*(Ray Arritt, Iowa State University, USA)*
18:00	Meeting adjourned	
19:00	Prudence dinner	

Wednesday 5 December

Presenting PRUDENCE plenary session *(chair: Ole Bøssing Christensen)*

9:00	Presenting PRUDENCE. Given the high profile of PRUDENCE, we need to define efficient means and procedures to communicate within the project and our findings to the public. A first attempt of the PRUDENCE home page will be presented.	
	Reports from break out sessions and general discussion.	
10:15	Coffee break	

Statistical/dynamical down scaling *(chair: Jean Palutikof)*

10:30	Introducing Integrated Regional Impact Studies (IRIS)	*(Manfred Lange, invited speaker)*
11:15	Statistical-dynamical methods in regional climate assessments	*(Dieter Heimann & Maria José Costa Zemsch, DLR)*
12:00	On the concept of weather generators	*(Jørgen E. Olesen, DIAS)*
12:30	Lunch	

Wrapping up

13:30	From here to the annual report - practical matters, outstanding issues.
	Stimulating inter-institutional and interdisciplinary work. Identifying possible scientific presentations, papers, etc.
	General discussion continued
15:00	End of meeting

7. ABSTRACTS

7.1 F. Giorgi, ICTP Abdus Salam International Centre for Theoretical Physics

Emerging patterns of simulated regional climatic changes for the 21st century due to anthropogenic forcings

Temperature and precipitation changes for the late decades of the 21st century have been analyzed for 23 land regions of the world from 18 recent transient climate change experiments with coupled atmosphere-ocean General Circulation Models (AOGCMs). The analysis involves two different forcing scenarios (the A2 and B2 IPCC emission scenarios) and nine models. Both biases in reproducing present day average climate (1961-1990) and changes in average climate between 2071-2100 and 1961-1990 are examined. The overall analysis of changes reveals that a number of consistent patterns of regional change across models and scenarios are emerging. For temperature, in addition to maximum winter warming in northern high latitudes, warming much greater than the global average is found over Central Asia, Tibet and the Mediterranean region in summer.

Consistent warming lower than the global average is found in some seasons over Southern South America, Southeast Asia and South Asia, while cases of inconsistent warming amplification compared to the global average occur mostly in some tropical and southern sub-tropical regions. Consistent patterns of precipitation change emerge from the analysis. Consistent increase in winter precipitation is found in northern high latitude regions, as well as Central Asia, Tibet, Western and Eastern North America, and Western and Eastern Africa regions. The experiments also indicate an increase in South and East Asia summer monsoon precipitation. A number of regions show a consistent decrease in precipitation, such as Southern Africa and Australia in winter, the Mediterranean in summer and Central America in both seasons. When focusing on the northern European and Mediterranean regions, the average warming from the ensemble of simulations in the A2 scenario is 5.5 K in DJF and 4 K in JJA over Northern Europe, and 3.5 K in DJF and 5 K in JJA over the Mediterranean. The ensemble average precipitation change is +20% in DJF over Northern Europe and -20% in JJA over the Mediterranean, with small changes in the other seasons. A general consistency of signals is found between the A2 and B2 scenarios, both for temperature and, to a lesser extent, precipitation. The ratio of temperature changes between the A2 and B2 scenarios is about 1.4. In terms of average, the differences across models are greater than the differences across realizations with the same model.

7.2 R. Jones, Hadley Centre for Climate Prediction and Research, Met Office, Bracknell

Regional information from high-resolution atmospheric global climate modelling

Climate scenarios result from a series of assumptions and modelling activities. On the basis of expert judgement and projections of the results of future human activities estimates are made of future emissions of gases producing perturbations to the radiative forcing of climate. These are then converted into concentrations of the relevant atmospheric constituents. In order to calculate the likely impact on climate the effect of these changing concentrations on the world's climate they are included in global coupled ocean atmosphere models. These then give large-scale patterns of changes in the climate but due to their computational complexity their resolution is coarse (~300km) and so local and regional details are poorly represented. One method to overcome this deficiency is to use the coupled model predictions of changes in sea-surface temperature sea-ice and to use these to drive higher resolution atmospheric global models for particular periods of interest. This talk then focuses on this approach, explaining the methodology, presenting some results and describing some issues relating to consistency of and uncertainty in predictions.

Atmospheric global climate models (GCMs) used for providing high resolution climate change scenarios will have similar representations of atmospheric and land surface processes as in coupled models. In some cases these may be identical to those in the atmospheric component of the coupled model providing the sea-surface forcing. Where they differ is in resolution which is either increased uniformly over the globe or locally over a particular area of interest. Some of the variable resolution techniques also imply a region of low resolution, generally over the opposite side of the globe. The climate change forcing for these models is then provided via changes in the atmospheric composition, as with the global coupled model, along with changes in sea-surface temperatures and sea-ice from the coupled model. The latter can either be taken from relevant segments of a coupled model present-day and future integration or from observations (for the control simulation) and observations plus anomalies derived from the coupled model (for the climate change simulation).

In addition to allowing higher resolution, there is another major advantage to using an AGCM for simulating climate changes. In a coupled model the primary constraint is to provide a stable coupled system which is mainly realised through simulating the correct fluxes of heat at the top of the atmosphere and heat and moisture at the air-sea interface. By having specified sea-surface conditions the latter constraint is removed and the former is not so critical in which case other aspects of the model's climatology can be focused on. Thus more attention can be paid to, for example, the surface climate over land which is more relevant when assessing many potential impacts of climate change. However, there are potential problems with increasing resolution as often an acceptable climate in a model at a given resolution is partially the result of compensating errors. If these are in components of the model which are dependent on resolution then increasing resolution can result in some aspects of the model performance getting worse. In this case it is important to remove any scale-dependencies in the model.

When an AGCM is used to predict climate change, its response is forced by the changes in sea-surface temperatures and sea-ice derived from the driving coupled model and the matching changes in the atmospheric composition. As the evolution of the atmosphere is not tightly constrained by sea-surface conditions then the patterns of climate change can be quite different between the driving coupled model and the AGCM. This is demonstrated in an example where the CNRM Arpege model driven by the sea-surface conditions from the Hadley Centre's coupled model HadCM2. This poses the question as to whether the response in the AGCM is then inconsistent with the driving coupled model. A series of experiment run using the latest Hadley Centre AGCM, HadAM3H, driven by sea-surface changes derived from slab-ocean coupled models with HadAM3 and HadAM3H as atmospheric components has shown that in this case the HadAM3H response is consistent with the coupled model. However, the question as to whether the response of HadAM3H driven by the coupled model sea-surface changes is a good approximation to the response of a fully coupled model with HadAM3H as the atmospheric component has not been investigated.

7.3 J. H. Christensen, Danish Meteorological Institute, Copenhagen

Regional climate models: The nesting approach

The nested regional climate modeling 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 frequently 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.

The nested regional modeling technique essentially originated from numerical weather prediction. RCMs are now used in a wide range of climate applications, from palaeoclimate to anthropogenic climate change studies. They can provide high resolution (up to 10-20 km or less) and multi-decadal simulations and are capable of describing climate feedback mechanisms acting at the regional scale. A number of widely used limited area modeling systems have been adapted to, or developed for, climate application.

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. A number of examples of successfully applications of RCMs for present day conditions are available.

Only recently, new insight has been gained concerning the robustness of RCM simulations of climate change. The present paper will present results from the first multi-model approach to assess climate change over Scandinavia.

7.4 O. B. Christensen, J. H. Christensen, and S. Kiilsholm, Danish Meteorological Institute, Copenhagen

Regional Climate and Climate Change Modeling at the DMI

At the DMI the regional climate model HIRHAM has been used for almost a decade, frequently within EU-financed projects. Recent experiments on a 110 times 104 European domain at 50 km resolution include a 15-year reanalysis simulation and 30-year control/scenario A2/scenario B2 simulations.

Some work on the variability of regional climate models has been carried out in the past, focusing on internal model variability. Also a Nordic intercomparison of regional models has been carried out recently; here numerical experiments from Norway, Sweden, and Denmark were compared, and robust results being identified by scaling climate change signals with global temperature change in order to give a more meaningful inter-experiment comparison.

In the PRUDENCE project sources of model variability will be addressed through a “multi-dimensional” design of experiments: downscaling of several OAGCM ensemble members with HIRHAM; downscaling of a different OAGCM simulation of the same emission scenario with HIRHAM; comparison to a downscaling of one of these experiments with a different regional model. Some building blocks of this design have already been created.

The recent 3 times 30 years of SRES experiments performed at the DMI cover 1961-1990 as well as 2071-2100 in both A2 and B2 scenarios, based on ECHAM4/OPYC. Preliminary findings from these experiments will be discussed. Having both reanalysis-based and GCM-based regional experiments enables a two-dimensional intercomparison. Climate change signals of GCM and RCM will also be compared. Finally, the method of inter-experiment scaling of results with global temperature change can be tested here and seems in general to give sensible results.

7.5 D. Jacob, Max Planck Institut für Meteorologie, Hamburg

MPI-Modeling activities related to Prudence, WP1

Within Prudence both global and regional model simulations will be performed. The global atmospheric climate model ECHAM4 will be used for a time slice experiment on a horizontal resolution of T106. The A2 scenario will be simulated once with ECHAM4/Opyc (at DMI) and at the MPI ECHAM4 will be driven by SST and sea-ice conditions coming from the Hadley center model. Therefore the influence of the sea surface boundary conditions on the climate in Europe will be investigated.

During the last years the regional climate model REMO was used to simulate today's climate. It is a part of the MPI modeling chain ECHAM-REMO-GESIMA, which covers global to local scales. Currently REMO is used in two standard horizontal resolutions 1/6° and ½° within several national and international projects. The major focus lies on the validation of REMO in order to establish a solid frame for climate change experiments.

REMO is the atmospheric component of the fully coupled modeling system BALTIMOS, which explores the energy and water cycle in the Baltic Sea drainage basin within BALTEX. REMO has also been used in tropical to arctic climates to investigate the differences in the water cycles eg. annual cycles, means and extremes in simulations up to 20 years.

Within Prudence REMO will be used on both horizontal resolutions driven by lateral boundary conditions coming from the Hadley center atmospheric global model for SRES A2. The results will be compared to results from the partner models and they will be used for impact assessment within WP3.

MPI-Modeling activities related to Prudence, WP3

REMO is coupled to two hydrological models: the HD-model, a global run-off model on 1/2° resolution and the LARSIM-model on 1/6° resolution for the river Rhine drainage basin.

Within WP3 the HD-model will be used driven by atmospheric fields from several regional climate models to compare the performance of the HD-model to the HBV- model (investigated at SMHI).

For the Rhine basin an intercomparison of LARSIM to the hydrological model used at the ETH is planned.

7.6 M. Déqué, Météo-France/CRNM, Toulouse

European impact of an IPCC-B2 scenario simulated by a global variable resolution model

Introduction

Numerical simulations of the regional climate impact of greenhouse gas concentration can be obtained by two methods: a global GCM with high resolution, or a LAM forced by the output of a global GCM. We have chosen the first approach, and demonstrated that a large amount of computer time can be saved by the use of variable horizontal resolution (Déqué and Piedelievre, 1995). In both approaches, Sea Surface Temperature must be prescribed by a preliminary simulation with a coupled ocean-atmosphere model. We present here a scenario simulation covering the second half of the XXth century and the XXIst century. Up to 2000, the simulation uses an observed forcing. Beyond this year, the forcing comes from IPCC-B2 concentration scenario.

Figure 1: A selection of the model grid points (one black square per grid point) over land and over Europe (the actual model grid covers the whole globe).

Description of the model

In the RACCS European project (Machenhauer et al., 1998) two time-slice simulations were performed with a variable resolution version of ARPEGE-IFS cycle 12 (Déqué et al., 1998). The simulations performed in PRUDENCE use a new version of the ARPEGE-IFS model (cycle 18). The new version uses a semi-lagrangian advection (the former used an eulerian advection), a two time-level discretization (the former used a leap frog scheme). The spectral truncation is T106, the 31 vertical levels are mainly in the troposphere and the time step is 30 min. This compares to the old version of resolution T63, 20/31 levels in the stratosphere, and a 7 min time step. The pole of stretching is at the same place (40°N, 12°E, i.e. approximately at the center of the Mediterranean basin), but the stretching factor is 3 instead of 3.5. The grid has 120 pseudo-latitudes and 240 pseudo-longitudes (with a reduction near the pseudo-poles to maintain isotropy), whereas it had 96 pseudo-latitudes and 192 pseudo-longitudes in the former version. As a result, the maximum horizontal resolution is similar (about 0.5°), but the resolution gradient is slower in the new version. Figure 1 illustrates the resolution over Europe.

Except the convection scheme (Bougeault, 1985), which has undergone only minor changes, all other physical parameterizations have been modified or replaced. The Morcrette (1990) scheme is used to calculate the radiation, which includes the effect of 4 greenhouse gases (CO2, CH4, N2O and CFC) in addition to water vapor and ozone, and of 5 aerosol types (land, sea, urban, desert and sulfate) in addition to background aerosols. Indirect effects of sulfate aerosols are parameterized by an empirical function for the cloud drop effective radius. The cloud-precipitation-vertical diffusion scheme uses the statistical approach of Ricard and Royer (1993). The soil scheme is no longer relaxed towards climatology. Instead, a 4-layer diffusion scheme is used along with other improvements from the ISBA soil vegetation scheme (Douville et al., 2000). Representation of orographic gravity wave drag has been improved by the addition of mountain blocking and the lift effect (Lott and Miller, 1997; Lott, 1999).

Description of the experiment

The design of the experiment is different from the RACCS project. In the former experiment, control and perturbation simulations were ran over 10 years, with two forcings: (i) a radiative forcing from a doubling of carbon dioxide concentration in the perturbation simulation, and (ii) surface forcing using the sea surface temperature (SST) from a Hadley Centre coupled simulation. In the present project, the variable resolution model is run with radiative forcing (greenhouse gases and aerosols) following IPCC-B2 scenario. The CO_2 concentration increase is less than 1% per year and is updated every 10th year.

