Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects

PRUDENCE
EVK2-CT2001-00132

http://prudence.dmi.dk

Co-ordinator: Dr Jens Hesselbjerg Christensen

Final Report
1 November 2001 – 31 October 2004
(Section 1)
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Participants information:

Partner	**Country**
1. Danish Meteorological Institute, Copenhagen	DK
2. CINECA, Bologna	I
3. Météo-France/CNRM, Toulouse	F
4. Deutsches Zentrum für Luft- und Raumfahrt e.V., Weßling	D
5. Hadley Centre for Climate Prediction and Research, Met Office, Bracknell	UK
6. Climate Research ETH (Eidgenoessische Technische Hochschule), Zürich	CH
7. GKSS Research Center (Institute for Coastal Research), Geesthacht	D
8. Max Planck Institut für Meteorologie, Hamburg	D
9. Swedish Meteorological and Hydrological Institute, Rossby Centre, Norrköping	S
10. Universidad Complutense, Madrid	E
11. Universidad Politecnica, Madrid	E
12. International Centre for Theoretical Physics, Trieste	I
13. Danish Institute of Agricultural Sciences, Foulum	DK
14. Risø National Laboratory, System Analysis Dept.	DK
15. University of Fribourg	CH
16. Finnish Environmental Institute, Helsinki	FIN
17. University of Reading	UK
18. University of Lund	S
19. Centre International de Reserche sur l'Environment et Developpement,SMASH, Paris	F
20. Climate Research Unit, University of East Anglia	UK
21. Finnish Meteorological Institute, Associated to FEI (No. 16)	FIN

1.1 Objectives of the reporting period

The sixth and final six month-period of the project had the following main objectives:

1. To bring the project to its completion
2. Revising the PRUDENCE data centre hosted at DMI to its final form and securing data availability after the end of the project
3. Detailed planning of the PRUDENCE special issue of *Climatic Change*

1.2 Scientific/technical progress made in different work packages according to the planned time schedule

During the sixth six-month period, all Work Packages have been at play. Furthermore, all Work Packages had activities until Month 36. While WP1 and WP2 have been almost completed in terms of model simulations, WPs 3-6 have been at full speed throughout the period, as impacts models had to process data from nearly all regional models, also the few latecomers, although not critical for a timely completion of the project. In the following we discuss progress with respect to each of the objectives listed in Section 1.1.

Objective 1: To bring the project to its completion

The activities within WP3, WP4, and WP5 have all made substantial use of the suite of RCM simulations provided in the PRUDENCE archive. Most of the activities continued within the last six month of the project, and all deliverables have been provided nearly on time (see section 1.4). The partners have demonstrated the usefulness of the data for assessing uncertainties in climate change impacts at a number of scientific meetings, and several scientific papers have been prepared including most of those foreseen to appear in the planned PRUDENCE special issue of *Climatic Change*, see also objective 3 below.

Two month before the formal end of the project a fourth and final PRUDENCE workshop was organized. Unlike most of the previous PRUDENCE workshops, this final workshop had little external participation. It was decided in advance that the project had so many results to document that there would not be time to organise a larger meeting, where PRUDENCE would only be one component. Besides, all WPs needed time to direct themselves towards the final report. The minutes from the meeting is available from http://prudence.dmi.dk.

Objective 2: Revising the PRUDENCE data centre to its final form

During the course of the PRUDENCE project the PRUDENCE web site (http://prudence.dmi.dk) has been a very successful means of communication between the partners. Apart from management related material posted there, partners have had access to scientific papers produced within the project as well power point presentations from all of the meetings. This has provided an excellent opportunity for partners to familiarise themselves with the entire project concept, which has truly been multi disciplinary in the approach towards the completion of the project. It is a general impression from most partners that their interest and understanding of climate change related research has been broadened, due to the interplay with colleagues from other disciplines – ranging from climate modelling on the one end to socio-economic sciences on the other.

Objective 3: Detailed planning of the PRUDENCE special issue of Climatic Change (PSICC)

It was agreed during annual PRUDENCE workshop in Wengen in 2003 that the coordinator should follow the idea of producing a special issue of a scientific journal summarising findings of the PRUDENCE project. As has already been reported, an agreement with *Climatic Change* has secured this idea. A timely plan for this special issue has been worked out and it has been decided to have 1. January 2005 as the dead line for contributions to the PSICC. This would ensure that the papers could be cited for the upcoming IPCC 4th assessment report. Ideally, revised versions would be made available before summer 2005 and allow for papers to be accepted in due time for the third LA meeting in December 2005, at which time only literature accepted for publication should be cited.

As seen by the long list of suggested papers provided in the previous report, it was necessary to screen the abstracts and make a proper selection of papers. In section 1.7 all the papers that have been selected are listed and an abstract for each paper is provided (a few papers are not expected before the end of February, which is reflected by missing abstracts).

1.3 Milestones and deliverables obtained

Tables 1 and 2 are, respectively, the staff effort and project planning timetables. Table 3 shows all project milestones, and progress towards their completion, whilst Table 4 shows progress with respect to deliverables. The assessment of the overall project progress can be summarized as follows:

Most Milestones and Deliverables have been completed on time, although several of the model simulations have been completed later than according to the original time plan. However, the many simulations, which have been completed and made available from the PRUDENCE web site, provide a substantial basis for further analysis, which is already well under way within the project group and a large number of external groups have requested access and granted it. Data made available only after month 30 has in most cases not been accommodated into the final synthesis of results. However, it seems as good practise in handling even data coming late may and still allow for some general utilisation in the overarching synthesis of the project, particularly in connection with planned publishing of PRUDENCE results in the special issue of *Climatic Change*.

1.4 Deviations from the work plan and/or time schedule and their impact on the project

All GCM simulations have now been completed. Down scaling experiments using ECHAM5 has been initiated and will be completed by the time of the submission of this report. It appears, however, that good progress has been made lately, and that data will become available within the next two months. In particular, it should be mentioned here that ETH has now provided the T106 experiments with the ECHAM5 model following the PRUDENCE strategy concerning sea surface temperatures. DMI and ETH have performed down scaling experiments of these GCM runs. Although these simulations are not formally part of PRUDENCE, ETH has agreed to make them available for the project.

Partner 14, Risoe made an agreement with the commission to subcontract 1-2 months of their activities within he last year of the project to IIASA, Austria. This has lead to some analysis within WP6, which otherwise would not have seemed possible.

Partner 15, University of Fribourg was originally responsible for deliverable D5A5 “Sensitivity of hydro-power supply to changing temperature and precipitation patterns”. During the completion of the project, it turned out that much of the same work was carried out within the SWURVE project and therefore efforts within PRUDENCE was concentrated on deliverable D5A4 “Assessments of the general change in heat waves and cold spells as related to human health, agricultural risk and energy demand” in stead. In return analysis of PRUDENCE results using the ANOVA technique was provided from the SWURVE project. This was then applied to a national level for all European nations, and this material handed out at COP10 (see below).

The coordinator was made aware of a technical change in personnel allocation for partner 15. Efforts in WP3 have been set to 9 (instead of 7.5) for Year 2 and to 0 (instead of 1.5 months) for Year 3 because they were not involved in task D3B5. This was due to misunderstanding of the list of deliverables, in page DoW-19 of the report 'PRUDENCE Description of Work', (dated 29-11-01) where they were mentioned for both D3B4 and D3B5 tasks. This had no implication for the work carried out.

Partner 16, SYKE: The overall staff effort for the project as a whole was as planned for WP2, WP5 and WP7. SYKE exceeded the planned person-months in WP4 by 3, 9. This is because the staff costs were somewhat lower than originally anticipated for Stefan Fronzek, who was hired after the project was approved. Timothy Carter used additional person-months to cover work in WP4 and project dissemination tasks in WP7 that were not originally accounted for. The budget for both salaries and travel was used in full from both EU (50%) and SYKE (50%) sources (Full cost basis).

The planned workshop in month 33, the final deliverable from WP6 (D6A4), was revisited during the Toledo meeting. It was proposed to hold an arrangement in Brussels shortly after the completion of the project. However, as it was realised that COP10 in Buenos Aires would form an excellent platform to brief policymakers directly about the outcome of the PRUDENCE project, together with the commission, the co-ordinator organised an EU side event with this purpose. It was decided to include also brief presentations of the STARDEX and MICE projects in this presentation. Between 40 and 60 people was attending the event. Below the program for the two hours is presented.

EUROPEAN COMMISSION

Side event on:

PREDICTION OF REGIONAL SCENARIOS AND UNCERTAINTIES FOR DEFINING EUROPEAN CLIMATE CHANGE RISKS AND EFFECTS:
THE PRUDENCE PROJECT

MONDAY, 13 DECEMBER 2004 – 13-15 HRS
EU PAVILION – ROOM 1

1) **Introduction**
Dr. Georgios Amanatidis, European Commission, DG Research, Environment and Climate System Unit

2) **The rationale and purpose of PRUDENCE**
Dr. Jens Hesselbjerg Christensen, DMI, Denmark

3) **PRUDENCE major findings**
Dr. Jens Hesselbjerg Christensen, DMI, Denmark

4) **Using the PRUDENCE products**
Dr. Anne Ohloff, UNEP RISØ Centre, Denmark

5) **Introducing the MICE project**
Dr. Jean Palutikof, IPCC WGII TSU, Met Office, UK

6) **Introducing the STARDEX project**
TBD

7) **Questions and discussion**

Based on the results of the EU PRUDENCE – STARDEX - MICE research projects

1.5 Co-ordination of information between partners and communication activities

Project Meetings
There has been one overall PRUDENCE related meetings in this period:

- The PRUDENCE final workshop, 6-10 September in Toledo, Spain

Co-operation with other projects/networks
PRUDENCE is part of an informal cluster of three projects, which includes, in addition to PRUDENCE, STARDEX (STAtistical and Regional Downscaling of EXtremes) and MICE (Modelling the Impact of Climate Extremes). Two of the coordinators of the projects have met at the EGU meeting in April. A major contribution from this team has been the coordinated input to the ENSEMBLES proposal, which was initiated in September 2004.

The PRUDENCE project has been followed closely by colleagues all over the world, but in particular in the US and Canada. During the Lund workshop in spring, the PRUDENCE participation in the recent workshop in Lund 29/3-2/4 "High-resolution climate modelling: Assessment, added value and applications" made it as a news item in *Nature,* **428**, 593, by Quirin Schiermeier. Some quotes:

"We're not yet at the promised level where regional climate models can really influence policy-making," Georgios Amanatidis, a scientific officer at the European Commission's research directorate, told the meeting.

"If you don't believe in the value of global climate models then there's no point in downscaling them," says Filippo Giorgi, an atmospheric physicist now at the ICTP in Trieste, Italy]. "But if you do - and global models do provide a quite consistent pattern of climate change - then it makes sense to translate global patterns into local information." Thanks to Prudence, Europe is currently leading the field, Giorgi adds. "There is quite some envy over here of how well things are organized and funded in Europe," says Francis Zwiers, head of the Canadian Centre for Climate Modelling and Analysis in Victoria, British Columbia. American and Canadian modellers are seeking funds for a similar collaboration of their own. "This would really come at the right time," says René Laprise, principal investigator at the Canadian regional climate modelling group in Montreal, "now that we are finally understanding what we're doing - some of the time!"

and a Figure from the modelling efforts was also shown (inserted below)

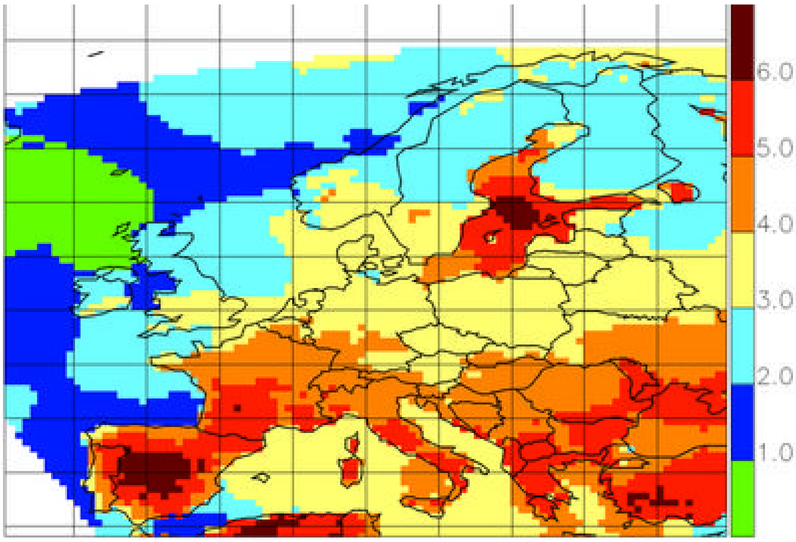

Figure 1: Scientists say that only long-range projections, such as this one for Europe in 2071-2100, count for much

Through the open door policy adopted throughout the duration of the project, American colleges have joined in at projects meeting. The PRUDENCE project this way has served as a role model for colleagues in North America, some of whom served as external evaluators of the project. The NARCCAP initiative (Mearns et al. 2004) is the most obvious example of a scientific impact at the organisational level. A large scale North American collaboration such as NARCCAP has never been attempted before, and the well organised collaboration and high scientific standard of the PRUDENCE work provided a significant impetus for this effort.

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Web pages

The external and internal Web pages have been set up for PRUDENCE, and can be accessed at http://prudence.dmi.dk/. This site is developing fast, and holds important information, useful for partners as well as outside groups, see also objective 2 above.

Publications:

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Palutikof, J., EU-sponsored workshop 'Agriculture, climate change and economic consequences' organized for the European Phenological Network, Copenhagen. 'Studying the response of climate extremes to global warming'

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Seneviratne S.I., M. Hirschi, P. Viterbo, D. Lüthi and C. Schär, Water-balance estimates of changes in terrestrial water storage using ERA-40 reanalysis data: Validation and potential applications (poster), Nice, April 8, 2003, Joint Assembly of the EGS/EGU and AGU

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Seneviratne, S.I, 2004: Combined water-balance computations to estimate basin-scale variations in terrestrial water storage. Geophysical Fluid Dynamics Laboratory, Princeton, USA, July 15, 2004 (Invited).

Seneviratne, S.I, 2004: Large-scale estimates of changes in terrestrial water storage using streamflow measurements and ERA-40 atmospheric reanalysis data. GMAO Seminar, NASA Goddard Space Flight Center, February 5, 2004.

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Stephenson, D.B., Invited talk on PRUDENCE extreme events, One-day Royal Meteorological Society meeting on extreme weather and climate events (organized by D.B. Stephenson and C.A.T. Ferro), 21 January 2004.

Stephenson, D.B., Overview of WP5 results, PRUDENCE Regional Climate Change conference, Toledo, September 2004.

Stöckli R., Modeling seasonal water and heat exchanges at European Fluxnet sites, Monte Verita, Ascona, Oct. 31, 2003, ZOeK Ph.D. Conference: Magic Behind Ecosystem Research

Stöckli R., Vidale P.L., Atmosphere-Biosphere Feedbacks. Part I: Modeling the soil-vegetation-atmosphere system and its processes, Grindelwald, Switzerland, Sep. 2, 2003, Swiss NCCR Climate Summer School

Stöckli R., Vidale P.L., The hydrological cycle at European Fluxnet sites: modeling seasonal water and energy budgets at local scale, Nice, France, April 6-11, 2003, EGS+AGU General Assembly

Stöckli R., Vidale P.L., The interplay between the seasonal soil moisture cycle and vegetation evapotranspiration, Long Beach CA, USA, Feb. 11, 2003, AMS Meeting

Stöckli, R., 2002: European Plant Phenology and Climate as Seen in a 20 Year AVHRR Land-Surface Parameter Dataset. Satellitenmeteorologie und NWP, MeteoSchweiz, Zurich, 5 Dec. 2002.

Stöckli, R., 2002: Simulation of Micro-Scale Evaporation and Runoff Processes with Euroflux Micrometeorological Data. NCCR Summer School, Grindelwald, 7-14 Sep. 2002. (poster)

Stöckli, R., 2002: The Role of the Hydrological Cycle in European Climate Modeling. NCCR Ph.D meeting, Gwatt, 20-21 June 2002.

Stöckli, R., 2004: Modeling and observations of seasonal land-surface heat and water exchanges at local and catchment scales over Europe (invited presentation). FAL Reckenholz, February 4, 2004

Stöckli, R., Rogiers N., 2004: Water and carbon exchange at a Swiss alpine grassland during 2003: measurements versus model results (poster). European Geophysical Union (EGU), Nice, April 27, 2004

Stöckli, R., Vidale, P.L., 2004: Using Fluxnet tower data to evaluate diurnal- to seasonal-scale storage processes in the land surface model SiB 2.5. European Geophysical Union (EGU), Nice, April 27, 2004

Stöckli, R., Vidale, P.L., Rogiers, N., Schmid, H.P., 2004: Sensitivity of modeled heat, water and carbon fluxes to AVHRR- and MODIS-derived biophysical land-surface parameters. European Geophysical Union (EGU), Nice, April 30, 2004

Sykes et al., Modelled Carbon fluxes of simulation experiments from various EUROFLUX sites were presented at the 2nd PRUDENCE meeting in Trieste-Italy. Sep. 2002.

Verbunt, M., 2002: The Impact of Climate Change on Snow Processes and Runoff Regime in a Swiss Alpine Catchment. NCCR Summer School, Grindelwald, 7-14 Sep. 2002. (poster)

Vidale, P.L., D. Lüthi , C. Schwierz and C. Schär, Synoptic-dynamics in a Europe without Alps: a climatology, Brig, Switzerland, May 21, 2003, CAM/MAP Conference

Vidale, P.L., D. Lüthi and R. Stöckli, Prognostic canopy air space solutions for land surface modeling, Sapporo, Japan, July 11, 2003, XXIII General Assembly of the International Union of Geodesy and Geophysics

Vidale, P.L., D. Lüthi, C. Frei and C. Schär, 2001: Physical processes affecting the seasonal and inter-annual variations of the European water cycle. PRUDENCE kick-off meeting, Snekkersten, Denmark, 3-5 Dec. 2001.

Vidale, P.L., D. Lüthi, C. Frei and C. Schär, Predictability and uncertainty in a Regional Climate Model : lessons from perfect models and perfect data, Sapporo, Japan, July 11, 2003, XXIII General Assembly of the International Union of Geodesy and Geophysics

Vidale, P.L., D. Lüthi, C. Frei and C. Schär, Regional climate change research at IAC-ETH, MPI Hamburg, Jan. 21, 2003, II PRUDENCE modelers meeting

Vidale, P.L., D. Lüthi, C. Frei, J. Kleinn and C. Schär, Regional climate under a warming scenario: views from the Alps. Wengen, Switzerland, Sept. 30, 2003, Workshop on Regional Climatic Change in Europe: Processes and Impacts

Vidale, P.L., D. Lüthi, C. Frei, S. Seneviratne and C. Schär, Predictability and uncertainty in a Regional Climate Model, Nice, France, April 8, 2003, Joint Assembly of the EGS/EGU and AGU

Vidale, P.L., D. Lüthi, C. Schwierz and C. Schär, The climate of an Alpless Europe, Nice, France, April 10, 2003, Joint Assembly of the EGS/EGU and AGU

Vidale, P.L., D. Lüthi, J. Kleinn, C. Frei and C. Schär, 2002: PRUDENCE at IAC-ETH. 2nd PRUDENCE workshop, ICTP Trieste, 3 Oct. 2002.

Vidale, P.L., J. Kleinn, J. Gurtz, C. Frei and C. Schär, 2001: Coupled climate-runoff simulations: a process study of current (and warmer) climate in the Rhine basin. PRUDENCE kick-off meeting, Snekkersten, Denmark , 3-5 Dec. 2001.
Vidale, P.L., D. Lüthi, C. Schwierz, R. Wegmann, M. Liniger, C. Schaer, Changes in European summer variability: results from a heterogenous multi-model ensemble, Workshop on High-resolution climate modelling: Assessment, added value and applications, Lund, April 2004
Vidale, P.L., D. Lüthi, R. Wegmann, M. Liniger, C. Schaer, Changes in European summer variability: results from a heterogenous multi-model ensemble, Final PRUDENCE Science Workshop, Toledo, September 2004
Vidale, P.L. and R. Stöckli, From leaf to globe: biophysics and scaling issues in simulating land surface processes for atmospheric models, Grindelwald, Switzerland, Sep. 2,2003, NCCR Climate Summer School
Vidale, P.L., 2001: From leaf to globe: biophysics and scaling issues in simulating land surface processes for atmospheric modelling. Seminar, Institut für terrestrische Oekologie, Schlieren, 18 Dec. 2001.
Vidale, P.L., D. Lüthi, C. Frei and C. Schär, Regional climate modeling at IAC-ETH, Yokohama, Japan, July 14, 2003, Earth Simulator
Vidale, P.L., D. Lüthi, J. Kleinn, C. Hohenegger, C. Frei and C. Schär, 2002: Regional Climate Modeling at IAC-ETH: the HRM as CHRM. DWD, Offenbach, Germany, 4 Dec. 2002.
Vidale, P.L., Land surface modeling in NWP and climate modeling, a 2-lecture series, within the ETH (Zürich) postgruaduate course in hydrology, Jan 2004
Vidale, P.L., Climate modeling, a 2-lecture series, within the post-graduate course in physics, Univ. of Heidelberg, Germany, April 2004
Vidale, P.L. and D. Majewski, Climate HRM, 1st HRM workshop, Niteroi (Rio de Janeiro), Brazil, September 2004
Vidale, P.L., D. Lüthi, R. Wegmann, M. Liniger, C. Schär, Regional Climate Models: Heat wave summer 2003, NCCR Science Colloquium, Meteo Swiss, Zurich, 25 November 2004
Vidale P.L. et al., PRUDENCE WP1+2 workshop, MPI Hamburg, January 2003
Vidale, PL , D. Lüthi, C. Frei, J. Kleinn, and C. Schär, 2003: Predictability and uncertainty in a regional climate model. Zürich, Switzerland, NCCR review panel, June 2003
Vidale, PL , D. Lüthi, C. Frei, J. Kleinn, and C. Schär, 2003: Regional climate activities at IAC-ETH. Zürich, Switzerland, IAC-MeteoSuisse Meeting, June 2003.
Vidale, P.L., The relationship between CO2 and warming: measurement methods. Public lecture on climate change, Bellinzona, 15. Oct. 2003.
Woth, K: Studies of Recent and Future Storm Surge Climate of the North Sea. Poster presentation at the 2nd PRUDENCE meeting in Trieste-Italy. Sep. 2002.
Woth, K: Future Storm Surge Climate of the North Sea coastline. 2nd PRUDENCE meeting in Trieste-Italy. Sep. 2002.
Woth, K: Expected North Sea storm surge extremes at the end of the 21st Century? First results. RUDENCE WP5 meeting, Chateau d'Oex, Switzerland, 15-18 March 2003.
Woth, K. et al. Expected North Sea storm surge extremes at the end of the 21st century / EGS - AGU - EUG Joint Assembly, Nice, France, 06. - 11. April 2003
Woth, K. et al., Changes in the North Sea climate expected at the end of the 21st Century, Wengen workshop, Oct. 2003

Woth, K. Et al., North Sea storm statistics based on a series of climate change projections, Regional Climate Workshop, Lund 2004

Woth, K., Changes in the North Sea surge and wind climate simulated for the end of the 21st century, PRUDENCE workshop on extremes, Chateau d'Oex, Switzerland, 6-9 March 2004

von Storch, H. and K. Woth, Climate change and North Sea storm surge extremes - an ensemble study, AGU fall meeting, 13- December 2004, San Francisco.

Reports on media appearances:

Danish Meteorological Institute:

Nature paper on extreme summer precipitation
TV interview: appearance in Denmark (4 times), Sweden (2 times)
Radio interview: appearance in Denmark (6 times), UK (1 time)
Newspapers: The paper was cited in almost all European countries, more than 20 interviews worldwide

ETH paper in the media involving DMI staff:
Radio interview: appearance in Denmark (3 times)
Newspapers: Interview for more than 3 Danish newspapers

Beniston's GRL paper involving DMI staff:
Radio interview: appearance in Denmark (1 interview)
Newspapers: Interview in 2 newspapers

Furthermore, The PRUDENCE project was thoroughly cited in many others newspaper articles at various occasions:
Kickoff meeting: Berlingske Tidende, Politiken, KlimaNyt (Denmark)
Final meeting: El Pais (Spain)
Lund meeting: Nature (Int.)

The results from the Wengen meeting were broadcasted on Danish radio via a telephone interview.

Météo France:

The PRUDENCE outcome is that it has been an upstream project to a national project named IMFREX (IMpact on FRequency of EXtreme climatic events). In this project, one of the partners, Electricité de France, calculated the maximum expected temperature for 2100 for dimensioning the new generation of nuclear plants. As perhaps known, in summer 2003, some plants were near to stop because of the insufficient cooling. There will be a wide dissemination, through the ministry of environment (MEDD), in the French impact community from IMFREX about results concerning detailed response about extremes in temperature, precipitation and wind over France.
Twice appearances in the TV during the 2003 heat wave, but no explicitly mentioning of the word "PRUDENCE" during the 2 minutes of the clips. In the same stream, very frequent contacts by newspaper journalists about climate change over France, but again the word "PRUDENCE" does not appear.

Hadley Centre:

Many contacts with the media, in which case PRUDENCE related work has been cited.

Climate Research ETH:

Schär C.: "Wetterfeste Prognosen", FACTS, 10. Januar 2002. (von Klaus Jacob)
Schär C.: "Der Wintersport ist bald Schnee von gestern", CASH, 1. Februar 2002. (von Priscilla Imboden)
Schär C.: "Klimawandel", Tele, März 2002. (von Marco Morosoli)
Zappa, M.: "Ausgezeichnete Alpenforschung". Bulletin SEV/VSE 10/02 p.45.
Zappa, M.: "Ausgezeichnete Alpenforschung". ETH-Life (Online) 19 März 2002.

Zappa, M.: Auftritt bei der Hauptausgabe der Tessiner Tagesschau, 15. März 2002. Anlass: Tagung der Interakademischen Kommission Alpenforschung (ICAS): Phil. Alp 2002, Die Alpen aus der Sicht junger Forschender. Chur, 14.-15. März 2002.

Frei C.: Zahlreiche Radiointerviews zu den Hochwassern in Zentraleuropa. August 2002.

Frei C.: "Hochwasser in Europa und Klimaänderung", Climate-Press, August 2002. (von Urs Neu)

Frei C.: "Klimaprognosen sind noch nicht wetterfest" NZZ am Sonntag, 18. August 2002. (von Andreas Hirstein)

Schär, C., Fernsehinterview: "Klimaerwärmung und Ski-Weltcuprennen" im Sportapanorame, SF1, Ausstahlung am 12. Januar 2003

Fallstudie UMNW: "35 ETH-Studenten nehmen Thurlandschaft unter die Lupe", Bericht über Fallstudie UMNW, Tages-Anzeiger, 6. Februar 2003 (von Jürg Schmid)

Fallstudie UMNW: "Studenten geben gute Noten", Bericht über Fallstudie UMNW, Tagblatt, 6. Februar 2003 (von Markus Schoch)

Schär, C., Medienauskunft: "Klimaproblem drängt – Auftakt zu den 'early morning'-Gesprächen", Tagblatt, 7. Mai 2003 (von Martin Sinzig)

Schär, C., Medienauskunft: "Wetter und Klima im Alpenraum", Walliser Bote, 20. Mai 2003 (von fm)

Schär, C., Medienauskunft: "Hat sich das Klima verändert", Walliser Bote, 20. Mai 2003 (von fm)

Schär, C., Medienauskunft: "Natürliche Klimaschwankung oder langfristige Veränderung?", Anzeiger vom Rottal (CH-Forschung), 26. Juni 2003

Schär, C., Medienauskunft: "Klimaschwankung oder langfristige Veränderung?", Bündner Tagblatt, 5. Juli 2003 (von Andreas Walker / CH-Forschung)

Schär, C., Medienauskunft: "Klima: Schwankung oder Veränderung?", Prattler Anzeiger, 11. Juli 2003 (CH-Forschung)

Schär, C., Medienauskunft: "Klima: Der Süden so nah …" MERIAN Gardasee Oberitalien, Juli 2003, p.98-99 (von Andreas Weber)

Schär, C., Medienauskunft: "Von einer Dürre kann man noch nicht sprechen", Basler Zeitung, 16. Juli 2003 (von Roland Fischer)

Schär, C., Medienauskunft: "Verbrannte Erde", Facts, 24. Juli 2003 (von Rainer Klose)

Schär, C., Medienauskunft: "Und immer noch kein Ende in Sicht" (Artikel über heissen Sommer 2003). NZZ am Sonntag, 10. August 2003 (von Andreas Hirstein)

Schär, C., Medienauskunft: "Droht uns im Herbst dann die grossen Unwetter?", Aargauer Zeitung, 12. August 2003 (von Hans Peter Roth)

Schär, C., Medienauskunft: "Alle paar Jahre ein Jahrhundertereigniss?", Aargauer Zeitung, 12. August 2003 (von Christoph Bobb)

Schär, C., Medienauskunft: "Beginnt eine neue Klimaepoche?", Werdenberger und Obertoggenburger", 22. August 2003 (von Andreas Walker / CH-Forschung)

Schär, C., Medienauskunft: "Ein Sommer den es gar nicht geben sollte", Mittelland-Zeitung, 2. September 2003 (von Hans Peter Roth)

Schär, C., Fernsehinterview "Mensch, Technik Wissenschaft" über Klimawandel und heissen Sommer 2003. Ausstahlung am 4. September 2003

Schär, C., Medienauskunft: "Heisse Sommer sind stark im Kommen", Coop-Zeitung, 24. September 2003 (von Irene Bättig)

Schär, C., Medienauskunft: "Zunehmend bewölkt und regnerisch". Sonntags-Zeitung, 28. September 2003 (von Volker Mrasek)

Schär, C., Radio Interview, DRS 2, "Kyoto Protokoll – vor dem Anfang schon das Ende?" Sendung "Kontext" (Redaktion Christian Heuss), 1. Oktober 2003

Schär, C., Medienauskunft: "Sonne von Frühling bis Spätherbst". Tages-Anzeiger, 22. Dezember 2003 (von Janine Hosp)

Schär, C., 2004: Tagesschau SF DRS. Statement über Klimaänderung und Klimavariabilität. 12. Januar 2004 (auch ausgestrahlt auf SF RTSR und RTSI, sowie auf TF1),

Schär, C., 2004: "Ein Vorbote der Klimazukunft". ETH Life (von Felix Würsten). 12. Januar 2004.

Schär, C., 2004: "Extreme heat on the rise". Nature Science Update (Michael Hopkin). 12. Januar 2004.

Schär, C., 2004: "Freak Summers". The Guardian (Tim Radford). January 12, 2004.

Schär, C., 2004: "Der Sommer 2003 tanzt völlig aus der Reihe". Basler Zeitung (von Lukas Denzler). 12. Januar 2004.

Schär, C., et al. 2004: "Record summers might become more common" Newsletter of the European Geophysical Union. 12. Januar 2004.

Schär, C., et al. 2004: "Climate models predict more long hot summers". Scientific American online. January 12, 2004.

Schär, C., et al. 2004: "Europe's summers 'to get hotter". BBC News World Edition Online (Alex Kirby). January 12, 2004.

Schär, C., et al. 2004: "Europe to have more killer summers". CNN.com (Reuters). January 12, 2004.

Schär, C., et al. 2004: "Vers des étés de plus en plus chauds". Le Monde. January 12, 2004.

Schär, C., et al. 2004: "Europa droht jeden zweiten Sommer Superhitze". Spiegel online. 12. Januar, 2004.

Schär, C., et al. 2004: "Ricerca su «Nature»: in Europa estati torride". Corriere della Sera. January 12, 2004.

Schär, C., et al. 2004: “European Heatwaves Could Become The Norm, Study Says”. U.N. Wire. January 12, 2004. Schär et al.
Schär, C., et al. 2004: “Rekordsommer könnten zur Regel werden”. Frankfurter Allgemeine Zeitung. 12. Januar 2004.
Schär, C., et al. 2004: “Un été torride sur deux à l’avenir”. Le Soir. January 13, 2004.
Vidale, P.L., 2004: A follow-up to the Nature paper, interviews with Radio Switzerland International, the French Canal 2 and RTSI, January 2004
Schär, C., et al. 2004: “Canicule, ce n’est que le début”. Le Nouvelle Observatoire. January 13, 2004.
Schär, C., 2004: “Der Sommer 2003 als Vorbote der Zukunft?” Neue Zürcher Zeitung (von Heidi Blattmann). 14. Januar 2004
Schär, C., et al. 2004: “European heatwave update”. Benfield Hazard News, University College, London. Januar 2004.
Schär, C., 2004: Wettervorhersagen – immer langfristiger und genauer. Neue Zürcher Zeitung, Seite 12, 15. September 2004
Vidale, P.L., 2004: "Climate models: what they are, how they function, what they can tell us". A 20 mins. radio lecture inside the program "Laser", aired every 2 hours on RTSI 2, all day, on 27 March

Max Planck Institut für Meteorologie
TV in Germany 1
Radio in Germany 2 and one internet appearance

Swedish Meteorological and Hydrological Institute:
Very frequent contact with newspapers, radio and TV. PRUDENCE related work has been mentioned on numerous occasions, but mostly interviews have been given in a broader context.

Universidad Complutense Madrid:
Many contacts with the media, in which case PRUDENCE related work has been cited. During the final meeting in Toledo, a major article was issued in ‘El Pais’ on PRUDENCE related work with a Spanish focus.

International Centre for Theoretical Physics:
El Pais Article from the Toledo meeting – final PRUDENCE workshop
Nature article from the Lund meeting

DIAS media contacts
Olesen, J.E. (2003). Nordafrikas ørken på vej mod Europa. Kristeligt Dagblad. 31 July 2003.
Olesen, J.E. (2003). Heatwave’s warning on future for farming. New Scientist. 23 August 2003.
Olesen, J.E. (2003). Heatwave in Europe. Focus Magazin. September 2003.
Olesen, J.E. (2003). Klimaændringer og fosfortab fra landbruget. Berlingske Tidende. 9 December 2003.
Olesen, J.E. (2004). Ud med rødgranen – ind med vinmarker. Jyllandsposten. 2 May 2004.
Olesen, J.E. (2004). Landmænd i drivhuset. Nordjyske. 6 July 2004.
Olesen, J.E. (2004). Klimaændringer og nye afgrøder. Nyhedsradioen 24-7. 6 July 2004.
Olesen, J.E. (2004). Nye afgrøder i dansk landbrug. Fyens Stiftstidende. 8 July 2004.
Olesen, J.E. (2004). Dansk landbrug under ændret klima. Nyhedsradioen 24-7. 16 July 2004.