The SST/sea ice forcing varies from year to year. From 1960 through 2000, we use monthly mean observed SST. This allows validation of the variable resolution model by comparing the simulation with observations, and the first 30 years of the period have been used in the MERCURE European project. Another advantage is that we can test SST forcings from different models without running different control simulations, allowing more experiments due to saved computer time. From 2001 through 2099, artificial monthly SSTs were created by adding to observed SSTs an increment obtained from a coupled run. This increment has an annual cycle and is updated every 10^{th} year. Thus the intradecadal variability of SST and sea ice is assumed not to change during the XXIst century. The coupled simulation is a scenario described by Royer et al. (2001) and Douville et al. (2001). It consists of a pair of 150-year integrations with the same ARPEGE-IFS version, except that the horizontal resolution is T63 uniform and vertical resolution is higher in the stratosphere (45 levels instead of 31). The first integration uses the 1950 radiative forcing. The second undergoes the IPCC-B2 radiative forcing scenario throughout the whole period. The artificial SST used by the variable resolution model after year 2000 is obtained by adding to a 40-year “cycle” of observed data (1960-1999 repeated 3 times) a 30-year running mean anomaly based on the coupled low-resolution simulations. This anomaly is calculated as the difference between the target period and the actual observed period (e.g. 2070-2099 minus 1960-1989). The anomaly is then corrected by subtracting the same quantity obtained in the control coupled simulation, in order to avoid confusing the coupled model natural drift (about 1 K per century) with the true response to the radiative forcing (about 2 K per century).

Figure 2 shows the mean SST anomaly and sea ice extent in DJF and JJA between the two focus periods of PRUDENCE, i.e. 2070-2099 and 1960-1989. Temperature anomalies over sea ice are not plotted. It is clear that SST warming, reaching 1 to 2K, is quite uniformly distributed. In winter a warm-cold dipole is found in the North Atlantic. This is due to a reduction in the Gulf Stream intensity. This also occurs in summer but to a lesser extent. The reduced warm water advection is not sufficient to compensate the radiative forcing at higher latitudes, and the sea ice extent is decreased in both hemispheres and seasons (it even disappears during summer in the northern hemisphere).

Perspectives

The size of this extended abstract does not allow to include maps of systematic errors between 1960-1989 averages and observed climatology, nor maps of impacts between 2070-2099 and 1960-1999 for various seasons and climate parameter. These data are available and may be included in the web pages of PRUDENCE or in a PRUDENCE atlas, once a common format is decided among the participants. Raw data (at daily frequency for the whole 140-year period) are also available for the project participants. Additional simulations have been completed in order to get a better statistical accuracy for the two focus period. Two 30-year simulations for the periods 2070-2099 and 1960-1989 have been performed with the same model and forcing. The difference comes from the initial condition. We have thus two ensembles of 3 simulations. Figure 3 shows the year to year variability of January mean temperature over Europe in the various simulations, together with a 30-year running mean of the 140-year simulation. It appears that long periods (more than 30 years) are necessary to detect the warming trend. In particular temperature is steady between 1990 and 2010 and cold Januaries are obtained till 2020. We must be prudent when interpreting a warm winter or a sequence of warm winters as a proof of the long term warming: the next cold winter could be objected as a proof that the global warming does not exist.

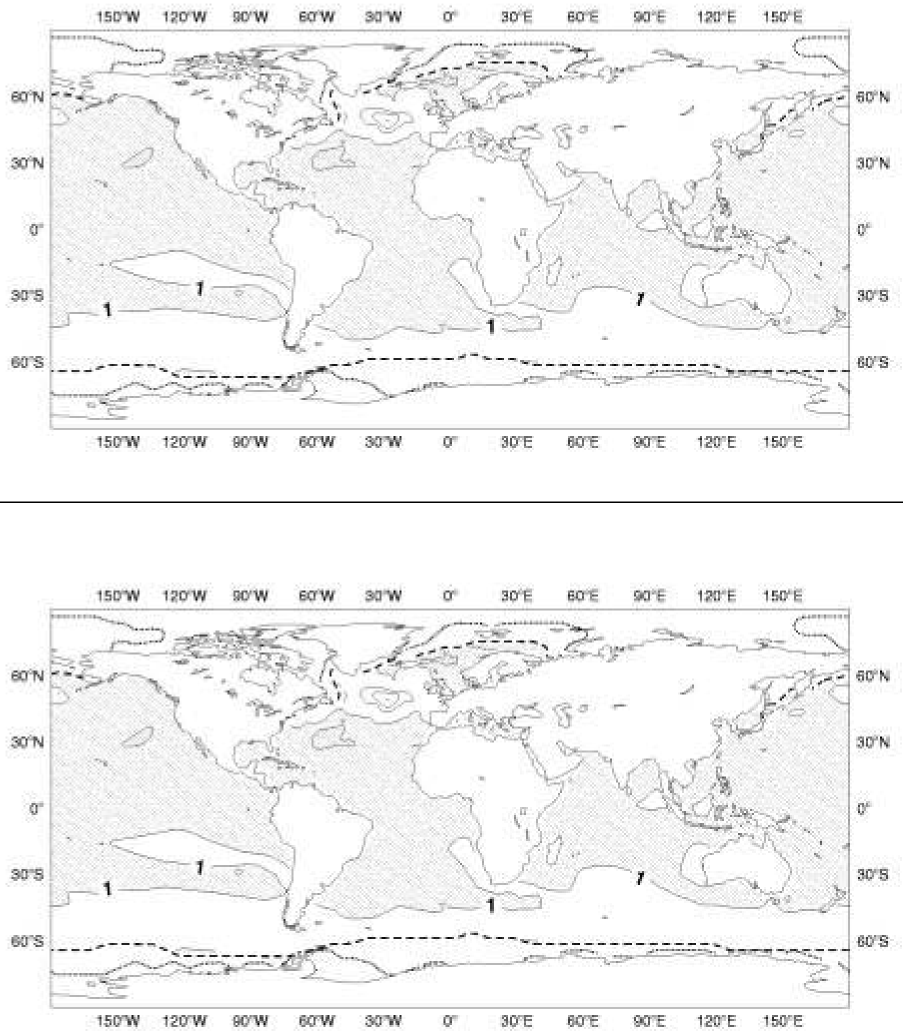

Figure 2:	*Mean sea surface temperature difference between 2070-2099 and 1960-1989 in the scenario coupled simulation, after correction of the drift obtained in the control coupled simulation: DJF (top) and JJA (bottom). Contour interval 1K, values above 1K shaded, zero contour omitted. The dashed and dotted lines show the sea ice limit in 1960-1989 and 2070-2099 respectively.*

Two additional simulations are planned in order to better document the sources of uncertainty. The first one uses the same radiative forcing (IPCC-B2), but the boundary conditions (SST and sea-ice extent) come from another coupled simulation performed with the Hadley Centre model. Comparison with earlier simulations with Météo-France SST. The second simulation uses a stronger radiative forcing (IPCC-A2) and SST from another coupled simulation performed with the Hadley Centre model. Comparison between the last two simulations will allow to estimate the uncertainty due to the radiative forcing. It will be then possible to compare three sources of uncertainty:

- statistical sampling (through ensemble simulations)
- SST forcing
- radiative forcing

Comparison with results from the partners who use the IPCC-A2 radiative forcing and the corresponding Hadley Centre coupled scenario will document a fourth cause of uncertainty: the atmosphere model.

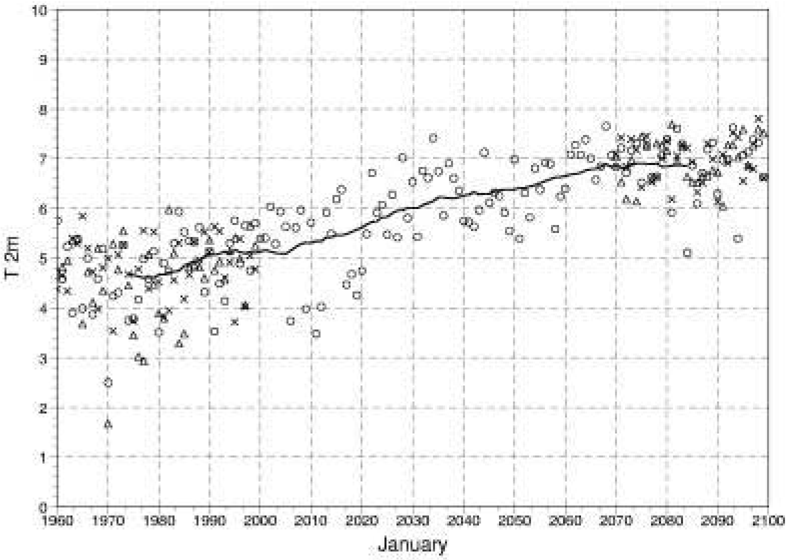

Figure 3: January mean screen level temperature (°C) averaged over Europe in the 140-year simulation (circles) and in the two additional snapshot simulations (triangles and crosses). The solid line is the 30-year running average of the circles.

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7.7 D. Rowell, R. Jones and D. Hassell, Hadley Centre for Climate Prediction and Research, Met Office, Bracknell

European Climate Change: Model Experiments and Initial Results

We will describe the model simulation data available to PRUDENCE from the Hadley Centre, some initial results from this data, and our research priorities for the duration of PRUDENCE.

Two types of model data will be used and are available. One is from simulations with a high resolution (1.25°x1.875°) global atmospheric model (HadAM3H), consisting of (a) a control ensemble of experiments – 3 runs forced by observed SSTs and sea-ice extents (HadISST1) for 1960-1990, (b) an A2 ensemble of experiments – 3 runs for 2070-2100 forced by the SRES A2 greenhouse gas and aerosol scenario with mean SST anomalies and trends taken from 3 coupled model (HadCM3) A2 experiments, and (c) a single B2 experiment for 2070-2100 forced by the SRES B2 scenario and mean SST anomalies and trends taken from a HadCM3 B2 experiment. The second set of experiments have been run with a regional model (HadRM3H) encompassing Europe with a 50km resolution and identical physics to that of HadAM3H. These have the same forcing and ensemble sizes as the HadAM3H experiments, from which they also take their lateral boundary forcing. Finally, 2 experiments with a 25km version of the regional model are also in progress: a control simulation for 1960-1990, and an A2 simulation for 2070-2100.

Initial analysis has focussed on describing the European seasonal responses to the SRES scenarios, focussing on surface air temperature and precipitation, and including projected changes to the 30-year mean climate, the interannual variance, and the risk of individual years having much wetter or drier seasons. Furthermore, the differences between the global atmospheric model's climate and the regional model's climate are also shown to be relatively small, both now and in the future, and do not lead to statistically significant differences in their responses to climate change. Finally, the 50km regional model adds (not surprisingly) a significant amount of local information on the projected response to climate change, particularly for precipitation. One source of such added information is a tendency towards a slight warming and drying at higher altitudes in the future compared to the local large-scale response (though this effect does not necessarily dominate the local response anomaly at any one site).

7.8 P.L. Vidale, D. Lüthi, C Frei, S. Seneviratne, and C. Schär, Climate Research ETH (Eidgenoessische Technische Hochschule), Zürich

Physical processes affecting the seasonal and inter-annual variations of the European water cycle.

The Climate High Resolution Model (CHRM) in use at IAC-ETH for Regional Climate Modeling (RCM) studies (MERCURE, NCCR, PRUDENCE projects) has undergone several important changes in the last year, meant to allow it to complete multi-year simulations while retaining sustainable water and energy cycles. This represents a departure from the weather version of the model, which is not addressing these conservation aspects and relies on continuous re-initialization through soil data (temperature and soil moisture) assimilation in order to guarantee forecast quality.

The principal physical parameterization improvements have come in the area of soil water vertical transfer, which is now occurring at normal rates, permitting normal winter re-charge of the root zone and correcting a summer ET bias of 40 W/m2 (monthly mean) over most of central and southern Europe. The other important changes have been introduced in the area of cloud-radiation interactions, permitting to correct a surface (short wave) negative bias of 40 W/m2 (monthly mean) at the peak of summer. Surface temperatures, which were kept artificially high in the weather version through artificial soil water depletion (resulting however in severe summer warm biases over certain regions) have initially suffered (with the creation of a 2 K negative bias) from the more accurate summer ET rates, but have been improved after the corrections in radiation, due to a better representation of the surface energy balance.

7.9 F. Giorgi, Abdus Salam International Centre for Theoretical Physics and S. Corti, CINECA, Bologna

Activities of the Abdus Salam ICTP and CINECA planned for the PRUDENCE project

The PRUDENCE activities will be conducted in close collaboration between the Physics of Weather and Climate (PWC) group of the Abdus Salam International Centre for Theoretical Physics (ICTP) and the Consorzio Interuniversitario per la Gestione del Centro di Calcolo Elettronico dell'Italia Nord-Orientale (CINECA). The PWC group was recently created within ICTP to conduct research in different fields of the atmosphere and ocean sciences. These include the areas of anthropogenic climate change (emphasis on the regional scale), natural climate variability, seasonal climate prediction, land-atmosphere and ocean atmosphere interactions and the effects of atmospheric tracers and aerosols on climate. A suite of climate models of different complexity, both regional and global, are currently in use at the ICTP. CINECA is the largest supercomputing centre in Italy and has been involved in a number of European projects related to climatology and meteorology. The PRUDENCE activities planned by the ICTP/CINECA team include two primary lines:

1) Completion of time slice experiments with a uniform resolution AGCM.

The CCM3, the Community Climate Model developed at the National Center for Atmospheric Research (NCAR), will be run for this purpose at a spectral resolution of T80, corresponding to a grid interval of approximately 150 km.

Two realizations of the periods 1961-1990 (reference period) and 2071-2100 (future period) for the A2 scenario will be completed using forcing SST and aerosol concentration from one of the HadAMH time slice experiments.

2) Completion of nested regional model simulations over the European region at a grid interval of 50 km. The regional model RegCM, developed over the last 12 years by the current PWC research team, will be used for this activity. Two sets of experiments for the A2 scenario will be performed, both for the 1961-1990 and 2071-2100 periods, one with forcing fields from the HadAMH simulation and one with forcing fields from the CCM3 time slice experiments.

The analysis of these experiments and their comparison with other experiments within PRUDENCE will allow to address uncertainties related to use of different driving and nested models as well as to the internal model variability.

7.10 M. Rummukainen, R. Döscher, P. Graham, U. Hansson, C. Jones, M. Meier, J. Räisänen, P. Samuelsson, A. Ullerstig and U. Willén, Swedish Meteorological and Hydrological Institute/Rossby Centre, Norrköping

PRUDENCE-related regional climate modeling at the SMHI/Rossby Centre

The regional climate modeling system developed at the Rossby Center of the SMHI consists of a coupled atmosphere-inland lake-ocean-sea ice-hydrology system (RCAO), set up for the European region.

The atmospheric model component, including the land surface, is based on the international HIRLAM model, although most of the physical parameterizations have either been modified (e.g. radiation) or replaced (e.g. turbulence, condensation and convection) with schemes more specific for high-resolution regional modeling. Much effort has been put in the description of the land surface and, especially, in an integration of the inherently "meteorological" HIRLAM and a more "hydrological" treatment of the soil moisture and runoff. Another major effort has concerned the (flux) coupling between the atmospheric part of the model system (RCA) and the 3-D Baltic Sea model (RCO) developed at the Rossby Center. The OASIS coupling tool is used for the atmosphere-ocean coupling. Transformation of runoff from land to the river mouths around the Baltic Sea is based on river routing concepts from the hydrological HBV-model. Inland lakes in the Baltic Sea region are modeled with the PROBE-lake concept.

The RCAO-system is run on a CrayT3E at the National Supercomputer Centre, Linköping University. A typical set-up of regional simulations features a resolution of 40-50 km and 19-24 levels in RCA and 6 nautical miles in RCO (2 nm in off-line mode). Using the HIRLAM semi-Lagrangian time scheme, a time step of the order of 30-60 minutes is feasible in RCA. In the 6 nm RCO, the time step is 10 minutes. In coupled simulations, exchange of information between the RCA and the RCO occurs every three hours.

The coupled system has been tested in the "perfect boundary condition" mode using ERA-15 as the forcing. Off-line RCO-simulations have been performed also using gridded meteorological databases, as well as reconstructed meteorological forcing for the entire 20th century. In addition to simulations for the European region, the RCA has been run also for the continental U.S. and for the eastern Pacific, using both ERA-15 and the NCEP reanalyzes.

Within the PRUDENCE-project, the coupled RCAO system will be used to downscale 30-year time slices from HadCM3/AM3-simulations, including a control period and scenarios corresponding to one realization of the SRES A2-driven global projections and an SRES B2-driven global projection. Preliminary plans exist for repeating the regionalizations using projections made with the ECHAM4/OPYC3 global model. Finally, one RCAO-regionalization on a resolution ~20 km is also aimed for within PRUDENCE.

Acknowledgements

The development of regional climate modeling and regional climate simulations and scenarios worked on at the Rossby Center belong to the Swedish regional climate modeling program (SWECLIM), which has been funded mainly by the Swedish Foundation for Strategic Environmental Research (MISTRA) and SMHI. Much of the development work on moist physics and radiation belongs to the EU-contracts EVK2-CT-1999-00007 and EVK2-CT-1999-00051.

7.11 M. Castro and A. Arribas, Universidad Complutense Madrid

Contributions to PRUDENCE by UniCM

The PROMES-RCM is a fully compressible, primitive equation and hydrostatic regional climate model, entirely developed at the Geophysics and Meteorology Department of the University Complutense of Madrid (Spain). It includes a complete set of physical parameterisations of short and long-wave radiative processes, PBL exchanges, stratiform and convective precipitation and land surface processes. This model has been tested in several intercomparison projects, being the most recent ones MERCURE and PIRCS (C.J. Anderson et al., 2001) over Europe and North America respectively. In these simulations the PROMES model has shown an acceptable representation of the current climate, obtaining a rather good classification when compared to other regional climate models.

The model has been also used for carrying out diverse climate change sensitivity studies related with global CO2 increase (Gallardo et al., 2001) and regional land degradation scenarios (Gaertner et al., 2001; Christensen et al., 2001 and Arribas et al., 2001) in the Iberian Peninsula and the Western Mediterranean region. The 2xCO2 sensitivity experiments were performed by a nesting of PROMES-RCM in the HADCM2 global model, and has shown results comparable to the obtained by the Hadley Centre RCM nested in the same AOGCM. The most relevant results can be summarized in a surface average temperature warming in all seasons, more rainy winters in northern Iberian Peninsula and a significant increase in precipitation interannual variability in winter and autumn. The model output data from this series of experiments were used as input for crops models, to study the 2xCO2 scenario impact on water resources for crops in Spain (Guereña et al., 2001).

The PROMES RCM will be used in PRUDENCE project for simulations of high resolution (50 km) climate change projections for 2071-2100 climate in Europe, corresponding to A2 and B2 SRES emission scenarios.

7.12 B. Denis, R. Laprise, D. Caya, R. de Elía, Université du Québec à Montréal, Canada and J. Côté, Recherces en Prévision Numérique, Canada

Testing the downscaling ability of Regional Climate Models with the "Big-Brother Experiment"

The purpose of this research is to evaluate the downscaling ability of one-way nesting regional climate models (RCM). To do this, a rigorous and well-defined experiment for assessing the reliability of the one-way nesting approach is developed. This experiment, nick-named the Big-Brother Experiment (BBE), is used for addressing some important one-way nesting issues. The BBE consists in first establishing a reference virtual-reality climate from an RCM simulation using a large and high-resolution domain. This simulation is called the "Big Brother". This big-brother simulation is then degraded toward the resolution of today's global objective analyses (OA) and/or global climate models (GCM) by removing the short scales. The resulting fields are then used as nesting data to drive an RCM (called the "Little Brother") which is integrated at the same high-resolution as the Big Brother, but over a sub-area of the big-brother domain. The climate statistics of the Little Brother are then compared with those of the big-brother simulation over the little-brother domain. Differences between the two climates can thus be unambiguously attributed to errors associated with the dynamical downscaling technique, and not to model errors nor to observation limitations. In this talk, we present results of BBEs showing the sensitivity of a RCM to the spatial resolution of the lateral boundary conditions.

7.13 Aad van Ulden, KNMI, de Bilt, Netherland

KNMI activities related to PRUDENCE

Envisaged contribution to PRUDENCE:
RCM experiments: WP 1 and WP 2.

We will use RACMO : Regional Atmospheric Climate Model

Dynamics: HIRLAM

Physics: ECMWF (23R4 = ERA-40 parameterizations)

We will perform:

RACMO control run with ERA-15 boundaries.

RACMO control and scenario run with HadAM boundaries.

Emphasis of our analysis is on:

Precipitation statistics over the Rhine and Meuse river basins.

Wind statistics over the North Sea near the Dutch coast.

PRUDENCE-related activities at KNMI:

Statistical downscaling activities.

Participating persons:

Project leader: Bart van den Hurk, bart.van.den.hurk@knmi.nl

Erik van Meijgaard, erik.van.meijgaard@knmi.nl

Aad van Ulden, aad.van.ulden@knmi.nl

KNMI English home page http://www.knmi.nl/indexeng.html

7.14 W. May, Danish Meteorological Institute, Copenhagen, and R. Voss, Max Planck Institut für Meteorologie, Hamburg

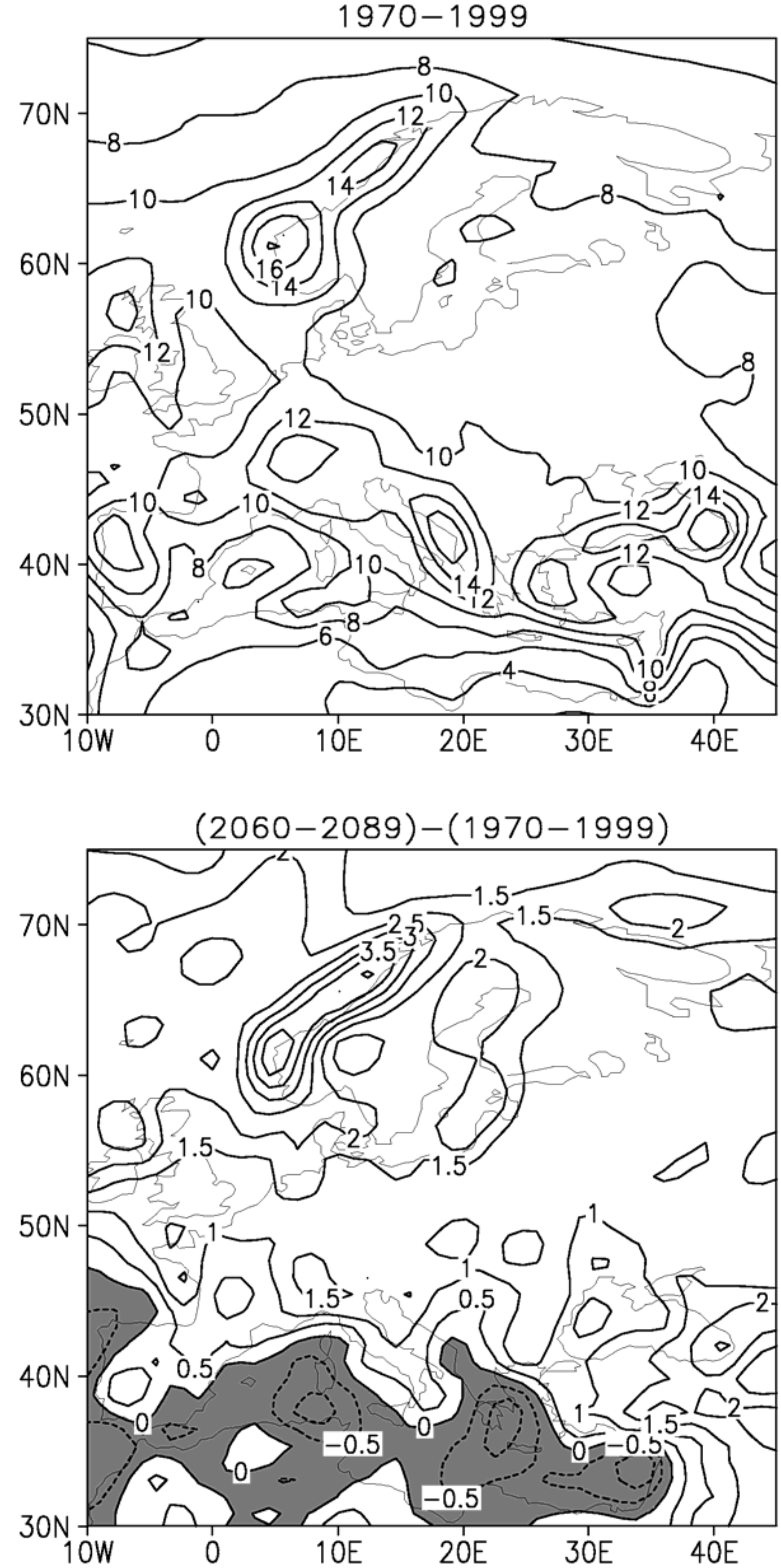
Changes in intense precipitation in Europe under enhanced greenhouse gas conditions in a global time-slice experiment

A time-slice experiment has been performed with the ECHAM4 AGCM at an enhanced horizontal resolution of T106, corresponding to a grid-spacing of about 100 km in the extratropics. The two time-slices cover a period of 30 years each. The first time-slice (period 1970-1999) represents the present-day climate and the second one (period 2060-2089) the climate at a time, when the carbon dioxide concentration in the atmosphere has doubled. In these time-slices the atmosphere has been forced by monthly mean values of the sea surface temperatures, the sea-ice extent and the sea-ice thickness originating from a transient simulation with the ECHAM4/ OPYC AOGCM at a horizontal resolution of T42, corresponding to a grid-spacing of about 300 km. In these simulations, i.e., the time-slice experiment and the coupled simulation, the concentrations of the important greenhouse gases have been prescribed according to observations until 1990 and according to the IPCC scenario IS92a after 1990. A thorough discussion of the changes in the mean climate inferred from the two time-slices as well as an assessment of the impact of the high horizontal resolution for the simulation of the climatic change can be found in *May and Roeckner (2001)* or *May (2001)*. In *May (2001)* I focus on the Atlantic/European area. The paper also includes an evaluation of the simulations of the present-day climate against observational data, and I distinguish between the different seasons.

In this presentation we investigate the predicted changes in the characteristics of intense precipitation as well as of extremes of related meteorological variables (i.e., dry and wet spells) in Europe associated with the climatic changes caused by the increase in the atmospheric concentrations of the important greenhouse gases. This is motivated by the marked environmental and socio-economic impacts of the possible changes in intense precipitation in particular and in climate extremes in general. Some results shown in our presentation can be found in *May et al. (2001)*, while in *Voss et al. (2001)* further details on the statistical methods as well as some related results for the global scale are given.

The main results of our presentation can be summarized as follows: the time-slice experiment predicts an increase in the frequency and/or intensity of heavy precipitation events in Europe for the future (warmer) climate. This is also the case in those areas (i.e., southern Europe), where the total amount of precipitation is reduced in the future. These changes are accompanied by a prolongation of extreme dry spells in the future on the entire European continent except for northern Scandinavia and northern Russia, in particular in western and southern Europe. In the Mediterranean area the dryness will, for instance, make the soil more vulnerable, so that the more intense heavy precipitation events will cause serious erosion in this region. As for extreme wet spells, the time-slice experiment predicts only a minor change for the future climate, with a general tendency of reduced (extended) extreme wet spells in southern (northern) Europe.