University of Fribourg:

August 2004	Interview on Radio Suisse Romande programs "*Forum*" on 07.08.2004 related to the precipitation regime of the Summer of 2004
August 2004	Interview on the French Service of "*Deutsche Welle*" related to the precipitation regime of the Summer of 2004
August 2004	Articles in *La Liberté* and *Le Temps* related to the precipitation regime of the Summer of 2004
July 2004	Review article in *Science News* (Washington, DC) on the GRL paper published in January 2004 on the 2003 heat wave in Europe
June 2004	Citation in the Swiss daily newspaper *Le Temps* regarding the movie "The Day After Tomorrow"
June 2004	Citation in the *British Medical Journal* related to the GRL paper published in January 2004 on the 2003 heat wave in Europe
April 2004	Article in the French popular science journal *Science et Vie* on our work on extreme events and climatic change
April 2004	30-minute interview on Radio Suisse Romande program "*Météo-Plus*" on the 2003 heat wave and future trends in summers by the end of the 21st century
March 2004	Citation on French radio *France Inter*
February 2004	Press articles in "The Guardian" (London, UK), by Reuters, and in "New Scientist" (London, UK) following the paper published in *Geophysical Research Letters* (Beniston, 2004); also appears as a highlighted paper in the AGU press (http://www.eurekalert.org/pub_releases/2004-02/agu-ajh021704.php)
January 2004	Article in PhysicsWeb on the paper published in *Geophysical Research Letters* (Beniston, 2004) on the 2003 heat wave in Europe
December 2003	Special full-page interview in the Lausanne daily newspaper "24-Heures" on issues related to climatic change, impacts, and policy
August 2003	Following the public interest in the summer heat wave of 2003, additional newspaper and TV Suisse Romande Téléjournal, also Radio-France, CNN News (14.08.2003)), and Deutsche Welle (Germany)
July 2003	Following the public interest in the summer heat wave of 2003 in the alpine region, several newspaper and TV interviews, namely "L'Illustré", the "Tribune de Genève", "24-Heures", "Le Matin", "Tages-Anzeiger", "Der Bund", "Facts" "St.-Galler Tagblatt", "SonntagsBlick", TV Svizzera Italiana (Telegiornale, 20:00 on 03.07.2003), Radio Suisse Romande, Swiss Radio International, TV Suisse Romande Téléjournal 19:30 (15.07.2003), and France-Inter. Also taken up in many French newspapers following AFP press release, in addition to newspapers in Bolivia and Chile.
June 2003	Following the interest generated by the purchase of our new 32-processor computer, and the exceptional heat wave of June 2003 in Switzerland, several newspaper, radio, and TV interviews, including two articles in "Le Temps", "La Liberté"; "Freiburger Nachrichten", "Le Matin Dimanche", "Basler Zeitung","Neue Luzerner Zeitung". Radio Suisse Romande, Radio Suisse Internationale, Radio DRS, TV Suisse Romande Téléjournal 19:30 (27.06.2003), Tele-Bärn, Radio-Top.
June 2003	In the context of the inauguration of a new French government service on climate impacts (ONERC : Office National pour l'étude des Effets du Réchauffement Climatique), interview on Radio-France

Finish Meteorological Institute:

There have been several media contacts during last summer due to flooding in Finland. Appearance in interviewed TV news (YLE1, FST, Nelonen). Similarly there have been press stories e.g. in Ilta-Sanomat and Itä-Savo. Although PRUDENCE has not been explicitly mentioned in these stories PRUDENCE has given scientific background information in preparations for interviews.

1.6 Difficulties encountered at management and co-ordination level, and proposed/applied solutions

All partners have communicated their progress on the project satisfactorily.

1.7 Contend of planned Special Issue of Climatic Change

The manuscripts without an abstract were delayed by the time of the write up of the present project, thus no abstract was yet available.

Evaluating the performance and utility of regional climate models in climate change research: Reducing uncertainties in climate change projections – the PRUDENCE approach.
J.H. Christensen et al.

An intercomparison of regional climate models for Europe: design of the experiments and model performance. (WP1 contribution)
D. Jacob et al.

An intercomparison of regional climate models for Europe: assessing uncertainties in model projections. (WP2 contribution)
M. Déqué, D.P. Rowell, D. Lüthi, F. Giorgi, J. H. Christensen, B. Rockel, D. Jacob, E. Kjellström, M. de Castro, and B. van den Hurk

Abstract
Ten regional climate models (RCM) have been integrated with the standard forcings of the PRUDENCE experiment: IPCC-SRES A2 radiative forcing and Hadley Centre boundary conditions. The response over Europe, calculated as the difference between the 2071-2100 and the 1961-1990 means can be viewed as an expected value about which some uncertainty exists. Uncertainty is measured here by variance in eight sub-European boxes. Four sources of uncertainty can be evaluated with the material provided by the PRUDENCE project. Sampling uncertainty is due to the fact that the model climate is estimated as an average over a finite number of years (30). Model uncertainty is due to the fact that the models use different techniques to discretize the equations and to represent sub-grid effects. Radiative uncertainty is due to the fact that IPCC-SRES A2 is merely one hypothesis. Some RCMs have been run with another scenario of greenhouse gas concentration (IPCC-SRES B2). Boundary uncertainty is due to the fact that the regional models have been run under the constraint of the same global model. Some RCMs have been run with other boundary forcings. The contribution of the different sources varies according to the field, the region and the season, but the role of boundary forcing is generally greater than the role of the RCM, in particular for temperature. Maps of minimum expected 2m temperature and precipitation responses for the IPCC-A2 scenario show that, despite the uncertainties, the signal from the PRUDENCE ensemble is significant.

On interpreting hydrological change from regional climate models. (WP3 contribution)
L.P. Graham, S. Hagemann, S. Jaun, and M. Beniston

Abstract
Evaluating changes to hydrological regimes due to climate change can be carried out in different ways. Although representation of hydrology is included in all regional climate models (RCM), the utility of hydrological results from RCMs can vary considerably from model to model. Studies to evaluate and compare the hydrological components of a suite of RCMs over Europe were therefore carried out. This included different methods to transfer RCM runoff directly to river discharge. This work also analyzed climate change impacts on hydrology from the different RCMs by coupling to offline hydrological models of varying scale and detail, ranging from regional scale to finer basin scales. Different methods to transfer the climate change signal between models were employed. The work focused on drainage areas to the Baltic Basin, the Bothnian Bay Basin and the Rhine River Basin. A total of 20 anthropogenic climate change scenario simulations from 11 different RCMs were used.

Uncertainties in projected impacts of climate change on European agriculture, forestry and ecosystems based on scenarios from regional climate models
J.E. Olesen, T.R. Carter, C.H. Díaz-Ambrona, S. Fronzek, T. Heidmann, T.Hickler, T. Holt, M.I. Minguez-Tuleda, M. Quemada, M. Ruiz-Ramos, P. Morales, J. Palutikov, F. Sau, B. Smith, M. Sykes

Abstract
Impacts of climate change on natural and managed ecosystems can be evaluated using models operating at different scales from individual fields to continental levels. Site-based crop models were applied to study crops and cropping systems in Denmark and Spain. The response of soil water availability in the Mediterranean region was analysed using a simple water balance model. At the European level, the LPJ-GUESS ecosystem model and simple indices were used to analyse productivity of natural ecosystems and indicators of crop suitability. The models and indices were applied to output for range of regional climate models (RCMs) describing climate change over Europe from 1961-1990 to 2071-2100 representing the IPCC SRES A2 and B2 scenarios. A test of different downscaling methods showed large differences in some cases for the baseline period between the simulated site-based crop yields for observed baseline climate and the control climate for the RCM simulations. The results indicate that RCM output may be used directly as input to ecosystem models, but this is not generally the case. There is a consistent northward migration of ecosystems and cropping zones across all emission scenarios and RCM runs with slightly higher impacts for the A2 scenario compared to B2. The greatest increase in ecosystem productivity were predicted to occur in Northern Europe (on average 27%), while the smallest changes were predicted for South-Western Europe (on average 9%), and this was consistent across all scenarios. In general, the A2 scenarios were associated with larger changes than B2 scenarios. Estimates of the changes in winter wheat productivity for were consistent among the RCM's for the A2 scenario with increases in most areas north of the Alps and decreases in southern Europe, especially over the Iberian Peninsula. A considerably larger spatial variation was seen in response of N leaching to the climate change scenarios. The yield decreases in Mediterranean region were driven by higher temperature and considerably less water and available soil moisture during the summer period. This will lead

to changes in cropping patterns towards winter agriculture and more drought tolerant agricultural systems.

Future Extreme Events in European Climate: An Exploration of Regional Climate Model Projections (WP5 contribution)

M. Beniston, D.B. Stephenson, O.B. Christensen, C.A.T. Ferro, C. Frei, S. Goyette, K. Halsnaes, T. Holt, K. Jylhä, B. Koffi, J. Palutikof, R. Schöll, T. Semmler, K. Woth

Abstract

This paper presents an overview of changes in the extreme events that are most likely to affect Europe in forthcoming decades. A variety of diagnostic methods are used to determine how heat waves, heavy precipitation, drought, wind storms, and storm surges change between present (1961-90) and future (2071-2100) regional climate model simulations produced by the PRUDENCE project. A summary of the main results follows.

Heat waves . Regional surface warming causes the frequency, intensity and duration of heat waves to increase over Europe. By the end of the 21st century, countries in central Europe will experience the same number of hot days as are currently experienced in southern Europe. The intensity of extreme temperatures increases more rapidly than the intensity of more moderate temperatures over the continental interior due to increases in temperature variability.

Precipitation . Heavy winter precipitation increases in central and northern Europe and decreases in the south; heavy summer precipitation increases in north-eastern Europe and decrease in the south. These changes reflect changes in mean precipitation. Mediterranean droughts start earlier in the year and last longer.

Winter storms . Extreme wind speeds increase between 45°N and 55°N, except over and south of the Alps, and become more north-westerly. These changes are associated with reductions in mean sea-level pressure and generate more North Sea storms, leading to increases in storm surge along the North Sea coast, especially in Holland, Germany and Denmark.

The value of information from regional climate models in guiding policy. (WP6 contribution)

K. Halsnaes et al.

The STARDEX project

C. Goodess et al.

Modelling the Impact of Climate Extremes: An overview of the MICE project

C.E. Hanson, J.P. Palutikof, M.T.J. Livermore, L. Barring, M. Bindi, J. Corte-Real, R. Duaro, C. Giannakopoulos, T. Holt, Z. Kundzewicz, G. Leckebusch, M. Radziejewski, J. Santos, P. Schlyter, M. Schwarb, I. Stjernquist, and U. Ulbrich

Abstract

This paper provides an overview of the aims, objectives and research activities undertaken in the EU-funded project entitled "Modelling the Impact of Climate Extremes" (MICE) - a pan-European end-to-end assessment, from climate model to impact model, of the potential impacts of climate change on a range of economic sectors important to the region. MICE has focussed on changes in temperature, precipitation and wind extremes. The research programme had three main themes – the evaluation of climate model performance, an assessment of the potential future changes in the occurrence of extremes, and an examination of the impacts of changes in extremes on six activity sectors using a blend of quantitative modelling and expert judgement techniques. MICE culminated in a large stakeholder-orientated workshop, the aim of which was not only to disseminate project results but also to develop new stakeholder networks, whose expertise can be drawn on in future projects such as ENSEMBLES.

The use of a climate-type classification for assessing climate change effects in Europe from an ensemble of regional climate models

M. de Castro, C. Gallardo, K.Jylha and H. Tuomenvirta

Abstract

Making use of the Köppen-Trewartha (K-T) climate classification, we have found that a set of nine high-resolution regional climate models (RCM) are fairly capable of reproducing the current climate in Europe. The percentage of grid-to-grid coincidences between climate subtypes based on the control simulations and those of the Climate Research Unit (CRU) climatology varied between 73% and 82%. The best agreement with the CRU climatology corresponds to the RCM "ensemble mean". The K-T classification was then used to elucidate scenarios of climate change for 2071-2100 under the SRES A2 emission scenario. The percentage of land grid points with unchanged K-T subtypes ranged from 41 to 49%, while those with a shift from the current climate subtypes towards warmer or drier ones ranged from 51 to 59%. As a first approximation, one may assume that in regions with a shift of two or more climate subtypes, ecosystems might be at risk. Excluding northern Scandinavia, such regions were projected to cover about 12% of the European land area.

Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs

S. Fronzek, T. Carter, K. Jyhlä

Abstract

We present analyses of the estimated impacts of climate change on different aspects of the natural environment, agriculture and energy demand in Europe under a wide range of RCM- and AOGCM-based climate scenarios. A suite of simple models and indices are used to assess impacts on the growing season, potential biomass, thermal suitability for the

cultivation of crops, and potential energy demand for indoor cooling.
Impacts have been estimated for observed climate in the 1961-1990 baseline period and projected climate during 2071-2100 based on outputs from a range of RCMs using SRES emission scenarios A2 and B2 and from seven GCMs using a wider range of emission scenarios. All analyses are conducted on a regular 0.5 x 0.5° grid across Europe.
Uncertainties in the projected impacts of climate change are assessed with respect to: 1) the direct model output vs. delta change approach, 2) differences in the driving GCMs and the RCM runs, 3) the model range vs. a range of emission scenarios, 4) changes in long-term mean climate, and 5) changes in inter-annual climate variability.
The future simulations show substantial changes in all analysed impact sectors with relatively large ranges of climate-scenario uncertainty: shift of the northern limits of areas suitable for the cultivation of soya bean and grain maize by several hundred kilometres; lengthening of the thermal growing season by four to twelve weeks with slightly stronger changes in autumn than in spring; strong increases of potential biomass in northern Europe and slight decreases in the south; and increased energy demand for cooling. The inter-annual variability increased in the future simulations compared to the baseline.

Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods - a case study on the Lule River Basin

L.P. Graham, J. Anréasson, and B. Carlsson

Abstract
This paper investigates how using different regional climate model (RCM) simulations affects climate change impacts on hydrology in northern Europe using offline hydrological models. Climate change scenarios from an ensemble of seven RCMs, two global climate models (GCMs), two global emissions scenarios and two RCMs of varying resolution were used. Studies were performed for 15 anthropogenic climate change scenario simulations on the Lule River basin in Northern Sweden. Two different approaches to transfer climate change from the RCMs to hydrological models were included. A rudimentary estimate of change in hydropower potential on the Lule River due to climate change is also presented. The ensemble results indicate an overall increase in river flow and earlier spring peak flows compared to the present climate.

Gradient in the climate change signal of European discharge predicted by a multi-model ensemble.

S. Hagemann and D. Jacob

Abstract
Ten regional climate models (RCMs) participated in the European project PRUDENCE, which aim was to predict uncertainties in RCM simulations over Europe. Within PRUDENCE two major climate simulations were performed by each participating RCM. A control simulation representing current climate conditions for the period 1961-1990, and a scenario simulation representing climate change conditions according to the IPCC scenario A2 for the period 2071-2100. Lateral boundary conditions were provided by the atmospheric general circulation model (GCM) HadAM3H for both simulations. In order to perform hydrological studies on these RCM simulations, a special focus was put on the discharge

from large river catchments located in northern and central Europe. The discharge was simulated with a simplified land surface (SL) scheme and the Hydrological Discharge (HD) model. The daily fields of precipitation, 2m temperature and evapotranspiration from the RCM simulations were used as forcing. Therefore the total catchment water balances are constrained by the hydrological cycle of the different RCMs. The validation of the simulated hydrological cycle from the control simulations shows that the multi-model ensemble mean is closer to the observations than each of the models, especially if different catchments and hydrological variables are considered. Therefore, the multi-model ensemble mean can be used to largely reduce the uncertainty that is introduced by a single RCM. This also provides more confidence in the future projections for the multi-model ensemble means. The scenario simulations predict a gradient in the climate change signal over Northern and Central Europe. Common features are the future warming and a general increase of evapotranspiration. But while in the northern parts the warming will enhance the hydrological cycle leading to an increased discharge, the large warming, especially in the summer, will slow down the hydrological cycle caused by a drying in the central parts of Europe which is accompanied by a reduction of discharge. The comparison of the changes predicted by the multi-model ensemble mean to the changes predicted by the driving GCM HadAM3H indicates that the RCMs can compensate problems that a driving GCM may have with local scale processes or parameterizations.

Using Climate Analogues for Assessing Climate Change Economic Impacts in Urban Areas

S. Hallegatte, J.-C. Hourcade, and P. Ambrosi

Abstract

This paper aims at proposing a way to get round the intrinsic deadlocks of the economic assessment of climate change impacts (absence of credible counterfactuals and of fully-etched description of adaptation behaviours under uncertainty). First, we use the climate scenarios of 2 models of the PRUDENCE project (the regional climate model of the Hadley Centre (HadRM3H) and the global climate model of the CNRM (ARPEGE)) to search for cities whose present climates can be considered as reasonable analogues of the future climates of 17 European cities. These analogues meet rather strict criteria in terms of monthly mean temperature, total annual precipitations, and monthly mean precipitations. Second, we use these analogues as an heuristic tool to understand the main features of the adaptation required by climate change. The availability of two analogues for each city provides a useful estimate of the uncertainty on the required adaptation. Third we carry out a cost assessment for various adaptation strategies, taking into account the cost of possible ill-adaptations due to wrong anticipations in a context of large uncertainty (from sunk costs to lock-in in suboptimal adaptation choices). We demonstrate the gap between an enumerative approach under perfect expectation and a calculation accounting for uncertainty and spill-over effects on economic growth.

Changes in frost and snow in Europe and sea ice in the Baltic Sea by the end of the 21st century
K. Jylhä et al.

Present-day and future summertime precipitation in the Baltic Sea region as simulated in a suite of regional climate models
E. Kjellström and K. Ruosteenoja

Abstract
Here we investigate simulated changes in the precipitation climate over the Baltic Sea and surrounding land areas for the period 2071-2100 as compared to 1961-1990. We analyze precipitation in nine regional climate models taking part in the European PRUDENCE project. Forced by the same global driving climate model and the same emission scenario the mean of the regional climate model simulations captures the observed climatological precipitation over the Baltic Sea runoff land area to within 15% in each month, while single regional models have errors up to 25%. In the future climate, the precipitation is projected to increase in the Baltic Sea area, especially during winter. During summer increased precipitation in the north is contrasted with a decrease in the south of this region. Over the Baltic Sea itself the future change in the seasonal cycle of precipitation is markedly different in the various regional climate model simulations. We show that the sea surface temperatures have a profound impact on the simulated hydrological cycle over the Baltic Sea. The driving global climate model used in the common experiment projects a very strong increase in summertime sea surface temperature, leading to a significant increase in precipitation. In addition to the common experiment some regional models have been forced by either lateral boundary conditions from another global climate model, a different emission scenario, or different initial conditions. We make use of the full matrix of experiments in the PRUDENCE project, providing an ensemble consisting of more than 30 realizations of climate change, to illustrate uncertainties in climate change projections.

Variability in daily maximum and minimum temperatures: Recent and future changes over Europe.
E. Kjellström, L. Bärring, D. Jacob, R. Jones, G. Lenderink, and C. Schär

Abstract
Simulated variability in daily maximum and minimum temperature is compared to the observed climate. We use regional climate model simulations from ten different centers taking part in the European project PRUDENCE. An ensemble of ten different realizations of climate change is investigated in terms of changes in the daily variability of the temperature climate. These simulated future changes in daily variability of mean, maximum and minimum temperatures are also compared to observed temperature records. For this purpose we use selected daily station data from a network of 200 stations covering the normal period 1961-1990 and seven stations with records reaching back to the start of the instrumental era. The spatial pattern of bias is assessed, both with respect to the ensemble median bias and inter-model spread, as well as the regionally averaged patterns for each model. We focus on the winter climate in the northern and

eastern parts of Europe and the summer climate in the southern half of Europe. During these seasons, these regions are projected to experience large changes not just in the average temperatures but especially in the tails of the probability distributions of daily values. The changes are manifested through a very strong increase in temperature on the coldest days in winter while the median temperature changes to a lesser degree. In summer the increase of temperature on the warmest days is larger than the increase in median.

Summertime inter-annual temperature variability in an ensemble of regional model simulations: analysis of the surface energy budget

G. Lenderink, A. van Ulden, B. van den Hurk, and E. van Meijgaard

Abstract

The inter-annual variability in monthly mean summer temperatures derived from nine different regional climate model (RCM) integrations is investigated for both the control climate (1961-1990) and a future climate (2071-2100) based on A2 emissions. All models are driven by the same boundaries of the HadAM3H global atmospheric model. These integrations were carried out in the context of the PRUDENCE project. Compared to the CRU TS 2.0 observational data set most RCMs (but not all) overpredict the temperature variability significantly in their control simulation. Results obtained with one RCM using analysed boundaries from the ERA40 project are also discussed. The results obtained using ERA40 boundaries are close to those obtained using the HadAM3H boundaries, indicating that errors in the circulation statistics in the HadAM3H boundaries are not likely to be a major contributor to the overestimation in temperature variability. The behaviour of the different regional climate models is analysed in terms of the surface energy budget, and the individual contributions of the different terms in the surface energy budget to the temperature variability are estimated. This analysis shows a clear relation in the model ensemble between temperature variability and the combined effects of downward long wave, net short wave radiation and evaporation. However, it appears that the overestimation of the temperature variability has no unique cause. The effect of shortwave radiation dominates in some RCMs, whereas in others the effect of evaporation dominates. In all models the temperature variability increases when imposing future climate boundary conditions, with particularly high values in central Europe. The surface energy budget analysis again shows a clear relation between the sum of the responses in evaporation, net short wave radiation, and downward long wave radiation, on the one hand, and the change in temperature variability, on the other hand.

First-order agricultural impacts assessed with various high-resolution climate models in the Iberian Peninsula – a region with complex orography

M.I. Minguez, M. Ruiz-Ramos, C.H. Diaz-Ambrona, M. Quemada, and F. Sau

Abstract

The main objective of this work, within the PRUDENCE project, was to evaluate and compare predictions of initial, i.e. first-order agricultural impacts generated by linking several high-resolution climate models (RCMs) to crop simulation models that used their daily

weather data for control, A2 and B2 scenarios. All RCMs used boundary conditions from the atmospheric general circulation model (AGCM) HadAM3 and two of them were also bounded to two different AGCMs. We have standardised the analysis to control the sources of variation and uncertainties that were added in the process. Yield was used as an indicator that summarised the non-linear effects of climate and enabled us to quantify initial impacts, and differentiate among regions. Comparison among RCMs was done through the choice of different crop management options. All RCMs detected crop failures for winter wheat in the South under control and future scenarios, and projected yield increases for spring wheat in northern and high altitude areas. Although projected impacts differed among RCMs, similar trends emerged from the mapped distributions produced for relative yields for some regions. Uncertainties were quantified as the standard deviation of the mean obtained for all RCMs in each location and differed greatly between winter (wheat) and summer (maize) seasons, being lower in the latter.

Future changes in near surface wind speed extremes over Europe from an ensemble of RCM simulations

B. Rockel, and K. Woth

Abstract

In this study we analyse the uncertainty of the effect of enhanced greenhouse gas conditions on windiness projected by an ensemble of regional model simulations driven by the same global control and climate change simulations. These global conditions, representative for 1961-1990 and 2071-2100 were prepared by the Hadley Centre based on the IPCC A2 SRES scenario. The basic data sets are the simulated daily maximum and mean wind speed fields (over land) from the PRUDENCE data archive at Danish Meteorological Institute. The main focus is on the results from the standard 50km runs of eight regional models. From these data sets the best parameter for determining possible future changes in extreme wind speeds and possible change in number of storm events is the maximum daily wind speed. It turned out during this study that the method for calculating maximum daily wind speed differs among the regional models. A comparison of simulated winds with observations for the control period show that models without gust parameterization are not able to capture high wind speeds. The two models with gust parameterization estimate an increase of up to 20% of number of storm peak events over Middle-Europe in the future.

In order to use a larger ensemble of models than just the two with gust parameterization we also look at the 99-percentile of the daily mean wind speed. We divide Europe into eight subregions (e.g. British Isles, Iberian Peninsula, Scandinavia) and investigate the inter monthly variation of wind over these regions as well as possible differences between today's climate and possible future climate. Results show differences and similarities between the subregions in magnitude, spread, and seasonal tendencies. Future mean daily wind speed may increases during winter months and may decreases in autumn in areas influenced by North Atlantic extra-tropical cyclones.

GCM-based regional temperature and precipitation change estimates for Europe under four SRES scenarios, applying a new version of pattern-scaling method.

K. Ruosteenoja, H. Tuomenvirta, and K. Jylhä

Abstract

Seasonal GCM-based temperature and precipitation change projections for the end of the 21st century are presented for five regions covering continental Europe; these projections are compared with corresponding estimates given by the PRUDENCE RCMs. For most of the six global GCMs studied, only responses to the SRES A2 and B2 forcing scenarios have been simulated. In order to formulate projections for the highest (A1FI) and lowest (B1) forcing scenarios, a super-ensemble pattern-scaling technique has been developed. This method uses linear regression to represent the relationship between the local GCM-simulated temperature/precipitation response and the global mean temperature change simulated by a simple climate model. The method has several advantages: e.g., the noise caused by natural variability is reduced, and the method utilizes the information provided by GCM runs performed with various forcing scenarios effectively. The super-ensemble method proved especially useful in a situation with only one A2 and one B2 simulation available for an individual GCM.

95% probability intervals for regional temperature and precipitation change were constructed by fitting a normal distribution to the set of projections calculated by the various GCMs. The highest estimates of the A1FI temperature response are close to 10C in the southern Europe summer and northern Europe winter. In contrast, the lowest seasonal B1 estimates are 1C. The upper and lower estimates of precipitation change are generally of opposite sign, but the mean estimate is one of a marked increase in the north in winter and a drastic reduction in the south in summer.

In the RCM simulations driven by a single global model, the spread among temperature and precipitation projections is generally much smaller than in the GCM simulations, but it appears to be possible to reduce this disparity markedly by running all these RCM experiments with several driving models. The difference between the mean GCM and RCM projections is mostly fairly small.

Circulation Statistics and Climate Change in Central Europe: PRUDENCE Simulations and Observations

A. van Ulden, G. Lenderink, B. van der Hurk, and E. van Meijgaard

Abstract

Atmospheric circulation statistics produced by three global models and by nine regional models are analysed and compared with observations over Central Europe. The global models show significant biases, in particular in the strength of west-circulations in winter and in summer. The nine regional models used the same boundary conditions from the global model HadAM3H. In winter, the dynamic boundary forcing is strong and the circulation statistics of the regional models are close to those simulated by HadAM3H. In summer, the dynamical coupling is weaker and the regional models show a larger spread in the simulated circulation statistics, depending on the boundary relaxation scheme and other model characteristics. For two regional models (HadRM3H and RACMO2) we have investigated in more detail the relations between circulation and simulated temperature and precipitation, both for the control runs and for the A2-scenario. It appears that biases and changes in the

atmospheric circulations have a significant impact on simulated temperatures and precipitation. In winter, a positive bias in the strength of westerlies lead to a wetter and milder maritime climate with a lack of very cold months. In summer, an easterly bias in the circulation produces higher than observed frequencies of warm and dry days, but the response to this circulation bias is much stronger for HadRM3H, than for RACMO2, in particular in the scenario run. The strong response of HadRM3H to the easterly bias in the circulation is probably related to a dry bias in the model. HadAM3H is sensitive to summer drying as well and this may be partly responsible for the pronounced bias in the summer circulations simulated by this global model. The conclusion is that both the biases and changes in the circulation and biases in the treatment of energy and water cycle have to be understood and accounted for when climate change scenarios are to be derived from the model simulations analysed in this paper..

European climate variability in a heterogeneous multi-model ensemble

P.L. Vidale, D. L¨uthi, R. Wegmann, C. Schär

Abstract

Recent results from an enhanced greenhouse-gas scenario over Europe suggest that climate change might not only imply a general mean warming at the surface, but also a pronounced increase in interannual surface temperature variability during the summer season (Schär et al. [2004]). It has been proposed that the underlying physical mechanism is related to land surface-atmosphere interactions. In this study we expand upon the previous analysis, by including results from a heterogeneous ensemble of 11 highresolution climate models from the PRUDENCE project. All simulations considered comprise 30-year control and enhanced greenhouse-gas scenario periods. While there is considerable spread in the models ability to represent the observed summer variability, all models show some increase in variability under the enhanced greenhouse-gas scenario, confirming the main result of the previous study. Averaged over a large-scale Central European domain, the models simulate an increase in the standard deviation of summer mean temperatures between 20 and 80%. The amplification occurs predominantly over land points and is particularly pronounced for surface temperature, but also evident for precipitation. Locally, the effects may be even stronger. It is also found that the simulated changes in Central European summer conditions are characterized by an emergence of dry and warm years with depleted root-zone water. There is thus some evidence that the change in variability may be linked to the dynamics of soil-moisture storage and the associated feedbacks on the surface energy balance and precipitation.

1.8 Aspects from the final workshop

The minutes can be accessed at http://prudence.dmi.dk. The expressions by the members of the External Advisory Board after the final meeting of the board are included here.

Martina Jung

Hamburg Institute of International Economics, Germany

My following judgements as an external advisor to the PRUDENCE project are based on reading the project summary, the information on the PRUDENCE homepage as well participating in the PRUDENCE workshop and Business Meeting in Toledo.

I am quite impressed by the overall achievements of the PRUDENCE project. Its innovative approach to analyze impacts of climate change and their uncertainties due to the use of different climate and impact models (as well as different emissions scenarios) has proven successful.

One ambitious goal of the project was the linking of the climate and impact modelling community. For achieving this goal, problems regarding different data formats, types of data and research concepts had to be solved. In the course of the project, most of these issues have been addressed successfully. It would be interesting for future research projects to get insights into which problems in linking the different areas have come up and how they have been addressed. Furthermore, PRUDENCE should report on how the magnitude of uncertainties found in the climate and impact models relates to the uncertainties connected with the translation of those physical impacts into economic ones.

While the dissemination of outputs at the most detailed level (data set) seems to be almost completed, dissemination of results on a non-technical level (part of WP 7) are still less developed. The project management is aware of the importance of dissemination of results to the general public and policy-makers, though. For accomplishing this challenging task, it would, therefore, be important to get a clearer picture of which results are especially policy-relevant, and to which level of policy-makers as well as which results are interesting to the general public. This will determine which dissemination approaches (some of them proposed in the workshop, e.g. brochures, national workshops…) are most appropriate. General questions regarding the existence of anthropogenic climate change and its uncertainty levels might be more interesting at the international level (UN climate negotiations, EU), while at the national and sub national level information on ranges of impacts to be expected, their importance for particular sectors and possible adaptation measures might be more relevant for the formulation of climate policy strategies.

Furthermore, it should be considered to establish contacts to other projects focussing on impacts and adaptation, which could take advantage from the knowledge gained in the PRUDENCE project. Since the subject of adaptation has gained political importance in the last years, the PRUDENCE outputs regarding impacts could be highly relevant for future adaptation policies.

Münster, 20. September 2004

Westfälische Wilhelms -Universität Münster

Institut für Geophysik

Prof. Dr. Manfred A. Lange

Comments on PRUDENCE

Prof. Dr. Manfred A. Lange

PRUDENCE is a major EU-funded project that is getting close to its completion. The project aims at a number of objectives including:

- a series of high resolution climate change scenarios for Europe for 2071-2100,
- an assessment of uncertainties of European regional climate models (RCMs),
- an assessment of risks caused by climate change for Europe,
- the application of RCM results to a number of climate impact studies,
- an assessment of implications of climate change for socio-economic and political decision making and
- a broad dissemination of PRUDENCE results.

PRUDENCE has been carried out by 20 partners over three years. Thus, managing, steering and integrating the project and individual results have been substantial challenges. The coordinator and the project steering group should be commended on succeeding in navigating the project smoothly and effectively. As a measure of productivity within the project, the recent list of publication includes some 60 papers and reports, some in high ranking journals such as NATURE or Geophysical Research Letters. The publication record and other means of communication have resulted in a high profile within the international scientific community. PRUDENCE has thus significantly underlined the leading position of European climate modelling on an international level. This is also reflected by attempts of a number of research groups in North- and South America to use the PRUDENCE approach and major methodologies in similar national projects.

PRUDENCE has resulted in a wealth of data, scenarios and information. There have been a fairly large number of individual RCMs developed and implemented under PRUDENCE. One of the major results from the modelling work to be highlighted is the conclusion that RCMs are indeed capable of resolving meso-scale features that the global models that serve as boundary conditions are incapable of showing. Furthermore, there has been a fruitful dialogue between the modelling community and the impact scientists within PRUDENCE. This should still be enlarged and intensified in the future and will undoubtedly contribute towards progress in both communities.

Looking at the results of the RCMs presented at the meeting, the fairly large spread in the scenarios obtained for a common region and a common time slice is still striking. This spread is then also translated into the results of some of the impact studies leading to sometimes quite confusing conclusions.

A commonly applied practice to deal with differing RCM results has been to look at the ensemble of all results, employing suitable statistical techniques to come up with an aggregate outcome. In the simplest case, mean values and standard deviations may be computed. However, this raises the issue to what extent an aggregation of different model results represents an appropriate or even an acceptable way of pursuing the derivation of ensemble results. One issue to note here is the question to what extent such a process does justice to the "good" models on the expense of the "bad" models or vice versa. However, these issues are apparently subject to new projects such as the EU-funded ENSEMBLE.

This withstanding and in summary, PRUDENCE has successfully assessed uncertainties in detailed climate scenarios for Europe based on RCM runs. The uncertainly due to the underlying GCM data seem to be constrained by the way sea surface temperatures are represented. Despite considerable efforts to improve RCM performances within PRUDENCE, the inter-model differences and the individual model uncertainties remain significantly. This notwithstanding, PRUDENCE, over only a three-year period has produced impressive and important results and has significantly enhanced our insight into the future development of European climate.

Notes on PRUDENCE **Oslo Oct. 5th 2004**

Trond Iversen
Professor,
Dep. Of Geosciences,
University of Oslo, Norway;
(Project leader of RegClim)

The following points of view from an external advisor are based on reading the work description, and participating in the third and fourth PRUDENCE workshops including the internal "Business Meeting". The downscaling group of the Norwegian RegClim-project I am leading (at met.no), is an associated partner to PRUDENCE without financial commitments.