As an example, the enclosed figure (Fig. 4 in *May et al. (2001)*) shows the geographical distribution of the 95% percentile of daily precipitation (including all seasons), namely the values for the present-day climate (a) and the predicted change for the future (b). For the present-day climate the simulation reveals large amounts of precipitation associated with heavy precipitation events in areas with strong orographic forcing, such as in southwestern Norway, western Scotland, northwestern Portugal and Spain as well as over the Alps and on the Balkans. As for the future, the time-slice experiment predicts increases in the 95% percentile over the entire European continent. Only over the Mediterranean Sea is the amount of precipitation related to heavy precipitation events reduced. The increases are smallest in the Mediterranean region and largest in northern Europe, in particular in western Norway. In the southwestern part of the country, the 95% percentile is actually increased by more than 25%.



a)

b)

Figure 1: *95% percentile of daily precipitation for the simulation of the present-day climate (a) and b) the change of the 95% percentile of daily precipitation between the simulations for the future and the present-day climate. Units are [mm/day].*

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7.15 R. Laprise, Universite du Quebec a Montreal

Summary of report submitted to WGNE/WGCM by the RCM panel

The Joint Steering Committee noted with interest the WGCM and WGNE reviews of regional climate modelling, and the various points and issues discussed. The JSC itself additionally raised the question of the predictability and reproducibility of the smaller scales simulated in regional climate models. At its twenty-first session in March 2000, the JSC endorsed the establishment of a "joint WGNE/WGCM ad hoc panel on regional climate modelling". The members of this panel are:

R. Laprise (Convener, Universite du Quebec a Montreal, Montreal, Canada),
R. Jones (United Kingdom Meteorological Office, Bracknell, England),
H. von Storch (GKSS Research Centre, Geesthacht, Germany),
W. Wergen (Deutscher Wetterdienst, Offenbach, Germany), and
B. Kirtman (Center for Ocean-Land Studies, COLA, Calverton MD, USA).

The following is a summary of the report recently submitted by the RCM panel to WGNE at their 17th meeting held in Offenbach October 29 - November 2, 2001.

Dynamical atmospheric regional climate models (RCM) have matured over the past decade and allow for meaningful utilisation in a broad spectrum of applications. At horizontal scales of 300 km and larger simulations are consistent with the nesting (driving) data. At fine spatial and temporal scales, the RCM-simulated patterns of important surface variables, such as precipitation and winds, have demonstrable skill. The grid spacing in RCMs is currently limited by available computing resources to about 50 km, which limits the amount of detail available at the finest scales. Future increases in computer power and applications of multiple nesting techniques will allow increase resolutions to grid spacing of order of 1 km; this horizontal resolution will require the use of fully non-hydrostatic models and scale-dependent parameterisations.

It is recognised that RCMs have deficiencies that need to be ameliorated. The sensitivity of RCM-simulated results to computational domain size, to jump in resolution between nesting data and RCM, to errors or deficiencies of nesting data, and to nesting technique, needs further investigation. Research is required in many areas related to the various applications of RCM. The added value provided by regional modelling should be assessed relative to simpler statistical post-processing of coarse-grid data. An assessment of the performance of an RCM requires climate data on much finer spatial and temporal scales than is traditionally used for validating global models. In some regions such data are available but not necessarily easily accessible, and appropriate gridded analyses have not been carried out. Where such data are not available, methods of validation other than comparison with standard climatological variables need to be developed or applied. The performance of different RCMs needs to be compared both in the simulation of current climate and in their use as dynamical downscaling tool to provide high-resolution climate-change information. This is required both to guide future developments in regional climate modelling and to contribute to the assessment of uncertainty in regional climate simulation and projections.

It is stressed that the final quality of the results from a nested RCM depends in part on the realism of the large scales simulated by the driving General Circulation Model (GCM). GCMs remain the ultimate and most sophisticated tool for climate simulations. Hence the reduction of errors, systematic or otherwise, in GCM remains a priority for climate modellers.

7.16 T. R. Carter, Finnish Environment Institute, Helsinki

Developing and applying scenarios

Introduction

The assessment of regional impacts of climate change requires an integrated approach that accounts for concurrent socio-economic and environmental changes acting on multiple sectors and systems. Given the enormous uncertainties associated with estimates of future human behaviour, it is impossible to predict the future with any confidence; rather it is customary to construct "scenarios", which describe plausible future conditions. The environmental changes and impacts that result from these driving factors can then be estimated along a chain of dependencies typified by the well-known IPCC model of socio-economic drivers → greenhouse gas and aerosols emissions → atmospheric concentrations → radiative forcing → climate change → sea-level rise → regional impacts. Uncertainties propagate through each level, and it is a considerable challenge for impact assessors to capture these uncertainties.

The role of non-climate scenarios

The central objective of PRUDENCE is "....to quantify our confidence and the uncertainties in predictions of future climate and its impacts, using an array of climate models and impact models and expert judgement on their performance". Hence, a major focus in on uncertainties attributable to climate projections. However, while there is a range of natural systems and human activities that are sensitive to climate and which are already undergoing observable change, climate change may nevertheless represent only one (perhaps minor) agent of change. The inclusion of impact assessments in PRUDENCE is a useful way of assessing the potential value of the most recent climate projections, but for those impact assessments to have any relevance for policy making, many of them must necessarily consider the concurrent roles of socio-economic, technological and environmental change on future vulnerability, adaptive capacity and likely impacts. A number of ongoing impact studies in Europe are currently addressing this integration question.

Methodological questions in applying climate scenarios

It is important to decide, at an early stage of the project, how climate projections are to be applied in impact studies. Some potentially interesting intercomparison studies would be possible that would need to be partitioned among impact groups, including:

1. Applying direct climate model outputs versus observations to represent the present-day baseline climate;
2. Applying alternative baselines climates from the observational record (e.g. 100-year versus 30-year – this also relates to point 5, below);

3. Comparing direct interpolations of AOGCM outputs versus high resolution AOGCM outputs versus RCM outputs versus statistically-downscaled information;
4. Applying climate projections as changes in long-term means only versus changes in both means and variability (inter-annual variability and, in some cases, daily variability);
5. Comparing the impacts of modelled multi-decadal unforced climate variability (from unforced model simulations) versus the impacts of forced climate change;
6. Comparing the effect of expressing changes in quantities such as precipitation as percentages versus absolute differences.

In addition, different impact groups will need to consider how best to explore the range of uncertainties in alternative climate projections. Some groups will only be able to address a subset of projections; others will have the capacity to consider the full range.

7.17 J.-C. Hourcade and P. Ambrosi Centre International de Resercher sur l'Environment et Developpment, SMASH, Paris

Assessing damages: Is 2% of GDP losses a relevant information?

To date, only three main studies provide an overall assessment of global warming damages, both by world regions and by categories of impacts. These figures – which are expressed as a gain or a loss of GDP - have helped to draw a (rather sketchy) picture of the vulnerability to climate change of economic activities, human settlements and ecosystems. Since then many debates about these data have arisen but they have focused mostly on conflicting methodologies, diverging experts opinions or uncertainties assessments but not on the very notion of climate change damages.

This presentation is aimed at revisiting this notion to point out the pitfalls of debates about damages and help to identify what useful piece of information about impacts is needed in a policy advising perspective.

A clear distinction between impacts and damages

First of all it is important to stress the distinction between climate change *impacts* and climate change *damages*: it is the diffusion of climate change impacts through various pathways involving the environment, economic activities and societies which may induce welfare losses, *i.e.* damages. Hence, climate change damages are not restricted to the consequences on human welfare of variations in agricultural productivity or property loss due to sea level rise but they include more complex phenomena such as retroactions on economic growth and socio-economic development or the depletion of valuable environmental assets. Moreover productivity loss or gain is not an appropriate measure of damage since it does not give an account of the consequences of climate change on populations at risk in terms of welfare variations.

Data and models shortcomings and useful information

Second, existing impacts assessment studies provide only point estimates of the possible consequences of climate change and modellers community has to rely on various assumptions to write down damage functions for integrated assessment models.
Indeed only the consequences of a *changed* climate have been studied by applying a shock on the environment, production activities and human societies but not the consequences of a *changing* climate, moving towards a new equilibrium with unknown risks. In particular, no information is available on the consequences of alternative climate scenarios with a distinctive pace or magnitude of climate evolution signal, nor with evolving climate variability. In the same way, uncertainty ranges are hardly estimated.
Moreover, aggregated damage functions are rather crude tools to represent very complex dynamics like climate change ones: for instance, they fail to give account of high consequences outcomes (like the possible shutdown of North Atlantic thermohaline circulation) or more local discontinuities (like disruption of agriculture or water resources).

It is therefore important to progress in integrated assessment modelling of climate change by improving impacts modelling (climatic stimuli, determinants of vulnerability, shape of the function) and paying attention to the complex links between impacts and welfare.

The aggregation-compensation pitfalls

Last, impacts assessment studies provide regional amounts of climate change impacts and adding up this figures to calculate a world total might seem legitimate. Nevertheless such a practice is misleading because aggregating damages between sectors and regions dilutes climate signals and masks potential local non linearities. Besides aggregating damages between regions comes to assume a compensation hypothesis between winning and loosing regions. Nevertheless, some particularly vulnerable countries may suffer from irreversible (and therefore non compensable) losses forcing people to abandon land and migrate.

It is thus necessary to build a common analytical framework to integrate information coming from a taxonomy of impacts and a taxonomy of damages. The main aim of this heuristic model is to translate physical information from impacts studies into damages in view to identify what matters for short term decision.

7.18 K. Halsnæs, Risø National Laboratory, System Analysis Department

Regional Climate Change Impacts in the EU- Socio-economic Issues and Policy Implications

Improved information about climate change impacts in the EU can provide a basis for more efficient and equitable climate change policy decisions in a number of areas. The scope of PRUDENCE activities in this area will be to identify linkages between climate change impact scenarios for the EU and assessments of how economic and social development priorities can be met efficiently given global climate change and international commitments.

The approach will be to use cost assessment as a tool for developing a comprehensive understanding of the broad socio-economic setting in our region that provides a framework for implementing climate change policies. The output of this activity will be a review of the relationships and potential linkages between economic development and climate change impact scenarios for the EU. Following that, the project will undertake a qualitative assessment of the data requirements and modelling tools needed for the assessment of socio-economic impacts of climate change impacts, and the costs and benefits of adaptation and mitigation policies.

It is beyond the scope of the PRUDENCE project to conduct a full scale quantitative modelling of social economic impacts of climate change that goes all the way from climate modelling output to the assessment of the costs of climate change policies in the EU. Such a comprehensive modelling would require the development of a new generation of European integrated assessment models, that different to existing global models, have a detailed representation of specific vulnerable sectors and economic development trends in the region.

More specifically the project will consider the following issues:

1. Global and EU regional efficiency and equity principles applied to climate change adaptation and mitigation policies.
2. Approaches for transforming physical impact studies for the EU into climate change damages that can be considered in economic studies.
3. Costs and benefits of climate change impacts, and adaptation and mitigation policies in the EU.
4. Evaluation of the impacts of climate change in the EU considering how this would influence different stakeholders, and how these can react to various policy scenarios.

Finally, the activity will conclude with a policy-science dialogue where stakeholders including decisions makers, the private sector, technology developers, and environmentalists are invited to discuss how long term climate change policies in the EU can be linked to current sub-regional and regional economic policies, and how various stakeholders can react through public policies, financing, insurance schemes, and research and development programmes.

7.19 K. Jylhä and H. Tuomenvirta, Finnish Meteorological Institute, Helsinki

Assessing the uncertainties in Impact-relevant changes in climate and weather: seasonal means and daily extremes in Europe

Introduction

The work within the PRUDENCE project, to be conducted by the Finnish Meteorological Institute (FMI) in close collaboration with the Finnish Environment Institute (FEI), comprises four tasks:

(1) To assess the full range of uncertainties in European temperature change attributable to the SRES emission scenarios and climate sensitivities considered by IPCC (WP 2).

(2) To provide gridded climate data required by FEI for analysis of climate change impacts on resource potential in Europe. (WP 4).

(3) To analyse changes in indices of resource risk in using daily climate model outputs and to assess uncertainties in estimated changes, these results to be further processed by FEI (WP 5).

(4) To take part in reporting and dissemination (WP 7).

The data needed in these tasks are to be obtained from PRUDENCE partners and other international sources. In the following, a brief description is given of tasks (1) and (3).

The full range of uncertainties in seasonal temperature projections

A thorough assessment of regional climate change and its impacts requires the full range of plausible future emission scenarios and climate sensitivities to be considered. Although many new aspects concerning climate model uncertainties are covered in the model intercomparison exercises to be carried out in PRUDENCE, these still do not embrace the full range of uncertainties attributable to the SRES emissions scenarios and climate sensitivities considered by the IPCC (Houghton *et al.*, 2001). Since no more than two of the 35 quantified SRES scenarios will be applied, along with a limited range of climate sensitivities from four high-resolution Atmospheric General Circulation Models (AGCMs), it is important to place the model outputs in the perspective of a wider range of emission scenarios and climate sensitivities. This aspect will be addressed using a pattern-scaling method (e.g. Hulme and Carter, 2000; Carter *et al.*, 2000). The method employs a simple climate model (MAGICC - e.g., Smith *et al.*, 2000) in conjunction with patterns of regional climate change from GCMs, and it will be used to provide upper and lower estimates of seasonal mean temperature change in Europe.

Indicators of weather extremes

Potential changes in extreme meteorological conditions and in climate variability in general pose a hazard for human society and ecosystems. Various indicators of weather extremes, or resource risk indices (e.g. consecutive dry days, related to drought risk; number and timing of frost events, important for transport, agriculture and forestry), will be used as simple quantitative measures of the risk involved with climate change. The uncertainties calculated for changes in these indices may serve to identify and describe the uncertainties likely to be met in more detailed impact modelling studies. Computation of the indices requires climate information at a daily time step.