PRUDENCE is an ambitious and innovative project in climate change research over Europe. It is ambitious with respect to the number of models included and amount of data produced, as well as the wide participation of research-groups from widely different fields. It is innovative most importantly due to its systematic use of model-generated climate data to assess risks of adverse weather events, and uncertainties associated with scenarios of climate change and its potential impacts on nature and society. The project represents an important step forward towards a Pan-European evaluation of climate change and its effects. Its potential impact on European policy development and industry is strong, whilst at the same time high-quality research is highly probable.

The basis for all time-dependent climate scenario predictions for the next few hundred years are scenarios of external parameters that produce radiative forcing. Global climate models that fully couple the atmosphere, the deep oceans and sea-ice, and the land-surface (AOGCMs) calculate the climate response. Computer resources hamper the use of geographical resolution needed for most impact studies, and to represent geographical features important for the weather (mountains and coastlines), and dynamics associated with extreme weather. For these reasons, atmospheric models with higher resolution are run to downscale the AOGCM-results. PRUDENCE employs three types of downscaling models: high-resolution (typically 100 km) atmospheric global circulation models (AGCMs), and regional circulation models (RCMs) of high (typically 50 km) and very high (20 km and finer) resolution. The AGCMs and RCMs have a varying degree of sophistication with respect to the atmospheric processes and the description and coupling to land-surface and oceanic/lake processes.

A unique feature of PRUDENCE is the systematic use of several AGCMs and RCMs which enables quantifications of uncertainty in climate scenario predictions of different origins, such as choice of scenarios for anthropogenic climate forcing, approximations and weaknesses in the model formulations, and natural random variations in climate. Another important feature is the interdisciplinary structure of the project. PRUDENCE has been designed to study changes in the occurrence of different types of adverse weather events under changing anthropogenic forcing, and to estimate their environmental and socio-economic impacts.

An important aspect of these features concerns a number of practical issues related to scientists coming from very different fields and traditions. In PRUDENCE important issues such as data formats, the degree of match between data required for impact studies and what climate models can provide, have a high chance of being solved successfully.

Status

The participants in PRUDENCE are highly skilful and are able to comply with the commitments of their plans. My ability to judge this is mainly for the work-packages focusing on climate modelling (WP1 and 2) and impact-related work-packages linked to physical climate (WP3 and 5).

Based on presented scientific results and a reporting of status of deliverables and milestones, my clear impression is that PRUDENCE is able to meet the requirements according to its plans. There are some delays of deliverables, but none seems to be crucial. It is my clear impression that the management of PRUDENCE is well undertaken in order to secure that the targets are reached for the project.

Scientific contributions

PRUDENCE has had significant scientific impacts through an impressive list of published papers. More papers, including a special issue, are also underway. Two major articles concerning extreme events have been published in Nature.

I am, in particular, happy for recent results from careful investigations of uncertainties in downscaled scenarios allocating their sources. Parts of this discussion include data from global climate models with considerably different characteristics for Atlantic-European climates (the model of the Hadley Centre, and that of MPI-Hamburg). Work along these lines will be necessary to pursue in further research.

Even though there is a considerable amount of results produced, I have an impression that further synthesis of the results should be made in order to extract the information on important uncertainty issues. I presume some resources will be allocated for this towards the end of the project and with the special issue for publication.

Finally, I need to mention that I am not able to judge the significant importance of results in impact-related and socio-economic parts of the project. That should be commented by other advisors to PRUDENCE. Nevertheless, it still is a challenge for the scientific community dealing with anthropogenic climate change issues to communicate between wide scientific disciplines.

All in all, I judge PRUDENCE to be a considerable success scientifically as well as for the assistance of decision makers. Perhaps some active popularization of the findings is needed, for example by producing a brochure.

2. Executive publishable summary

Problem to be solved:

European decision-makers in government, non-governmental organisations (NGOs), and industry as well as the general public need detailed information on future climate. In this way it becomes possible to evaluate the risks of climate change due to anthropogenic emissions of greenhouse gases. Projections of future climate change already exist, but are deficient both in terms of the characterisation of their uncertainties and in terms of their regional detail, particularly in dealing with extreme events. To date, the assessment of potential impacts of climate change has generally relied on projections from simple climate models or coarse resolution Atmospheric-Ocean General Circulation Models (AOGCMs), neither capable of resolving spatial scales of less than ~300km. This coarse resolution precludes the simulation of realistic extreme events and the detailed spatial structure of variables like temperature and precipitation over heterogeneous surfaces e.g. the Alps, the Mediterranean or Scandinavia. Simple models include, at best, a limited physical representation of the climate system.

Scientific objectives and approach:

PRUDENCE is a European-scale investigation with the following objectives:

a) to address and reduce the above-mentioned deficiencies in projections;
b) 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;
c) to interpret these 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, due to higher temperatures, an intensified hydrological cycle or more vigorous atmospheric motions. A major limitation in previous studies of extremes has been the lack of: appropriate computational resolution - obscures or precludes analysis of the events; long-term climate model integrations - drastically reduces their statistical significance; co-ordination between modelling groups - limits the ability to compare different studies. These three issues are all thoroughly addressed in PRUDENCE, by using state-of-the-art high resolution climate models, by co-ordinating the project goals to address critical aspects of uncertainty, and by applying impact models and impact assessment methodologies to provide the link between the provision of climate information and its likely application to serve the needs of European society and economy.

Expected impacts:

PRUDENCE provides a series of high-resolution climate change scenarios for 2071-2100 for Europe, characterising the variability and level of confidence in these scenarios as a function of uncertainties in model formulation, natural/internal climate variability, and alternative scenarios of future atmospheric composition. The project will provide a quantitative assessment of the risks arising from changes in regional weather and climate in different parts of Europe, by estimating future changes in extreme events such as flooding and windstorms and by providing a robust estimation of the likelihood and magnitude of such changes. The project will also examine the uncertainties in potential impacts induced by the range of climate scenarios developed from the climate modelling results. This will provide useful information for climate modellers on the levels of accuracy in climate scenarios required by impact analysts. Furthermore, a better appreciation of the uncertainty range in calculations of future impacts from climate change may offer new insights into the scope for adaptation and mitigation responses to climate change. In order to facilitate this exchange of new information, the PRUDENCE work plan places emphasis on the wide dissemination of results and preparation of a non-technical project summary aimed at policy makers and other interested parties.

3. Status of activities by Work Package for the last year

3.1 Status of activities in WP1: European climate scenarios

3.1.1 Objectives

The objective of WP1 is to carry out a series of 30-year-simulations for todays and future climate with four high-resolution atmospheric general circulation models (AGCMs). In using observed and model derived sea surface temperature conditions as well as atmospheric radiative forcing from different IPCC emission scenarios the spread in AGCM simulations should be determined. The different AGCM simulations are used to drive eight regional climate models (RCMs). The responses in these experiments are analysed to determine the confidence in the differences of the driving AGCM simulations as well as the reliability in the fine scale details of the RCM simulations.

3.1.2. Methodology and scientific achievements

In this work package four different AGCMs and eight different RCMs are applied. To get an estimate of the uncertainty for present day climate (1961-1990) caused by the different model formulations, the same observed time series of sea surface temperature and emissions of trace gases and sulphate aerosols are used to drive the models. For future climate (2071-2100) the sea surface conditions as predicted from state of the art atmosphere ocean general circulation models (AOGCMs) and the changes in the radiative forcing derived from the SRES-A2- and B2-scenarios from IPCC are used. In varying the radiative forcing, exchanging the driving AOGCM, the AGCM, the RCM or varying the initial conditions in the AGCM and RCM simulations, the main sources of the uncertainty can be determined.

All participants have completed their AGCM simulations. From MPI ECHAM4 simulations are available. In addition ETH has conducted ECHAM5 with the sea surface temperature from the Hadley Centre AOGCM. The regional climate simulations with a horizontal resolution of 50 km are all finished. From the high resolution regional climate model simulations (20 to 25 km) the ones from Hadley-Centre, SMHI and DMI are completed. DMI has performed an additional high resolution run (12km) with their regional model. Thus the promised climate simulations have been finished, and additional runs from participants outside the consortium; KNMI and met.no have been included as well.

Each modelling group has evaluated their model results. In addition for the RCM simulations a common evaluation for mean sea level pressure, 2m mean, minimum and maximum temperature and precipitation for present day and future climate is provided at http://prudence.dmi.dk and included in the manuscript from WP1 to be included in the special issues of *Climatic Change* mentioned elsewhere in this report. For present day climate the simulated temperature and precipitation have been compared to interpolated observations from the Climatological Research Unit (CRU).

3.1.3. Socio-economic relevance and policy implication

Climate changes can have severe impacts on the vegetation, the hydrology, agriculture and economy. Identification of potential trends for change will thus have policy implications. As yet, specific details of policy implication have only been addressed in WP6.

3.1.4. Discussion and conclusion

The evaluation of the RCMs has shown that the models are able to capture the climatological large scale circulation as well as precipitation and temperature patterns. No model could be figured out to be the best. Furthermore there are groups of models, which behave quite similar. For example the models of GKSS, MPI and ETH form such a group. These three models use a similar dynamics and vertical diffusion. It would be interesting to further investigate the reasons for this group formation.

Up to now only mean parameters of all different RCM simulations have been evaluated and compared to observations. Many additional evaluations have only taken place for selected simulations. In order to use the whole variety of models, all evaluations should take place for as many climate models as possible.

Deliverables for WP1 have now all been completed.

3.1.5. Plans and objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.2 Status of activities in WP2: Uncertainty Assessment of European Regional Climate Model Responses to a Common Forcing

3.2.1. Objectives

• To analyse the responses to climate change in each of the AOGCM experiments, focussing on climate impacts related variables and studying mechanisms to provide guidance on the reliability of the responses.
• To combine the analysis of 8 RCM models, which used identical driving data, to assess the uncertainty in regional model responses due to model formulation.

3.2.2. Methodology and scientific achievements

As an aid to management, WP1 and WP2 deliverables have been grouped together into ‘merged deliverables’, each covering a set of related topics. Progress on those deliverables contained in WP2, are as follows:

a. Uncertainty assessment using high-resolution global model scenarios

Partners: Met-Fr, MO/HC, MPI

• All partners above have provided global model data to the central distribution site at DMI.

• Met-Fr has developed a methodology for objectively assessing and comparing uncertainty from 4 sources: sampling error of climate noise, radiative forcing, driving AOGCM, driven AGCM. A paper has been submitted on this.

• DMI has plotted the responses of all models in a common format to enable a subjective comparison. The results are displayed at http://prudence.dmi.dk . These will later be published in an internal report.

• MO/HC have completed an investigation of the causes of central European summer drying in their global model integrations, to better understand the uncertainty of this regional response.

b. Assessment of RCM current climate simulations

Partners: DMI, DLR, MO/HC, ETH, GKSS, MPI, SMHI, UCM, ICTP

• All partners above have provided RCM data to the central distribution site at DMI (except DLR who are not contracted to do so).

• DMI has plotted the responses of all models in a common format to enable a subjective comparison. The results are displayed at http://prudence.dmi.dk . These will later be published in an internal report.

• Individual centres have compared the current climate of their RCM with observations, and some have prepared papers for publication describing this and the construction of their RCM.

c. Uncertainty assessment using regional model scenarios

Partners: DMI, DLR, MO/HC, ETH, GKSS, MPI, SMHI, UCM, ICTP

• All partners above have provided RCM data to the central distribution site at DMI (except DLR who are not contracted to do so).

• DMI has plotted the responses of all models in a common format to enable a subjective comparison.

• Met-Fr have developed a methodology for objectively assessing and comparing uncertainty from 4 sources, and applied a preliminary version to the available RCMs. A paper has been submitted on this.

• UCM and FMI have used Köppen climate types to assess uncertainty (cross-cuts with WP4).

• GKSS have analysed changes in the components of the energy and water budgets.

• SMHI has analysed changes in summer precipitation over the Baltic.

• DNMI (informal partners) have analysed changes in Norwegian winter precipitation.

• KNMI (informal partners) have analysed changes in blocking.

• MO/HC has used sensitivity experiments to understand projected summer drying over central and southern Europe.

• GKSS have investigated changes in North Sea and Baltic near-surf ace wind and pressure.

• UCM have analysed MSLP changes over the Mediterranean and southern Europe.

• KNMI (informal partners) investigated projected changes over the Rhine catchment.

• DLR have analysed changes in circulation types.

• DMI has assessed the change in intense summer rainfall events (cross-cuts with WP5).

d. Upper/lower estimates for regional temperature change using pattern scaling
Partners: FEI, FMI

• FMI and FEI have developed a pattern scaling methodology to assess the 'full' uncertainty range of regional temperature change across Europe due to emissions scenarios, model formulation and natural variability. This has been applied to AOGCMs from the IPCC-DDC. Applicability of the pattern-scaling method to RCMs is under investigation.

• DMI and UCM have produced probabilistic seasonal climate change projections per degree global warming for European nations. Results have been presented at COP10

3.2.3. Socio-economic relevance and policy implication

A detailed evaluation and understanding of the reliability and uncertainty of RCM climate projections, which WP2 is in the process of producing, is an essential component of assessing the socio-economic impacts of climate change.

3.2.4. Discussion and conclusion

Good progress has been made towards all deliverables, which have now all been completed, and although a couple of partners have experienced some delays, no major problems have been encountered.

3.2.5. Plan and objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.3 Status of activities in WP3: Impacts on Hydrology

3.3.1. Objectives

The objective of WP3 is to analyse the impacts of climate change scenarios on hydrological regimes. The work package focuses on hydrology for the entire Baltic Sea drainage basin, the Lule River basin in Sweden, and the Rhine River basin in Central Europe. SMHI is conducting hydrological modelling in the northern basins, while ETH concentrates on the Rhine. Hydrological studies at MPI are being conducted both in the north and in the Rhine basin. In addition, U. Fribourg conducts studies on climate change impacts to snow and glaciers in the Alpine region, which are important contributors to runoff generation.

3.3.2. Methodology and scientific achievements

This work consists primarily of applying hydrological models in offline mode to assess impacts from the climate model simulations. Some of the modelling is aimed strictly at hydrological flow routing, which uses runoff generation outputs directly from the climate models. The applications cover a range of time and space scales, as well as different methods for transferring the climate change signal to hydrological models.

The work at ETH, MPI, and SMHI, has focus on hydrological simulations using RCM output. Unlike the other partners in WP3, U. Fribourg does not perform any hydrological modelling work, but focuses on analysis to specific hydrological variables.

SMHI focuses on performing simple hydrological modelling on as many RCM simulations as possible to get an indication of the range of differences that occur from using different RCMs in impacts assessment. Moreover, diagnostics of the hydrological outputs of the RCMs is also performed, resulting in comparisons of variables such as runoff coefficient over various hydrological basins. Such work has been done for four scenarios using the RCA model simulations. Results using several other RCMs simulations have also been done.

MPI has used their HD Model to perform flow routing of runoff from RCM simulations. As this model uses different runoff levels to represent fast and slow runoff responses, MPI had expressed interest in getting more detailed results in the form of runoff from different soil layers from the RCMs. Practically, only total runoff has been delivered to PRUDENCE and generation of additional results fields was not deemed worthwhile, particularly given the low scientific significance of these fields. In place of multiple runoff variables, MPI instead performed additional analyses to partition total runoff into components that represent fast and slow responses.

U. Fribourg has used climate change scenario results from RCMs to do studies of impacts on snow and glaciers in the Alpine region. They have submitted a scientific article that combines the use of the HIRHAM scenario results with observational analysis and surface energy balance modelling.

3.3.3. Socio-economic relevance and policy implication

Climate change impacts to hydrological regimes can have substantial impact on socio-economic systems in terms of both flooding and drought. Identification of potential trends for change will thus have policy implications. See also WP6

3.3.4. Discussion and conclusion

Deliverables for WP3 are now all completed and several scientific papers have been produced.

3.3.5. Plan and objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.4 Status of activities in WP4: Impacts on agriculture, forestry and ecosystems

3.4.1 Objectives

The objective of WP4 is to analyse the impacts of a range of detailed climate change scenarios on agriculture, forestry and ecosystems for selected regions in Southern and Northern Europe, and to evaluate adaptation options and possible effects on mitigation strategies. ISAg-UPM studies impacts on agricultural production in Spain with a focus on effects of changes in water availability on production. DIAS studies impacts on agricultural production in Denmark with a focus on the relationship with nitrogen cycling and effects on nitrate leaching. University of Lund studies the effects of climate change on productivity of natural ecosystems and forests across Europe. FEI uses simple climate indices to study uncertainties in estimating resource potential under climate change across Europe. UEA-CRU performs analyses of uncertainty in the Mediterranean Basin focusing on heat waves, cold spells, droughts and high-intensity rainfall.

3.4.2 Methodology and scientific achievements

The work consists primarily of applying ecosystem models and climate impact indices in offline mode to assess impacts from climate model simulations. Some of the modelling is aimed directly as effects on productivity of natural and managed ecosystems, whereas others is aimed at indirect effects, including effects on resource availability (e.g. water) and secondary environmental effects (e.g. nitrate leaching). The impact studies cover a wide range of temporal and spatial scales and details of the impact models used (dynamic or static models). Also different methods for transferring the climate change signal to the dynamic impact models are being tested.

ISAg-UPM has verified agricultural impact models for current climate and is now ready for simulation with RCM outputs. Crops and system models (DSSAT and CropSyst) have been linked to the geographical information system for verification with reanalysis data from ERA-15. Applications to the RCM simulations have now been completed.

DIAS has used the DAISY soil-plant-atmosphere model to simulate crop production and changes in soil C and N for range of crop rotations under changing temperature, rainfall and atmospheric CO_2 concentration. The DAISY modelling system has been set up for the crop rotations used in the project. After initial tests, the application of the methodology to RCM simulations has now been completed.

University of Lund uses the LPJ-GUESS dynamic ecosystem model to simulate current forest composition, biomass NEP, NPP, soil and vegetation carbon in a number of natural and semi-natural forested regions in Europe included in the EUROFLUX projectLPJ-GUESS model must be run for 200 years from 1901 to 2100. This requires filling the gap from 1991 to 2070 and together with the Hadley Centre a method has been developed to fill this gap. Simulations with various outputs (based on Hadley and Hamburg GCMs from SWECLIM Regional climate model) have been done for a gridded window over Sweden both to predict

Ecosystem processes, but also biomass and biodiversity. This is the type of approach that has been applied to all other RCM output at the appropriate scale for the entire Europe.

FEI have performed analyses of the estimated impacts of climate change on the thermal suitability for cultivation of grain maize, sunflower, and soya in Europe. Model-based analysis was carried out using temperature estimates from 7 GCMs for the SRES A2 and B2 emission scenarios. The analysis of the PRUDENCE suite of RCM data has been completed. Computer routines to calculate the remaining climate impact indices (heating degree days, cooling degree days, Lieth models of biomass, growing season) have also been applied to the RCM data sets.

The analyses by UEA-CRU of uncertainty in the Mediterranean Basin concentrates primarily on analysis of heat waves and cold spells, and of droughts and high-intensity rainfall. Daily data have been downloaded for the following RCM's: DMI, HadRM3, SMHI, UCM and MF. The variables include daily maximum, minimum and mean temperatures, rainfall and evapotranspiration from a selection of grid points in the RCM, chosen to represent the geographical diversity of Mediterranean environments. The scenarios and ensembles include a common period *a* (1961-1990), *A2a*, and *B2a* (both 2070-2100). These are available for all models. HadRM3 has the additional ensembles *A2b*, and *A2c* that will improve assessment of uncertainty. The HadRM3 data have been used data to create the following indices of annual precipitation extremes and indices of annual temperature extremes. The precipitation and temperature extreme indices were used to provide a preliminary assessment of likely changes in the primary conditions affecting soil water balance between 1961-1990 and 2070-2100 for the A2a and B2a scenarios.

3.4.3 Socio-economic relevance and policy implication

Climate change has a considerable impact on both natural and managed ecosystems. The impact on agricultural productivity is of primary concern for the rural population, but in some European countries of interest for the national economy. The direct effects on natural ecosystems and forest are essential for the European landscape and for many ecosystem functions provided clean air and water for the European population. Indirect effects of climate change on N-losses from agricultural systems can in some regions have profound effects on natural ecosystems. The EU Water Framework Directive will in the future regulate N-losses to surface waters in the EU, and during the preparation for the implementation of this Directive in Denmark results of climate change on N-leaching from agriculture was used. Other policy effects of climate change will be addressed in the remaining part of the project.

3.4.4 Discussion and conclusion

A common methodology for using the RCM data in dynamic impact models has been discussed and document, but specific adaptation to the particular model has been identified as well. Several of the impact models need additional information on development in atmospheric CO_2 concentration as this also drives photosynthesis. All the validation and sensitivity analyses have been performed successfully and the models and indices have now been applied to the RCM output.

The results obtained emphasises the large discrepancy in ecosystem impacts between Southern Europe and Northern Europe. In Southern Europe impacts are going to be dominating by effects on heat stress and water shortage, whereas impacts in Northern Europe will be dominated by changes in the duration of the growing season, increases in productivity and possible negative effects on increases in N-losses from agriculture.

Deliverables for WP4 are completed.

3.4.5 Plan and objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.5 Status of activities in WP5: Risk assessment of European weather and climate extremes.

3.5.1. Objectives

The objective of WP5 is to analyse the risk of European weather and climate extremes in future regional forecast scenarios. The work package focuses on the following major types of European climate-related risk: winter wind storms (UFRI and GKSS), storm surges (GKSS), heat waves and cold waves (UFRI and CRU), hydropower (UFRI), Mediterranean droughts and floods (CRU), and resource risk (FMI/SYKE). In addition, WP5 also involves the development of new statistical methodology for exploring and describing changes in extremes (UREADMY). WP5 is focussed on analysing these extremes in the output from the Regional Climate Models (not the AGCMs).

3.5.2. Methodology and scientific achievements

All WP5 partners have completed analysing the available RCM runs. All deliverables have been achieved.

For deliverable D5A3 on windstorms, UFRI has performed an analysis of the spatial and temporal mean changes over Europe of the observed daily maximum wind speed over the 20th century, identified winter windstorm episodes over Western Europe from the analysis of 1961-90 HIRHAM model wind velocity data, and performed a downscaling of a specific identified strong wind episode, using the Canadian Regional Climate Model (C-RCM), driven by HadRM3 model outputs. The C-RCM uses a self-nesting procedure allowing simulating wind flows at very high resolution. In addition, a novel approach to simulate the wind gust is used to analyse the location where the strongest winds will impact at the surface. For deliverable D5A4, UFRI has considered the definition of site relative indices of heat waves (HW indices, hereafter) that consist of frequency (2 indices), duration (1)and intensity (1) annual indices, based on the daily maximum temperature. A validation has been performed of the HW indices as derived from HIRHAM 1961-1990 control run data against those derived from observations, for 13 individual stations over Europe. An analysis has been made of past, future and changing patterns of the occurrence of heat waves in Europe.

GKSS has finished the storm surge model runs (control run and A2 scenario) produced with meteorological forcing data from various RCMs. GKSS has also performed analyses of these storm surge datasets with the focus on extremes (high percentiles and return values for the relevant coastal cells of the modelled area. A moderate increase in the higher percentiles has been found when comparing the CTL and A2 runs. The increase of expected storm surges is partly a bit higher in the A2 run with HIRHAM-forcing. Analysis of the RCM wind used for the TRIM model integration

FMI/SYKE have used daily outputs from a subset of the PRUDENCE RCMs to analyse present-day and future resource risk indices, including maximum number of consecutive dry days, maximum 5-day precipitation total, total number of frost days and dates of first and last frost.

3.5.3. Socio-economic relevance and policy implication

The most costly and catastrophic impacts of climate change in Europe are likely to be due to changes in the frequency, intensity and persistence of extreme events. WP5 are addressing these risks by developing new techniques and applying them to output produced by regional climate models. The improved understanding gained of how extremes are likely to change across Europe will be beneficial to decisions concerning protective actions against such risks.

3.5.4. Discussion and conclusion

All deliverables have been achieved. This completes WP5

3.5.5. Plan and objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.6 Status of activities in WP6: Climate policies

3.6.1 Objectives

The objective of WP6 is to assess of the role of detailed climate change impact information provided by PRUDENCE on European climate policies. This will include the assessment of the potential effect on European climate policies given economic consequences related to better uncertainty measures and more detailed scenarios of regional climate change.

3.6.2 Methodology and scientific achievements

The main aim of the research in this area is to work with the other partners to ensure that the information produced by the climate and physical impact models is consistent with the information needs of economic and policy modellers. Collaboration in this area focused on how appropriate climate modelling outputs can be used as inputs in economic models and broader policy analysis.

Special concern was given to:

- Identification of the climatic and environmental variables and their distributions related to how producers, consumers, and factor owners respond under risk and uncertainty in different sectors (This activity relates in particular to WP3 and WP4).
- Identification of the relevant spatial and temporal resolution of these variables and their influence on production, consumption and investment decisions under risk and uncertainty (this activity in particular relate to WP5).

Because policy makers require detailed information about economic impacts at the sectoral level, the emphasis of WP6 has been be on national and regional economic sector models.

The sectoral frameworks for integrated physical and economic assessment of climate change impact considered in WP6 include the following sub-components:

- Construction of taxonomy of climate change damages to highlight the relevance of magnitude, pace, variability, vulnerability and uncertainty.
- Selection of sectors to include in the analysis based on such criteria as their economic importance, climate risk, data availability and other such considerations.
- Definition of different types of climate risk and uncertainty in climate projections that will affect the decisions of economic agents in the sector and policy makers and a review of alternative approaches for assessing economic decisions in these sectors under risk and uncertainty.
- Description of how existing climate, physical impact and economic-sector models could be linked to assess the impacts of climate risk and uncertainty in climate projections on economic impacts in the sector, using existing models. This will include the evaluation of how uncertainty can be incorporated in the policy response for example through the use of precautionary principles.

3.6.3 Socio-economic relevance and policy implication

Climate change can have significant economic impacts in Europe, and it is expected that these impacts can be reduced in the agricultural sector, water management, the health sector and other sectors if these sectors have access to improved information about climate change as provided by Prudence. WP6 contributes to the "translation" of the physical climate change impact data to information that are relevant to policy decisions in the climate vulnerable sectors.

3.6.4 Discussion and conclusion

The discussions with other Prudence WP's in various project meetings demonstrated a strong need for integrating analytical concepts and data focus across the project, and WP6 decided on this background to give a high priority to the assessment of socio-economic implications of results provided by other team members. WP6 therefore in a general e-mail have asked other WP members to send relevant case material to the team, which took place, and a broad inter disciplinary paper has been prepared.

3.6.5 Plans and Objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers.

3.7 Status of activities in WP7: Management etc.

3.7.1 Objectives

WP7 is designed to ensure a proper management of PRUDENCE together with the widespread dissemination of PRUDENCE's results, in a usable form, to a wide range of users also outside the project partners. A parallel activity will collate and publish information in forms more suitable to the non-climate specialist and to the general reader. The specific objectives are designed as follows:

1. To ensure the effective dissemination of AOGCM and AGCM boundary conditions required for many of the simulations performed in WP1.
2. To make available a range of impact assessments based on the climate scenarios for the period 2071-2100.
3. To make available a large range of documented climate scenarios for the period 2071-2100.
4. To disseminate the results of the impact models.
5. To encourage widespread use of the results from the climate modelling experiments performed by the PRUDENCE consortium.

3.7.2 Methodology and scientific achievements

The major means for carrying out the tasks of this WP is the PRUDENCE web-site. This was established early on in the project and has evolved considerably since. So far most activities have been on the user protected area, but many scientific analyses findings has made their way to the scientific literature as well as to the public. PRUDENCE climate simulations have now been completed and are available from the web-site. At this point in time all relevant material has been made publicly available.

Another important achievement has been the strong connection of PRUDENCE to the projects STARDEX and MICE. Although this has been most obvious at the coordination level, many partners in PRUDENCE have participated in discussions and actually carried out analyses, which has been useful for the two other projects. Likewise, PRUDENCE has benefited from various developments in the two other projects, most obvious in the case of defining analysis of extremes based on the PRUDENCE simulations.

The PRUDENCE project will be detailed described in an upcoming special issue of *Climatic Change*

3.7.3 Socio-economic relevance and policy implication

As the web-site becomes more our reaching, the information as well as data hosted at the site will have a great potential for use in support of EU policy development. However, the majority of this will be highlighted by the work carried out within WP6.

3.7.4 Discussion and conclusion

The PRUDENCE web site is well functioning and the communication between partners and towards other interested parties works well. It is obvious that the major tasks of this WP has been within the final year, where more and more activities was brought to the public part of the web site

3.7.5 Plans and Objectives for the next period

The project is finished, but much scientific work will continue to be collected and presented at meetings and in scientific papers. The PRUDENCE web site will serve the needs directly in the ENSEMBLES project before this project has completed their climate change experiments.

4: Technological Implementation plan (cumulative)

Guidelines, explanations and annexes for completion of the T.I.P. could be downloaded separately from the CORDIS address (http://www.cordis.lu/fp5/tip.htm) .

5. Executive publishable summary, related to the overall project duration

Contract n°	EVK2-CT2001-00132	Project Duration:	3 years
Title	**Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (PRUDENCE)**		

Objectives: PRUDENCE's primary objective was to provide high resolution climate change scenarios for Europe at the end of the 21st century using dynamical downscaling methods with climate models.

The specific objectives of PRUDENCE were to:

1. provide a series of high resolution climate change scenarios for 2071-2100 for Europe;

2. in practical terms characterise the level of confidence in these scenarios and the variability in them related to model formulations and climate natural/internal variability;

3. assess the uncertainty in European regional climate scenarios resulting from model formulation;

4. quantitatively assess the risks rising from changes in regional weather and climate over all of Europe, and estimate future changes in extreme events such as flooding and wind storms, by providing a robust estimation of the likelihood and magnitude of the changes;

5. demonstrate the value of the wide-ranging climate change scenarios by applying them to climate impacts models focusing on effects on adaptation and mitigation strategies;

6. assess socio-economic and policy related decisions for which such improved scenarios could be beneficial;

7. disseminate the results of PRUDENCE widely and provide a project summary aimed at policy makers and non-technical interested parties.

Scientific achievements: It is anticipated that climate change will affect the frequency and magnitude of extreme events through an intensified hydrological cycle. Major limitations to model-based studies of these phenomena in the past have been the lack of appropriate spatial resolution (and a consequent smearing out of the character of sub-grid-scale events), the lack of sufficiently long integrations (which drastically reduces the statistical significance of projections), and the lack of co-ordination between different modelling groups (which led to unresolved differences between different studies). These three issues have all been thoroughly addressed in PRUDENCE, using state-of-the-art climate models at a variety of (high) resolutions, a co-ordinated project layout that also addresses critical aspects of uncertainty, and the application of impact models and impact assessment methodologies to provide a link to the needs of society and the economy. Furthermore, model-based results generated in PRUDENCE have already provided scientific background information in the aftermath of some extreme weather events recently experienced in Europe (e.g. Christensen and Christensen, 2003; Schär et al., 2004).

A special issue of *Climatic Change* will summarise the scientific outcome of the PRUDENCE project. The opening papers encompass the final results from the six integrated work packages (WP) of the project, comprising the design of the model simulations and analyses of RCM behaviour (WP1), evaluation and intercomparison of simulated climate changes (WP2), specialised analyses of hydrological (WP3) and other sectoral (WP4) impacts, investigation of extreme weather events (WP5) and implications of the results for policy (WP6). In addition, PRUDENCE joined with two other related EC-funded projects to form the PRUDENCE-STARDEX-MICE cluster. STARDEX (Statistical and Regional dynamical Downscaling of Extremes for European regions; Contract EVK2-CT2001-0115) was concerned with improving statistical downscaling methods for constructing scenarios of changes in the frequency and intensity of extreme events, and MICE (Modelling the Impact of Climate Extremes; Contract EVK2-CT2001-0018) made use of information from both dynamically and statistically downscaled methods to explore the potential impacts of extreme events in Europe. Summaries of these projects are also presented in the special issue. The remaining papers in the issue comprise individual contributions from project Partners that offer a more in-depth analysis of specific topics covered in the work packages.

In total more than 100 scientific papers have been produced during the 3 years and more are still to come. Overall, this collection of papers by specialists from the climate modelling, impacts and social science communities represents the first comprehensive, continental-scale intercomparison and evaluation of high resolution climate models and their applications.

Main deliverables: The PRUDENCE data base with daily values of simulated surface climate variables from more than 50 simulations of climate representing the present day and the period 2071-2100. All experiments were for a horizontal grid of 50km or finer.

A special issue of *Climatic Change*, projected to appear in late 2005 or early 2006, summarises main scientific findings of the project and will feed directly into the IPCC Fourth Assessment Report.

More than 100 specialised scientific papers, including two high profile papers in *Nature* and additional citation of project results in the same journal.

Christensen, J.H. and O.B. Christensen, 2003: Severe Summer Flooding in Europe, *Nature*, **421**, 805-806.

Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M.A. Liniger and C. Appenzeller, 2004: The role of increasing temperature variability for European summer heat waves. *Nature*, **427**, 332-336; doi:10.1038/nature02300

Schär, C. and G. Jendritzky, 2004: Hot news from summer 2003. *Nature*, **432**, 559-560

Schiermeier, Q., 2004: High-resolution climate modelling: Assessment, added value and applications. *Nature*, **428**, 593.

Socio-economic relevance and policy implications: Europe is taking the lead on implementing policies to reduce emissions of greenhouse gases. The present project provides a community effort that has improved the scientific basis for justifying and refining this policy. Preliminary probabilistic estimates of projected changes in seasonal temperature and precipitation over Europe have been produced along with quantitative estimates of changes in extreme weather events, both of which were presented at COP10 by this project. These new results are already being exploited and extended in numerous other climate change studies in Europe, including several of Sixth Framework Integrated projects (*e.g.* ENSEMBLES, ALARM).

Conclusions: The results obtained and new insights gained within the PRUDENCE project and projects benefiting from the data sets made available by the project are testimony to the vigorous and multifaceted nature of climate change research in Europe. In demonstrating the feasibility of such a combined "end-to-end" research effort, and in spite of inevitable resource constraints that precluded a full geographical or sectoral coverage of all elements covered in the project, PRUDENCE can justifiably claim to have set a new standard for interdisciplinary climate change research in Europe.

Dissemination of results: http://prudence.dmi.dk

More than 100 scientific publications

Media coverage on TV, radio and in newspapers across Europe, featuring many of the PRUDENCE PIs.