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7.20 T. R. Carter and S. Fronzek, Finnish Environment Institute, Helsinki

Assessing climate related uncertainties in future natural resource potential in Europe

Introduction

The Finnish Environment Institute (FEI) will undertake research for PRUDENCE in collaboration with the Finnish Meteorological Institute (FMI) comprising the following four tasks:

1. Supporting FEI in the design and use of pattern scaling methods for estimating the uncertainty range of regional climate in Europe attributable to the SRES emissions scenarios (WP 2)
2. Preparing a GIS environment for mapping uncertainties in impacts, and conducting scenario analysis using a range of simple models of resource potential (Table 1, top – WP 4)
3. Analysing, interpreting and presenting uncertainties in impacts both of resource potential (task 2) and of resource risk (research by FMI – Table 1, bottom) (WP 4/WP 5)
4. Contributing to the preparation of the Final Report to the Commission (WP 7)

Table 1: Impact models and indices to be applied in uncertainty analysis

Index	**Description (and impact sector)**	**Resolution of climate data**	
		Temporal	**Spatial**
1. Resource potential			
Thermal growing season	Temperatures above 5°C (agriculture, natural ecosystems)	Monthly/ daily	Grid
Accumulated temperature	Growing degree-day requirements for crops (agriculture)	Monthly	Grid
	Heating degree-days (energy)	Monthly	Grid
	Cooling degree-days (energy)	Monthly	Grid
Potential biomass	Lieth model (ecosystems)	Annual	Grid
Potential vegetation	Holdridge life zones (natural vegetation)	Monthly	Grid
Wind potential	Wind speed (energy)	Monthly	Grid/site
Baltic sea ice	Annual maximum extent of sea ice cover based on temperature (transport, marine life)	Monthly	Grid
2. Resource risk			
HWDI (Heat wave duration index)	Longest period >5 consecutive days with Tmax >5°C above the 1961-90 daily Tmax normal (health)	Daily	Grid/site
CDD	Maximum number of consecutive dry days (Rday < 1mm) (agriculture)	Daily	Grid/site
R5D	Maximum 5-day precipitation total (water resources)	Daily	Grid site
FD (frost days)	Total number of frost days (Tmin<0°C) (ecosystems, transport)	Daily	Grid/site
Frost-free season	Dates of first and last frost (ecosystems, transport)	Daily	Grid/site
Snow season	Total number of days with snow depth < 20 cm (recreation/tourism)	Daily	Grid/site

7.21 Mínguez, M. I., Ruiz-Ramos, M., Díaz-Ambrona C. H., Quemada, M., Universidad Politécnica, Madrid and Sau, F., Universidad de Santiago de Compostela, Spain

UniPM: Uncertainties of impact assessments

The uncertainties of impact assessment made by crop simulation models under current observed climate will likely increase when applied to climate change. These current uncertainties arise because while models are calibrated on well-managed experiments, production, water use, crop rotation management at the farm level are generally less precise. Also, effects of pests, diseases, and non-optimal management are not taken into account in most modelling procedures. The quality of the input data for the models may also be questioned as, for instance, weather, soil properties, and management details may be unavailable for some sites. The up-scaling from sites to regions exacerbates these problems. In our work, we have attended to these problems by using representative soils and management techniques (e.g. cultivars, sowing dates, fertilisation rates, crop sequences).

Under climate-change scenarios, uncertainties increase because the complete crop response to elevated CO2 is not well known. Studies are showing the complexity of responses: root growth may be enhanced under drought conditions leading, in some cases, to a greater resistance to water stress, canopy photosynthesis may not be increased uniformly over the crop growing season, and high temperatures may reduce radiation-use efficiency. Furthermore the effects derived from better on-farm management are not usually considered in the models.

UniPM (partner 11) will apply the cropping systems simulation model CropSyst (Stöckle and Nelson, 1998) and the CERES models within the DSSAT (Tsuji et al., 1994), for simulation of biomass production, development and growth, yield, evapotranspiration, and irrigation requirements of crops representative of current rainfed and irrigated cropping systems. Other crop models could be considered. The procedure will be similar to our previous work described in Guereña et al., 2000). The models will also be used to analyse sustainability of crop rotations in long term simulations for a range of soils typical of the main agricultural areas (Díaz-Ambrona and Mínguez, submitted). The models are currently being used for drought-impact studies and for sustainability analysis for current weather conditions in the semiarid areas of the Iberian Peninsula. The choice of sustainability indicators will be an important issue in this study.

Using crop and system models fed with the outputs from the various climate models, our group will analyse the variability of crop performance and sustainabilty to establish possible trends under climate change. This spatial and temporal application of the crop models will allow us to establish if the effects of the climate uncertainties will be attenuated or enhanced when transferred to production, water use, and sustainability.

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7.22 J. E. Olesen, Danish Institute of Agricultural Sciences, Foulum, Denmark

DIAS contribution to PRUDENCE

DIAS will apply the DAISY soil-plant-atmosphere model for simulation of crop growth and nitrogen turnover in soil and plants and for estimation of losses from the agricultural system. The DAISY model has been extensively tested internationally on datasets from long-term field experiments and always ranked amongst the models giving the most realistic performance (Hansen et al., 1991; Jensen et al., 1997; Smith et al., 1997; Hansen et al., 1999).

The model will be applied to a crop rotation typical for arable farming in Denmark (Table 3). The crop rotations consist of winter and spring cereals and oil seed crops. The three crop rotations vary in proportion of spring sown crops, which is considered as one of the possible adaptive responses to climate change. The other adaptive response to being tested is the use of catch crops, which is taken to be an undersown ryegrass crop. All crop rotations will therefore be tested with and without catch crops.

Three soil profiles has been selected covering the range of soil types relevant for Denmark (Table 1). Two climate stations representing major differences in Danish climate will be used initially (Table 2). The model requires the following daily climate data as input:

- Mean daily temperature
- Rainfall
- Global radiation
- Potential evapotranspiration, which will be estimated using the Makkink formula (Aslyng and Hansen, 1982)

The ability of the model to realistically simulate responses to change in fertiliser N rates, atmospheric CO_2 concentration and temperature and rainfall will be initially tested by sensitivity analyses using the following response levels shown in Table 4. Data from the climatic stations from 1970-2000 will be used in the initial sensitivity analyses. The model will thus be run for 40 years with current or changed climate data. Initially an 8-year (2 courses of the rotations) initialisation of the model will be used.

The sowing date will be prescribed to assume some adaptation to climate change (Olesen et al., 2000). The winter cereals will be sown on a fixed date. The sowing date will be set 5 days later for each 1°C increase in mean temperature. For winter rape a fixed sowing date will be used throughout all scenarios. For spring cereals the sowing date will be determined from a temperature sum and a soil water content criteria.

Irrigation will be applied on the sandy soil according to the principles of the MarkVand irrigation scheduling programme (Plauborg et al., 1996). Only 15 mm will be applied in each irrigation.

The model results will be evaluated with respect to

- Yields (dry matter and N of both grain and straw) of individual crops
- C and N in returned crop residues
- Date of sowing and maturity of the individual crops
- Irrigation (only on the sandy soil)
- N-leaching and denitrification for the entire crop rotation calculated for the period April to April
- Total N and C in the soil profile
- Nitrous oxide emissions will be calculated based on the IPCC (2000) methodology

The results of the sensitivity analyses will be compared with responses reported in literature.

The responses of crop production, nitrogen use and nitrogen losses to the range of climate change scenarios for 2071-2100 delivered by WP1 and WP2 will be analysed. The responses will be simulated for the three soil types in Table 1 and the two climate stations in Table 2. The climate change scenario data will be used to parameterise a weather generator (Semenov and Barrow, 1997), which will then be used to generate 50-100 years of climate data to estimate effects of climate change. A smaller range of regional climate change scenarios (3-5) will subsequently be selected to estimate effect of adaptive responses separately for the three soil types.

Table 1. Soil types and main soil texture (g/kg) of the top 25 cm of soil profiles selected.

Soil type	Profile name	Clay	Silt	Fine sand	Coarse sand	OM
Sand	Jyndevad	4.1	3.8	20.4	69.4	2.3
Loamy sand	Foulum	7.7	9.9	46.0	33.9	2.5
Sandy loam	Rønhave	14.2	15.3	60.0	8.4	2.1

Table 2. Normal climatic variables for the period 1961-90 at the two climate stations selected (Olesen, 1991).

Climatic variable	Jyndevad	Roskilde
Geographic location	54°54'N 9°46'E	55°37'N 12°03'E
Mean temperature, annual (°C)	7.9	7.6
Mean temperature, January (°C)	0.1	-0.7
Mean temperature, July (°C)	15.7	15.9
Rainfall, annual (mm)	859	586
Pot. evapotranspiration (mm)	554	573

Table 3. Arable crop rotations to be tested with and without catch crop. Undersown ryegrass is used as catch crop. The straw from fields 1 and 2 will be incorporated, whereas the straw from fields 3 and 4 will be removed.

Catch crop	Field	Rotation 1	Rotation 2	Rotation 3
Without	1	Winter barley	Winter barley	Spring barley
	2	Winter rape	Spring rape	Spring rape
	3	Winter wheat	Winter wheat	Winter wheat
	4	Spring barley	Spring barley	Spring barley
With	1	Winter barley	Winter barley/grass	Spring barley/grass
	2	Winter rape	Spring rape	Spring rape
	3	Winter wheat/grass	Winter wheat/grass	Winter wheat/grass
	4	Spring barley	Spring barley	Spring barley/grass

Table 4. Response levels used in initial sensitivity analyses.

Variable	Level changes
N fertiliser	-10%, recommended, +10%, +20%
CO_2 concentration	Current, +25%, +50%
Temperature	Normal, +2°C, +4°C
Rainfall	-20%, normal, +20%

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7.23 M. Beniston and S. Goyette, University of Fribourg

Shifts in extreme climatic events and implications for severe impacts

While change in the long-term climatic mean state will have many important consequences, the most significant impacts of climate change are likely to come about from shifts in the intensity and frequency of extreme events.

Regions now safe from catastrophic wind storms, heat waves, and floods could suddenly be vulnerable. It seems appropriate, therefore, considering the environmental, human and economic costs exerted by extreme climatic events, to address the problem of whether there may be significant shifts in extremes of wind, precipitation or temperature in a changing global climate.

A regional climate modeling system used at the University of Fribourg (the Canadian Regional Climate Model - CRCM-2) will complement the models applied to the PRUDENCE project in order to enhance the potential for understanding the processes underlying extremes, their inception, amplification, and duration. A further scope of the Fribourg contribution will be to contribute to international efforts in the assessment the impacts of changing extreme events on a number of key environmental and economic sectors, such as the Alpine cryosphere, mountain ecosystem response, health, and agriculture. The impacts studies will be achieved through collaborative actions with European experts in these domains.

7.24 B. Rockel and K. Woth, GKSS Research Center (Institute for Coastal Research), Geesthacht

Modelling activities at GKSS

GKSS contributes with two models to the PRUDENCE project:

- the regional atmospheric model LM (Lokal-Modell) and
- the stream model TRIM3D

The LM will be one of the models taking part in the regional atmospheric climate simulation on a grid with 50km horizontal resolution. Since the LM has been originally developed for short range weather forecasts (by the German Weather Service) it had to be adapted for longer time scales. A first version of the climate version of the LM has been put together at the PIK (Potsdam Institute for Climate Impact research).

The LM is non-hydrostatic and can therefore be used for simulations with very high resolutions (< 10km) on regional areas. However, at present nearly all physical parameterisations are the same as in the old "Europamodell", which was run routinely with a resolution of about 55km.

The TRIM3D will lay the main part in the GKSS contributions to PRUDENCE. TRIM3D has been developed at the University of Trento. It is a stream model and will be used in PRUDENCE to simulate storm surges in the North Sea. For TRIM3D the wind velocities near the sea surface calculated by atmospheric models in PRUDENCE will be used as boundary conditions. Thus for each of the atmospheric models separate statistics will be produced. TRIM3D is based on the 3D Navier-Stokes equations and can be run in non-hydrostatic mode. Required input is:

Initial data for TRIM (covering the North Sea)	
mean water-level	
Boundary data for TRIM (covering the North Sea, 6 hourly)	
at the ocean-atmosphere interface	
U_10M	10metre U-velocity
V_10M	10metre V-velocity
PS	Surface air pressure
at the ocean-ocean interface	
	water-level
at the ocean-land interface	
	freshwater inflow
	tidal-coefficients

TRIM3D calculates water level, salinity and water current velocities. To save computing time the salinity will only be calculated within this project, if it is needed by other partners.

7.25 M. T. Sykes and P. Morales, University of Lund, Sweden

Modelling climate impacts on forest landscapes and ecosystem processes using the LPJ modelling framework.

The modelling of processes within ecosystems has developed in different ways. Continental scale descriptions of equilibrium potential vegetation were simulated using biogeography models of the type of BIOME (Prentice et al. 1992). At the same time biogeochemistry models e.g. Century (Parton et al. 1994) were developed to simulate biogeochemical fluxes through the system. These approaches were combined in the development of biogeography–biogeochemistry models which not only predict potential vegetation equilibrium distributions but net primary production (NPP) and leaf area index LAI (e.g. BIOME 3: Haxeltine & Prentice 1996). More recently, a number of different approaches have allowed vegetation dynamics and biogeochemical fluxes at the global and continental scale to be modelled. The Lund-Potsdam-Jena model (LPJ) (Sitch 2001, Sitch et al., in prep), a dynamic global vegetation model, simulates interactions between ecosystem structure e.g. plant functional type, vegetation height and biomass; and ecosystem functions such as carbon and water fluxes based on the BIOME3 linked carbon-water architecture (Haxeltine & Prentice, 1996). Vegetation dynamics in large-scale application are represented in a parameterized way that captures the essentials of processes simulated by individual-based models such as self-thinning, gap-phase dynamics (Smith et al., 2001). Natural disturbance by fire is expressed as a probability, determined by fuel availability and moisture content (Thonicke et al. 2001). LPJ-DGVM was used with others in the recent IGBP-GCTE intercomparison project (Cramer et al. 2001) and utilised in CO_2 scenario calculations (Joos et al., in press) for the 3rd Assessment Report of the Intergovernmental Panel on Climate Change.

LPJ-DGVM forms part of the new and innovative approaches to modelling vegetation dynamics and biogeochemistry using modular structures pioneered within the EU FP4 ETEMA project co-ordinated from Lund. Alternative process modules can be coupled within a common framework, allowing simulations at different scales and different complexities. This approach is combined within a modular C++ implementation of LPJ (Sitch, 2000, Smith, et al. 2001,) for regional to continental scales and a generalised ecosystem model (LPJ-GUESS) for finer scales such as landscapes or forest patches (Smith, et al. 2001).

LPJ-GUESS.(Smith et al. 2001) is the formulation on the LPJ C++ platform that is to be used in PRUDENCE. It operates both at the landscape scale and for the European grid. It simulates the growth of individuals on a number of replicate patches (within a grid cell), corresponding in size approximately to the maximum area of influence of one large adult individual (usually a tree) on its neighbours. Patches are spatially independent that is, plants on different patches do not affect one another in respect of light or uptake of water. However, patches are close enough together to share a common propagule pool, establishment of new saplings of each PFT after initial colonisation being directly related to the reproductive output of all individuals of that PFT the previous year. Each woody individual belongs to one PFT (c.f. taxon), with its associated parameters controlling establishment, phenology, carbon allocation, allometry, survival response to low light conditions, scaling of photosynthesis and respiration rates, and the limits of the climate space the PFT can occupy. Individuals are not distinguished for grasses. A layer of grass at ground level in each patch is treated as two "individuals" — one each with the C3 and C4 photosynthetic pathways. Each grass is represented by patch totals of leaf and root carbon. Partitioning of assimilated carbon is done according to the balance between water and light limitation, as for trees. Model formulations of establishment and mortality are based on those employed within the "forest gap" model FORSKA (Leemans & Prentice, 1989; Prentice *et al.*, 1993).

In PRUDENCE we plan to use LPJ-GUESS to predict an envelope of responses to climate change in a number of European forested landscapes by simulating the distribution, dynamics and biomass of the forest vegetation and the ecosystem processes. This will be done using present and future climatic parameters derived from the regional climate models (RCM) and their SRES scenarios (time series climate data of monthly mean temperature, precipitation and sunshine).We will also use the ecosystem model as a means to compare and assess the different RCM outputs and their various SRES scenarios. We will drive the model using the CRU 1901-2000 gridded time series climate dataset to simulate current forest composition, biomass, NPP, carbon storage in a number of natural and semi-natural forested regions. Modelled results from selected regions in Europe will be compared to available forestry inventory data on biomass etc from selected forested landscapes as a means of validating model output. Modelled carbon and water fluxes will be compared to the long term measurements of fluxes carried out under the EU funded EUROFLUX project (from 1994) at selected forest sites in Europe as another way of validating the ecosystem model and its processes. The simulations will be then projected forward to 2071 using the modelled climate data from available GCMs e.g. Hadley, MPI/DMI models. Simulations 2071-2100 will be done using the full range of anomalies produced from the different regional climate scenarios including the various SRES scenarios. Simulations will be carried out both at the different forest sites within Europe and in selected EUROFLUX sites used under the present climate. Vegetation and fluxes between 2071 and 2100 will be compared with present-day simulations and data. Interpretation of the different results obtained by using the range of RCMs and their scenarios at the different forestry and EUROFLUX sites will be done in terms of the strengths and weakness of each RCM and their SRES scenarios.

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7.26 J. Palutikof, Climatic Research Unit, University of East Anglia

Climate extremes in the Mediterranean in a warmer world

Abstract

The Mediterranean region already experiences extremes of heat, drought and intense rainfall which have the potential to destroy property, to cause crops to fail and to take human lives. These three types of extreme, and the changes in their occurrence in a future warmer world, will be studied by UEA as part of the PRUDENCE project. In particular, we will emphasise the following:

- *Heat stress* in southern Spain, Italy and Greece is already a cause of excess deaths during summer extreme spells. Although acclimatisation will play a role in the future, it is likely that in the very hottest regions of Europe, such as these, the death toll due to heat stress will rise in response to global warming.
- *Occurrence of drought.* It is not only agriculture which is affected by drought, but also economic activities such as tourism. It is already the case that water resources are stressed in the summer season as holidaymakers flock to the beach hotels of the Mediterranean. Saline incursion into coastal aquifers is already a problem.
- *Intense rainfall.* Flash floods in the region have caused devastating damage to property and fatalities.

The first task will be to define the climate extremes we intend to study. Clearly, we will need to work at the daily scale. However, taking the example of temperature, it is not enough to study the hottest day in the month. The duration of a hot spell, and the number of hot spells, are also important contributing factors to deaths from heat stress. It is likely that derived indices, such as degree-days, will be important. Equally, for rainfall, it is not simply the daily amount which is important. Spell length, for drought, and antecedent conditions, for intense rainfall, must also be taken into account.

The PRUDENCE project provides the following opportunities for research into the impacts of climate extremes:

1. Evaluation of the performance of regional climate models in simulating extremes of the distribution of the two climate variables of interest, daily temperature and rainfall. These two provide an interesting contrast: whereas temperature is widely accepted as being reasonably-well simulated by climate models, the same cannot be said for rainfall.
2. Evaluation of future changes. Past studies at UEA have looked at changes in extremes linked to global warming, using statistical downscaling procedures from the Hadley Centre model. It will be of interest to compare the predictions from the regional climate models used in PRUDENCE.

7.27 J. Kleinn, C. Frei, J. Gurtz, C. Schär, P. L. Vidale, Climate Research ETH (Eidgenoessische Technische Hochschule), Zürich

Coupled Climate-Runoff simulations: a process study of current and a warmer climate in the Rhine basin

The consequences of extreme runoff and extreme water levels are within the most important weather induced natural hazards. The question about the impact of a global climate change on the runoff regime, especially on the frequency of floods, is of utmost importance.

In winter-time, two possible climate effects could influence the runoff statistics of large Central European rivers: the shift from snowfall to rain as a consequence of higher temperatures and the increase of heavy precipitation events due to an intensification of the hydrological cycle. The combined effect on the runoff statistics is examined in this study for the river Rhine. To this end, sensitivity experiments with a model chain including a regional climate model and a distributed runoff model are presented. The experiments are based on an idealized surrogate climate change scenario which stipulates a uniform increase in temperature by 2 Kelvin and an increase in atmospheric specific humidity by 15% (resulting from unchanged relative humidity) in the forcing fields for the regional climate model.

The regional climate model CHRM is based on the mesoscale weather prediction model HRM of the GermanWeather Service (DWD) and has been adapted for climate simulations. The model is being used in a nested mode with horizontal resolutions of 56 km and 14 km. The boundary conditions are taken from the original ECMWF reanalysis and from a modified version representing the surrogate scenario. The distributed runoff model (WaSiM) is used at a horizontal resolution of 1 km for the whole Rhine basin down to Cologne. The coupling of the models is provided by a downscaling of the climate model fields (precipitation, temperature, radiation, humidity, and wind) to the resolution of the distributed runoff model. The simulations cover the five winter seasons 1989/90 till 1993/94, each from November until January.

A detailed validation of the control simulation shows a good correspondance of the precipitation fields from the regional climate model with measured fields regarding the distribution of precipitation at the scale of the Rhine basin. Systematic errors are visible at the scale of single subcatchements, in the altitudinal distribution and in the frequency distribution of precipitation. These errors only marginally affect the runoff simulations, which show good correspondance with runoff observations.

The presentation includes results from the scenario simulations for the whole basin as well as for Alpine and lowland subcatchements. The change in the runoff statistics is being analyzed with respect to the changes in snowfall and to the fequency distribution of precipitation.

7.28 L. P. Graham, M. Gardelin, B. Carlsson, J. Räisänen, S. Bergström, Swedish Meteorological and Hydrological Institute /Rossby Centre, Norrköping

Modeling climate change impacts on hydrology at SMHI/Rossby Centre: a starting point for PRUDENCE

Modeling the hydrological impacts from climate change scenarios is carried out at both the Rossby Centre and the Research and Development Unit of SMHI. Work at the Rossby Centre focuses on large scale hydrological modeling while the research unit focuses on basin and river scale modeling. The HBV hydrological model is used on all scales for the impact simulations. The analyses performed to date were based on simulations from the Rossby Centre regional atmospheric climate model (RCA).

The “delta change” approach was used for all simulations carried out thus far. This implies that only the differences between climate model control and scenario simulations are used to transfer the signal of climate change into hydrological models. These differences in variables are used to modify a database of the existing climate, which is then used as a proxy for the future climate. This approach has been applied directly for temperature and precipitation. It has also been applied indirectly to evapotranspiration for some simulations.

Although many hydrological simulations have been performed under SWECLIM, they were all based on results from only two different GCMs driving the RCA model. Other differences in the simulations include different versions of RCA, variations in the delta change interface between climate and hydrological models, and variations in the hydrological models. Results indicate significant differences, depending on the GCMs driving the RCM as well as how the changed climate is represented in the hydrological models.

There are many uncertainties associated with this approach, ranging from the basic scenario assumptions of the global models to calibration of the hydrological models. A drawback of the delta change approach, as it has been applied here, is that changes in extremes are not properly represented. The extreme events in the existing climate are simply adjusted upward or downward according to the scenario changes applied. However, as only 10-year climate simulations were used, the ability to analyze extremes from these simulations is questionable.

Within PRUDENCE, we will improve our hydrological models for the Baltic Basin and the River Luleälven, and further develop the interface with the climate models. Among others, the increased variability from the 30-year climate simulations will be analyzed to account for changes in extremes. These models will then be used to assess the potential impact of future climates for the Nordic Region at both continental and river basin scales. A number of climate scenarios produced in WP1 will drive the hydrological impacts analyses. The Baltic Basin model will also be forced with results from climate model control simulations to assess the ability of the climate models to represent the hydrological processes of the present climate.

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7.29 D. Heimann and M. J. Costa Zemsch, German Aerospace Centre (DLR), Oberpfaffenhofen

Statistical-dynamical methods in regional climate assessments

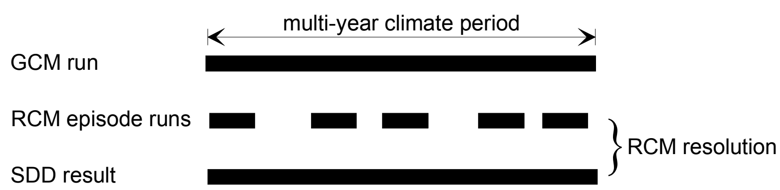
Abstract

Nested multi-year regional climate simulations are rather expensive in terms of computational effort. Statistical-dynamical methods can significantly reduce this effort without reducing the accuracy of regional climate predictions too much. Statistical-dynamical methods are based on large-scale weather-type (circulation pattern) classifications and statistical relationships between weather-types and regional climate elements.

During the preceding EU projects (Regionalization, RACCS, and MERCURE) the following methods were developed:

- Statistical-dynamical downscaling SDD [1], [2], [3]
- Statistical-dynamical extrapolation SDE [4]

SDD approximates a regional climate of a multi-year period by a limited number of regional-scale multi-day episode simulations using a RCM. Each episode is representative of a large-scale weather-type. The results of the RCM episode simulations are weighted by the frequency of occurrence of the respective weather-type class. The frequencies are determined from a GCM simulation that covers the climate period of interest.



[1] Fuentes U., Heimann D, 2000: An improved statistical-dynamical downscaling scheme and its application to the Alpine precipitation climatology. Theor.Appl.Climatol., 65, 119-135.
[2] Heimann D., Sept V., 2000: Climatic change estimates of summer temperature and precipitation in the Alpine region. Theor.Appl.Climatol., 66, 1-12.
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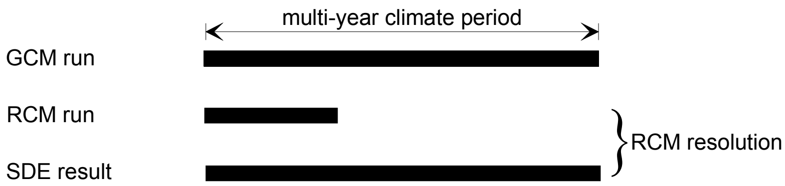
SDE prolongs the validity of a consecutive RCM climate run that covers only a fraction of a climate period that was simulated by a GCM. Again the GCM result of the full period is disaggregated into weather-type classes. Relationships between large-scale weather-types and regional-scale events are derived from the overlapping RCM and GCM time-series. The regional climate of the full period is approximated by re-weighting the weather-type specific RCM results according to the changes in the frequency distribution of weather types between the overlapping period and the full period.



Statistical-dynamical methods can also be used to evaluate nested long-term RCM runs with respect to the effect of changing large-scale circulation patterns on the regional climate.

7.30 J. E. Olesen, Danish Institute of Agricultural Sciences, Foulum, Denmark

Use of weather generators in PRUDENCE

The outputs of global general circulation models (GCMs) and higher-resolution limited area models (LAMs) are often restricted in their usefulness for many subgrid scale applications by their coarse spatial resolution and the uncertain reliability of their output on timescales of months or less, especially for variables related to hydrology or biological impacts (Wilby *et al.*, 1998). This is related both to changes in absolute values and changes in variability when the model outputs are compared with observed surface variables (e.g. for temperature and rainfall). Many of the processes in the impact models are non-linear in their nature (Semenov and Porter, 1995). Changes in both absolute values and in variability can therefore be critical to the use of GCM/RCM model output (Barrow *et al.*, 1996).

Some sort of downscaling of the GCM/RCM data will often need to be performed, and weather generators are often applied for this (Semenov and Barrow, 1997). There are several reasons for applying weather generators:

Weather generators can simulate changes in climatic conditions by supplying data on change in mean and variability of weather parameters (i.e. simple to use).

Weather generators can provide a long series (>100 years) of inherently consistent weather data, which may be needed to properly estimate the impact of changes in climatic conditions.