The PRUDENCE project has provided the inspiration for north American scientists, in collaboration with some European colleagues, to propose a similar effort for their region, NARCCAP (Mearns *et al*. 2004).This is a very clear scientific impact at the organisational level resulting in an unprecedented collaboration over the region which will provide scientific resources to the many state governments, corporations and other interested bodies of the region.

Mearns, L. O., R. Arritt, G. Boer, D. Caya, P. Duffy, F. Giorgi, W. J. Gutowski, I. M. Held, R. Jones, R. Laprise, L. R. Leung, J. Pal, J. Roads, L Sloan, R. Stouffer, G. Takle, and W. Washington, 2004: NARCCAP: North American Regional Climate Change Assessment Program. Preprints of the 85th Annual Meeting of the American Meteorological Society.

Keywords: Regional climate change, climate change impacts, methods of climate scenario application, changes in climate extremes, methods of extreme event analysis, impacts on water resources, agriculture, forestry, ecosystems and health, risk assessment, European climate policies

6. Detailed report, related to overall project duration

6.1 Background

In Europe, as elsewhere in the world, there is a growing demand from decision-makers in the public and private sectors, from non governmental organisations (NGOs), and from the general public for detailed information on future climate. Only with such information does it become possible to quantify the risks of a changing climate brought about by anthropogenic emissions of greenhouse gases. Quantification is absolutely necessary in order to formulate and implement realistic adaptation and mitigation strategies (Arnell, 1996).

Projections of future climate change from numerical models have existed for three decades, but these remain deficient both in regional detail and in the characterisation of their uncertainty. The assessment of potential regional impacts of climate change has, to date, generally relied on data from coarse resolution Atmosphere-Ocean General Circulation Models (AOGCMs), which do not resolve spatial scales of less than ~300km (Mearns *et al.*, 2001). Such AOGCMs do not provide information on the spatial structure of temperature and precipitation in areas of complex topography and land use distribution (*e.g.* the Alps, the Mediterranean, and Scandinavia). Their depiction of regional and local atmospheric circulations (*e.g.* narrow jet cores, mesoscale convective systems, sea-breeze type circulations) and representation of processes at high frequency temporal scales (*e.g.* precipitation frequency and intensity, surface wind variability) are likewise insufficient to provide accurate information.

The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) includes several recommendations for intensifying research into high resolution model-based climate projections: *"The need is there to co-ordinate RCM simulation efforts and to extend studies to more regions so that ensemble simulations with different models and scenarios can be developed to provide useful information for impact assessments. This will need to be achieved under the auspices of international or large national programmes. Within this context, an important issue is to provide RCM simulations of increasing length to minimise limitations due to sampling problems"* (Giorgi *et al.*, 2001, p. 616).

6.2 Scientific/technological and socio-economic objectives

In order to address such inadequacies on a European scale, a fully interdisciplinary approach seems needed. The PRUDENCE *project* was undertaken with these recommendations in mind. Its primary objective was to provide high resolution climate change scenarios for Europe at the end of the 21st century using dynamical downscaling methods with climate models. But equally important it was realised that the added value of such information had to be assessed within the project.

The specific objectives of PRUDENCE were to:

1. provide a series of high resolution climate change scenarios for 2071-2100 for Europe;

2. in practical terms characterise the level of confidence in these scenarios and the variability in them related to model formulations and climate natural/internal variability;
3. assess the uncertainty in European regional climate scenarios resulting from model formulation;
4. quantitatively assess the risks rising from changes in regional weather and climate over all of Europe, and estimate future changes in extreme events such as flooding and wind storms, by providing a robust estimation of the likelihood and magnitude of the changes;
5. demonstrate the value of the wide-ranging climate change scenarios by applying them to climate impacts models focusing on effects on adaptation and mitigation strategies;
6. assess socio-economic and policy related decisions for which such improved scenarios could be beneficial;
7. disseminate the results of PRUDENCE widely and provide a project summary aimed at policy makers and non-technical interested parties.

While European collaboration on climate modelling and impacts analyses has been performed for more than a decade based on various EU research and development initiatives, rising to this challenge required a truly international and interdisciplinary effort. In order to provide practically useful measures of the uncertainty in climate projections, the uncertainty space of emission scenarios, model parameterisations, model resolution and natural variability needed to be probed en masse. This required co-ordinated involvement from as many climate-modelling groups as possible. PRUDENCE succeeded in designing, executing, analysing, and synthesising European high-resolution climate change simulations involving four high-resolution Atmospheric General Circulation Models (AGCMs) and eight Regional Climate Models (RCMs). All RCMs were run at horizontal spatial scales of ~50 km though a few were also run at ~20km. The "open doors" policy of the project in encouraging the participation of other research groups from Europe and beyond, added two more European RCMs to this list, funded from non-EC sources. Furthermore, all of the climate model results have now been made freely available to the general research community.[1]

Numerous model-based studies have been conducted in Europe to investigate the potential impacts of climate change on natural and human systems. Many of these have been summarised in the ACACIA report (Parry, 2000) and in successive IPCC reports (Beniston et al., 1998; Kundzewicz et al., 2001). The scenarios used to represent future changes in climate vary widely between impact studies, but only in a few cases the main sources of scenario uncertainty are acknowledged, let alone evaluated (e.g. Hulme and Carter, 2000; Mearns et al., 2001). There are differences not only in the model projections of climate but in the methods of applying these in impact assessments. Impact studies in PRUDENCE have intercompared various methods of scenario development and application.

There is a general perception among impact analysts that estimates of impacts at small spatial scales (i.e. sub-GCM-grid scale) should necessarily be based on information about future climate that has been generated at a comparable spatial resolution. There has been a clamour for access to high-resolution projections, either based on statistical downscaling techniques, or generated by RCMs such as those employed in this project. PRUDENCE has provided

[1] http://prudence.dmi.dk

convincing new examples that demonstrate how the application of RCM-based scenarios can confer significant advantages over AOGCM-based scenarios in selected impact studies. However, it should also be understood that such procedures introduce uncertainties of their own (Giorgi et al., 2001). RCMs clearly do not yet provide a universal panacea, and some of the impact studies also highlight potential limitations of relying solely on RCM-based information.

6.3 Applied Methodology, Scientific Achievements and Main Deliverables

The urgent need for improved numerical models and scenarios becomes particularly apparent when considering extreme weather events. The importance of extreme events for the European economy and environment has been demonstrated in dramatic fashion during the last few years with a number of serious events affecting the European continent, including major flooding events in central Europe (May 1999 and August 2002), the southern Alps (October, 2000), and the UK (October/November 2000), severe storms accompanied by avalanches in the Alps (February 1999), storm surges in the North Sea (December 1999) and major wind damage in central Europe (December 1999) and Scandinavia (January 2005); and the unprecedented summer heat wave affecting large areas of western and central Europe in 2003. Each of these events caused fatalities and tremendous capital damage.

It is anticipated that climate change will affect the frequency and magnitude of extreme events through an intensified hydrological cycle (Stocker et al., 2001). Major limitations to model-based studies of these phenomena in the past have been the lack of appropriate spatial resolution (and a consequent smearing out of the character of sub-grid-scale events), the lack of sufficiently long integrations (which drastically reduces the statistical significance of projections), and the lack of co-ordination between different modelling groups (which led to unresolved differences between different studies). These three issues have all been thoroughly addressed in PRUDENCE, using state-of-the-art climate models at a variety of (high) resolutions, a co-ordinated project layout that also addresses critical aspects of uncertainty, and the application of impact models and impact assessment methodologies to provide a link to the needs of society and the economy. Furthermore, model-based results generated in PRUDENCE have already provided scientific background information in the aftermath of some of the above-mentioned extreme weather events (e.g. Christensen and Christensen, 2003; Schär et al., 2004).

A planned special issue of Climatic Change summarises the scientific outcome of the PRUDENCE project. The opening papers encompass the final results from the six integrated work packages (WP) of the project, comprising the design of the model simulations and analyses of RCM behaviour (WP1), evaluation and intercomparison of simulated climate changes (WP2), specialised analyses of impacts on water resources (WP3) and on other sectors including agriculture, ecosystems, energy, and transport (WP4), investigation of extreme weather events (WP5) and implications of the results for policy (WP6). In addition, PRUDENCE joined with two other related EC-funded projects to form the PRUDENCE-STARDEX-MICE cluster. STARDEX (Statistical and Regional dynamical Downscaling of Extremes for European regions; Contract EVK2-CT2001-0115) was concerned with improving statistical downscaling methods for constructing scenarios of changes in the frequency and intensity of extreme events, and MICE (Modelling the Impact of Climate Extremes; Contract EVK2-CT2001-0018) made use of information from both dynamically and statistically downscaled methods to explore the potential impacts of extreme events in Europe. Summaries of these projects are also presented in the special issue. The remaining papers in the issue comprise individual contributions from project participants that offer a more in-depth analysis of specific topics covered in the work packages.

Overall, this collection of papers by specialists from the climate modelling, impacts and social science communities represents the first comprehensive, continental-scale intercomparison and evaluation of high resolution climate models and their applications. The results obtained and new insights gained are testimony to the vigorous and multifaceted nature of climate change research in Europe. In demonstrating the feasibility of such a combined "end-to-end" research effort, and in spite of inevitable resource constraints that precluded a full geographical or sectoral coverage of all elements covered in the project, PRUDENCE can justifiably claim to have set a new standard for interdisciplinary climate change research in Europe.

The following sections further summarises the activities carried out within each of the 6 scientific work packages.

6.3.1 Workpackage 1: European regional climate simulations for 2071-2100 and their analyses

Within the first workpackage a series of 30-year simulations for present day and future climate were designed and executed. Four high resolution atmospheric general circulation models provided information for regional downscaling. The GCMs used observed and modelled sea-surface conditions (from AOGCMs) and radiative forcing specified according to IPCC SRES scenarios A2 and B2. The regional downscaling of these global simulations for Europe has also been carried out in this workpackage after an agreement on the boundary conditions. Ten RCMs have participated in this exercise and contributed to a large set of regional climate change simulations with several simulations covering identical time periods of 30 year slices as well as spatial domains of interests. They all used horizontal grid spacing of about 50 km and a few additional simulations have been made on about 20 km and even finer, eg. 12 km.

The ‘open doors’ policity allowed to increase the number of participating regional climate models from 8 to 10. It was agreed that all of the RCMs used lateral boundary conditions as well as sea surface temperature and sea ice information from the baseline PRUDENCE driving model HadAM3H. In addition several runs have been made using driving data from Arpege, CCM3 and ECHAM.

It was agreed within this WP that the baseline emission scenario is IPCC SRES A2, which has been used by all partners to be downscaled. In addition several simulations have been done using B2, too.

The analyses of the performance of the models has been evaluated through an agreed validation strategy, which includes the comparison of simulated monthly, seasonal and annual means against observations as well as extreme value statistic of appropriate observed and simulated data. These results determine the level of confidence for the driving models as well as for the regional scale details.

6.3.1.1 Large series of global and European regional climate changes simulations for 2071 to 2100

Original deliverables D1A1, D1A2, D1A3, D1A4, D1A6, D1B1, D1B2, D1B3, D1B4, D1B5, D1B6

As mentioned above a large set of global and regional scale simulations for Europe has been carried out, which was the bases for 10 deliverables in WP1. They encompasses the work with 4 GCMs and 10 RCMS, stretching from grid scales of more than 100 km down to 12 km and investigating the IPCC SRES scenarios A2 and B2. A large set of boundary data for driving RCMs have been created and used. Most of the RCMs runs were done on a grid spacing of about 50 km, which can been seen as the standard resolution, only a set of 2 members were able to do A2 simulation on a 20 km grid. One more simulation was done on about 20km using B2 and another was provided data on 12 km. All data are store in the PRUDENCE data base at DMI and have now been made freely available to the general research community.

The GCM and RCM modelling groups have provided estimates of the timing of various phases of their PRUDENCE experiments at an early stage of the project. At the time of writing this report, this is the status of data in the PRUDENCE archive

Institute/ Contact	Model	Driving data	Ens.	Exp.	Acronym	Beginning	Finish	Seasonal data	Monthly data	Daily data
DMI	HIRHAM	HadAM3H A2	1	Control	HC1	Done	Done	Done	Done	Done
			1	Scenario	HS1	Done	Done	Done	Done	Done
			2	Control	HC2	Done	Done	Done	Done	Done
			2	Scenario	HS2	Done	Done	Done	Done	Done
			3	Control	HC3	Done	Done	Done	Done	Done
			3	Control	HS3	Done	Done	Done	Done	Done
		HadAM3H A2 (SMHI Baltic SSTs)	1	Scenario	HS4	Done	Done	Done	Done	Done
		ECHAM4/OPYC (OGCM SSTs)		Control	ecctrl	Done	Done	Done	Done	Done
		ECHAM4/OPYC A 2		Scenario	ecscA2	Done	Done	Done	Done	Done
		ECHAM4/OPYC B2		Scenario	ecscB2	Done	Done	Done	Done	Done
		ECHAM5 A2		Control	ECC	Done	Done	Done	Done	Done
				Scenario	ECS	Done	Done	Done	Done	Done
	HIRHAM High res.	HadAM3H A2	1	Control	F25	Done	Done	Done	Done	Done
			1	Scenario	S25	Done	Done	Done	Done	Done

Hadley Centre	HadCM3 A2 (OAGCM)		1	Control	aaxzx	Done	Done	Done	N/A	N/A
			1	Scenario	aaxzi	Done	Done	Done	N/A	N/A
			2	Control	abqza	Done	Done	Done	N/A	N/A
			2	Scenario	abwad	Done	Done	Done	N/A	N/A
			3	Control	abqzb	Done	Done	Done	N/A	N/A
			3	Scenario	abwae	Done	Done	Done	N/A	N/A
	HadCM3 B2			Scenario	aaxzz	Done	Done	Done	N/A	N/A
	HadAM3H A2 (AGCM)		1	Control	acdhd	Done	Done	Done	Done	Done
			1	Scenario	acftc	Done	Done	Done	Done	Done
			2	Control	acdhe	Done	Done	Done	Done	Done
			2	Scenario	acftd	Done	Done	Done	Done	Done
			3	Control	acdhf	Done	Done	Done	N/A	N/A
			3	Scenario	acfte	Done	Done	Done	N/A	N/A
	HadAM3H B2			Scenario	acftf	Done	Done	Done	Done	Done
	HadRM3H	HadAM3H A2	1	Control	achgi	Done	Done	Done	Done	Done
			1	Scenario	ackda	Done	Done	Done	Done	Done
	HadRM3P	HadAM3P	1	Control	adeha	Done	Done	Done	Done	Done
			1	Scenario	adhfa	Done	Done	Done	Done	Done
			2	Control	adehb	Done	Done	Done	Done	Done
			2	Scenario	adhfe	Done	Done	Done	Done	Done
			3	Control	adehc	Done	Done	Done	Done	Done
			3	Scenario	adhff	Done	Done	Done	Done	Done
		HadAM3P B2		Scenario	adhfd	Done	Done	Done	Done	Done
	HadRM3H High res.	HadAM3H A2	1	Control		Done	Done	N/A	N/A	N/A
			1	Scenario		Done	Done	N/A	N/A	N/A
ETH	CHRM	HadAM3H A2	1	Control	HC_CTL		Done	Done	Done	Done
			1	Scenario	HC_A2		Done	Done	Done	Done
	ECHAM5		1	Control		Done	Done	N/A	N/A	N/A
			1	Scenario		Done	Done	N/A	N/A	N/A
	CHRM	ECHAM5 A2	1	Control			2005	2005	2005	2005
			1	Scenario			2005	2005	2005	2005
GKSS	CLM	HadAM3H A2	1	Control	CTL		Done	Done	Done	Done
			1	Scenario	SA2		Done	Done	Done	Done
	CLM		1	Control	CTLsn		Done	Done	Done	Done

	(improved)									
			1	Scenario	SA2sn		Done	Done	Done	Done
	REMO	HadAM3H A2	1	Control	3003		Done	Done	Done	Done
MPI			1	Scenario	3006		Done	Done	Done	Done
	REMO High res.	HadAM3H A2	1	Control			2005	2005	2005	2005
			1	Scenario			2005	2005	2005	2005
	RCAO	HadAM3H A2	1	Control	HCCTL		Done	Done	Done	Done
			1	Scenario	HCA2		Done	Done	Done	Done
		HadAM3H B2		Scenario	HCB2		Done	Done	Done	Done
SMHI		ECHAM4/OPYC A2		Control	MPICTL		Done	Done	Done	Done
				Scenario	MPIA2		Done	Done	Done	Done
		ECHAM4/OPYC B2		Scenario	MPIB2		Done	Done	Done	Done
	RCAO High res.	HadAM3H A2	1	Control			Done	Done	Done	Done
			1	Scenario			Done	Done	Done	Done
UCM	PROMES	HadAM3H A2	1	Control	control		Done	Done	Done	Done
			1	Scenario	a2		Done	Done	Done	Done
		HadAM3H B2		Scenario	b2		Done	Done	Done	Done
	RegCM	HadAM3H A2	1	Control	ref		Done	Done	Done	Done
			1	Scenario	A2		Done	Done	Done	Done
ICTP		HadAM2H B2	1	Scenario	B2		Done	Done	Done	Done
		CCM3 A2	1	Control		Done	Done	N/A	N/A	N/A
			1	Scenario		Done	Done	N/A	N/A	N/A
		CCM3 A2	2	Control		Done	Done	N/A	N/A	N/A
			2	Scenario		Done	Done	N/A	N/A	N/A
met.no	HIRHAM	HadAM3H A2	1	Control			Done	Done	Done	Done
			1	Scenario			Done	Done	Done	Done
KNMI	RACMO	HadAM3H A2	1	Control	HC1		Done	Done	Done	Done
			1	Scenario	HA2		Done	Done	Done	Done

Météo-France	Arpège	Observed SST	1	Control	DA9		Done	Done	Done	Done
			2	Control	DE3		Done	Done	Done	N/A
			3	Control	DE4		Done	Done	Done	N/A
		HadCM3 A2	1	Scenario	DE6		Done	Done	Done	Done
			2	Scenario	DE7		Done	Done	Done	Done
			3	Scenario	DE8		Done	Done	Done	N/A
		HadCM3 B2		Scenario	DE5		Done	Done	Done	Done
		Arpège/OPA A2		Scenario	DE9		Done	Done	Done	N/A
		Arpège/OPA B2	1	Scenario	DC9		Done	Done	Done	Done
			2	Scenario	DC7		Done	Done	Done	N/A
			3	Scenario	DC2		Done	Done	Done	N/A

6.3.1.2 A comprehensive analysis of the simulations and assessment of reliability of the scenarios
Original deliverables D1A5, D1B7

The analysis of the global and regional simulations as well as the reliability assessment has been carried out on the full set of simulations available. This was done in very close cooperation with the other WPs, especially WP2 and WP3. Many results can be found in the appropriate sections of the related WPs.

The investigations encompasses fundamental aspects like the ability to simulate the long term mean climate and the inter-annual variability; the variability on a seasonal scale and special topics like range of minimum and maximum temperature, wind speed, geostrophic flow pattern, water storage and hydrological regimes.

Several data sets of observed data have been used according to the investigated scientific question.

The results (output according to the deliverable) are summarized in parts in this report, but mainly in the papers contributing to the PRUDENCE special issue.

6.3.2 Work package 2: Uncertainty Assessment of European Regional Responses

In order to aid the management and execution of the deliverables in this work package, these deliverables were refocused into 4 topics, which are discussed in the following 4 sub-sections. In particular, 6.3.2.3 represents the merger of 5 of the original deliverables which could best be dealt with together.

6.3.2.1 Uncertainty assessment using high-resolution global model scenarios
Original Deliverable: D2A1

In PRUDENCE, 10 RCMs are available, 3 forcing GCMs (including the special case of ARPEGE which is both GCM and RCM), 2 scenarios (A2 and B2) and 3 samples for some experiments. It is thus in principle possible to evaluate the variance due to the four sources of uncertainty: RCM, GCM, scenario and sampling. However, out of the 180 (i.e. 10x3x2x3) elements of the matrix, only 28 simulations have been actually performed. Calculating and comparing variances with the available experiments would not allow a fair comparison, because the experiments are not distributed evenly in the matrix, the A2 with HadAM3 forcing scenario being favoured. The missing cases in the matrix have therefore been estimated by a simple statistical technique, so that 180 model responses are available for temperature and precipitation, DJF and JJA, and 8 sub-areas of the European domain.

The uncertainty introduced by the choice of the driving GCM dominates, except for summer precipitation, where the choice of the RCM is the major source. There are also geographical differences. In the Scandinavian area, the RCM dominates, whereas in central Europe the GCM dominates whatever the season or the field. The uncertainty due to sampling is marginal, except for winter precipitation over the Iberian Peninsula. The uncertainty about the choice of the scenario (A2 versus B2) is maximum for summer temperature in the southern half of Europe. A 99% confidence interval can also be calculated (here for the A2 scenario). For temperature, the minimum warming is 1.4 K in winter for the British Isles, and 1.7 K in summer for Scandinavia. If we exclude these two areas, the upper boundary for the warming reaches 6 K in summer. For precipitation, one of the boundaries is close to zero in a few cases: Iberian Peninsula and Alps precipitation increase in winter, Scandinavia and East Europe precipitation decrease in summer. The results show however that the use of several GCMs and RCMs increase the confidence in the mean response.

6.3.2.2: Assessment of RCM current climate simulations
Original Deliverable: D2B1

Here two fundamental aspects of model validation have been addressed: The ability to simulate i) the long term (30 or 40 years) mean climate and ii) the inter-annual variability. Efforts were concentrated on near-surface air temperature and precipitation. First the systematic mean flow error in the baseline PRUDENCE driving model HadAM3H was addressed.

The main winter-time features are that HadAM3H exhibits a stronger pressure gradient across a large part of central to northern Europe than the ECMWF reanalysis ERA-40. This is caused by a too high pressure over the Mediterranean region and a too low Icelandic low reaching too far into the Nordic seas. As a consequence, the moisture and heat transport (in the mean as well as from eddies) from the Atlantic sector to most of Northern Europe is too high, leading in general to too high temperatures and too high precipitation rates. It is less certain what this means for Southern Europe as this also depends more delicately on the balance between energy and moisture transport in the mean field and from the eddies.

In summer HadAM3H is closer to ERA40. However, the MSLP in HadAM3H is more homogeneous over most of the continent and has a less pronounced Azorean high. Therefore the region with subsiding air over Europe is displaced somewhat to the east, which would imply less moisture transport to this region than suggested by observations, leading to too dry and hence too warm conditions.

A comparison of the mean sea level bias in the 10 PRUDENCE RCMs for DJF and JJA show the following: The model mean deviation from the driving model is always small, with the largest differences over mountainous regions. The latter can be explained by different algorithms for reducing surface pressure to the mean sea level in the various models and in the driving model. This is also reflected by a relatively high inter-model standard deviation in these regions. During summer, there is a tendency towards a general increase of pressure in the eastern part of the region of subsidence, which would indicate that the RCMs could be enhancing the expected dry and warm bias imposed by the boundary conditions as indicated above. The inter-model standard deviation is very small over the entire domain, which indicates that this is a common feature and therefore most likely inherent to the nesting technique.

Generally, winter weather is determined by the large scale circulation and thus results in similar bias patterns for all regional models; in summer the inter-model spread is larger, as much of the weather is locally generated. Hence, the biases in summer depend on the regional model formulation. There is a warm bias with respect to observations in the extreme seasons and a tendency to cold biases in the transition seasons.

In winter this warm bias is particularly strong for Scandinavia; as an exception the southernmost region tends to be too cold (bias around -0.5 degrees) and dry (bias around -1 mm/day). The ensemble mean model bias is generally below 1 degree. A typical spread (standard deviation) between models is 1 degree. This warm bias is consistent with the systematic bias in the MSLP as explained above. It could also be influenced by a possible cold bias in the CRU observational data set in Scandinavia. The high inter-annual variability in the observations makes this difference less significant (the CRU mean temperature is only claimed to be accurate to within approximately 1 degree). The inter-annual variability of the regional models is reduced compared to observations in most areas, particularly in northern and Western Europe. This suggests that the driving HadAM3H model is probably too zonal and simulating insufficient amounts of blocking events, which are the main source for the inter-annual variability in this season. This large-scale feature is obviously inherited by the RCMs.

In summer most, but not all, of the models are too warm and dry. The ensemble mean model bias is in general lower. This is consistent with the bias in the MSLP as explained above. During summer there is generally a better agreement between observed and simulated values of inter-annual variability although the modelled variability is larger than observations. This suggests that the quasi-stable high pressure system over the Mediterranean region is more frequently broken down in the simulations than observed, consistent with the reduced ability by the HadAM3H to simulate long lasting blocking events.

With respect to the CRU climatology of temperature and precipitation, the areas with warm (cold) bias in winter generally exhibit positive (negative) precipitation biases, whereas the relationship is the reverse during summer, though much less clear, coupling warm (cold) biases with negative (positive) precipitation ones. The too zonal winter climate of the

HadAM3H simulation is reflected in the wet climate in central and northern Europe in contrast to the dry climate in the Mediterranean region. The well-known tendency of too little precipitation during summer in many RCMs is present in the PRUDENCE experiments as well; the strength of the negative precipitation bias varies, however. The DMI, ICTP and MPI models have a very modest negative bias, whereas SMHI, KNMI and ETH all have a considerable bias. Note that southern Europe is already very dry during summer.

A comparison of the experiments at different resolution from the DMI and the SMHI shows that change of resolution has a minor impact on large scale climate features. There is a small increase of precipitation with resolution, though.

By a simple ranking procedure area by area and season by season it can be determined that the ensemble mean behaves better than individual models: It is the best "model" with respect to temperature and MSLP and the second best (a little bit behind the DMI model) with respect to precipitation among the 50km RCMs. Furthermore, the mean model is less prone to having large deviations in particular areas; it tends to have similar quality for most areas.

In winter, the mean model exhibits the same warm and wet bias as most individual models. This again reflects that the winter climate to a dominating extent is determined by the boundary conditions. In summer the mean model performs rather well.

The bias of the ensemble mean is generally below 1 degree and in only one case above 2 degrees – Scandinavia in winter, where there is also some doubt about the CRU data's validity. Precipitation is generally below 0.5 mm/day and never more than 1 mm/day. In relative terms most values are less than 30% wrong and always less than 50%. Note that some of this bias will be due to inter-annual variability, since the 30 years of the driving GCM simulation have different weather than reality in spite of having observed sea-surface temperatures.

6.3.2.3: Uncertainty assessment using regional model scenarios
Original Deliverables: D1B7, D2B2, D2B3, D2C1, D2C2

Analysis on this topic has taken two complimentary directions. First, objective statistical approaches have been used to roughly quantify the differing sources of uncertainty. One study has taken a Europe-wide view, using the methodology outlined in 6.3.2.1, whereas other studies are taking a national view. In general the uncertainty in the formulation of the GCM driving the regional scenario is dominant, though there are exceptions to this.

Second, we have used the immense range of output variables saved from the global and regional model runs to better understand the model projections, focussing on particular regions and phenomena. When coupled with an understanding of each model's strengths and weaknesses this leads towards a subjective interpretation of the reliability of the chosen aspects of the projections. The specific regions and phenomena on which analysis has focussed are: rainfall in the Baltic Sea region; near-surface winds over the North Sea, Baltic and Europe; European blocking events; the Rhine catchment area; Mid and Southern-European summer drying; late-summer cyclogenesis over the Mediterranean; the frequency of specified circulation types; the interannual variability of summer temperature; the timing of seasonal transitions; impact on terrestrial water storage; the redistribution of different vegetation zones; and the sensitivity to specified vegetation parameters. A wide range of techniques have been used, and have included detailed technical analyses, comparison with recent observations, model intercomparison, case studies, and additional sensitivity experiments to examine or elucidate hypotheses. The results have inevitably varied widely, and are too extensive to summarise here. Some studies have usefully focussed on erroneous aspects of the models, whereas many find support for physically plausible future climate changes. All studies will be described in detail in peer-reviewed journals.

6.3.2.4: Upper/lower estimates for regional temperature change using pattern scaling
Original Deliverable: D2A3

Computationally demanding coupled atmosphere-ocean general circulation models (GCMs) and regional climate models (RCMs) can be employed for calculating climate responses to a limited number of SRES scenarios. Within the PRUDENCE project, for instance, only simulations for A2 and B2 scenarios are available. In order to formulate projections for the highest (A1FI) and lowest (B1) forcing scenarios, a super-ensemble pattern-scaling technique has been elaborated. In addition, ranges of temperature and precipitation change from six GCMs have been compared with corresponding estimates given by RCMs participating in the PRUDENCE project.

The super-ensemble pattern-scaling technique uses linear regression to represent the relationship between the local GCM (or RCM) simulated temperature/ precipitation response and the global mean temperature change simulated by a simple climate model. The method has some advantages: e.g., the noise caused by natural variability is reduced, and the method effectively utilizes the information given by GCM/RCM runs performed with various forcing scenarios. Compared with the simple time slice method, the super-ensemble method proved especially useful in a situation with only one A2 and one B2 simulation available for an individual GCM.

6.3.3 Work package 3: Impacts of future climate scenarios on hydrology

The objective of WP3 was to analyse the impacts of climate change scenarios on hydrological regimes. This work consisted primarily of applying hydrological models in offline mode to assess climate change impacts from the Prudence climate model simulations. Analysis of the hydrological outputs from the climate models themselves was also included. Some of the modelling was aimed strictly at hydrological river flow routing, which uses runoff generation outputs directly from the climate models. The applications cover a range of time and space scales, as well as different methods for transferring the climate change signal to hydrological models. In addition to hydrological modelling, studies were conducted on climate change impacts to snow and glaciers, which are important contributors to runoff generation.

The work package focused on hydrology for the entire Baltic Sea drainage basin, the Lule River basin in Sweden, and the Rhine River basin in Central Europe. SMHI conducted hydrological modelling in the northern basins, while ETH concentrated on the Rhine. Hydrological studies at MPI were conducted both in the Baltic and Rhine basins. U. Fribourg conducted studies on climate change impacts to snow and glaciers in the Swiss Alpine region.

6.3.3.1 Hydrological models of North European drainage basins interfaced with a range of regional climate models for climate change impact studies
Original deliverables: D3A1, D3A2, D3A3, D3A4

SMHI focused on using the HBV hydrological model combined with results from as many PRUDENCE RCM simulations as possible to get an indication of the range of differences that occur from using different RCMs in impacts assessment. This included RCM simulations with common forcing as well as RCMs forced with different SRES emissions scenarios, different GCMs at the boundaries and at varying horizontal resolution. Moreover, diagnostics of the hydrological outputs of the RCMs was also carried out, resulting in comparisons of variables such as runoff coefficient over hydrological basins. This work was performed in large scale over the entire Baltic Sea drainage basin and its major sub-drainage basins (Graham, 2004). More detailed catchment-scale studies used an application of the HBV hydrological model specifically for the Lule River basin in northern Sweden. Some 17 scenario simulations from 8 different RCMs driven by 2 GCMs were included in these studies.

For both the large-scale and the catchment-scale studies, different methods for transferring the signal of climate change from the climate models to the hydrological models were tested and used. These included variations of the de facto standard delta change approach as well as more direct approaches that require some form of precipitation scaling. In addition, RCroute, the simple large-scale river routing module developed for the RCAO RCM, was used offline to route total runoff generation from the RCM simulations to river discharge into the Baltic Sea.

MPI used the HD Model to perform river routing of runoff generation from RCM simulations. As originally designed for use with MPI climate models, the HD Model typically uses runoff generation from different climate model soil levels that represent fast and slow runoff responses. For this application, as it is not likely that runoff from different layers of different RCMs represents something that can be compared, a different approach was taken. In place of multiple runoff variables directly from the RCMs, MPI performed additional analyses to partition total runoff generation into components that represent fast and slow responses before input to the HD Model. This included 8 pairs of RCM control and scenario simulations for the Baltic Sea drainage basin.

6.3.3.2 Hydrological models of a Central European drainage basin interfaced with a range of regional climate models for climate change impact studies
Original deliverables: D3B1, D3B2, D3B3, D3B5

ETH applied a 1 km high resolution application of the WaSIM Model on the Rhine River basin for use in hydrological impacts studies in Central Europe. This was coupled offline to the CHRM RCM at both 56 km and 14 km resolutions and tested with ECMWF ERA15 reanalysis as forcing (Kleinn et al., 2005). As little change between the two RCM resolutions was noted in these WaSIM simulations, further studies focused only on 56 km RCM simulations. Additional CHRM simulations driven by ECMWF ERA40 reanalysis were used in WaSIM to attain bias correction factors that were in turn applied to control and scenario simulations. This led to detailed assessment of hydrological impacts for the Rhine from the

CHRM scenario simulation, whereby impacts to both lowland and alpine hydrological regimes can be identified.

As for the Baltic Basin above, MPI also used the HD Model to perform flow routing of runoff from RCM simulations in both the Rhine and Danube River basins. This was done for 10 pairs of RCM control and scenario simulations.

6.3.3.3 Impacts on snow amount and glacier mass balance in the Alpine domain
Original deliverable: D3B4

U. Fribourg used climate change scenario results from RCMs to perform studies of impacts on snow and glaciers in the Alpine region. By analysing extensive observational data, they determined key relationships between temperature, precipitation and snow pack extent in the Swiss Alpine region (Beniston et al., 2003). This can be used as an analogue to what could be expected in a future climate, when mild winters as encountered during the 20th century are likely to occur with greater frequency. Using this analysis with RCM scenario results provides empirical estimates of changes to snow pack according to changing temperature. They applied HIRHAM RCM scenario results in a case study analysis.

6.3.4 Work package 4: Impacts on agriculture, forestry and ecosystems

The objective of WP4 was to analyse the impacts of a range of detailed climate change scenarios on agriculture, forestry and ecosystems for selected regions in Southern and Northern Europe, and to evaluate adaptation options and possible effects on mitigation strategies. ISAg-UPM studied impacts on agricultural production in Spain with a focus on effects of changes in water availability on production. DIAS studied impacts on agricultural production in Denmark with a focus on the relationship with nitrogen cycling and effects on nitrate leaching. University of Lund (UL) studied the effects of climate change on productivity of natural ecosystems and forests across Europe. FEI used simple climate indices to study uncertainties in estimating resource potential under climate change across Europe. UEA-CRU performed analysed uncertainty in the Mediterranean Basin focusing on water availability.