The weather generators work by initially calculating a series of wet and dry days, and thereafter estimate rainfall, temperature etc. depending on dry/wet days and including autocorrelation of the weather variables.The weather generators vary in the methodology used to simulate the climate, especially with respect to precipitation. The first-order Markov chain models of precipitation implemented in weather generators like WGEN (Richardson and Wright, 1984) have been found to adequately simulate the climate of many sites (Semenov *et al.*, 1998; Wilks, 1999). However, this methodology may be too simplistic under certain climatic conditions, where the use of lengths of dry/wet spells may give a more appropriate description of the climatic conditions for use in weather generators (Semenov *et al.*, 1998; Wilby *et al.*, 1998).

There is an opportunity in PRUDENCE to evaluate the effect of and the need for downscaling RCM model data for a range of impact analyses (see Fig. 1). This opportunity should be seized. Weather generators play an important role in this evaluation of downscaling methodology.

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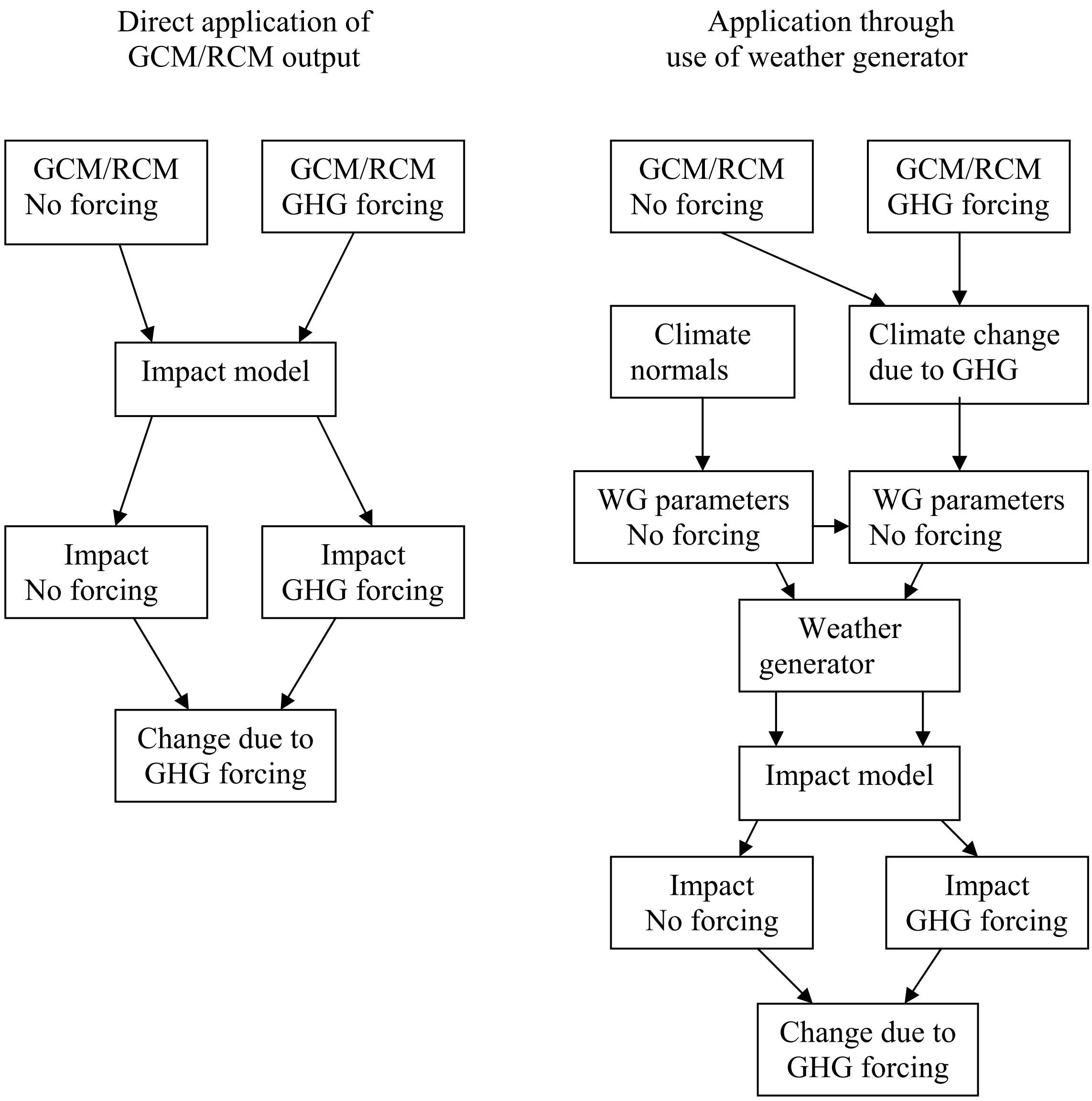

Figure: Two alternatives for applying GCM/RCM data in impact analyses.

7.31 M. Lange, University of Münster, Germany

Introducing Integrated Regional Impact Studies (IRIS)

Background/ Rationale

The realisation that man is appreciably altering the Earth system has caused concern by scientists, political decision makers and the public and has lead to a number of international conferences and negotiations aimed at mitigation measures such as the *United Nations Framework Convention on Climate Change* (UNFCCC). However, these measures gain only gradually acceptance and momentum. A possible explanation for the slow progress likely lies in a lack of broad public understanding of the **concrete consequences** of global changes for a **particular country or region**. *Integrated Regional Impact Studies* aim to address this problem by

- focusing on a specific region, thus accounting for the specific non-uniform manifestations of global changes and for the need to address issues of concern to the public at large
- and by adopting an interdisciplinary approach to the assessment of global changes which gives equal weight to social- and human sciences on the one hand and natural sciences on the other.

Integrated assessment

As to the latter issue, *Integrated Assessment* (IA) can be considered an adequate tool to address this challenging task. It comprises the process of combining, interpreting and integrating of various information and of informing about and communicating knowledge and results to a wide audience. This process involves various stakeholders such as scientists, political decision makers, private enterprises and the interested public at large.

IA provides a conceptual framework that enables the integration of knowledge from a wide variety of disciplines and sources and strives to reach the following goals:

- a comprehensive and co-ordinated exploration of future projections of human and natural systems;
- the provision of information and background to key questions of policy formulation;
- a specification of priorities on research needed to enhance the ability to specify robust policy options.

Integrated assessment modelling

In order to describe **quantitatively** the functioning of cause-effect relationships within a particular part of an overall system (e.g., a particular ecosystem within the biosphere or a certain economic sector within a national economy) through appropriate tools and to quantify the interrelationships and dependencies between these parts *Integrated Assessment Models* (IAMs) have been developed. To construct and carry out an IAM represents a significant challenge, which requires a balance between simplicity and complexity, aggregation and realistic prognosis, stochastic and deterministic elements, qualitative and quantitative linkages and between transparency and uncertainty. While serious attempts are underway to construct an integrated model of the global system as a whole, such models are currently hardly feasible. Thus, simpler versions of such models (meta-models, reduced-form models) have been constructed. They are based on a single mathematical framework that harmonises aggregation levels, spatial and temporal scales and data as well as various other characteristics. It is to be noted that the interpretative and instructive value of an IAM is far more important than its very limited predictive capability. Thereby, IAMs of climate change attempt to offer a picture of the processes relevant to global change and should not be assumed to be comprehensive by any means.

However, IAMs provide a number of distinct advantages:

- they enable the exploration of interactions and feedback between various elements of the system/process considered;
- they comprise flexible and rapid simulation tools and allow swift prototyping of new concepts and an exploration of their implications;
- they point out counterintuitive results that may arise from the interstices of the science elements incorporated in the modelling;
- they also provide valuable tools for communication among scientists of various disciplines as well as of between scientists and the public or political decision makers.

IRIS and Regional Integrated Assessment Modelling

IA and IAM represent valuable tools for dealing with global/ climate change on a **global scale**. However, global climate changes show distinctly **regional manifestations**. Therefore, in order to carry out an IRIS, IA and IAMs have to be complemented by similar studies on a regional scale. The latter have been called *Regional Integrated Assessment Models* (RIAMs).

The major goal of an IRIS/IAM is to provide insight into the ways that locales or regions contribute to or are affected by climate change.

Three basic concepts are central to an IRIS:

Sensitivity: What is the individual and collective sensitivity of an environmental or socio-economic sector to change?

Adaptability: To what extent is an environmental or socio-economic sector capable to adjust to changes?

Vulnerability: What is the remaining disturbance of an environmental or socio-economic sector to a given change?

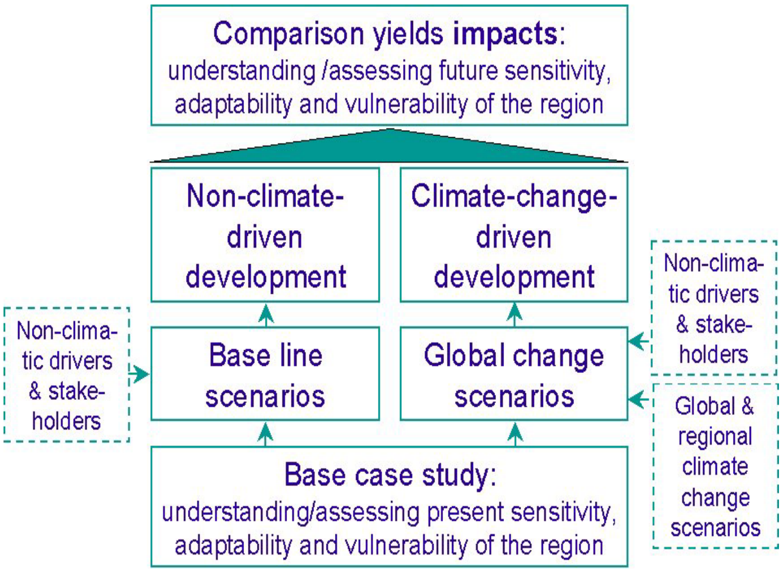

Figure 1: Basic methodology of an IRIS; please note the explicit involvement of stakeholders in the development of scenarios

The assessment of future vulnerability to global climate change in a given region can be considered one of the key objectives of an IRIS. The basic methodology of an IRIS is given in Figure 1.

IRISs in the Arctic

Climate changes are expected to be enhanced in the Arctic compared to the rest of the world. This is due to a number of factors, including:

- arctic ecosystems are particularly sensitive to shifts in physical/chemical conditions;
- impacts on the productivity of terrestrial and marine ecosystems will affect important resource-dependent economic sectors;
- arctic communities rely on natural resources, particularly those still practising subsistence life styles.

These factors underline the need to assess the possible impacts of climate change in the Arctic. So far, mainly three studies, designed as IRIS, have been/are undertaken: the *Barents Sea Impact Study* (BASIS), the *Bering Sea Impact Study* (BESIS) and the *Mackenzie Basin Impact Study* (MBIS).

IRIS and stakeholders

A major challenge of an IRIS lies in the specification of economic and social costs of impacts and the benefits of adaptation measures. In order to pursue adaptation options in an appropriate manner, the importance of stakeholder participation in impact studies needs to be recognised. This can be achieved (among other formats) through the formation of a joint scientist-stakeholder steering committee. Such a committee/collaborative should be involved in all phases of an IRIS. The advantages of such a collaborative comprise:

- an opportunity for stakeholders to gain some ownership of the study;
- the encouragement of interdisciplinary approaches to research;
- the provision of common ground for linking scientific expertise and stakeholders' knowledge;
- the enabling of better description of indirect/ implications of climate change, which may be more costly than direct impacts.

However, the involvement of stakeholder is not without challenges. The involvement of stakeholders may become difficult, when the study region comprises more than one country, each with a different social/political/economical background. In this case, language and the cultural heritage of the populations involved represents a major problem. Moreover, stakeholders have widely differing interests/motivations to get (or not to get) involved into an IRIS. In addition, because of their different backgrounds, stakeholders will have their 'own agenda', which needs to be integrated into the overall study design.

RIAM in BALANCE

The planned IRIS BALANCE (*Global Change Vulnerabilities in the Barents Region: Linking Arctic Natural Resources, Climate Change and Economies*) aims to carry out a regional integrated impact model. The major components of the RIAM in BALANCE comprise:

- a regional climate model, which provides climate scenarios based on results of a global climate model;
- a model package aimed to capture processes in the terrestrial ecosystem;
- a model package aimed to capture processes in the marine ecosystem;
- (empirical) models of three important natural-resource-dependent economic sectors in the study region.

More specifically, the elements of the RIAM in BALANCE can be characterised as follows:

- model packages A and B provide information on the available natural resources from terrestrial and marine ecosystems as well as changes in land surface characteristics (vegetation, albedo), furthermore, they yield clues as to the terrestrial and marine CO2-budget;
- the economic models capture changes in socio-economic parameters as a consequence of climate change in the study region;
- the results of the integrated modelling (CO2-emissions/ sinks; modified land use; changes in vegetation cover) of a model run are utilised as boundary condition for the regional climate model in the following run; the overall result as being obtained after a multiple iteration of the complete model runs.

Conclusions

Integrated assessments (IAs) and integrated assessment modelling (IAM) provide useful tools for the study of possible climate change impacts on a global scale. Integrated regional impact studies (IRISs) and regional integrated assessment models (RIAMs) are needed to complement IA and IAM on a regional to sub-regional scale. IRISs should explicitly strive to involve stakeholders in the analysis through various mechanisms, e.g., a scientist – stakeholder collaborative. RIAMs, while potentially useful tools for an IRIS are still in their infancy and need considerable additional work.

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9. LIST OF PARTICIPANTS

Philippe Ambrosi
SMASH, CIRED
45 bis Avenue de la Belle Gabrielle
F-94 736 Nogent-sur-Marne
FRANCE

Tel. +33 1 43 94 73 74
Fax +33 1 43 94 73 70
Email ambrosi@centre-cired.fr

Prof. Martin Beniston
Geosciences Dept.
University of Fribourg
Perolles
CH-1700 Fribourg
SWITZERLAND

Tel. +41 (0) 26 300 9011
Fax +41 (0) 26 300 9746
Email martin.beniston@unifr.ch

Dr Alberto Arribas
Dept. Geofisica y Meteorologia
Universidad Complutense
Avda. Complutense s/n
E-28040 Madrid
SPAIN

Tel. +34 91 394 44 40
Fax +34 91 394 43 98
Email aarribas@fis.ucm.es

Michael Botzet
Max Planck Institute for Meteorology
Bundesstrasse 55
D-20146 Hamburg
GERMANY

Tel. +49 40 41173 137
Fax +49 40 41173 298
Email botzet@dkrz.de

Dr Raymond Arritt
Dept. of Agronomy
Iowa State University
3010 Agronomy Hall
50011 Ames, Iowa
USA

Tel. +1 (515) 294 9870
Fax +1 (515) 294 2619
Email rwarritt@iastate.edu

Dr Jean-Yves Caneill
EDF R&D/SPE
6 quai Watier
F-78401 CHATOU Cedex
FRANCE

Tel. +33 1 30 87 79 60
Fax +33 1 30 87 71 08
Email Jean-Yves.Caneill@edf.fr

Prof. Timothy Carter
Research Programme for Global Change
Finnish Environment Institute (SYKE)
Box 140
FIN-00251 Helsinki
FINLAND

Tel. +358 9 40 300 315
Fax +358 9 40 300 390
Email tim.carter@vyh.fi

Dr Jens Hesselbjerg Christensen
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 428
Fax +45 39 157 460
Email jhc@dmi.dk

Prof Manuel de Castro
Facultad de Ciencias Ambientes
Universidad de Castilla La Mancha
E-45071 Toledo
SPAIN

Tel. +34 925 265 738
Fax +
Email mcastro@amb-to.uclm.es

Prof João Corte-Real
Geophysics Centre
University of Evora-CGE
Rua Romão Ramalho 59
7000 Evora
PORTUGAL

Tel. +351 2667 44 616
Fax +351 2175 00 172
Email jcr@fc.ul.pt

Dr Daniel Caya
Dept. of Earth and Atmosphere Sci. UQAM
PO 8888, Stn Downtown
Montreal, QC,
H3C 3P8
CANADA

Tel. +1 (514) 987 3126
Fax +1 (514) 987 7749
Email caya.daniel@uqam.ca

Dr Susanna Corti
CINECA - Interuniversity Consortium
Laboratory for numerical Analysis of
Meteorological and Oceanographic data
Via Magnanelli 6/3
I-40033 Casalecchio di Reno, Bologna
ITALY

Tel. +39 051 6171581
Fax +39 051 6132198
Email s.corti@cineca.it

Dr Ole Bøssing Christensen
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 426
Fax +45 39 157 460
Email obc@dmi.dk

Dr Michel Déqué
CNRM/GMGEC/EAC
Météo France
42 Avenue Coriolis
F-31057 Toulouse Cedex 01
FRANCE

Tel. +33 561 07 93 82
Fax +33 561 07 96 10
Email michel.deque@meteo.fr

Dr Henrik Feddersen
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 422
Fax +45 39 157 460
Email hf@dmi.dk

Dr. Stépane Goyette
Dept. of Geosciences
University of Fribourg
Perolles
CH-1700 Fribourg
SWITZERLAND

Tel. +41 26 300 90 22
Fax +41 26 300 97 46
Email stephane.goyette@unifr.ch

Dr Christoph Frei
Institute for Atmospheric and Climate Science – ETH
Winterthurstrasse 190
CH-8057 Zürich
SWITZERLAND

Tel. +41 (0)1 635 5232
Fax +41 (0)1 362 5197
Email christoph.frei@geo.umnw.ethz.ch

Dr Phil Graham
Swedish Meteorological and Hydrological Institute
SE-60176 Norrköping
SWEDEN

Tel. +46 11 495 8245
Fax +46 11 495 8001
Email Phil.Graham@smhi.se

Stefan Fronzek
Research Programme for Global Change
Finnish Environment Institute (SYKE)
Box 140
FIN-00251 Helsinki
FINLAND

Tel. +358 9 40 300 301
Fax +358 9 40 300 390
Email Stefan.Fronzek@vyh.fi

Dr Kirsten Halsnæs
UNEP Collaborating Centre on Energy & Environment, Risø
P.O.Boks 49
DK-4000 Roskilde
DENMARK

Tel. +45 46775112
Fax +45 46321999
Email kirsten.halsnaes@risoe.dk

Dr Filippo Giorgi
Physics of Weather and Climate Section
Abdus Salam CTP
P.O.Box 586 / Strada Costiera 11
I-34100 Trieste
ITALY

Tel. +39 040 2240 425
Fax +39 040 2240 449
Email giorgi@ictp.trieste.it

David Hassell
Hadley Centre for Climate Prediction and Research
London Road
RG12 2SY Bracknell, Berkshire
UNITED KINGDOM

Tel. +44 (0) 1344 854518
Fax +44 (0) 1344 854898
Email david.hassel@metoffice.com

Tove Heidmann
Dept. of Agricultural Systems
Research Centre Foulum
Danish Institute for Agricultural Sciences
P.O.Boks 50
DK-8830 Tjele
7DENMARK

Tel. +45 89 99 17 30
Fax +45 89 99 18 19
Email Tove.Heidmann@agrsci.dk

Dr Dietrich Heimann
Institute for Atm. Physics
DLR
Oberpfaffenhofen
D-82234 Wessling
GERMANY

Tel. +49 8153 28 2508
Fax +49 8153 28 1841
Email d.heimann@dlr.de

Dr Jan Erik Haugen
Norwegian Meteorological Institute
P.O. Box 43 Blindern
N-0313 Oslo
NORWAY.

Tel: +47 22 96 33 31
Fax +47 22 69 63 55
Email j.e.haugen@dnmi.no

Dr Jean-Charles Hourcade
SMASH, CIRED
45 bis Avenue de la Belle Gabrielle
F-94 736 Nogent-sur-Marne
FRANCE

Tel. +33 1 43 94 73 73
Fax +33 1 43 94 73 70
Email hourcade@centre-cired.fr

Gunnar Hovsenius
Elforsk
Olof Palmes Gata 31, 6 tr
SE-10153 Stockholm
SWEDEN

Tel. + 46 8 677 27 51
Fax + 46 8 677 25 35
Email gunnar.hovsenius@elforsk.se

Dr Daniela Jacob
Max Planck Institute for Meteorology
Bundesstrasse 55
D-20146 Hamburg
GERMANY

Tel. +49 40 41173 313
Fax +49 40 41173 298
Email jacob@dkrz.de

Dr Richard Jones
Hadley Centre for Climate Prediction and Research
London Road
RG12 2SY Bracknell, Berkshire
UNITED KINGDOM

Tel. +44 (0) 1344 856418
Fax +44 (0) 1344 854898
Email richard.jones@metoffice.com

Dr Anne Mette Jørgensen
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 450
Fax +45 39 157 460
Email amj@dmi.dk

Dr Kirsti Jylhä
Meteorological Research
Finnish Meteorological Institute
P.O.Box 503
Vuorikatu 15
FIN-00101 Helsinki
FINLAND

Tel. +358 9 1929 4125
Fax +358 9 1929 4129
Email kirsti.jylha@fmi.fi

Dr Eigil Kaas
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 424
Fax +45 39 157 460
Email ek@dmi.dk

Sissi Kiilsholm
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 452
Fax +45 39 157 460
Email sk@dmi.dk

Sirpa Kilund
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 405
Fax +45 39 157 460
Email slk@dmi.dk

Prof. Dr Manfred Lange
Institute for Geophysics
University of Münster
Correnssstrasse 24
D-48149 Münster
GERMANY

Tel. +49 251 833 3591
Fax +49 251 833 6100
Email langema@uni-muenster.de

Prof René Laprise
Dept. of Earth and Atmosphere Sci.
UQAM
PO 8888, Stn Downtown
Montreal, QC
H3C 3P8
CANADA

Tel. +1 (514) 987 3302
Fax +1 (514) 987 7749
Email laprise.rene@uqam.ca

Dr Bennert Machenhauer
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 400
Fax +45 39 157 460
Email bm@dmi.dk

Dr Wilhelm May
Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK

Tel. +45 39 157 462
Fax +45 39 157 460
Email wm@dmi.dk

Dr Axel Michaelowa
Institute of International Economics
Neuer Jungfernstieg 21
D-20347 Hamburg
GERMANY

Tel. +49 40 4283 4309
Fax +49 40 4283 4451
Email a-michaelowa@hwwa.de

Prof. Maria Inés Mínguez-Tudela
Depto. de Producción Vegetal: Fitotecnia
Universidad Politécnica de Madrid
Ciudad Universitaria
E-28040 Madrid
SPAIN

Tel. +34 91 5491122
Fax +34 91 5449983
Email iminguez@pvf.etsia.upm.es

Dr Franco Molteni
Physics of Weather and Climate Section
Abdus Salam CTP
P.O.Box 586 / Strada Costiera 11
I-34100 Trieste
ITALY

Tel. +39 040 2240 572
Fax +39 040 2240 449
Email moltenif@ictp.trieste.it

Pablo Morales
Department of Physical Geography &
Ecosystems Analysis
University of Lund
Sölvegatan 13
SE-22362 Lund
SWEDEN

Tel.
Fax
Email Pablo.Morales@natgeo.lu.se

Dr Jørgen E. Olesen
Dept. of Crop Phys. and Soil Sciences
Research Centre Foulum
Danish Institute of Agricultural Sciences
P.O.Boks 50
DK-8830 Tjele
DENMARK

Tel. +45 89 991 659
Fax +45 89 991 619
Email JorgenE.Olesen@agrsci.dk

Anne Olhoff
UNEP Collaborating Centre on Energy &
Environment, Risø
P.O.Boks 49
DK-4000 Roskilde
DENMARK

Tel. +45 46775172
Fax +45 46321999
Email anne.olhoff@risoe.dk

Dr Jean Palutikof
Climatic Research Unit
University of East Anglia
NR4 7TJ Norwich
UNITED KINGDOM

Tel. +44 (0) 1603 593 647
Fax +44 (0) 1603 507 784
Email j.palutikof@uea.ac.uk

Dr Jouni Räisänen
Rossby Centre
Swedish Meteorological and Hydrological
Institute
SE-60176 Norrköping
SWEDEN

Tel: +46 11 495 8501
Fax +46 11 495 8001
Email Jouni.Raisanen@smhi.se

Dr Burkhardt Rockel
Institute for Coastal Research
GKSS Research Centre
Max Planck Strasse
D-21502 Geesthacht
GERMANY

Tel. +49 (0) 4152 87 2008
Fax +49 (0) 4152 87 2020
Email rockel@gkss.de

Dr Dave Rowell
Hadley Centre for Climate Prediction and Research
London Road
RG12 2SY Bracknell, Berkshire
UNITED KINGDOM

Tel. +44 (0) 1344 856077
Fax +44 (0) 1344 854898
Email dave.rowell@metoffice.com

Margarita Ruiz-Ramos
Depto. de Producción Vegetal: Fitotecnia
Universidad Politécnica de Madrid
Ciudad Universitaria
E-28040 Madrid
SPAIN

Tel. +34 91 5491122
Fax +34 91 5449983
Email mrramos@pvf.etsia.upm.es

Dr Markku Rummukainen
Rossby Centre
Swedish Meteorological and Hydrological Institute
SE-60176 Norrköping
SWEDEN

Tel: +46 11 495 860
Fax +46 11 495 8001
Email Markku.Rummukainen@smhi.se

Torben Schmith
Danish Meteorological Institute
Lyngbyvej 100
2100 Copenhagen
DENMARK

Tel. +45 39 157 444
Fax +45 39 157 460
Email ts@dmi.dk

Tido Semmler
Max Planck Institute for Meteorology
Bundesstrasse 55
D-20146 Hamburg
GERMANY

Tel. +49 40 41173 205
Fax +49 40 41173 391
Email semmler@dkrz.de

Prof Martin Sykes
Department of Physical Geography & Ecosystems Analysis
University of Lund
Sölvegatan 13
SE-22362 Lund
SWEDEN

Tel. +46 (0) 46 222 9298
Fax +46 (0) 46 222 0321
Email Martin.Sykes@planteco.lu.se

Dr Ib Troen
Directorate-General RTD
European Commission
Rue de la Loi 200/Wetstraat 200
B-1049 Brussels
BELGIUM

Tel: +32 2 2950465
Fax +32 2 2963024
Email Ib.Troen@cec.eu.int

Dr Aad van Ulden
KNMI
Box 201
3730 AE de Bilt
NETHERLAND

Tel. +31 30 2206447
Fax
Email aad.van.ulden@knmi.nl

Dr Pier Luigi Vidale
Institute for Atmospheric and Climate Science
– ETH
Winterthurstrasse 190
CH-8057 Zürich
SWITZERLAND

Tel. +41 (0)1 635 5218
Fax +41 (0)1 362 5197
Email pier-luigi.vidale@ethz.ch

Dr Maria José Costa Zemsch
Institute for Atm. Physics
DLR
Oberpfaffenhofen
D-82234 Wessling
GERMANY

Tel. +49 8153 28 2519
Fax +49 8153 28 1841
Email maria.zemsch@dlr.de

THE DANISH CLIMATE CENTRE

The Danish Climate Centre was established at the Danish Meteorological Institute in 1998. The main objective is to project climate into the 21 st century for studies of impacts of climate change on various sectors and ecosystems in Denmark, Greenland and the Faroes.

The Climate Centre activities include development of new and improved methods for satellite based climate monitoring, studies of climate processes (including sun-climate relations, greenhouse effect, the role of ozone, and air/sea/sea-ice interactions), development of global and regional climate models, seasonal prediction, and preparation of global and regional climate scenarios for impact studies.

The Danish Climate Centre is organised with a secretariat in the Research and Development Department, and it is co-ordinated by the Director of the Department. It has activities also in the Weather Service Department and the Observation Department, and it is supported by the Data Processing Department.

The Danish Climate Centre has established the Danish Climate Forum for researchers in climate and climate related issues and for others having an interest in the Danish Climate Centre activities. The Centre issues a bi-annual newsletter "KlimaNyt" (in Danish).

DMI has been doing climate monitoring and research since its foundation in 1872, and establishment of the Danish Climate Centre has strengthened both the climate research at DMI and the national and international research collaboration.