6.3.4.1 Applied methodology
Site-based crop models (Daisy, CERES and CropSyst) were applied to study impacts of climate change on crops and cropping systems in Denmark and Spain. These models require daily climate data, detailed data on soil conditions and information on crop management. The response of natural ecosystems at the continental level was evaluated using the LPJ-GUESS ecosystem model. The response of soil water availability in the Mediterranean region was analysed using a simple water balance model. At the European level, simple indices were used to analyse the suitability for grain maize cultivation, the yield of winter wheat and the nitrate leaching from winter wheat cultivation. The LPJ-GUESS model and the studies in the Mediterranean region and at the European level all make use of monthly climate data, which had been interpolated onto the CRU 0.5° latitude $\times$ 0.5° longitude grid.

6.3.4.2 Site-based crop models
The study of crop production on the Iberian Peninsula applied the CERES dynamic models for wheat and maize as included in the DSSAT v. 3.5 support tool. These models have been

calibrated and validated for various locations in the Iberian Peninsula (*D4A1*). The crop model requires information on soils, which were obtained from available databases. The crop management was set for either rain-fed or irrigation, and no nitrogen limitation was assumed. The current sowing dates for each region in the Iberian Peninsula were used.

The Daisy dynamic soil-plant-atmosphere model was used to analyse the interaction of climate change and nitrogen (N) cycling for continuous winter wheat and crop rotations in Denmark. The model has been extended to simulate effects of increased CO_2 concentration (*D4B1*). The sowing date was prescribed to assume adaptation to climate change by delaying the sowing date with increasing temperature. The model was run for different rates of fertiliser N (50 to 250 kg N/ha), and the optimal N fertiliser rate was estimated from the simulated yield response.

6.3.4.3 Ecosystem model
The LPJ-GUESS ecosystem model is a process-based model of the dynamics of ecosystem structure and functioning. Vegetation in LPJ-GUESS is represented as a mixture of different plant functional types (PFTs). The model simulates linked changes in ecosystem function (water, energy and carbon exchange) and vegetation structure in response to different scenarios of changes in climate and atmospheric CO_2 concentrations. The model was tested against flux data from the EUROFLUX network (*D4C2*).

The simulations performed in this study were of the potential natural vegetation. The simulations were initiated by running the model for 300 years to. The model was then driven using transient climatology for the period 1901-1998 from CRU05 monthly dataset. Climate data for the gap between the observed data and climate input for the scenario period (1991-2070) was derived by linear interpolation between means for the final 30 years of the historical data and rescaled data for the scenario period (2071-2100).

6.3.4.4 Simple climate indices
The thermal suitability for the successful cultivation of grain maize was estimated with the effective temperature sum. Daily mean temperatures above 10 °C were cumulated for all days of the year. A location was classified as suitable for grain maize if a threshold of 850 degree-days was attained. The Daisy model was run at 9 climate stations across Europe with varying soils, N fertiliser and climate changes in order to develop an empirical function for N leaching and yield of rain fed winter wheat as affected by climate and climate change. This was used to estimate a multiple linear regression model of N leaching and yield at optimal N rate dependent on soil and climate variables.

6.3.4.5 Soil water availability for the Mediterranean region
The soil moisture amount was calculated from a simple balance of potential evapotranspiration and rainfall. The potential evapotranspiration was calculated using a simple function of temperature and day length. The soil moisture amount was calculated by subtracting the monthly total evapotranspiration from the monthly total rainfall for each grid square.

6.3.4.6 Climate change scenarios
The impact models were driven by outputs from a range of regional climate models (RCM's). The RCM's were run both for a control period (1961-1990) and for a future time period

(2071-2100). The emissions scenarios were the IPCC SRES A2 and B2 scenarios representing rather high and more modest future greenhouse gas emissions, respectively (IPCC, 2000). The RCM's were driven by boundary conditions taken from two different global models, HadAM3H and ECHAM4/OPYC3. However, the runs of the HadRM3P regional model used the HadAM3P for boundary conditions. The Arpège stretched grid simulations has a global coverage, but with a spatial resolution of RCM's over Europe. Not all impact models applied all climate model simulations. The atmospheric CO_2 concentrations were taken as the estimates used in the climate modelling experiments.

6.3.4.7 Downscaling methodologies

For the site-based crop models three different downscaling methodologies were tested, which included using the RCM outputs directly, adjusting the observed baseline climate with the difference between the scenario and control climate, or by adjusting the scenario climate with the difference between the observed and simulated baseline (control climate). For the other studies the absolute difference between modelled present-day (1961-1990) and future (2071-2100) climate was added to the CRU observed baseline, for both temperature and (where applicable) precipitation.

6.3.5 Work package 5: Risk assessment of European weather and climate extremes in future regional forecast scenarios

The aim of work package 5 was to quantify objectively the risk of European weather and climate extremes in future regional forecast scenarios. In particular, high-impact extremes related to heat waves, heavy precipitation events, drought, winter storms, and resulting sea surges. For good adaptation of European policies and industry to the impacts caused by extremes, it is vital to quantify the likely future changes in such risks.

Climate change is one of the greatest threats facing mankind in the 21st century. Surface temperatures are expected to continue to increase globally and major changes are likely to occur in the global hydrological and energy cycles (IPCC, 2001). The greatest threat to humans (and other components of terrestrial ecosystems) will be manifested locally via changes in regional extreme weather and climate events. European society, for example, is particularly vulnerable to changes in the frequency and intensity of extreme events such as heat waves, heavy precipitation, droughts, and wind storms.

Insurance statistics reveal that, after earthquakes, climate-related hazards take the heaviest toll on human life and generate some of the highest claims for insured damage. In the second half of the 20th century, earthquakes caused 71 ‘billion-dollar events’ globally but more than 170 events with similar costs were related to climatic extremes, in particular wind storms (tropical cyclones and mid-latitude winter storms), floods, droughts and heat-waves. Furthermore, there is evidence that insured losses from extreme climate events have increased in recent decades (Munich Re, 2002), due not only to increases in insured infrastructure – more cover, higher premiums (Swiss Re, 2003) – but also to recent changes in weather and climate extremes (e.g. more storms in the 1990s).

This work package has assessed changes in various high-risk events that are most likely to affect Europe in forthcoming decades. It aims to highlight some of the key findings from the extremes work undertaken as part of the European Union project PRUDENCE. Through a unique collaborative effort of nine European regional modelling groups, a coordinated set of climate modelling experiments has been conducted. The resulting large collection of model output makes it possible to examine the relative influence of emissions scenario, global model, and regional model on the spread of model results.

Work package 5 has focused on heat waves, heavy precipitation events, droughts, winter storms, and storm sea surges because of their large impacts on Europe. A variety of diagnostic methods are applied to determine features of these events in present (1961-90) and future (2071-2100) simulations produced by PRUDENCE and, therefore, how the events are predicted to change by the end of the 21st century.

The original deliverables of this work package can be summarised as follows:

- D5A1: Develop statistical tools for extremes
- D5A2: Apply tools to RCM output
- D5A3: Assess changes in severity of wind storms
- D5A4: Assess changes in heat waves/cold spells
- D5A5: Assess hydropower sensitivity to changes in temperature/precipitation
- D5A6: Assess Mediterranean droughts/floods
- D5A7: Map out future resource risk
- D5A8: Analysis of uncertainties in resource risk
- D5B1: Assess quality of surface winds in RCMs
- D5B2: Assess changes in N. Europe storm surges

Deliverable D5A1 is methodology while all the other deliverables are publications. All deliverables have been disseminated publicly via peer-reviewed publications, public presentations, and web sites.

With the exception of D5A5, all these deliverables have been addressed. In 2004, an exemption was requested and granted for D5A5 in order to allow U. of Fribourg more time to focus on the joint paper and the heat wave studies. A joint overall summary of the WP5 work has been co-written and submitted for publication (Beniston et al., 2005). What follows is a brief summary of the main results for each deliverable.

Deliverables D5A1 and D5A2 have developed and applied statistical methodologies in order to define and analyse extreme events. The following three criteria are often used in climate science to classify events as extreme:

- **Rare** – Events that occur with relatively low frequency. For example, the IPCC (2001) defines an 'extreme weather event' to be 'an event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare or rarer than the 10th or 90th percentile.’

- **Intense –** Events characterized by relatively small or large values. Not all intense events are rare: for example, low precipitation totals are often far from the mean precipitation but can still occur quite frequently.

- **Severe –** Events that result in large socio-economic losses. Severity is a complex criterion because damaging impacts can occur in the absence of a rare or intense climatic event: for example, thawing of mountain permafrost leading to rock falls and mud-slides.

Exploratory analysis techniques have helped reveal how the simulated climate responds to changes in emissions and model formulation, and therefore focus on meteorological events that are either rare or intense, but not necessarily severe. Methods based on maxima, percentiles, and threshold-based indices have all been successfully employed to explore the PRUDENCE RCM simulations. Threshold-based indices commonly summarize those data that exceed some threshold, such as the number of days per year on which the temperature at a particular location exceeds 30°C. A single, absolute threshold for all locations is simple to understand and ensures that indices measure events of a fixed intensity; however, a single, relative threshold ensures that indices measure events of a fixed rarity. Both types of index have been used to diagnose phenomena such as heat waves in this project.

Such a variety of complementary definitions is required to obtain a broad view of extreme events in the PRUDENCE simulations. A similarly wide range of techniques is required to analyze them and to assess differences between the extreme events in different simulations. Probability models, such as the generalized extreme-value distribution motivated from extreme-value theory have been fitted to maxima to obtain a more complete description of their statistical properties within a particular simulation. Percentiles with low or high values of p are useful for summarizing the tails of probability distributions and can easily be compared.

Statistical methodology has been developed for exploring changes in extreme events (deliverable D5A1). This has allowed changes in extreme percentiles to be related to changes in the location (e.g. mean) and scale (e.g. variance) of the distribution (Ferro *et al.*, 2005). As part of deliverable D5A2, the methodology has been widely applied in WP5 (e.g. Beniston et al. 2005, Beniston and Stephenson, 2004; Koffi, 2004; McGregor et al. 2005) and has been adopted in the wider research community both within PRUDENCE and elsewhere. Other statistical methodology has also been developed for addressing the clustering of extremes (Ferro and Segers, 2003; Ferro and Segers 2004; Ferro 2004).

Deliverable D5A3 has been addressed by several studies. Beniston and Jungo (2002) explored changes in pressure in the Alps related to factors such as the North Atlantic Oscillation. To remedy deficiencies in regional climate model surface winds, a new wind-gust parameterisation was developed and successfully implemented in a regional climate model (Goyette et al. 2003). Future changes in storminess have been studied in the RCMs by

Rockel and Woth (2005) Leckebusch and Koffi (2004). A summary of the changes in storminess is given in Beniston et al. (2005).

Deliverable D5A4 on heat waves and cold spells has been a focus of much interest especially after the 2003 summer heat wave in Europe. Based on PRUDENCE simulations, Beniston (2004) postulated that the 2003 event would be a regular event by the end of the 21st century. Beniston and Stephenson (2004) put this in historical context by exploring the nature of winter and summer temperature extremes in historical station data. Detailed PRUDENCE simulation studies of heat waves are presented in Beniston et al. (2005) and Koffi (2005). Deliverable D5A6 on droughts and high-intensity precipitation events has been addressed and the results summarized in Beniston et al. (2005). Semmler and Jacob (2004) have presented more detailed results on precipitation extremes.

Deliverables D5A7 and D5A8 have been addressed by investigating several different extreme indices from all the RCM simulations. The results are summarized in Beniston et al. (2005). Deliverables D5B1 and D5B2 have been addressed by successful storm surge modelling which is summarized in Beniston et al. (2005) and presented in more detail in Rockel and Woth (2005) and Woth et al. (2005).

In summary, WP5 work has successfully resulted in 16 peer-reviewed publications. In addition, it has helped contribute to training up two young researchers in the necessary skills to study extremes (PhD dissertations of K. Woth and C. Ferro).

6.3.6 Work package 6: Assessment of the role of PRUDENCE on European climate policies

WP 6 has included the following activities:

- Development of a conceptual framework for linking detailed climate change modelling results provided by PRUDENCE. Risoe has developed a working paper titled Climate Change Impacts and Adaptation Analysis – How to Link Physical Climate Data and Economic Studies.
- *Micro-level study on climate change impacts on European agriculture. Risoe has conducted a detailed assessment of climate change impacts on wheat production distribution in Danish regions. An econometric model based on farm enterprise surveys have been linked with Prudence DMI HIRHAM High resolution-model/Hadleys HadAM3H A2 scenarios for Europe.*
- Macro-level study on climate change impacts on European agriculture. Climate Change Impacts on Agricultural outputs in Europe and Economic Feedbacks from the World Market has been studied in collaboration between Risoe and International Institute of Applied System Analysis, IIASA.
- Climate change risks. Defining a dangerous climate change through successive indicators of risks and climate change has been assessed by Cired.
- Regional/sectoral disaggregation of climate change modelling, local non-linearities in climate change damages valuation and the potential masking effects of aggregation to a more global level.

Outputs

D6A1 A Work report that provides a discussion of the climate and physical impact information that is needed for economic and policy analysis at the national and regional sector level.

D6A2 A Work report that provides an overview of the methods and models available for linking climate, physical impact and economic sector models together to estimate the benefits and costs of mitigation and adaptation actions at the national and regional levels in climate sensitive sectors of the economy.

D6A3 A Work report that presents methodological framework for using the data generated by this project in conjunction with economic assessments to address the asymmetry between the costs and benefits of climate change actions in the EU.

D6A4 A workshop that presents the economic, social and policy making aspects of the regional climate change scenarios in order to establish a dialogue and link with other integrated assessment activities in Europe.

The reports D6A1, D6A2, and D6A3 are available from http://prudence.dmi.dk, while the D6A4 workshop was combined with the presentation of the PRUDENCE project by the coordinator at the COP10 in Buenos Aires (see also section 1.4)

Three journal papers and three working papers.

6.3.7 Work package 7: Management etc.

WP7 handles the overall management of PRUDENCE together with the widespread dissemination of PRUDENCE's results, in a usable form, to a wide range of users. These activities were motivated in the following main activities

- The dissemination of AOGCM and AGCM boundary conditions required for many of the simulations performed in WP1.
- Making available a range of documented climate scenarios for the period 2071-2100.
- The dissemination of the results for impact models.
- To encourage widespread use of the results from the climate modelling experiments performed by the PRUDENCE consortium.

Most of these activities were handled efficiently by the set up and maintainance of the PRUDENCE web site hosted by DMI. During the last year of the project, there has been an increasing interest in using the data from the climate simulations made available, and more than 15 groups have obtained access to the data server, even before it was made publically available. Means are under development to ensure appropriate acknowledgement of the data providers, when people are downloading data for their own need.

The scientific merits of the PRUDENCE project will be detailed described in an upcoming special issue of *Climatic Change*. This is more thoroughly discussed in Section 1

6.4 Conclusions, Including Socio-Economic Relevance, Strategic Aspects and Policy Implications

6.4.1 Workpackage 1: European regional climate simulations for 2071-2100 and their analyses

The major outcome of this workpackage is the large set of global as well as regional climate change simulations for Europe, which have now been made available to the general research community for further use.

The large number of simulations is needed for studies of possible climate changes. It became obvious that for some statistical investigations the number of available runs is still small.

Using the HadAM3H model as driving model, most of the RCMs behave similar in the simulation of basic quantities like MSLP and temperature. However regional flow pattern differ as well as precipitation.

The calculation of the model mean is a helpful tool to investigate basic trends.

The comparison against available climatologies, like the one provided by the Climate Research Unit (CRU) of the University of East Anglia is a prerequisite for addressing reliability. For example, there is a warm bias in the temperature with respect to the CRU data set in the extreme seasons and a tendency to cold biases in the transition seasons. This behaviour is investigated in detail in the WP1 paper contribution to the special issue.

6.4.2 Work package 2: Uncertainty Assessment of European Regional Responses

- There is significant uncertainty in most details of climate change, *e.g.* the magnitude of warming, which season will warm most, where significant changes in extreme precipitation will occur. Thus, current planning and risk assessment need to account for major uncertainties.
- Probably the largest source of uncertainty, especially when averaging over large time and space scales, comes from the different projections of global climate models. This implies that continuing diversity within and significant investment in the development of these models is very important.
- The modelled mechanisms of future climate change are becoming better understood for specific regions. This aids subjective assessments of the likelihood of these changes, which can then feed into impacts assessments.
- Events that are currently rare (such as the severe drought of summer 2003) may become commonplace by the end of the century. Thus we may already have a crude gauge of socio-economic reactions to future climate anomalies.

• There are likely to significant shifts in the climatic zones (supporting different vegetation types) across Europe. This has wide implications for national agriculture and international trading, for example.
• It is possible that future European climate may include the occasional genesis of tropical cyclones in the Mediterranean during late summer. The level of uncertainty is high, but if realised would have substantial socio-economic implications.

6.4.3. Work package 3: Impacts of future climate scenarios on hydrology

General conclusions from the results in Work package 3 are summarized below. They are organised into the three specific categories of 1) model outcomes, 2) Rhine River hydrological impacts and 3) Baltic Basin hydrological impacts.

6.4.3.1 Model outcomes

- Using different RCMs with the same GCM forcing and emissions scenario results in generally similar hydrological trends.
- Using different GCMs for forcing the RCMs has more effect on hydrological impacts than using different RCMs with the same GCM forcing.
- Partitioning of precipitation into evapotranspiration and runoff varies widely between different RCMs.
- Use of the delta change approach does not provide adequate information on hydrological extremes, but it offers a robust method to compare average outcome using many climate models.
- Successful use of precipitation scaling to drive a hydrological model directly from RCM outputs varies between different RCMs.
- River flow routing of RCM runoff generation can be used to analyse both model performance and scenario trends, however regard must always be given to the potential precipitation biases that most of the RCMs show.
- A strong gradient in the climate change signal from the RCMs is shown by a more active hydrological cycle over Northern Europe and a weaker, dryer hydrological cycle over Central Europe.

6.4.3.2. Rhine River hydrological impacts from scenario simulations

- On average, both summer and autumn river flows show a decrease, while winter flows show some increase.
- Most of the winter river flow increase comes from the lowland catchments.
- During some years, the winter river flow increase for lowland catchments is cancelled out by a decrease in alpine catchments.
- Snow pack duration in alpine catchments shows a considerable decrease and snowmelt peak flows show a shift to earlier occurrence in the season.
- Snow pack volume in alpine catchments could be reduced by up to 60%.

- Snow pack duration in alpine catchments shows a reduction of about 3 weeks for each degree of warming.

6.4.3.3. Baltic Basin hydrological impacts from scenario simulations

- On average, summer river flows show a decrease, while winter flows show an increase.
- On the large scale, annual river flows show an increase in the northernmost catchments of the Baltic Basin, while the southernmost catchments show a decrease.
- The occurrence of medium to high river flow events shows a higher frequency.
- Annual river flow in the Lule River shows a general increase.
- Depending on the transfer methods used, spring peak river flow in the Lule River shows either lower or similar magnitudes compared to present conditions; both cases show an earlier occurrence of as much as a month.

6.4.3.4. Socio-economic relevance, strategic aspects and policy implications

The water sector must oversee the management of both excess and scarcity of water in society. How climate change affects hydrological regimes can substantially impact on socio-economic systems in terms of both flooding and drought. Identification of potential trends for change will thus have both strategic and policy implications.

PRUDENCE conclusions about model outcomes provide an indication of how large the range of uncertainties is according to different model combinations and configurations. This provides insight into the error sources of both existing and future impacts assessments. It also highlights how impact assessment results can vary according to the methods of transfer from climate models to hydrological impacts. This will assist future work by providing guidance on how such impacts studies can be conducted and helping to pinpoint where more efforts are needed for improvement of the climate models.

PRUDENCE conclusions about the specific river basin impacts provide initial insight to decision makers on just how the hydrological regimes in these areas will respond to climate change. For some sectors this overview may be enough to initiate preliminary action; for others this may identify where further or more detailed studies are needed. Specific applications of relevance include, among others, municipal and industrial water supply, hydropower, flood prevention, drought management, irrigation management, dam safety, storm sewer design and maintenance, and nutrient transport analysis.

6.4.4 Work package 4: Impacts on agriculture, forestry and ecosystems

6.4.4.1 Downscaling methods (D4A2, D4B2)
The test of different downscaling methods showed large differences in some cases for the baseline period (1961-1990) between the simulated site based crop yields for observed baseline climate and the control climate for the RCM simulations. For the simulations of crop

production in Denmark this was primarily related to differences in rainfall in the RCM output and the observed climate, and the effects were largest at the site with the driest climate. For crop production in Spain the results were related to differences in both rainfall and temperature between the observed and simulated series. These differences between observed and simulated baseline climates also affected the simulated responses to climate change depending on the downscaling methods used.

6.4.4.2 Agriculture in the Iberian Peninsula (D4A1-D4A4)

Scenario analyses of effects of climate change were performed for winter wheat, spring wheat and maize. Winter wheat is currently cultivated in central and northern areas of the Iberian Peninsula but not in the South as the vernalisation requirements are not fulfilled. When simulating winter wheat, the model captured crop failure in the southern parts, where winter temperatures are too mild to induce flowering. The scenarios of future climate showed a gradient in the impact from North to South that differs in intensity among the RCMs. There were generally yield decreases of up to 50% in the South and yield increases of up to 30% in the North. In the case of spring wheat, general increases in yield were found for the future scenarios with most RCMs, because milder winter temperatures promote greater crop growth rates. Spring wheat, which has no vernalisation requirements, is sown in autumn in the Iberian Peninsula. New and highly productive spring wheat cultivars are currently being used by farmers for their versatility in sowing dates. This indicates that climate change will lead to a change from winter wheat to spring wheat, in particular in Central and Southern Spain.

Maize in Spain is sown in spring and harvested at the end of summer or beginning of autumn and is irrigated because the small summer rainfall is ineffective in most regions. Temperature then drives the impact of climate change for this summer crop and shortens crop duration. In the central areas of the Iberian Peninsula, milder temperatures in spring allow for earlier sowing dates that can compensate for the shortened crop cycle under A2 scenario. The results showed that the yield decreases under the A2 scenario, could be substantially reduced by sowing the same cultivar 45 days earlier. Choice of a cultivar with a longer crop cycle is the other possible strategy that could also be applied if changes in sowing dates are not sufficient to compensate for yield decrease

6.4.4.3 Agriculture in Denmark (D4B1-D4B3)

Analyses of yield and nitrogen cycling for continuous winter wheat showed average increases in optimal nitrogen (N) fertilisation rates of 1 to 43 kg N/ha for the A2-scenario for 2071-2100 compared with 1961-1990 with the greatest increases for sandy soils compared with loamy soils and the greatest increases for the low rainfall climates. The average yield increases at optimal N rate varied from 0.9 to 2.3 t/ha with the highest increases for the low rainfall sites and no systematic effect of soil type. There were only small differences between RCMs in estimated yield increase. The simulated nitrate leaching increased for the high rainfall site in West Denmark for all soil types and all RCMs with average increases of 5 to 18 kg N/ha. For the low rainfall site in East Denmark an average increase of 10 kg N/ha was simulated for the sandy soil and an average decreases of 1 to 2 kg N/ha was simulated for the loamy sand and sandy loam soils. Considering the distribution of rainfall and climate in Denmark this gives a trend in increase in N leaching West Denmark and no change in East Denmark.

The model was applied to three different crop rotations varying in proportion of winter crops and catch crops. The model was applied to climate data from two sites in Denmark and to two different soil types. In all cases the simulated increased in N leaching under the A2 scenario could the reduced considerably by changing the crop rotation from being dominated by winter cereals to spring cereals, in particular in combination with the use of catch crops. However, for the low rainfall site this resulted in a smaller increase in grain yields compared with the winter cereal dominated crop rotation.

6.4.4.4 Ecosystem responses (D4C1-D4C4)

For Europe as a whole, net primary production (NPP) estimated with the LPJ-GUESS model increased in both scenarios, slightly more under the A2 scenario compared to the B2. The differences among simulations were more prominent in northern than in southern Europe. In the north increases in atmospheric CO_2 and temperatures interacted positively to enhance growing season length and NPP, and lead to a shift in dominance from coniferous forest to a deciduous forest in some areas and to an advance in the tree-line especially in the Fennoscandian Alps. Decreases in NPP in the Mediterranean were particularly pronounced under the A2 scenario. This is likely related to the predicted decreases in precipitation and increased evapotranspiration, which leads to increasing soil water deficits and reduced plant productivity.

The greatest proportional changes in NPP were predicted to occur in Northern Europe (on average 27%), while the smallest changes were predicted for South-Western Europe (on average 9%), and this was consistent across all scenarios. In general, the A2 scenarios were associated with larger changes than B2 scenarios, both because the emission driven climatic changes were generally greater, and because of higher atmospheric CO_2 concentrations in the A2 scenario, both of which influence vegetation processes.

6.4.4.5 Simple indices (D4C5)

Estimates based on climate scenarios for 2071-2100 showed a substantial northward shift of the northern limits of grain maize suitability. However, the extent of this shift varied considerably across climate scenarios. Figure 1a shows the range of shifts estimated from climate scenarios based on seven RCMs that were nested in the same GCM (HadAM3H) for the A2 emissions scenario. The uncertainty attributable to different RCMs is illustrated by the area of expansion that is not common for all scenarios, shown in blue. The uncertainty range for shifts in maize suitability predicted from six GCMs for the SRES A2 scenarios is wider than the RCM range for nearly all locations along the northern and southern limits. The widest range is spanned under the four SRES emissions scenarios for the six GCMs (Figure 1b and 1c).

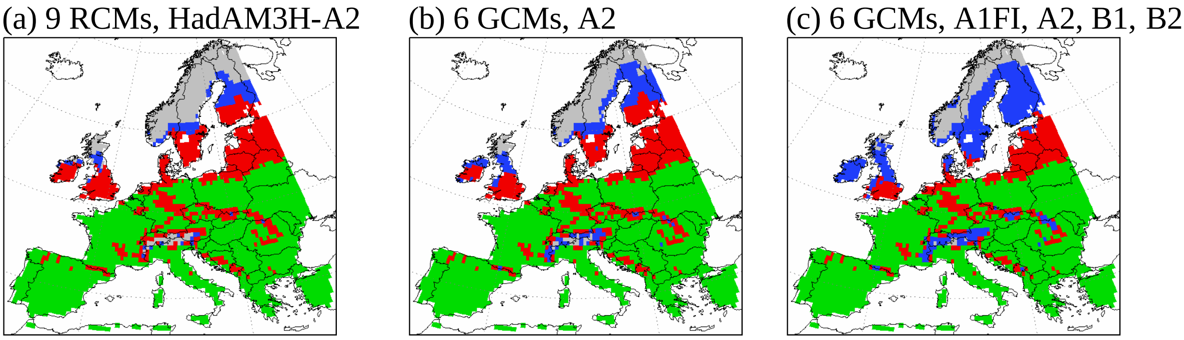


Figure 1. Modelled suitability for grain maize cultivation during the baseline (1961-1990) and future (2071-2100) periods for: (a) 7 RCM scenarios driven by HadAM3 for the SRES A2 scenario, (b) 6 GCM-A2 scenarios, and (c) 24 scenarios from 6 GCMs for the four SRES scenarios A1FI, A2, B1 and B2 (A1FI and B1 pattern-scaled). Green areas show the suitable area for the baseline, red depicts the expansion common under all scenarios and blue the uncertainty range of the respective scenario group. Grey areas are unsuitable under all scenarios.

The highest yields of rain fed winter wheat under the baseline climate (1961-1990) were estimated in central Europe with the largest estimates of more than 8 t DM ha^{-1} in France and parts of England. Smaller yields down to 4 t DM ha^{-1} were estimated for north-eastern and southern Europe. Estimates of the changes in productivity for 2071-2100 were consistent among the nine RCM scenarios for SRES A2 with increases in most areas north of the Alps and decreases in southern Europe, especially over the Iberian Peninsula.

The estimates of nitrate leaching from winter wheat cultivation for the baseline remained below 10 kg N ha^{-1} for most parts of Europe. The spatial pattern of changes by 2071-2100 is far patchier compared to the estimated changes in wheat yield. Decreases in N-leaching predominated over large parts of Eastern Europe and some smaller areas in Spain, whereas increases occurred in the UK and in smaller regions over many other parts of Europe Model results were therefore very sensitive to even small changes in temperature and precipitation.

6.4.4.6 Soil water availability for the Mediterranean region (D4C6)

Under the A2 scenario, mean summer temperatures were projected to increase over all Mediterranean countries by at least 5 °C. Even greater increases can be expected over Iberia, southern France, northern Africa, and southern Turkey. The models anticipate a decline in summer rainfall over the whole domain. The extent of this, however, is limited in most areas by the already low summer rainfall. The most interesting changes are for the Alps, where total summer rainfall is likely to decrease by over 150 mm (±30 mm). North of about 44°N, winter rainfall is expected to increase by 100 mm (±15 mm), with a much greater increase (and higher uncertainty) over the Alps. South of this line, winter rainfall will decline by 50-100 mm (±10 mm).

Soil moisture amount integrates the information in the temperature and rainfall projections. Summer soil moisture amount can be expected to decline by 300-400 mm (±15 mm) in most Mediterranean countries, with Iberian, southern France, and northern Africa being the worst affected areas. In winter, Western Europe north of the Mediterranean can expect an increase in soil moisture amount of 50-100 mm (±10-30 mm). The countries bordering the

Mediterranean are projected to experience winter deficits in soil moisture of 50-100 mm (±10 mm).

6.6.6.7 Main deliverables

No.	Institute	Deliverable
A. Agriculture in a South European region		
D4A1	ISAg-UPM	Crop-climate model verified for response to adaptive options under current climate
D4A2	ISAg-UPM	Report on response of crop and biomass production, water use and sustainability indicators for a wide range of climate change scenarios
D4A3	ISAg-UPM	Report on effectiveness of adaptive management options for a restricted range of climate change scenarios
D4A4	ISAg-UPM	Report on uncertainty in climate model estimation of soil water balance parameters in the Mediterranean region
B. Agriculture in a North European Region		
D4B1	DIAS	Soil-plant-atmosphere model verified for response to adaptive options under current climate
D4B2	DIAS	Report on response of crop production and nitrogen cycling for a wide range of climate change scenarios
D4B3	DIAS	Report on the effectiveness of adaptive management options and effect on mitigation strategies for a restricted range of climate change scenarios
C. Impacts on forestry, ecosystems, health, transport, energy, etc.		
D4C1	UL	Simulations of present day forest landscapes and ecosystem processes from selected regions under current climate
D4C2	UL	Validation of model output under current climate against forest inventory data at selected sites
D4C3	UL	Simulations of ecosystem processes at selected EUROFLUX sites from 1994
D4C4	UL	Modelled predictions of both vegetation and ecosystem processes for selected forest regions for the period 2071-2100 using the regional climate model outputs and their various SRES scenarios
D4C5	FEI	Analysis, interpretation and presentation of present and future resource potential (simple impact models and indices) in GIS
D4C6	UEA-CRU	Analysis, interpretation and presentation of uncertainties in D4C5 in GIS

All deliverables have been completed and reported as indicated in the list of literature produced.

6.4.4.8 Socioeconomic relevance and policy implications

Climate change has a considerable impact on both natural and managed ecosystems. The impact on agricultural productivity is of primary concern for the rural population, but in some European countries of interest for the national economy. The direct effects on natural ecosystems and forest are essential for the European landscape and for many ecosystem functions provided clean air and water for the European population. Indirect effects of climate change on N-losses from agricultural systems can in some regions have profound effects on natural ecosystems. The EU Water Framework Directive will in the future regulate N-losses to surface waters in the EU, and during the preparation for the implementation of this Directive in Denmark, results of climate change on N-leaching from agriculture obtained from the PRUDENCE project was used as a basis for designing the new policy.

The results obtained emphasises the large discrepancy in ecosystem impacts between Southern Europe and Northern Europe. In Southern Europe impacts a going to be dominate by effects on heat stress and water shortage, whereas impacts in Northern Europe will be dominated by changes in the duration of the growing season, increases in productivity and possible negative effects on increases in N-losses from agriculture. Agriculture in parts of Southern Europe (e.g. Spain) will shift towards grown short-season crops (e.g. spring wheat) during winter. For spring sown crops in large parts of Spain there will be an increasing demand for irrigation, and this irrigation water is likely to be very scarce.

The results of the project have shown that regional impacts on natural and managed ecosystems may vary considerably, and that the variation in simulated impact between different RCMs may depend on site. Future regional and national analyses of impacts on agriculture and ecosystems should therefore make use of RCM model output and preferably use the output of several models.

6.4.5 Work package 5: Risk assessment of European weather and climate extremes in future regional forecast scenarios

WP5 has focused on heat waves, heavy precipitation events, drought, winter storms, and resulting sea surges because of their large impacts on Europe. A variety of diagnostic methods were developed and applied to determine how these extreme events are predicted to change by the end of the 21st century in the set of PRUDENCE RCM experiments. A summary of the main results follows.

- **Heat waves** – Regional surface warming causes the frequency, intensity and duration of heat waves to increase over Europe. By the end of the 21st century, countries in central Europe will experience the same number of hot days as are currently experienced in southern Europe. The intensity of extreme temperatures increases more rapidly than the intensity of more moderate temperatures over the continental interior due to increases in temperature variability.

- **Precipitation** – Heavy winter precipitation increases in central and northern Europe and decreases in the south; heavy summer precipitation increases in north-eastern Europe and decrease in the south. These changes, which are weaker for the B2 than for the A2 scenario, are more robust to RCM in winter than in summer and reflect changes in mean precipitation. The RCMs all predict earlier and longer droughts in the Mediterranean.

- **Winter storms** – Extreme wind speeds increase between 45°N and 55°N, except over and south of the Alps, and become more north-westerly. These changes are associated with reductions in mean sea-level pressure and generate more North Sea storms, leading to increases in storm surge along the North Sea coast, especially in Holland, Germany and Denmark.

These are the highlights from the most comprehensive regional climate change study performed for Europe – for more information refer to the joint WP5 article by Beniston et al. (2005). Many intriguing and pressing issues have emerged and many more studies now need to be performed to dig deeper into the initial findings presented here. Despite the uncertainties present in these model simulations of future climate, it is clear that the regional changes in extremes presented here will cause Europe to face some major societal challenges in forthcoming decades.

6.4.6 Work package 6: Assessment of the role of PRUDENCE on European climate policies

The activities have included the development of a conceptual framework for linking detailed climate change modelling results provided by PRUDENCE partners with socio-economic analysis, and based on this a micro-level and a macro-level assessment of the economic consequences of climate change for European agriculture has been carried out. A more detailed assessment has been done including conceptual and empirical work considering how to derive information regarding climate change risks from climate scenarios and to consider the value-added by climate change projections on a finer spatial and temporal scale than traditional modelling resolutions. Finally Risoe and Cired has worked on a number of journal papers.

6.4.8 Scientific highlights

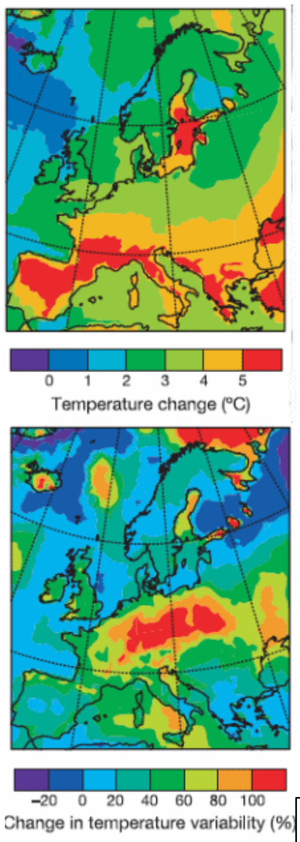
As evident from the list of Prudence related presentations and publications in section 1.5, there is no doubt that the project scientifically has been very successful. Two groups have submitted and published material in *Nature*. Partners from DMI presented an analysis of extreme summer time precipitation towards the end of the 21st Century. This material appeared in February 2003 (Christensen & Christensen, 2003). Towards the end of the second project year Schär *et al.* (2004) from ETH had their work on the heat wave of 2003 accepted for publication as well. The heat wave was also discussed in the view of PRUDENCE findings by Prof. Beniston from University of Fribourg, who had a *GRL* publication on this subject (Beniston, 2004). One of the more general findings, namely that the driving GCM is controlling large scale aspects of the climate change, was thoroughly investigated by the team at SMHI (Räisänen *et al.* 2004). Here the findings are briefly summarised as listed on the project web pages:

The Summer Heat Wave of 2003: A Signal of Climate Change?

The summer heat wave in southern and central Europe may have been more extreme and improbable than the many heat records and the strong droughts have first indicated. New investigations show that the weather in the summer 2003 may have been a taste of a climate that we are going to face in the future.

Hard to Explain

Even when considering the general warming that has taken place during the last 150 years (a bit less than 1 degree Celsius in Europe), it is very difficult to explain the extreme heat of this summer as a consequence of natural climate variations. The summer of 2003, however, is not particularly unusual if one compares it to simulations of the future climate towards the end of the century, as a result of man-made greenhouse gas emissions that affect our climate system. As part of the Prudence project, Prof. Christoph Schär from the Institute for Atmospheric and Climate Science at ETH-Zurich, and his colleagues has analyzed simulations from the project.



Simulated change in average summer temperature (upper panel) and in interannual variability (lower paned) from the period 1961-1990 to the period 2071-2100.

The Temperature Rises

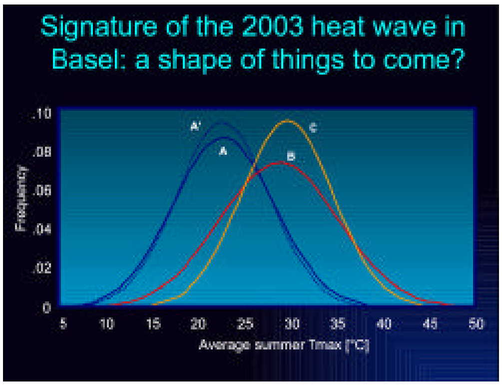
The analysis shows that we should not only expect higher average temperatures, but in many places also a significantly increased year-to-year variability during the summer seasons. Observations show that the temperature has increased over the previous 150 years, but an increase in variability has not yet been detected.

Very Rare, or a Glimpse of the Future?

According to the new investigations by Christoph Schär and co-workers, this summer was either an extremely rare event, or a taste of new climatic conditions to come, or a combination of the two. The anticipated increase in variability might make the adaptation to warmer climatic conditions even more challenging than previously expected.

The record-breaking heat wave that affected much of Europe in the summer of 2003 was very different from the heat waves recorded in 1947 and 1976, and more like the conditions that might be expected towards the end of this century.

M. Beniston and his team engaged in the EU project "PRUDENCE" used results from the HIRHAM regional climate model developed by the Danish Meteorological Institute for two 30-year simulations. The "current climate" simulation was run for the period from 1961 to 1990, while the "greenhouse-gas climate" simulation covered from 2071 to 2100. For both periods, M. Beniston studied the fluctuations in the daily maximum summer temperatures in Basel, Switzerland, a site that has long and high-quality climatic data (M. Beniston, 2004: Geophys. Res. Lett. 31 L02202) He then extended the model to different parts of Europe and found that in the latter half of this century, summer temperatures would increase across much of the continent leading to a "northward shift" in climatic zones. This implies that Switzerland could, by the end of this century, have a climate similar to that currently found in the South of France, i.e., a "Mediterranean-type" of climate with long, dry summers and a winter rainy season.



Gaussian distributions fitted to the mean summer maximum temperature data at Basel, Switzerland, for the 1961-1990 reference period (A: Observations; A': HIRHAM4 model results), the 2071-2100 A2 scenario simulation (B) and the 2003 heat wave (C). This shows that the smoothed probability density function (PDF) for maximum temperatures in 2003 fits entirely within the PDF projected to occur in the latter part of the 21st century, and is well out of the range of the 1961-1990 summer maximum temperature PDF.

Beniston observed a general increase of about 4-6°C in a band stretching across central Europe to the Black Sea, with greater increases over the Iberian Peninsula and the south west of France. In Basel, the 30°C threshold would be exceeded in the latter part of the century at least 40 days per year compared to less than 10 today. The summer period during which high temperatures could be expected is likely to be extended by 4 weeks or more compared to current climatic conditions, with the upper levels of summer maximum temperatures in the range of 38-45°C as compared to 30-35°C on average today.

The 2003 heat wave, by mimicking quite closely the possible course of summers in the latter part of the 21st Century (see Figure), can thus be used within certain limits as an analogue to what may occur with more regularity in the future. The severity of the impacts related to the persistence of elevated temperatures and drought conditions, in particular close to 15,000 excess deaths recorded in France, Italy and Spain, crop failures in many parts of the continent and strongly reduced river flow in much of western, central, and southern Europe, should be seen as a "shape of things to come" and should motivate both scientists in assessing the course of future climatic impacts and decision makers in formulating appropriate response strategies.

More Heavy Summer Rain over Europe in the Future

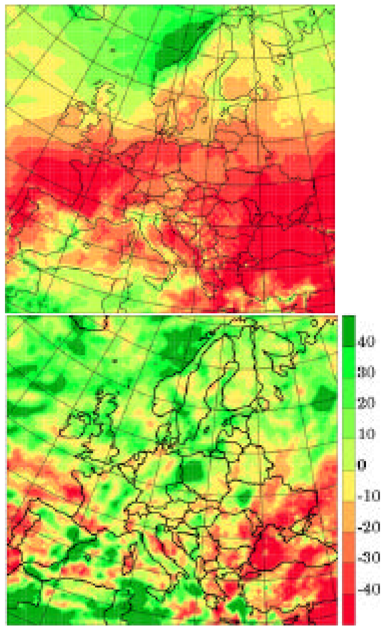
Most people will remember the many pictures of serious flooding in Central Europe during the summer of 2002. Most media attention was given to the flooding of Prague and Dresden. What should we expected to see in the future? New investigations indicate that more of this can be expected to take place as a consequence of global warming.

Drier and yet wetter!

For the first time it has been possible to quantify the likely changes related to summer time precipitation amounts and intensity due to global warming at a European scale.

As part of the Prudence project Dr. Jens Hesselbjerg Christensen & Dr. Ole Bossing Christensen from the Danish Meteorological Institute have analyzed simulations from the project. In their research they conclude that towards the end of the 21st Century:

The total summer time precipitation amounts will be substantially reduced over major parts of Southern and central Europe. Intensive rain events - like those leading to the flooding in the Moldova, Danube, Elbe and Rhone in 2002 - will become more frequent and even more intensive. In other words: When it finally rains in a drier and hotter Europe it pours down.



Top panel: Change in average precipitation in July-August-September from 1961-1990 to 2071-2100 in per cent. Bottom panel: Change in the exceedance of the 99th percentile, i.e., the change in the average precipitation on the 1% of the days during this season and period where it rains the most.

Future climate in Europe: warm and dry summers in the south, mild and wet winters in the north.

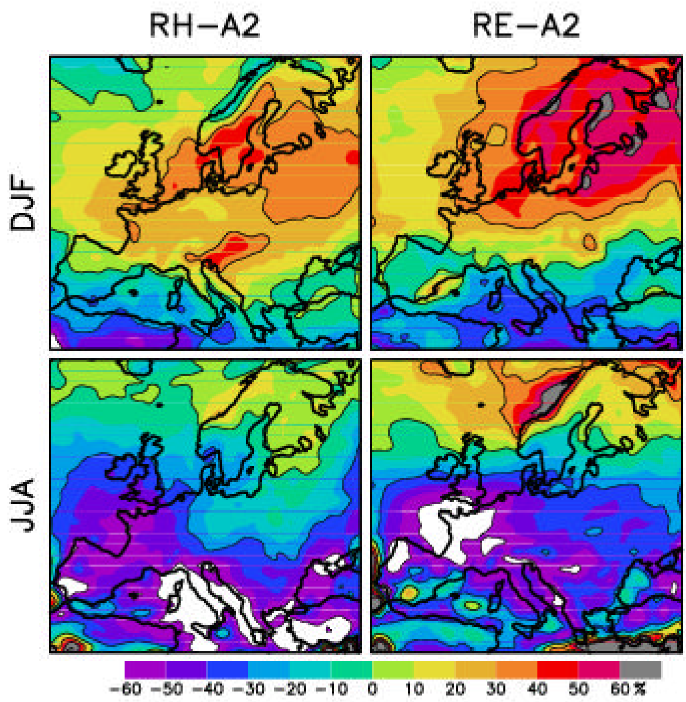
As part of the PRUDENCE project Dr. Jouni Räisänen and his colleagues at the Rossby Centre at SMHI have analyzed simulations from the project. Their results have been published recently in Climate Dynamics (2004). Four different realizations of future climate change were investigated. Two different emission scenarios and two different driving global models were used. The magnitude of the simulated climate changes differs between the experiments but all four experiments agree on:

A future warming that will be largest in winter in northern Europe and largest in summer in southern Europe.

Increased precipitation in northern Europe, especially during winter, and decreased precipitation in southern Europe during summer.

More ... or less ... precipitation in winter?

In some regions there are considerable differences between the experiments. A conspicuous example concerns the changes in wintertime precipitation in Norway. Depending on choice of the driving global model precipitation is either increased or decreased. The simulations show the profound impact on the regional modelling results from the driving global model.



Simulated changes in winter (DJF) and summer (JJA) precipitation from the period 1961-1990 to 2071-2100. Results from the Rossby Centre regional climate model are shown. To the left boundary conditions from the Hadley Centre and to the right boundary conditions from the Max-Planck Institute for Meteorology are used.

6.5 Dissemination and exploitation of the results

Workshops and meetings

PRUDENCE scientists have organized several useful workshops and meetings that have helped bring scientists together to discuss PRUDENCE related research. In several cases these meetings have lead to interaction with the media (see also Section 1.5):

- PRUDENCE kick-off meeting, Snekkersten December 3-5, 2001 (organized by J.H. Christensen)
- Second ICTP Conference on Detection and Modelling of Regional Climate Change, Trieste, Italy, 30 September – 4 October 2002 (organized by F. Giorgi)
- Open session on Extreme Climatic Events, their Evolution and their Impacts, EGS-AGU-EUG Joint General Assembly Meeting, April 7, 2003. (Organized by M. Beniston with D.B. Stephenson as co-convenor).
- Wengen-2003 Workshop on Regional Climatic Change in Europe: Processes and Impacts and PRUDENCE Annual Meeting, 29 Sep – 3 Oct 2003, Wengen, Switzerland (organized by M. Beniston).
- WP5 workshop on extremes, Chateau d'Oex, 16-18 March 2003. (organized by M. Beniston and D.B. Stephenson).
- WP5 workshop on extremes, Chateau d'Oex, 6-9 March 2004. (organized by M. Beniston and D.B. Stephenson).
- One-day Royal Meteorological Society meeting on extremes, London, 21 January 2004. This meeting organized by D.B. Stephenson and C.A.T. Ferro was well-attended by more than 100 people including representatives of the U.K. media. The meeting has been summarized in: M. Collins, Extreme weather and climate events, Weather, Vol. 59, 5, p. 138.
- Regional-Scale climate modelling workshop. High-resolution climate modelling: Assessment, added value and applications. WCRP-sponsored, Lund, Sweden, 29 March - 2 April, 2004 (J.H. Christensen and many PRUDENCE partners' co-organizers).
- PRUDENCE Regional Climate Change conference, Toledo, Spain, 6 – 9 September 2004 (organized by M. Castro).
- EU-Side event at the 10th Conference of the Parties (COP10), 13 December 2004, Buenos Aires, Argentina
- A Nordic seminar on "Adaptation of crops and cropping systems to climate change" is being organised in November 2005, and this will form the basis for a wider

communication of PRUDENCE impacts results among agricultural researchers, advisors and policy makers in Europe.

Web sites

The official PRUDENCE web site (http://prudence.dmi.dk) has been frequently visited by partners as well as external guests. The site is maintained after the project has ended, and it will be maintained as far as possible for a period of at least 5 years. This is due to a similar involvement by the staff at DMI in the ENSEMBLES project for regional climate aspects, as has been the case within PRUDENCE.

In collaboration with the MICE and STARDEX projects a commaon web portal was constructed. Here the three projects were briefly described as well as how they fitted together (http://www.cru.uea.ac.uk/projects/mps/)

The Reading partners created a web site for educating scientists about methods for extreme events: http://www.met.rdg.ac.uk/cag/extremes/. This site has received many hits and has helped many scientists learn more about how best to analyse extreme events.

Additional project material

During the first project year a brochure describing the cluster of projects PRUDENCE-STARDEX-MICE was made. It has been widely distributed by all partners, and it still serves as comprehensive introduction to the three projects. In addition a poster was made and distributed amongst the partners via the MPS web-portal

At the presentation of the project at COP10, a short document commenting on the overall findings regarding climate change at a European level was handed out. The document summarizes in a simple probabilistic sense the projected change in mean seasonal temperature and precipitation for the individual European nations covered by the integration domain applied within the project. This document is provided in Appendix A.

A set of power point presentations from the entire duration of the project are available from the PRUDENCE web site. This includes a tailored very brief project summary aiming at non-expert usage.

Additionally publications have been made in journals for end-users (e.g. farmers), in reports aimed at policy makers and also formed the basis for an entry in an international encyclopaedia.

During the preparation of a new Aquatic Action Plan in Denmark, the results of PRUDENCE was included in a report on the interaction of climate change and agricultural effect on the aquatic environment as a basis for policy decisions on further regulations of agriculture to reduce environmental impacts. In Spain, a report has on climate change impacts for agriculture have been prepared for the Ministry of Agriculture and this is expected to lead to further national assessments of impacts and adaptations.

Many results will be included in the 4th assessment report of IPCC. Several of the project participants are lead authors on Chapters for WG1, WG2, and WG3. The results will most likely also form the basis for parts of the reporting of likely impacts of climate change to the UNFCCC fourth national communications.

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Table 1 Staff Effort Chart for Period 1 November 2001 to 30 October 2004

Work-package No.	Workpackage title	Partner	Effort Planned (pm)				Year 3 Effort		Updated Effort (pm)			
							Actual	Total				
			Year 1	Year 2	Year 3	Total	mth 30	mth 36	Year 1	Year 2	Year 3	Total
WP1	European regional climate simulations for 2071-2100 and their analysis	1	4	4	4	12	3	5	4	3	5	12
		2	6	6	6	18	2,2	4,25	7,25	6,5	4,25	18
		3	5	5	6	16	4,6	8,23	5,57	2,2	8,23	16
		4	2,27	2,37	2,37	7	2,06	2,63	2,37	2	2,63	7
		5	8	9	9	26	2,1	2,1	13,9	10	2,1	26
		6	2	3	3	8	3	3,33	2	2,67	3,33	8
		7	4	3	3	10	0	0	4	6	0	10
		8	8,5	8,5	5,3	22,3	3	5	9	9,6	5	23,6
		9	2	1,5	1,5	5	1	1	2	2	1	5
		10	4	5	4	13	2	4	4	5	4	13
		12	4	4	4	12	1	1	9	2	1	12
WP2	Uncertainty assessment of European regional climate model responses to common forcing, model formulation, and resolution	1	6	6	6	18	2	12	2	4	12	18
		2	7	7	7	21	3,7	7	7	7	7	21
		3	4	4	4	12	4	6,42	0,58	3	6,42	12
		4	4,9	4,9	4,9	14,7	4	7,6	4,9	2,2	7,6	14,7
		5	12	12	12	36	6	10	12	14	10	36
		6	0	8	4	12	4	8	0	5	8	12
		7	0	9	9	18	5	9	0	9	9	18
		8	5	5	5	15	2,5	5	5	6	5	16
		9	3	5	4	12	3,1	4,5	3	4,5	4,5	12
		10	3	7	8	18	4,2	8,4	2,6	7	8,4	18
		12	0	0	0	0	0	0	0	0	0	0
		16	1,33	1,33	1,33	4	1,33	2,33	0	1,67	2,33	4
		21	0	6	6	12	2,5	6	0	6	6	12
WP3	Impacts of future climate scenarios on hydrology	6	4	9	11	24	6	12	4	8	12	24
		8	2	2	2	6	0	6	2	2	6	10
		9	8	9,5	6,5	24	4,1	8,86	7,37	7,77	8,86	24
		15	4	4	4	12	0	0	3	9	0	12
WP4	Impacts on agriculture, forestry, and ecosystems	11	11,6	10,7	10,7	33	4,75	9,5	14,5	15,5	9,5	39,5
		13	9	10	9	28	4	10,8	9	8,2	10,8	28
		16	8	8	8	24	7,3	10,4	5	12,5	10,4	27,9
		18	12,33	12,33	12,33	37	10,5	21	31	23	21	74
		20	1	5	2	8	4	7	0	1	7	8
		21	2	2	2	6	1	2	2	2	2	6
WP5	Risk assessment of European weather and climate extremes in future regional forecast scenarios	7	12	12	12	36	12,5	17,1	6,5	12,4	17,1	36
		15	8	8	8	24	5,5	10	4	10	10	24
		16	2,33	2,33	2,33	7	2,67	3,67	0	3,33	3,67	7
		17	12	12	12	36	12	18	6	12	18	36
		20	3	5	1	9	2	5	0	4	5	9
		21	3	6	6	15	3,5	6	3	6	6	15
WP6	Assessment of the role of PRUDENCE on European climate policies	5	1	1	1	3	0	1	1	1	1	3
		14	5,7	3,5	4,8	14	1,8	6,8	4	3,2	6,8	14
		19	7	8	15	30	9	18	7	14	18	39
WP7	Management, data, reporting and dissemination	1	8	8	8	24	7	15	4	5	15	24
		5	1	1	1	3	0	0,5	1	1,5	0,5	3
		8	1	1	1	3	0,5	2	1	1	2	4
		9	0,33	0,33	0,33	1	0,1	0,33	0,33	0,33	0,33	1
		11	0	1	1	2	0,67	1,34	0	0,66	1,34	2
		13	1	1	1	3	0,4	1	1	1	1	3
		16	1	1	1	3	0	2	0	1	2	3
		18	0,66	0,66	0,66	2	0	1,34	0,66	0,66	1,34	2
		20	0,33	0,33	0,33	1	0	1	0	0	1	1
		21	0	1	1	2	0	1	0	1	1	2

Table 2 PRUDENCE Project Planning Timetable

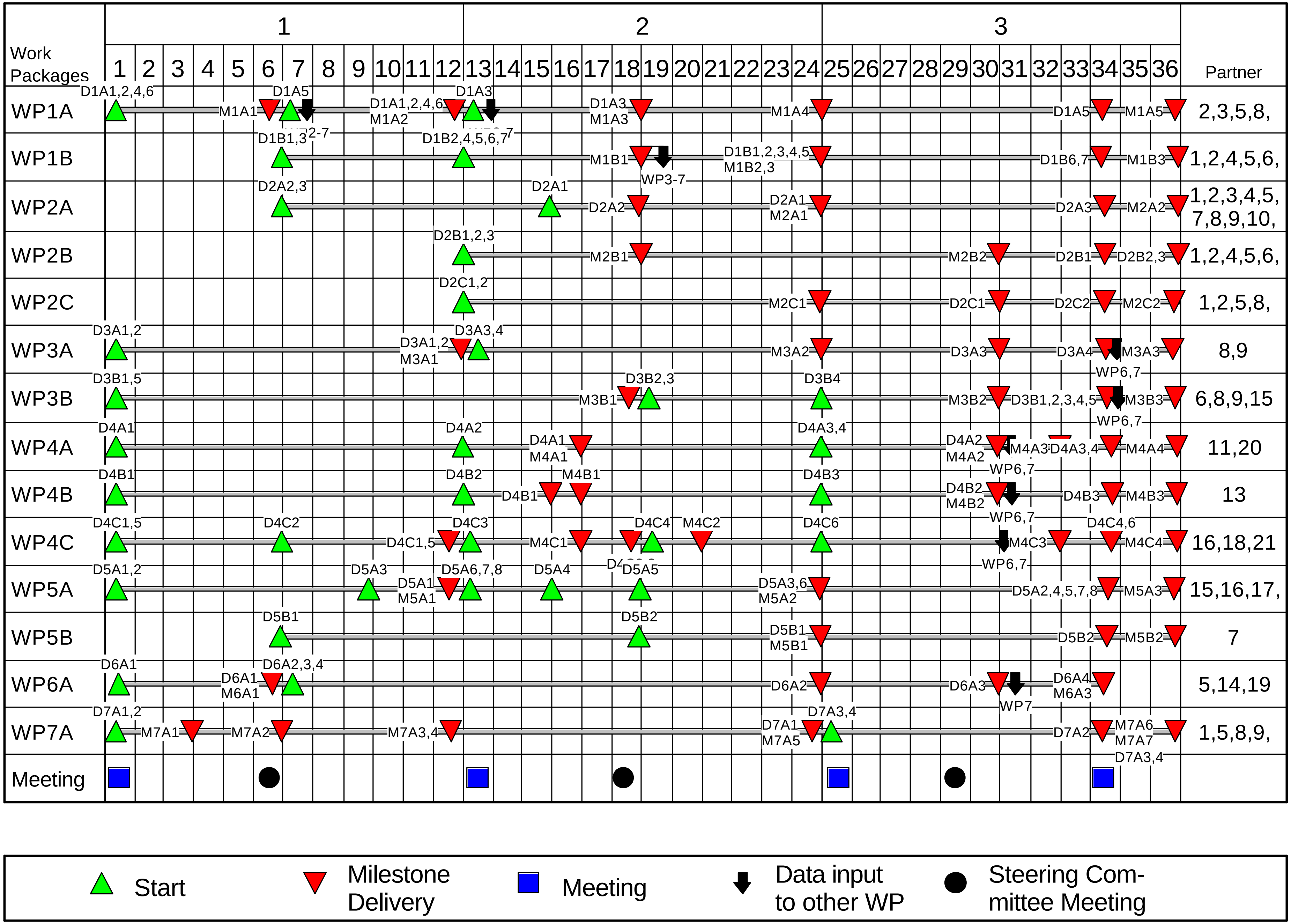


Table 3 Milestones for Months 0 to 36

Milestone number:	Description:	Due Date:	Progress:
M1A1	Data from first A2 scenario made available to regional modelling groups	Month 6	Completed
M1A2	Simulations with the B2 scenario and the A2 scenario ensemble completed and all relevant data made available to regional modelling groups.	Month 12	Completed
M1A3	Responses from first scenario simulations analysed and results passed to the WP co-ordinator	Month 18	Completed
M1A4	All scenario simulations completed and data passed to impacts modellers as required.	Month 24	Completed
M1A5	Responses from all scenario simulations analysed, results passed to the co-ordinator and synthesis of results produced.	Month 36	Completed
M1B1	Initial A2 scenario simulations completed	Month 18	Completed
M1B2	Responses from first scenario simulations analysed and results passed to the WP co-ordinator.	Month 24	Completed
M1B3	All scenario simulations completed and data passed to impacts modellers as required.	Month 24	Completed
M1B4	Responses from all scenario simulations analysed, results passed to the co-ordinator and synthesis of results produced.	Month 36	Completed
M2A1	Preliminary analysis of responses in parallel simulations from each partner made available to the co-ordinator and use of pattern scaling methods.	Month 24	Completed
M2A2	Reports detailing the uncertainties in high-resolution global climate scenarios and the authoritative A2-emissions driven high resolution global climate scenario for 2071-2100.	Month 36	Completed
M2B1	Report on the quality of simulations of current climate by European RCMs	Month 18	Completed

M2B2	Report on the uncertainty in European regional climate scenarios resulting from the formulation of the RCM indicating the level of confidence in any preferred or consensus responses.	Month 30	Completed
M2C1	Preliminary analysis of responses in ensemble and parallel simulations from each partner made available to the co-ordinator.	Month 24	Completed
M2C2	Reports detailing the uncertainties in European regional climate scenarios and summarising climate scenarios derived from the SRES A2 and B2 emissions scenarios.	Month 36	Completed
M3A1	Develop the interfacing between the large-scale hydrological model and the climate models.	Month 12	Completed
M3A2	Report on the performance of the hydrological components of the climate models	Month 24	Completed
M3A3	Report detailing the possible changes in river flow, flood frequency and water resources in climates responding to plausible future emissions scenarios for the period 2071-2100.	Month 36	Completed
M3B1	Develop the interfacing between the detailed hydrological model and climate models at various resolutions.	Month 18	Completed
M3B2	Complete the simulations of the detailed hydrological model of Central European river catchment driven by climate scenarios from a regional climate model run at standard and high resolution.	Month 30	Completed
M3B3	Report detailing the changes in river flow and flood frequency in a Central European river catchment for one realisation of a possible future climate of the period 2071-2100 and their sensitivity to the resolution of the driving model.	Month 36	Completed
M4A1	Crop-climate model verified under current climate conditions	Month 16	Completed

M4A2	Analysis of response of crop and biomass production, water use and cropping systems sustainability for a wide range of climate change scenarios completed	Month 30	Completed
M4A4	Analysis of effectiveness of adaptive management options completed	Month 36	Completed
M4B1	Soil-plant-atmosphere model verified for adaptive options under current climate conditions	Month 16	Completed
M4B2	Analysis of response of crop production and water use for a wide range of climate change scenarios completed	Month 30	Completed
M4B3	Analysis of effectiveness of adaptive management options and impact on mitigation strategies completed	Month 36	Completed
M4C1	Simulations from ecosystem model verified under present climate using inventory data and preparation of GIS environment.	Month 16	Completed
M4C2	Simulations of ecosystem processes verified using EUROFLUX sites	Month 20	Completed
M4C3	Predictions and analysis of vegetation and ecosystem processes in selected regions using the RCM SRES scenarios and results from impact modelling of resource potential.	Month 32	Completed
M4C4	Assessment of the different RCM modelled outputs in terms of the impacts on Forest ecosystems and analysis of uncertainties in impact modelling of resource potential.	Month 36	Completed
M5A1	Novel and innovative new methods for quantifying the probability of weather and climate extremes in Europe. Report detailing findings on extremes in observed data over Europe	Month 12	Completed
M5A2	European extremes simulated by low-resolution AGCM simulations and comparison with observed extremes. Present and future resource risks in gridded format.	Month 24	Completed

M5A3	Risk of future extremes as forecast by the high resolution regional climate models including estimates of uncertainty	Month 36	Completed
M5B1	Report on the quality of the driving data from the RCM control simulations	Month 24	Completed
M5B2	The possible changes in North sea storm surges in a future climate scenario for the period 2071-2100 and the uncertainty in these due to the formulation of the driving model	Month 36	Completed
M6A1	Work report D6A1 submitted to project group	Month 6	Completed
M6A2	Work report D6A3 submitted to workshop participants	Month 31	Completed
M6A3	Workshop to present the final project results	Month 33	Completed in month 38
M7A1	Specification of model output required for the WPs	Month 3	Completed
M7A2	First complete set of AGCM 30 year control and anomaly data available on the PRUDENCE ftp server	Month 6	Completed
M7A3	First complete set of RCM control and anomaly data available on the PRUDENCE ftp server.	Month 12	Completed
M7A4	PRUDENCE web-site developed incorporating an interface to the boundary data	Month 12	Completed. But boundary data now handled via special agreements
M7A5	Data from all relevant scenario simulations available to the consortium via a prototype internet interface.	Month 24	Completed.
M7A6	All PRUDENCE reports, including an assessment of the PRUDENCE climate scenarios, available on the PRUDENCE web-site along with an interface to the scenario data.	Month 36	Completed
M7A7	Summary presentation of the results of PRUDENCE produced and available from the web-site.	Month 36	Completed

Table 4 Deliverables progress

Deliverable No. Contributing partner	Deliverable title	Start and Delivery date (month)	Nature	Dissemination level / Status
D1A1 2,3,5,8,12	WP1: Four high-resolution realisations of global climate for 2071-2100 consistent with the SRES A2 emissions scenario and matching control simulations.	1 12	Si	RE / Completed
D1A2 3,5	WP1: Two high-resolution realisation of global climate for 2071-2100 consistent with the SRES B2 emissions scenario and matching control simulations.	1 12	Si	RE / Completed
D1A3 3	WP1: An additional B2 scenario using sea-surface conditions from a different AOGCM.	13 18	Si	RE / Completed
D1A4 2,5,12	WP1: Three additional control and A2 scenarios using two of the models used for D1A1 forming two and three member ensembles.	1 12	Si	RE / Completed
D1A5 3,4,5,8,12	WP1: A comprehensive analysis of the simulations and assessment of the reliability of the scenarios.	7 33	Da	PU / Completed
D1A6 5,8	WP1: A large set of boundary data for driving regional climate models.	1 12	Da	PU / Completed
D1B1 1,2,5,6,7,8,9,10,12	WP1: Eight RCM realisations of European climate for 2071-2100 consistent with the SRES A2 emissions scenario and matching control simulations.	7 24	Si	RE / Completed
D1B2 1,5	WP1: Two three-member ensemble European climate scenarios for 2071-2100 consistent with the SRES A2 emissions scenario and matching control simulations.	13 24	Si	RE / Completed
D1B3 5,9,10	WP1: Three RCM realisations of European climate for 2071-2100 consistent with the SRES B2 emissions scenario and matching control simulations.	7 24	Si	RE / Completed
D1B4 5,6,8,9	WP1: Three RCM realisations of European climate for 2071-2100 derived from one AGCM A2 scenario.	13 24	Si	RE / Completed
D1B5 1,2,4,8,12	WP1: A two-member ensemble European climate scenarios for 2071-2100 consistent with the SRES A2 emissions scenario using a different driving AGCM than for D1B2	13 24	Si	RE / Completed
D1B6 1,5,6,8,9	WP1: A four -member ensemble European climate scenario for 2071-2100 consistent with the SRES A2 emissions scenario using on a very high resolution of 20 km.	13 33	Re	PU / Completed
D1B7 1,4,5,6,7,8,10	WP1: A comprehensive analysis of the simulations and assessment of the reliability of the scenarios, including weather-type based interpretation of RCM results.	13 33	Re	PU / Completed

D2A1 3,5,8	WP2: An assessment of the uncertainty in high-resolution global climate scenarios resulting from the model formulation, the driving AOGCM and the emissions scenario.	16 33	Re	PU / Completed
D2A2 2,5,7,8,10, 12	WP2: An authoritative A2 emissions-driven high-resolution global climate scenario for 2071-2100.	7 18	Da	PU / Completed
D2A3 16,21	WP2: Upper and lower estimates of regional temperature change across Europe based on pattern scaling methods for the SRES emissions range and the IPCC range of climate sensitivities.	7 33	Re	PU / Completed
D2B1 1,2,4,5,6,7 ,8, 9,10,12	WP2: An assessment of the quality of simulations of current climate by European RCMs	13 33	Re	PU / Completed
D2B2 1,2,4,5,6,7 ,8, 9,10,12	WP2: A comprehensive assessment of the regional interpretation by eight European RCMs of an AGCM response to climate change driven by the SRES A2 emissions scenario.	13 36	Re	PU / Completed
D2B3 1,2,4,5,6,7 ,8, 9,12	WP2: An assessment of the uncertainty in European regional climate scenarios resulting from the model formulation, the driving AGCM, the emissions scenario and internal model variability.	13 36	Re	PU/ Completed
D2C1 1,2,5,8,12	WP2: An assessment of the reliability of three ensemble realisations of European regional climate for 2071-2100 consistent with the SRES A2 emissions scenario.	13 30	Re	PU / Completed
D2C2 5,8,9,10	WP2: An assessment of the reliability of three realisations of European regional climate for 2071-2100 consistent with the SRES B2 emissions scenario.	13 33	Re	PU / Completed
D3A1 9	WP3: Hydrological models of a major North European drainage basin interfaced with a range regional and high resolution global climate models.	1 12	Me	CO / Completed
D3A2 8,9	WP3: Hydrological models of a specific North European river basin interfaced with a range regional and high resolution global climate models.	1 12	Me	CO / Completed
D3A3 8,9	WP3: Validation of the hydrological components of control simulations in the climate models used for D2C1 & D2C2	13 24	Re	PU / Completed
D3A4 9	WP3: A comprehensive assessment of the potential impact of future climates on river flows, flooding and water availability in a North European drainage basin.	13 33	Re	PU / Completed
D3B1 6	WP3: A detailed hydrological model of a major Central European catchment interfaced with both standard and high resolution versions of a regional climate model.	1 33	Me	CO / Completed

D3B2 6,8	WP3: An assessment of the potential impact of future climates on river flows and flooding in a Central European catchment.	19 33	Re	PU / Completed
D3B3 6	WP3: An assessment of the impacts of degrading the resolution of the input data on the simulations of a Central European catchment hydrology in current and future climates.	19 33	Re	PU / Completed
D3B4 15	WP3: Impacts on snow amount and glacier mass balance in the Alpine domain.	25 33	Re	PU / Completed
D3B5 6,8,9,15	WP3: Validation of the hydrological components of the climate models used for D2C1 & D2C2	1 33	Re	PU / Completed
D4A1 11	WP4: Crop-climate model verified for response to adaptive options under current climate	1 16	Me	RE / Completed
D4A2 11	WP4: Report on response of crop and biomass production, water use and sustainability indicators for a wide range of climate change scenarios.	13 30	Re	PU / Completed
D4A3 11	WP4: Report on effectiveness of adaptive management options for a restricted range of climate change scenarios.	25 33	Re	PU / Completed
D4A4 11,20	WP4: Report on uncertainty in climate model estimation of soil water balance parameters in the Mediterranean region	25 33	Re	PU / Completed
D4B1 13	WP4: Soil-plant-atmosphere model for the North European region verified for adaptive responses under current climate	1 16	Me	RE / Completed
D4B2 13	WP4: Report on response of crop production and nitrogen cycling for a wide range of climate change scenario	13 30	Re	PU / Completed
D4B3 13	WP4: Report on effectiveness of adaptive management options and effect on mitigation strategies for a restricted range of climate change scenarios	25 33	Re	PU / Completed
D4C1 18	WP4: Simulations of present day forest landscapes and ecosystem processes from selected regions under current climates	1 12	Si	RE / Completed
D4C2 18	WP4: Validation of model output under current climate against forest inventory data at selected sites	7 18	Re	RE / Completed
D4C3 18	WP4: Simulations of ecosystem processes at selected EUROFLUX sites from 1994	13 18	Si	RE / Completed
D4C4 18	WP4: Modelled predictions of both vegetation and ecosystem processes for selected forest regions for the period 2071-2100 using the regional climate model outputs and their various SRES scenarios.	19 33	Re	PU / Completed
D4C5 16,21	WP4: GIS environment for mapping of uncertainties	1 12	Me	PU / Completed
D4C6 16,21	WP5: Analysis, interpretation and presentation of uncertainties in impacts in GIS	25 33	Re	PU / Completed

D5A1 17	WP4: Set of new statistical tools suitable for the proper robust estimation of risk due to weather and climate extremes	1 12	Me	PU / Completed
D5A2 17	WP5: Risk analysis of extremes in observed gridded data sets, AGCM, and RCM model output using the tools developed in D5A1	1 33	Re	PU / Completed
D5A3 15	WP5: Assessment of the frequency and intensity change of wind-storms and maps of damage potential of storms, particularly through wind-gusts	10 24	Re	PU / Completed
D5A4 15,20	WP5: Assessments of the general change in heat waves and cold spells as related to human health, agricultural risk and energy demand	16 33	Re	PU / Completed
D5A5 15	WP5: Sensitivity of hydro-power supply to changing temperature and precipitation patterns	19 33	Re	PU / This work has not been carried out
D5A6 20	WP5: Assessments of the change in frequency/severity of droughts and high-intensity rainfall events in the Mediterranean.	13 24	Re	PU / Completed
D5A7 16,21	WP5: Maps of present-day and future resource risk for Europe or for sub-regions of Europe, based on gridded or site-based information	13 33	Re	PU / Completed
D5A8 16,21	WP5: Analysis of uncertainties in estimated changes in resource risk	13 33	Re	PU / Completed
D5B1 7	WP5: An assessment of the quality of the surface winds and pressure in the RCM control simulations.	7 24	Re	PU / Completed
D5B2 7	WP5: An assessment of possible changes in North European storm surges in a future climate and of the uncertainty due to the driving model formulation.	19 33	Re	PU / Completed
D6A1 14,19	WP6: A Work report that provides a discussion of the climate and physical impact information that is needed for economic and policy analysis at the national and regional sector level	1 6	Re	RE / Completed
D6A2 5,14,19	WP6: A Work report that provides an overview of the methods and models available for linking climate, physical impact and economic sector models together to estimate the benefits and costs of mitigation and adaptation actions at the national and regional levels in climate sensitive sectors of the economy	7 24	Re	RE / Completed

D6A3 5,14,19	WP6: A Work report that presents methodological framework for using the data generated by this project in conjunction with economic assessments to address the asymmetry between the costs and benefits of climate change actions in the EU	7 30	Re	PU / Completed
D6A4 14,19	WP6: A workshop that presents the economic, social and policy making aspects of the regional climate change scenarios in order to establish a dialogue and link with other integrated assessment activities in Europe	7 33	O[2]	PU / Completed
D7A1 1,5	WP7: A directly accessible archive of boundary data for AGCM and RCM climate change experiments and of climate scenarios for climate impacts models.	1 24	Da	PU / Completed
D7A2 1,5	WP7: A PRUDENCE web-site incorporating interfaces to the boundary and scenario data, an assessment of the reliability of the scenarios and detailing other project findings.	1 33	Da,Eq	PU / Completed
D7A3 1,5,8,9,16,21	WP7: A presentation summarising the climate scenarios, their uncertainties, the example applications developed in PRUDENCE and other major findings.	25 36	Re	PU / Completed
D7A4 1,5,11,13,16,18,21	WP7: A presentation particularly summarising the impacts of climate change, their uncertainties, together with economic, social and policy making aspects of the regional climate change scenarios as obtained in PRUDENCE.	25 36	Re	PU / Completed

Green: partner or WP leader states progress as scheduled.
Yellow: partner or WP states task is pending or delayed.
Red: Critical information about status missing from partner.

[2] Public Workshop

Management Report and Scientific Highligts
1 November 2001 – 30 October 2004

Individual Partner Reports

(Section 2)

Using the template provided, partners were asked to supply a short (2-3 page) report on their activities in the preceding 6 months and their planned future activities. The information in these reports formed the basis for this Management Report

Partner no.: 1

Institution: Danish Meteorological Institute
Acronym: **DMI**
Responsibility: DMI is partner in WP 1, 2 and 7. DMI is the overall coordinator of PRUDENCE. DMI applies the HIRHAM model at 50km resolution to 3 sets of Hadley Centre A2 AGCM simulations and 1 experiment with the ECHAM4(5) AGCM. It carries out 1 high resolution AGCM experiment with ECHAM as well. One HIRHAM experiment will also be carried out with 20km resolution. DMI is the PI on WP7, management, data, reporting, and dissemination.

DMI is responsible for tasks: D7A1, D7A2, D7A3, D7A4
DMI participates in tasks: D1B1, D1B2, D1B5, D1B6, D1B7, D2B1, D2B2, D2B3, D2C1, D7A1, D7A2, D7A3, D7A4.

RESPONSIBLE FOR TASK: D7A1
WORK: Data archives with AGCM and RCM simulations for partners
RESULTS: The data archive has been updated with the full set of available PRUDENCE model output data as planned. Some further experiments have been added. The web based system for accessing data has been in operation without interruptions for the entire period and has been used frequently. The data archive has been public since August 2004.
ALLOCATED PERSON MONTH THIS PERIOD:
PRESENTATIONS:
DELIVERABLES: The system is functioning and all required data available

RESPONSIBLE FOR TASK: D7A2
WORK: PRUDENCE web-site and information
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: The PRUDENCE web site is accessed frequently both by participants and others. A decision of presenting interesting scientific results achieved within PRUDENCE on the front page has been very successful and serves to inform about project achievements, as does an on-line archive of PRUDENCE publications.
PRESENTATIONS:
DELIVERABLES: A continuously updated web site at http://prudence.dmi.dk/

RESPONSIBLE FOR TASK: D7A3
WORK: Presentation of climate scenarios
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: A summary of PRUDENCE was done by the coordinator at the COP10 meeting in Buenos Aires, Argentina, in December 2004. This presentation is available from the project web site.
PRESENTATIONS:
DELIVERABLES: One Power-Point presentation available from the web site.

RESPONSIBLE FOR TASK: D7A4
WORK: Final presentation of PRUDENCE
ALLOCATED PERSON MONTH THIS PERIOD
RESULTS: A presentation of results relating to changes in extreme weather events has been put together and shown at an international conference in Beijing, China. This presentation is available from the project web site.
PRESENTATIONS:
DELIVERABLES: Power-Point presentations available from the web site. This report.

CONTRIBUTOR TO TASK: D1B1
WORK: SRES A2 and control RCM simulations at 50km
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: Three sets of 30 year simulations with the HIRHAM model using boundary conditions from a coupled AOGCM representing present conditions (1961-1990) and two possible futures for the A2 and B2 scenario (2071-2100) has been made available for PRUDENCE partners. Three realisations of the first Hadley Centre control and A2 scenario have been conducted and are available for partners via the web-site. One set of boundary conditions has been applied to two further HIRHAM experiments in 25 km and 12 km resolution, respectively.
PRESENTATIONS:
DELIVERABLES: Five HIRHAM realisations of Hadley Centre control simulations and three realisations of Hadley Centre A2 scenario simulations. Extra set of present day and A2 plus B2 HIRHAM simulations with boundary data from ECHAM4/OPYC has been provided. Most experiments have been conducted at 50 km, one set at 25 km horizontal resolution, and one set at 12 km.

CONTRIBUTOR TO TASK: D1B2
WORK: 3 ensemble members of A2 simulations at 50km
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: See D1B1
PRESENTATIONS:
DELIVERABLES: Four HIRHAM realisations of a Hadley control simulation and three realisations of one Hadley A2 scenario simulations.

CONTRIBUTOR TO TASK: D1B5
WORK: HIRHAM experiment with ECHAM boundaries
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: Due to an unexpected delay in availability of the ECHAM 5 computer model, only a control simulation has been finalized within the project period. The scenario experiment data will be added to the PRUDENCE data archive in early 2005. Instead, earlier simulations with ECHAM4/OPYC as boundary conditions have been made available on the PRUDENCE data center.
PRESENTATIONS:
DELIVERABLES: One set of HIRHAM simulations with ECHAM4/OPYC as boundaries and one control simulation with ECHAM5 with observed sea surface temperatures as boundaries. The final scenario simulation with ECHAM5 and the same sea temperatures as the HadAM3H scenario simulations will be available in early 2005.

CONTRIBUTOR TO TASK: D1B6
WORK: 20km resolution HIRHAM simulations
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: 30 years of Hadley control and scenario A2 have been completed for a domain covering entire Europe at 25km. A corresponding simulation in 12 km resolution has been finished in the final project year.
PRESENTATIONS:
DELIVERABLES: One set of two 30-year HIRHAM simulations in 25 km resolution as well as one set of two 30-year simulations in 12 km resolution.

CONTRIBUTOR TO TASK: D1B7
WORK: Analysis and assessment of reliability of simulations
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: Analysis of realisations with HIRHAM using Hadley control run at boundaries reveals no substantial errors. 30 year climatology appears to be in better agreement with observations than previous 15 year experiment

using ECMWF reanalysis boundary conditions. In addition sensitivity experiments have been carried out to assess the role of the formulation in the handling of liquid water in the Hadley Centre boundary data.
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B1
WORK: Assessment of current climate simulations. This subject has been comprehensively studied and presented in a special issue of the journal *Climatic Change* with submission deadline December 1 2004.
ALLOCATED PERSON MONTH THIS PERIOD
RESULTS:
PRESENTATIONS:
DELIVERABLES: Reviewed papers to appear in a special issue of *Climatic Change*

CONTRIBUTOR TO TASK: D2B2
WORK: Assessment of climate change simulations
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS: A manuscript detailing this subject is part of the special issue of *Climatic Change* mentioned in D2B1
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B3
WORK: Uncertainty assessment across all models. Also this issue has been treated comprehensively in the above-mentioned special issue
ALLOCATED PERSON MONTH THIS PERIOD
RESULTS:
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2C1
WORK: Reliability of scenario simulations from SRES A2
ALLOCATED PERSON MONTH THIS PERIOD
RESULTS:
PRESENTATIONS:
DELIVERABLES:

GENERAL COMMENTS:
Data distribution is now well organised and easy access to model output is assured from the DMI data server.

PUBLICATIONS:

Christensen, O.B. and J.H. Christensen, 2004: Intensification of extreme European summer precipitation in a warmer climate, *Global and Planetary Change*, **44**, 107-117

Hagemann, S., B. Machenhauer, R. Jones, O. B. Christensen, M. Déqué, D. Jacob, and P. L. Vidale, 2004: Evaluation of water and energy bydgets in regional climate models applied over Europe, *Climate Dynamics*, **23**, 547-567

EMPLOYEES:
Name: Jens Hesselbjerg Christensen, Ole Bøssing Christensen, Willy May, Shuting Yang

PUBLICATION PLAN:

Several publications about the PRUDENCE work at DMI will appear, mostly in the special issue of *Climatic Change* which is in review at the moment.

PLANS FOR THE NEXT PHASE:
N/A

Partner no.: 2,12

Institution: CINECA, Abdus Salam International Centre for Theoretical Physics
Acronym: **CINECA, ICTP**
Responsibility:

CONTRIBUTOR TO TASK:
TASK: Completion of nested model simulations with the regional model RegCM driven by the HadAMH global model for the A2 scenario.

As part of this task three thirty-year simulations were completed with the ICTP regional climate model RegCM driven at the lateral boundaries by large scale fields from corresponding HadAM3H time slice simulations. The first experiment was for the present day period of 1961-1990 (reference simulation) while the other two experiments were for the future period of 2071-2100 under the A2 and B2 IPCC emission scenarios. The model domain covered the European and Mediterranean region at a 50 km grid point spacing. The required fields from these simulations were provided to the PRUDENCE community for intercomparison with the other PRUDENCE regional model simulations.

A detailed validation analysis of the reference simulation was first completed to identify systematic model biases. The focus of the analysis was on atmospheric circulations, temperature and precipitation and for the simulated mean, interannual variability and trends.
Analysis of daily precipitation intensities, length of drought periods and extreme events was also carried out. Results from the reference simulation were compared to various observation dataset, including that produced by the Climatic Research Unit (CRU) of the U. of East Anglia and that of Willmott and Matssura of the U. of Delaware.

The model biases in the present day simulation were generally small compared to previous analogous experiments with the RegCM, mostly less than 2 degrees for temperature and less than 25-30% for precipitation.
The model showed a tendency to overestimate precipitation over Europe, particularly in the spring season.
The regional topographical forcing on temperature and precipitation was captured well. The reference run also reproduced the basic seasonal large scale circulations over the European region.

Interannual variability was mostly overestimated compared to observations, particularly during the warm season. The model reproduced the winter drying trend over the Mediterranean and increase in winter precipitation over northern Europe observed in the period 1961-1990.
Because the NAO is a prominent mode of variability affecting the winter climate of Europe, a detailed analysis of the NAO signal in the reference simulation was performed. This showed that a number of features of the observed regional signals of NAO-induced variability over Europe were well reproduced, particularly in areas were this signal was modulated by the topographical forcing.

The analysis of the reference simulation is described in the following papers:

Pelino, V., A. Matera, T. Colombo and F. Giorgi, 2004: Validation of precipitation events in a regional climate model simulation using methods from complexity theory. Submitted to Theoretical and Applied Climatology.

Bojariu, R., and F. Giorgi, 2004: The North Atlantic Oscillation signal in a regional climate simulation for the European region. Tellus A, in press.

Giorgi, F., X. Bi and J.S. Pal, 2004: Mean, interannual variability and trends in a regional climate change experiment over Europe. Part I: Present day climate (1961-1990). Climate Dynamics, 22, 733-756.

Concerning the scenario experiments, a warming in the range of 2.5 to 5.5 degrees was simulated over the entire European region for the two scenario. The warming was 1-2 degrees greater in the A2 than the B2 experiment, and it was maximum over the Mediterranean and western European regions in summer and over the central and eastern European regions in winter. In winter, a substantial increase in precipitation was found over central and northern of Europe in response to increased storm activity there. In summer, precipitation decreases were found over western and southern Europe in response to increased anticyclonic circulation over the northeastern Atlantic. A high level of consistency between the change signals in the A2 and B2 scenarios was found.

The intensity of precipitation events mostly increased, while their frequency mostly decreased in all seasons. The maximum length of dry days, an indication of drought, increased considerably throughout western Europe in summer. Despite this increase in drought, also the maximum intensity of precipitation for 1-day, 3-day, and 5-day precipitation mostly showed increases. Interannual variability generally increased in the summer season, while it showed only small changes in the winter season. A comparison of the summer precipitation and temperature change patterns in the A2 and B2 scenarios with trends observed in recent decades showed a high level of consistency. This adds supporting material to the suggestion that some of the current observed climate trends over Europe might be due to the anthropogenic forcings.

A more detailed analysis of the climate change scenarios was conducted over some sub-regions of the domain as part of collaborative projects. These sub-regions included Italy, the Romania and Carpathians region, and the Alps Maritime in southern France.

The analysis of the scenario simulations is reported in the following papers:

Giorgi, F., X. Bi and J. Pal, 2004: Means, trends and interannual variability in a regional climate change experiment over Europe. Part II: Future climate scenarios. Climate Dynamics, in press.

Boroneant, C., G. Plaut, F. Giorgi and X. Bi, 2004: Extreme precipitation over the Maritime Alps and associated weather regimes simulated by a regional climate model: Present day and future climate scenarios. Submitted to Theoretical and Applied Climatology.

Busuioc, A., F. Giorgi, X. Bi, M. Ionita, 2004: Comparison of regional climate model and statistical downscaling simulations of different winter precipitation change scenarios over Romania. Submitted to Theoretical and Applied Climatology.

Déqué, M., R.G. Jones, M. Wild, F. Giorgi, J.H. Christensen, D.C. Hassell, P.L. Vidale, B. Rockel, D. Jacob, E. Kjellstrom, M. de Castro, F. Kucharski and B. van den Hurk, 2004: Global high resolution versus

Limited Area Model climate change scenarios over Europe: Results from the PRUDENCE project. Submitted to Climate Dynamics.

Pal, J.S., F. Giorgi and X. Bi, 2004: Consistency of recent European summer precipitation trends and extremes with future regional climate projections. Geophysical Research Letters, 31, L13202, doi:10.1029/2004GL019836.

Busuioc, A., M. Ionita, F. Giorgi and X. Bi, 2004: Analysis of dynamical and statistical downscaling approaches for generating winter precipitation change scenarios over Romania. Romanian Journal of Meteorology, 6, 1-17.

Giorgi, F., X. Bi and J. Pal, 2003: Variability and extremes in regional climate simulations for the European region. Proceedings of the World Climate Change Conference, Moscow, Russia, 29 September - 3 October, 12pp.

TASK: Completion of time slice simulations with the global atmospheric model FV GCM-CCM3 for the A2 scenario.

The FVGCM-CCM3, a finite volume element global model, was installed on the CINECA computer facilities and four 30-year time slice simulations were completed with a model horizontal resolution of 1 degree latitude and 1.25 degrees longitude: two realizations for the reference period (1961-1990) and two realizations for the A2 scenario (2071-2100). Forcing SST and GHG fields were the same as used in the HadAM3H simulations provided to the PRUDENCE community.

The model generally showed a good performance in reproducing the major features of the general circulation of the atmosphere, such as major jet streams and storm tracks and the seasonal migration of the Inter Tropical Convergence Zone. The seasonal and broad spatial patterns of the temperature and precipitation climatology were also reproduced. Overall, the FVGCM-CCM3 climatology compares well with that of other global models. Also the general broad patterns of warming and precipitation change were in line with other global model simulations, with maximum warming and a predominant increase in precipitation over high latitude regions during the cold season.

A more detailed analysis of both the reference and scenario simulations was conducted for the European region as well as for some tropical regions, namely South Asia, South America and sub-Saharan Africa. Over Europe the FVGCM-CCM3 time slice experiments showed temperature and precipitation change patterns consistent with those of other global models runs participating in the PRUDENCE project. In particualr the FVGCM-CCM3 also simulated a strong warming over the region in all seasons (up to several degrees), a predominant increases in precipitation over central to northern Europe in winter and a substantial drying over most of western Europe and the Mediterranean in summer. The intensity of precipitation events and extremes over Europe showed predominant increases. The consistency of the FVGCM-simulated European climate change signal with that of other models adds robustness to the projected changes.

Also over the tropical regions analysed the model generally reproduced the observed climate patterns under present day conditions. The greatest discrepancy with observations occurred for south Asia monsoon precipitation. Under A2 forcing conditions a warming in the range of 2-5 degrees was found in all the regions considered. The main features in the regional precipitation changes can be summarized as follows: 1) An intensification of monsoon precipitation over South Asia; 2) a decrease of precipitation over the Amazon Basin; 3) a northward shift of the monsoon precipitation band over the Sahel and equatorial Africa; and 4) a drying over southern equatorial Africa. In most cases these changes were statistically significant at the 95% confidence level. A robust result of the scenario simulations was a consistent predominant increase of interannual variability over the regions analyzed.

Finally, the differences between realizations were found to be much smaller than the projected climatic changes, so that the changes themselves are attributed to the external forcings rather than the internal model variability. The required data from the FVGCM-CM3 simulations were provided to the PRUDENCE modeling community for comparisons with other global model simulations.

Results and analysis of the FVGCM-CCM3 simulations are described in the following papers:

Coppola, E. and F. Giorgi, 2004: Climate change in tropical regions from high resolution time slice AGCM experiments. Submitted to the Quarterly Journal of the Royal Meteorological Society.

Déqué, M., R.G. Jones, M. Wild, F. Giorgi, J.H. Christensen, D.C. Hassell, P.L. Vidale, B. Rockel, D. Jacob, E. Kjellstrom, M. de Castro, F. Kucharski and B. van den Hurk, 2004: Global high resolution versus Limited Area Model climate change scenarios over Europe: Results from the PRUDENCE project. Submitted to Climate Dynamics.

Partner no.: 3

Institution: Météo-France Centre National de Recherches Météorologiques
Acronym: **CNRM**
Responsibility: D1A3

RESPONSIBLE FOR TASK:D1A3
WORK: an additional SRES B2 simulations using SST from ARPEGE/OPA and control simulations
ALLOCATED PERSON MONTH THIS PERIOD:0
RESULTS: simulation done
PRESENTATIONS: none
DELIVERABLES: selected fields sent to the database

CONTRIBUTOR TO TASK: D1A1
WORK: an SRES B2 simulation
ALLOCATED PERSON MONTH THIS PERIOD:0
RESULTS: simulation done
PRESENTATIONS: none
DELIVERABLES: selected fields sent to the database

CONTRIBUTOR TO TASK: D1A2
WORK: two SRES A2 simulation
ALLOCATED PERSON MONTH THIS PERIOD:4
RESULTS: simulation done and analyzed
PRESENTATIONS: Marseilles 25 May (M. Déqué)
DELIVERABLES: selected fields sent to the database

CONTRIBUTOR TO TASK: D2A1
WORK: assessment of uncertainty in high resolution scenarios
ALLOCATED PERSON MONTH THIS PERIOD: 3
RESULTS: analysis done
PRESENTATIONS:
Toledo 8 Septembre (M. Déqué)
Toledo 9 Septembre (S. Somot)
DELIVERABLES: Technical report: Uncertainties in PRUDENCE simulations: global high resolution GCM

GENERAL COMMENTS: very stimulating results found
PUBLICATIONS:

L. Terray, M.E. Demory, M. Déqué , G. de Coetlogon and E.Maisonnave, 2004: Simulation of late twenty-first century changes in wintertime atmospheric circulation over Europe due to anthropogenic causes. Journal of Climate (in press)

M. Déqué, R. G. Jones, M. Wild, F. Giorgi, J. H. Christensen, D. C. Hassell, P.L. Vidale, B. Rockel, D. Jacob, Erik Kjellström, M. de Castro, F. Kucharski and B. van den Hurk, 2004: Global high resolution versus Limited Area Model climate change scenarios over Europe: results from the PRUDENCE project. Submitted to Climate Dynamics

EMPLOYEES: 5

Scientific summary

Introduction

The primary contribution to PRUDENCE was the eleven 30-year simulations with ARPEGE. This model has a variable resolution, so that it can be seen as a regional model over Europe with horizontal resolution 50 km interactively nested in a global model. This provides a 3rd type of boundary forcing in the PRUDENCE database, besides ECHAM4 and HadAM3. Seasonal and monthly-mean data have been incorporated in the project database. Five out of the eleven simulations have been archived on a daily basis.

These simulations have been used in two kinds of applications. The first kind consists of using ARPEGE data for specific studies. The NAO index has been calculated from all simulations and it appears that in the scenario runs the frequency of positive phases (i.e. more zonal flow across Atlantic) is twice as large as in the reference runs. This result is very stable whatever the A2/B2, sea surface temperature or ensemble member used. The frequency of summer heat waves over France has also been calculated from the runs. With A2 scenario, this frequency is multiplied by about 10. The fluxes over the Mediterranean sea of the A2 scenario (connected to the reference simulation by a 2001-2070 run) have been used to drive an ocean model. The upper air velocity fields have been used to track cyclones over the Mediterranean basin. The results of both studies are described hereafter.

The second kind of applications consists of comparing ARPEGE with other GCMs or RCMs used in the project. A first study compares the A2 scenarios with GCMs against the A2 HadAM3 driven scenarios with RCMs. A second study calculates the fraction of the total variance explained by the four sources of uncertainty. The results of both studies are described hereafter.

Mediterranean air-sea fluxes

The ARPEGE-Climate model provides atmospheric fluxes for the PRUDENCE project at a resolution of 50 kilometres over the Mediterranean Sea. We have thus chosen to use these fluxes as surface conditions for our regional oceanic model of the Mediterranean Sea (OPAMED), which has a resolution that ranges from 9 to 12 km. We consider a study of the evolution of the Mediterranean Sea under a climate change scenario. Some observations have pointed out that the increases in salinity and temperature of the Western basin at depths greater than 800 m over the 1959-1997 period may be related to the greenhouse Effect. The Mediterranean basin is one of the few places in the world ocean where surface water sinks due to buoyancy loss and contributes to the global thermohaline circulation by the Gibraltar Strait. Knowing that a temperature and a salinity increase lead to opposite evolutions of the density field, we have tried to derive from this first Mediterranean scenario the evolution of these parameters and their influence on the thermohaline circulation.

Up until 1999, sea surface temperature (SST) together with greenhouse gas and aerosol concentration are imposed from observed values. Then for the 21st Century the IPCC-A2 scenario is prescribed. SST is calculated by adding to observed monthly values an anomaly evaluated through a former ARPEGE-Climate simulation coupled to a global ocean and sea-ice model (OPA/GELATO).
OPAMED needs the daily fluxes of momentum, heat and water as surface forcing. The SST relaxation provides the adaptation between the heat flux and the model SST by computing a

correction of this flux. There is an “Atlantic box” to simulate the currents of the Atlantic Ocean using a 3D relaxation in temperature and salinity. River runoffs come from observations until 1999, completed by a Black Sea “river runoff”, for the in- and out-flows at the Dardanelles Strait can be considered as a fresh water inflow. To compute the 21st Century scenario, apart from the daily fluxes and SST provided during the PRUDENCE Project, the salinity and temperature of the Atlantic box and the river runoff are modified to include their evolution as computed by the global scenario already mentioned. The TRIP routine scheme is also used, as for the rivers. The absence of a surface salinity relaxation is worth being pointed out because it is the first time we have done this in such an experiment. To be sure that no drift appears, a 100 year control oceanic simulation has been performed.
The increase in SST is spatially homogeneous and amounts to 2.5 K at the end of the 21st Century. It is mainly driven by the surface temperature relaxation. The increase in SSS is more regionally-dependent, and is driven by the evolution of river runoff, going from 0.23 psu to 0.70 psu, with a maximum value in the Aegean Sea due to the strong decrease in the Black Sea freshwater inflow. In the Western basin and the Levantine basin, the decrease in winter convection shows that the effect of the temperature is stronger than that of salinity. On the other hand, the salinity effect dominates in the Adriatic and Aegean Seas, where the winter convection remains unchanged. As a result the thermohaline circulation, driven by density differences, is modified. The trends in temperature and salinity at depths greater than 800 m in the Western basin over the 100 years of the scenario are respectively equal to $7.9\ 10^{-3}$ K/year and $1.4\ 10^{-3}$ psu/year, to be compared to $3.47\ 10^{-3}$ K/year and $1.07\ 10^{-3}$ psu/year in the observations

Mediterranean cyclones

Mediterranean cyclones are known to be sub-synoptic systems in comparison with Atlantic cyclones. Moreover Mediterranean cyclogenesis and Mediterranean cyclone tracks are mainly influenced by a local complex orography, land-sea contrasts and important air-sea fluxes. The rainfall decrease observed in the Mediterranean region during the last decades seems to be caused by a weakening of Mediterranean cyclones. These different issues lead to use high-resolution simulations performed with RCM for studying this particular cyclogenesis and its possible change during the 21st century.

In the framework of the PRUDENCE project, a study of Mediterranean cyclogenesis and cyclone tracks has been performed with present-day and future climate (IPCC-A2) simulations done with ARPEGE-Climate. The study of the Mediterranean cyclogenesis has been done by an objective tracking of individual cyclones. The algorithm was developed at CNRM (Ayrault and Joly, 2000). It detects and combines relative vorticity maxima at 850 hPa (1 field every 6h). A filtering is applied to only keep tracks completely included into the Mediterranean region, with a travelling distance longer than 600 km and a lifetime longer than 24h.

As a validating step, we compare the 1960-1989 period of the ARPEGE-Climate simulation with the same period of ERA40 reanalysis. We obtain a very good agreement between the two datasets. The number of tracks is very similar with a difference less than 10%. The tracks number interannual variability is also well represented by ARPEGE-Climate (interannual standard deviations are statistically the same). Moreover the main characteristics of the cyclone tracks (life-time, speed, travelling distance) are identical. On average, we obtain 840 tracks/year in the ARPEGE-Climate simulation with a mean lifetime of 2.5 days and a travelling distance of 1650 km. In addition, ARPEGE-Climate is able to simulate the position and the seasonal cycle of the Mediterranean cyclogenesis areas as mentioned in the literature (Alpert et al., 1990; Trigo et al., 1999) or obtained with ERA40: the Gulf of Genoa is the main area but the Aegean Sea, the Turkey Mountains, the Atlas Mountains, Spain and the Red Sea are also underlined by our study.

Nevertheless two main differences have to be pointed out: ARPEGE-Climate shows significantly less tracks than ERA40 in winter (-20% for February) and the maximum vorticity reached during a typical track is stronger in ARPEGE-Climate than in ERA40 (+50% on average). In winter, ARPEGE-Climate produces more zonal regimes over Europe than expected from ERA40. This can explain the first difference because northern zonal regimes are not in favour of Mediterranean cyclogenesis. The second difference could be due to a higher resolution in ARPEGE-Climate than in ERA40. However, the role of data assimilation in ERA40 and differences in physical parameterizations between ARPEGE and IFS could also explain this feature.

In the scenario, we obtain a small and significant decrease of the number of Mediterranean cyclogenesis (-8% for a maximum vorticity greater than 1.0 10^{-4} s^{-1} and -16% for a maximum vorticity greater than 1.5 10^{-4} s^{-1}) except for July and August for which an increase is observed. The annual decrease is more emphasized in winter. Besides, this result has been already obtained in two other studies, one with a 2xCO2 experiment with a different model and a tracking method based on MSLP (Lionello et al., 2002) and the other with an IPCC-B2 scenario with the same model and a different tracking method (Vérant, 2004). In our case, the decrease is specifically observed for the Gulf of Genoa and the Aegean/Turkey area. No significant change is noted for the track characteristics, the interannual variability and the cyclogenesis areas geography. However, important changes are obtained for the simulated precipitation associated with the cyclones. We have studied these relationships by the mean of composites. The chosen composites represent the radial structure of a typical cyclone for a given cyclogenesis area and a given season. For each track, the composite is computed at the time of the maximum vorticity. In summer, the amount of precipitation associated with a typical cyclone decreases up to -30% going from 18.5 to 13.0 mm/d (as in the following, this values are computed as an average in a 50 km-radius circle around the cyclone centre for cyclones born in the Gulf of Genoa and with a maximum vorticity greater than 1.5 10^{-4} s^{-1}). This result is similar for cyclones born in the Aegean Sea/Turkey Mountains area. We think that this large decrease explains at least partly the Mediterranean drying observed in our scenario for the Mediterranean region in summer.

Contrary to the summer situation, the cyclones associated precipitation increases in autumn (+17%, 21 mm/d in the scenario) and spring (+23%, 13 mm/d in the scenario) for the same Northern Mediterranean cyclogenesis areas. In the present-day climate, autumn and spring are already the seasons during which intense rainy events occur around the Mediterranean basin often associated with cyclones. Consequently this kind of events might increase at the end of the 21st century following our simulation. Finally, no change is observed for winter precipitation composites with a typical value of 11.0 mm/d in the scenario as in the present-day climate.

GCM-RCM comparison

PRUDENCE has involved 9 limited area models and 4 global models. An important question is whether the GCMs and the RCMs produce a similar response to A2 radiative forcing. An additional question is whether the GCMs exhibit more spread in the responses than RCMs because they are not driven at European boundaries. A statistical tool particularly adapted to these question is Multidimensional Scaling. The principle is to project the individual responses onto a plane, so that the distances between two points of the plane (representing two model runs) are as close as possible to the root mean square differences between the two maps of model responses. Such projections have been applied to temperature and precipitation, DJF and JJA. Four diagrams involving the 9+4 models have been plotted. It appears that all model scenarios are located in a region of the plane, rather far from the origin, which represents present climate. The « cloud » of the 9 RCMs is slightly shifted from that of the 4 GCMs, but the distance is smaller than the spread of the clouds. In winter, the GCMs have a slightly larger spread than the RCMs. This is explained by the dominating role of large-scale advection, which is mostly imposed in the RCMs. In JJA, the opposite effect is seen for precipitation, as GCMs have a coaser resolution than RCMs (except ARPEGE), the latter exhibiting original regional features due to a finer-scale orography.

The projection method can be used to compare the individual biases of the models with the individual responses. For temperature, the diagrams show that the projection of the individual reference runs are located in a region close to the observed climatology, whereas the individual scenarios gather in another region of the plane. For precipitation, the diagrams show a mixing of the cloud of reference runs with the cloud of scenario runs. However, the segments connecting a reference run with the scenario run with the same model are rather similar in length and orientation. This geometrical interpretation indicates that the models differ in their biases (i.e. distances between reference and observed climatology), which is a good news for the project: the models are really different. But they differ less in their responses, which is another good news: the A2 response over Europe is little model-dependent, although the models behave differently.

Variance partition and confidence intervals

In PRUDENCE, 10 RCMs are available, 3 forcing GCMs (including the special case of ARPEGE which is both GCM and RCM), 2 scenarios (A2 and B2) and 3 samples for some experiments. It is thus in principle possible to evaluate the variance due to the four sources of uncertainty: RCM, GCM, scenario and sampling. However, out of the 180 (i.e. 10x3x2x3) elements of the matrix, only 28 simulations have been actually performed. Calculating and comparing variances with the available experiments would not allow a fair comparison, because the experiments are not distributed evenly in the matrix, the A2 with HadAM3 forcing scenario being favored. The missing cases in the matrix have therefore been estimated by a simple statistical technique, so that 180 model responses are available for temperature and precipitation, DJF and JJA, and 8 sub-area of the European domain. The uncertainty introduced by the choice of the driving GCM is dominating, except for summer precipitation, where the choice of the RCM is the major source. There are also geographical differences. In the Scandinavian area, the RCM dominates, whereas in central Europe the GCM dominates whatever the season or the field. The uncertainty due to sampling is marginal, except for winter precipitation over Iberian peninsula. The uncertainty about the choice of the scenario (A2 versus B2) is maximum for summer temperature in the southern half of Europe.

If we restrict to A2 scenario and one member per experiment to reduce the errors introduced by data reconstruction, we have 30 samples (out of only 12 are independent) of the climate response for each sub-area and field. The mean response over the GCMs and RCMs can be considered. Moreover a Gaussian hypothesis for this mean is reasonable. A 99% confidence interval can be calculated. For precipitation, the minimum and maximum responses are defined according to the sign of the mean response (the minimum being the upper boundary of the interval when the mean response is negative). It appears that the confidence interval never includes 0, which shows that the response is always significant. For temperature, the minimum warming is 1.4 K in winter for the British Isles, and 1.7 K in summer for Scandinavia. If we exclude these two areas, the upper boundary for the warming reaches 6 K in summer. For precipitation, one of the boundary is close to zero in a few cases: Iberian peninsula and Alps precipitation increase in winter, Scandinavia and East Europe precipitation decrease in summer. The results show however that the use of several GCMs and RCMs increase the confidence in the mean response.

References

Alpert, P., Neeman, B.U., Shay-el, Y., 1990: Climatological analysis of Mediterranean cyclones using ECMWF data, Tellus, vol. 42A, 65-77

Ayrault, F., Joly, A., 2000: L'origine des dépressions météorologiques sur l'Atlantique : nouvelle perspective climatologique, Comptes Rendus de l'Académie des Sciences, Paris, Earth and Planetary Sciences, vol. 330, 167-178

Lionello, P., Dalan, F., Elvini, E., 2002: Cyclones in the Mediterranean region: the present and the doubled CO2 climate scenarios, Climate Research, vol. 22, 147-159

Trigo I.F., Bigg, G.R., Davies, T.D., 1999: Objective Climatology of Cyclones in the Mediterranean Region, Bulletin of the American Meteorological Society, vol. 12, 1685-1696

Vérant, S., 2004 : Etude des dépressions sur l'Europe de l'Ouest : climat actuel et changement climatique, Thèse, Paris, 207 pp.

Partner no.: 4

Institution: Deutsches Zentrum für Luft- und Raumfahrt
Acronym: **DLR**
Responsibility: statistical-dynamical downscaling and extrapolation

RESPONSIBLE FOR TASK:
WORK:
RESULTS:
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D1A5
WORK: analysis of scenarios
RESULTS: available
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D1B5
WORK: analysis of ensemble
RESULTS: n/a
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D1B7
WORK: analysis of GCM results
RESULTS: available
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B1
WORK: Quality of RCM
RESULTS: n/a
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B2
WORK: Assessment of regional climate change
RESULTS: available

PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B3
WORK: Assessment of uncertainties
RESULTS: n/a
PRESENTATIONS:

PRESENTATIONS:
DELIVERABLES:

GENERAL COMMENTS:

Preliminary results of Tasks D1A5, D1B7, D2B2 were presented at the final project conference. Because of an error in the data description (exchange of northern and southern hemisphere data) the evaluation had to be repeated.

The results are now available. These tasks will be completed by the end of the project. The accomplishment of our contributions to tasks D2B1 and D2B3 was not possible because of the delayed delivery of the datasets.

PUBLICATIONS: none

EMPLOYEES:
Name: Dr. Dietrich Heimann
Dr. Maria José Costa Zemsch

PUBLICATION PLAN:

The results of the project will be published in a peer-reviewed scientific journal until September 2005.

PLANS FOR THE NEXT PHASE: None

Evaluation of RCM control/scenario runs based on circulation patterns

Dietrich Heimann and Maria José Costa Zemsch

DLR - Institute of Atmospheric Physics, Oberpfaffenhofen, Germany

Summary
The objective of DLR contribution was to use developed statistical tools (first tested in a previous project) to evaluate GCM and RCM output in combination. For this purpose, a set of GCM/RCM runs from Hadley Centre was selected. First, it was established the frequency of weather-types (circulation patters) in GCM runs. Second, the change of circulation patterns from present climate to scenario was evaluated. Finally, it was quantified to what extent the change in the circulation patterns contribute to local/regional changes of climate parameters as simulated by RCMs.

1. INTRODUCTION
The basic idea originates in the assumption that *local climate change* might be composed of a *global chang*e, for example due to globally changed greenhouse gas concentration, *regional changes* due to 1) locally changed characteristics like SST, vegetation, soil moisture and 2) *regional changes* due to changed circulation pattern frequency, which can enhance and/or minimize particular phenomena like advection or lee effects. The present work was focusing on this later aspect, and tries to explain (partly) regional climate changes due to changes in the circulation pattern frequency distribution. A total of 60 years GCM simulation (1960-1990 plus 2070-2100, that means, present climate and scenario) was used to find changing frequency of occurrence of large-scale circulation patterns. The associated nested RCM simulation results were used to find local/regional anomalies associated with circulation patterns.

2. METHODOLOGY
2.1 General
The large-scale weather classification here used is described in Fuentes (1998), Fuentes & Heimann (2000) or Busch & Heimann (2001).
The two GCM simulation periods, present climate (1960-1990) and scenario (2070-2100), are connected to 60-year time series. This time series is now divided into a set of successive, non-overlapping multi-day episodes depending on their 500 hPa geopotential height (GPH)

anomaly pattern. The episodes are then classified into weather-type classes, according to the spatial patterns and temporal development of the 500 hPa GPH anomaly pattern. Once each episode is appointed to a class, the frequency of occurrence of each class is calculated in the present climate period and in the scenario period. The changes of the frequency of occurrence of each class between present climate and scenario are then determined.
Finally, it was evaluated how much of the change observed in the RCM simulations can be explained by changes in the frequency of occurrence of the circulation classes.

2.2 GCM/RCM data sets

The data used were provided by the UK Met Office Hadley Centre. They are results of simulations with the GCM model HadAM3P and the corresponding RCM nested simulations using HadRM3P.

2.3 Setup

As climate periods, the two above cited 30-year periods were used. The data were re-organized in seasons.
For the GCM scale, the so called PRUDENCE domain was selected, corresponding to longitudes of 60ºW-90ºE and latitudes of 10ºN-90ºN (81 × 65 grid points, with resolution 1.875º × 1.25º). To find the circulation patterns, the 500hPa GPH was used as large-scale predictor (later referred to as GCM-class). This weather type classification was also made using the RCM 500 hPa GPH anomaly pattern (referred to as RCM-class), in order to evaluate how the RCM resulting weather classes distribution of the nested RCM runs compares with that of the driving GCM simulations.
The time series used is made out of the two climate periods together, including a total of 60 years (previously separated into seasons: DJF (winter), MAM (spring), JJA (summer) and SON (autumn)). The continuous time series was then disaggregated into episodes of 2-5 days length. A cluster analysis (*K-means*) scheme was used to aggregate the episodes into 22 weather classes (classes 1 and 2 for the 2-day episodes, classes 3 to 7 for the 3-day episodes, classes 8 to 17 for the 4-day episodes and classes 18 to 22 for the 5-day episodes). The choice of the length of episodes and the number of the classes, as well of further details of the procedure can be found in Fuentes & Heimann (2000).
At RCM scale (resolution 0.44º × 0.44º) the evaluation was made using daily mean of surface parameters like 2m temperature (daily mean, max and min), total precipitation and wind speed (daily mean and max). For each class, it was investigated the associated RCM data and how the statistics of the selected parameters changes between control and scenario.

3. RESULTS

3.1 Frequency of occurrence of circulation classes in control and scenario periods

Once all the days of the whole time period (60 years) were distributed between the 22 circulation classes, the frequency of occurrence of each class in each period (control and scenario) was evaluated. As an example, it can be seen in Fig.1, the distribution of the frequency of occurrence of each class within a period, and how the frequency changes between control and scenario.

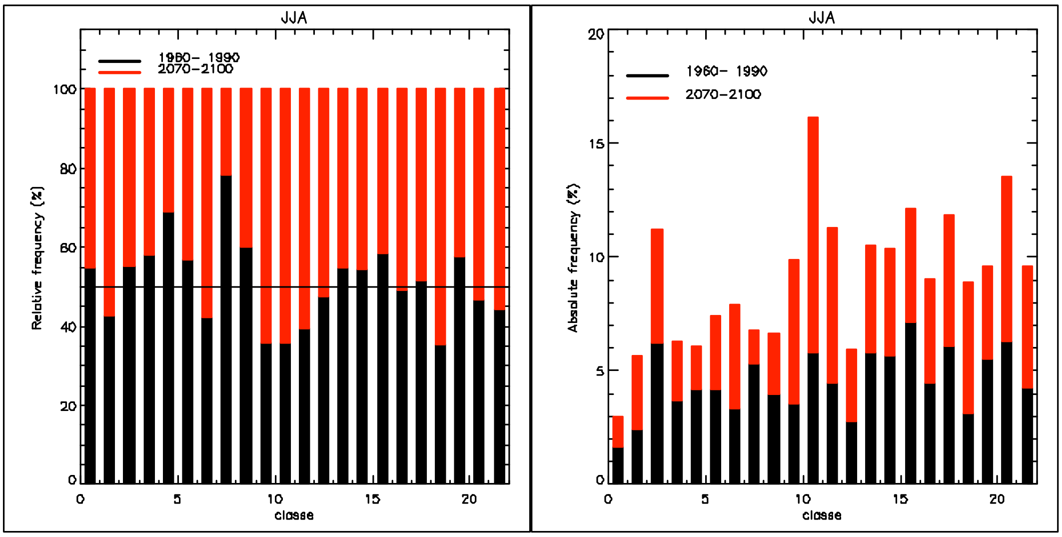


Fig. 1 Relative (left) and absolute (right) frequency of occurrence of the 22 circulation classes, JJA (GCM-class).

3.2 Persistency of anomalies from control to scenario

Each of the above circulation classes are associated with distinct regional anomaly patterns, in particular for temperature and precipitation. It was investigated if, within each of the classes, these anomalies (negative and/or positive) are maintained between control and scenario. For this, the correlation between control and scenario over all class anomalies were calculated. The results are visualized in Fig. 2, in terms of frequency distribution of the correlation coefficients within the RCM domain.

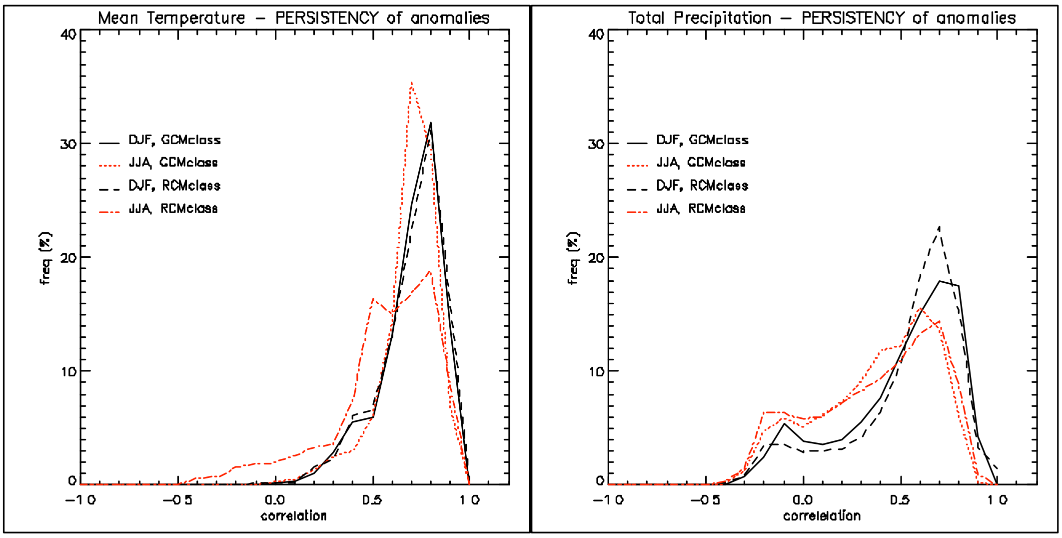


Fig. 2 Persistency of anomalies from control to scenario. GCM-class and RCM-class.

It was found that the global anomaly pattern associated with each class was generally maintained from control to scenario, in particular for the temperature, both for DJF and JJA and for both classification trials (GCM-class and RCM-class). The persistency of the anomalies is slightly smaller for precipitation. A view of the spatial correlation pattern (not presented here) shown that the regional mean temperature anomaly persistence is stronger over the continents than over sea; in case of precipitation, the anomaly patterns are generally maintained, with exception of western Mediterranean, in JJA.

3.3 Climate change

Finally, it was investigated how much of the simulated climate change can be explained by frequency changes in the circulation patterns. The simulated climate change, that means, the difference between the scenario and control mean values, was compared with the *regional climate change*, Δ, due to shift in the circulation pattern frequency:

$$\Delta = \sum_{classes} f_{scenario}(class)\times A_{control}(class) - \sum_{classes} f_{control}(class)\times A_{control}(class)$$

Where f = frequency of occurrence
A = Anomaly

The results are summarized in Fig. 3, for mean temperature and precipitation. The quantity Δ shows the tendency according to the change in circulation patterns only. It does not include global tendencies. Generally, it can be seen that only a small part of the simulated change can be explained by frequency changes in the circulation patterns.

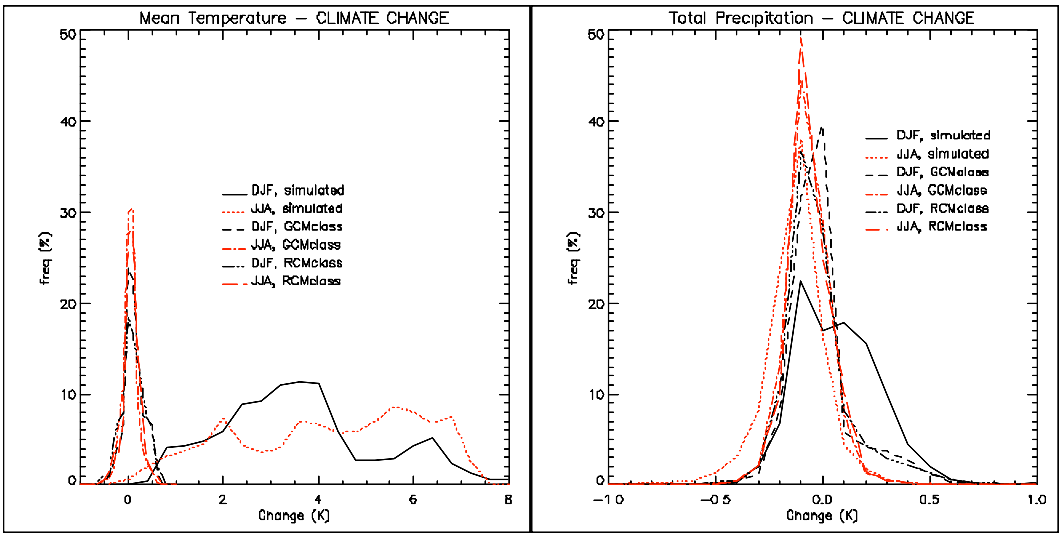


Fig. 3 Simulated and estimated climate change

4. CONCLUSIONS

The disaggregation of a 60-year period of daily meteorological values in 2-5 day episodes, later distributed in weather-type classes, results in circulation classes associated with distinct regional anomaly patterns of mean temperature and total precipitation.

The regional anomaly patterns are persistent (robust) with exception of JJA precipitation in western Mediterranean.

The regional climate change due to shift in circulation pattern frequency only explains a small part of the total simulated regional climate change.

5. REFERENCES

Fuentes, U. (1988) Statistical-dynamical downscaling based on a classification of synoptic weather types and their evolution. PhD Thesis, Meteorological Institute, University of Munich.

Fuentes, U. and Heimann, D. (2000) An improved statistical-dynamical downscaling schema and its application to the Alpine precipitation climatology. Theor Appl Climatol 65: 119-135.

Busch, U. and Heimann, D. (2001) Statistical-dynamical extrapolation of a nested regional climate simulation. Clim Res 19: 1-13.

Partner no.: 5

INSTITUTION: Met Office Hadley Centre
ACRONYM: **MO/HC**
RESPONSIBILITY: The Met Office Hadley Centre is a partner in WP 1, 2, 6, and 7, and is the leading contractor (PI) of WP 2.

The Hadley Centre is responsible for tasks:

RESPONSIBLE FOR TASK: D2A1
WORK: Uncertainty assessment of high-resolution global scenarios, resulting from model formulation and emissions scenarios.
RESULTS: Ongoing assessment of the reliability of the predicted summer drying over Central/Southern Europe.
PRESENTATIONS: Baltimore, June 2004.
DELIVERABLES: Months 13-36

RESPONSIBLE FOR TASK: D2A2
WORK: Authoritative A2 high-resolution global climate scenario.
RESULTS: MO/HC contribution complete.
PRESENTATIONS: Data provision; not applicable.
DELIVERABLES: Months 7-18

RESPONSIBLE FOR TASK: D2B1
WORK: Assessment of the quality of current climate simulations by RCMs.
RESULTS: Ongoing analysis and work on a paper.
PRESENTATIONS: Various (as in general comments).
DELIVERABLES: Months 19-33

RESPONSIBLE FOR TASK: D2B2
WORK: Assessment of regional interpretation of 8 RCMs consistent with SRES A2.
RESULTS: Analysis of uncertainty over the UK.
PRESENTATIONS: Toledo, Sept 2004.
DELIVERABLES: Months 19-36

RESPONSIBLE FOR TASK: D2B3
WORK: Uncertainty assessment of RCM scenarios, resulting from model formulation, emissions scenarios and internal variability.
RESULTS: Analysis of uncertainty over the UK.
PRESENTATIONS: Toledo, Sept 2004.
DELIVERABLES: Months 19-36

RESPONSIBLE FOR TASK: D2C1
WORK: Reliability assessment of 3 RCM ensembles consistent with SRES A2.
RESULTS: Analysis of uncertainty over the UK.
PRESENTATIONS: Toledo, Sept 2004.
DELIVERABLES: Months 13-30

RESPONSIBLE FOR TASK: D2C2
WORK: Reliability assessment of three realisations consistent with SRES B2
RESULTS: Complete (data sent to Partner 1).
PRESENTATIONS: None this period by MO/HC staff.
DELIVERABLES: Months 13-36

The Hadley Centre participates in tasks:

CONTRIBUTOR TO TASK: D1A1
WORK: Four high-resolution realisations for 2071-2100 consistent with SRES

A2 and matching control simulations [one with each of four models].
RESULTS: MO/HC simulations complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 1-12

CONTRIBUTOR TO TASK: D1A2
WORK: Two high-resolution realisations for 2071-2100 consistent with SRES B2 and matching control simulations [one with each of two models].
RESULTS: MO/HC simulation complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 1-12

CONTRIBUTOR TO TASK: D1A4
WORK: Three additional control and A2 scenarios using two models used for D1A2, forming two and three member ensembles.
RESULTS: MO/HC simulations complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 1-12

CONTRIBUTOR TO TASK: D1A5
WORK: Comprehensive analysis and reliability assessment of simulations.
RESULTS: Ongoing assessment of the reliability of the predicted summer drying over Central/Southern Europe.
PRESENTATIONS: Baltimore, June 2004.
DELIVERABLES: Months 7-36

CONTRIBUTOR TO TASK: D1A6
WORK: Large set of boundary data for driving regional climate models .
RESULTS: MO/HC contribution complete.
PRESENTATIONS: Data provision; not applicable.
DELIVERABLES: Months 1-12

CONTRIBUTOR TO TASK: D1B1
WORK: Eight RCM realisations for 2071-2100 consistent with SRES A2 and matching control simulations [one with each of eight models].
RESULTS: MO/HC simulations complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 7-24

CONTRIBUTOR TO TASK: D1B2
WORK: Two three-member RCM ensembles consistent with SRES A2 and matching control simulations [one with each of two models].
RESULTS: MO/HC simulations complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 13-24

CONTRIBUTOR TO TASK: D1B3
WORK: Three RCM realisations for 2071-2100 consistent with SRES B2 and matching control simulations [one with each of three models].
RESULTS: MO/HC simulation complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 7-24

CONTRIBUTOR TO TASK: D1B4
WORK: Three RCM realisations for 2071-2100 derived from 1 AGCM A2 scenario
RESULTS: MO/HC simulation complete.
PRESENTATIONS: Simulation; not applicable.
DELIVERABLES: Months 13-24

CONTRIBUTOR TO TASK: D1B6
WORK: Four-member RCM ensemble consistent with SRES A2, at very high

resolution [different models for each member]
RESULTS: Analysis of high resolution precipitation data, particularly extremes.
PRESENTATIONS: Various (as in general comments).
DELIVERABLES: Months 13-33

CONTRIBUTOR TO TASK: D1B7
WORK: Comprehensive analysis and reliability assessment of RCM simulations, including weather-type based interpretation.
RESULTS: Complete (data sent to Partner 1).
PRESENTATIONS: None this period by MO/HC staff.
DELIVERABLES: Months 13-36

CONTRIBUTOR TO TASK: D6A2
WORK: Working report on the methods and models available for inter-disciplinary links.
RESULTS: Held discussions with RISO/IIASA.
PRESENTATIONS: None this period.
DELIVERABLES: Months 7-24

CONTRIBUTOR TO TASK: D6A3
WORK: Working report on a framework for addressing costs/benefits of EU climate change action.
RESULTS: Held discussions with RISO/IIASA.
PRESENTATIONS: None this period.
DELIVERABLES: Months 7-30

CONTRIBUTOR TO TASK: D7A1
WORK: An archive of boundary data for AGCM and RCM simulations.
RESULTS: MO/HC contribution complete.
PRESENTATIONS: Data provision; not applicable.
DELIVERABLES: Months 1-24

CONTRIBUTOR TO TASK: D7A2
WORK: PRUDENCE web-site: data and reliability assessment.
RESULTS: Further contributions to web site made.
PRESENTATIONS: Data provision; not applicable.
DELIVERABLES: Months 1-33

CONTRIBUTOR TO TASK: D7A3
WORK: A presentation summarising the climate scenarios.
RESULTS: To be done later
PRESENTATIONS: None this period; not yet applicable.
DELIVERABLES: Months 25-36

CONTRIBUTOR TO TASK: D7A4
WORK: A presentation summarising the impacts of climate change.
RESULTS: To be done later
PRESENTATIONS: None this period; not yet applicable.
DELIVERABLES: Months 25-36

General Comments:

PUBLICATIONS: Paper submitted to *Int. J. Climatol.* on uncertainty of climate change over the UK. Publication of HadAM3P, HadRM3P and HadAM3H simulations is in preparation, and of other research mentioned above.
PRESENTATIONS: A large number of other presentations have been given, besides those noted above, which have included government advisors, government departments, government ministers, and international agencies. The material covered has included discussion of the uncertainties in regional modelling, where the role of PRUDENCE has been mentioned.

EMPLOYEES: Richard Jones, Dave Rowell, David Hassell, Erasmo Buonomo, Dave Hein
PUBLICATION PLAN: Complete current papers.

Scientific Highlights:

Mid-European Summer Drying:

In Year 2 we designed a suite of sensitivity experiments using a regional (European) version of HadAM3P, with the aim of roughly quantifying the relative importance of local versus and remote mechanisms for determining the projected Central/Southern European summer drying. Four of the seven planned experiments have been completed, and the methodology and software to enable the remaining experiments to be run has also been finalised. These experiments will enable us to assess whether future summer drying over Europe is predominantly caused by: regional variations in the local warming; remote circulation changes (divergence and/or storm track anomalies); or spring soil moisture anomalies. Furthermore, the role of positive feedbacks induced by evaporative anomalies over land is also being assessed. Preliminary results suggest that both local and remote processes play an important role.

Precipitation Extremes:

The quality of precipitation extremes generated by the Hadley Centre RCMs HadRM3H and HadRM3P has been assessed for the present and future climate (under the A2 scenario) by fitting the annual maxima to Generalized Extreme Value (GEV) distributions. Two accumulation periods, 1 day and 30 days, have been studied, and the statistical significance of differences has been evaluated by the profile likelihood method. Two ensembles of 3 members and 30 years for each model have been included in the study, giving a 90-year timeseries of annual maxima. The stationarity of the extreme precipitation has been assumed under the present and the future climate in order to consider each ensemble as a single realization of the present/future climate.

Results for the present climate have been validated over the UK, for both HadRM3H and HadRM3P models, with the Centre for Ecology and Hydrology (CEH) observational datasets, produced by aggregating station data over the RCM grid, giving a good agreement with the observational data. The main result from the predicted changes over Europe indicates an increase in intensity and frequency of extreme events. The results obtained from the two Hadley Centre models (HadRM3H and HadRM3P) are in good agreement, both in spatial distribution and intensity.

UK Climate Change:

Regional climate models (RCMs) are now commonly used to downscale climate change projections provided by global coupled models to resolutions that can be utilised at national and finer scales. Although this extra tier of complexity adds significant value, it inevitably contributes a further source of uncertainty, due to the regional modelling uncertainties involved. Here, an initial attempt is made to estimate the uncertainty that arises from typical variations in RCM formulation, focussing on changes in UK surface air temperature (SAT) and precipitation projected for the late twenty-first century. Data are provided by a relatively large suite of RCM and global model integrations with widely varying formulations.

It is found that uncertainty in the formulation of the RCM has a relatively small, but non-negligible, impact on the range of possible outcomes of future UK seasonal mean climate. This uncertainty is largest in the summer season. It is also similar in magnitude to that of large-scale internal variations of the coupled climate system, and for SAT, it is less than the uncertainty due to the emissions scenario, whereas for precipitation it is probably larger. The largest source of uncertainty, for both variables and in all seasons, is the formulation of the global coupled model. The scaledependency of uncertainty is also explored by considering its impact on projections of the gradient of climate change from the north to the south of the UK. Finally, the implications for the reliability of UK seasonal mean climate change projections are discussed. The strongest statements that can be made are that the southern UK will probably warm more than the northern UK, that UK-average precipitation will most likely increase in winter, and that it is moderately likely that mean summer rainfall will lessen over the southern UK.

Partner no.: 6

Institution: Eidgenössische Technische Hochschule (ETH) Zurich
Acronym: **IAC-ETH**
Responsibility: IAC-ETH is contributing to WPs 1,2,3. The CHRM regional climate model will be exercised over 56km grid spacing and its output will be used to drive the WASIM hydrological model.

IAC-ETH IS CONTRIBUTING TO TASKS:
D1B1,D1B6,D1B7,D2B1,D2B2,D2B3,D3B1,D3B2,D3B3,D3B5

CONTRIBUTOR TO TASK: D1B1
WORK: 1 SRES A2 simulation for 2071-2100 (together with control) @56km
RESULTS: Control and A2 simulations completed; all data delivered
PRESENTATIONS: Vidale et al. presentation at final project meeting Toledo.
PUBLICATIONS: Description of modelling system used by ETH: Vidale et al. (2003), Stöckli and Vidale (2004)
DELIVERABLES: by month 24

CONTRIBUTOR TO TASK: D1B6
WORK: A continuous 40-year simulation using perfect boundary conditions from ERA-40. (Replaces originally intended 5-year 15-km RCM integration.)
RESULTS: Simulations completed; all data delivered. Simulations used for evaluation of hydrological runoff simulations of WP3.
PRESENTATIONS: Vidale et al. presentation at final project meeting Toledo.
DELIVERABLES: by month 33

CONTRIBUTOR TO TASK: D1B7
WORK: Analyses of results from D1B1 AND D1B6
RESULTS: Analysis of climatology and variability of surface climate and precipitation from our D1B1 control simulation.
PRESENTATIONS: Vidale et al., High-Resolution RCM workshop, Lund, Apr. 2004; Vidale et al. and Frei et al. presentations at final project meeting Toledo; Schär et al. presentation at PRUDENCE Workshop in Wengen.
PUBLICATIONS: Schär et al. (2004), Vidale et al. (2005), Frei et al. (2005)
DELIVERABLES: by month 33

CONTRIBUTOR TO TASK: D2B1
WORK: Assessment of RCM simulations for present-day climate for interannual temperature variability and for hydrological components Analyses of results from D1B1 AND D1B6.
RESULTS: Detailed evaluation of RCMs against observed temperature variability, analyses of terrestrial water storage for Central European river basins and analyses of precipitation in the Alpine region.
PRESENTATIONS: Vidale et al. and Frei et al. presentations at final PRUDENCE project meeting Toledo.
PUBLICATIONS: Hirschi et al. (2004), van den Hurk et al. (2004), Frei et al. (2003), Frei et al. (2005)
DELIVERABLES: by month 33

CONTRIBUTOR TO TASK: D2B2 + D2B3
WORK: Contributions to joint analysis of PRUDENCE ensemble
RESULTS: Agreement between different RCMs in the character (continental patterns of the sign) of future changes in summer temperature variability but some quantitative differences.
PRESENTATIONS: Vidale et al. and Frei et al. presentation at final PRUDENCE meeting Toledo.
PUBLICATIONS: Déqué et al. (2004)
DELIVERABLES: by month 36

CONTRIBUTOR TO TASK: D3B1 + D3B2
WORK: WASIM simulations driven by CHRM output for present-day and future climate. Validation of runoff simulation under present-day climate. Analysis of climate change impacts on runoff statistics. Contribution to WP3 synthesis paper in PRUDENCE special issue.
RESULTS: Processing input from D1B1 AND D1B6 simulations. Reasonable agreement of simulated against observed runoff statistics. Shifts in runoff regime and daily runoff statistics under future climate.
PRESENTATIONS: Frei et al. presentation at final PRUDENCE project meeting Toledo.
PUBLICATIONS: Graham et al. 2004
DELIVERABLES: by month 33

CONTRIBUTOR TO TASK: D3B3
WORK: Analysis and comparison of WASIM simulations forced with RCM input at variable resolutions.
RESULTS: Experiments using reanalysis input suggest a marginal improvement in the representation of observed runoff variations. 30-year hydrological integration using output from a ERA-40 driven RCM integration.
PRESENTATIONS: Results are presented as part of a recently accepted
PUBLICATIONS: Kleinn et al. (2004)
DELIVERABLES: by month 33

CONTRIBUTOR TO TASK: D3B5
WORK: Validation of hydrological components of climate models. Processing input from D1B1, D1B6, D2C1, D2C2 simulations.
RESULTS: Detailed evaluation of RCMs against analyses of terrestrial water storage for Central European river basins and analyses of precipitation in the Alpine region.
PRESENTATIONS: Frei et al. presentation at final PRUDENCE project meeting Toledo
PUBLICATIONS: Hirschi et al. (2004), van den Hurk et al. (2004), Frei et al. (2005)
DELIVERABLES: by month 33

GENERAL COMMENTS: IAC-ETH OpenDAP system has been operational for the past 15 months: several Swiss and European groups are using/downloading data, upon authorization, for impacts studies. A transition to the Federal supercomputing facilities (CSCS, Manno) of the entire modelling suite, together with the data archive and all tools, has been completed effectively. Our operational capabilities have been normalized.

LIST OF PUBLICATIONS:

Beniston, M., D.B. Stephenson, O.B. Christensen, C.A.T. Ferro, C. Frei, S. Goyette, K. Halsnaes, T. Holt, K. Jylhä, B. Koffi, J. Palutikov, R. Schöll, T. Semmler and K. Woth, 2004: Future extreme events in European climate: An exploration of regional climate model projections. Climatic Change, submitted

Déqué, M., R. G. Jones, M. Wild, F. Giorgi, J. H. Christensen, D. C. Hassell, P.L. Vidale, B. Röckel, D. Jacob, Erik Kjellström, M. de Castro, F. Kucharski B. van den Hurk, 2005: Global high-resolution versus limited-area model scenarios over Europe: results from the PRUDENCE project. Clim. Dyn., submitted

Frei, C., J.H. Christensen, M. Déqué, D. Jacob, R.G. Jones, P.L. Vidale, 2003: Daily precipitation statistics in regional climate models: Evaluation and intercomparison for the European Alps. J. Geophys. Res., 108 (D3), paper 4124, doi:10.1029/2002JD002287

Frei, C., R. Schöll, J. Schmidli, S. Fukutome, P. L. Vidale, and C. Schär, 2005: Scenarios of precipitation extremes in Europe: An analysis and intercomparison of RCMs. In preparation.

Graham, L.P., S. Hagemann, S. Jaun and M. Beniston, 2004: On interpreting hydrological change from regional climate models. Climatic Change, submitted.

Hirschi, M., S.I. Seneviratne and C. Schär, 2004: Seasonal variations in terrestrial water storage for major mid-latitude river basins. J. Hydrometeorol., submitted

Hohenegger, C. and P.L. Vidale, 2004: Sensitivity of the European Climate to Aerosol Forcing as simulated with a Regional Climate Model, J. Geophys. Res. – Atmos., submitted

Kleinn, J., C. Frei, J. Gurtz, D. Lüthi, P.L. Vidale, and C. Schär, 2004: Hydrologic Simulations in the Rhine Basin driven by a Regional Climate Model', J. Geophys. Res. – Atmos, in press.

Schär, C., P.L. Vidale, D. Lüthi, C. Frei, C. Häberli, M.A. Liniger and C. Appenzeller, 2004: The role of increasing temperature variability for European summer heat waves. Nature, 427, 332-336; doi:10.1038/nature02300

Schär, C. and G. Jendritzky, 2004: Hot news from summer 2003. Nature, 432, 559-560

Schär C. and C. Frei, 2005: Orographic precipitation and climate change. In: U. M. Huber, H. K. M. Bugmann and M. A. Reasoner (eds): Global Change and Mountain Regions: A State of Knowledge Overview. Springer, Dordrecht, 255-266, in press

Stöckli, R. and P.L. Vidale, 2004a: European plant phenology and climate as seen in a 20-year AVHRR land surface parameters data set. Int. J. of Rem. Sensing, 25(17), 3303-3330

Stöckli R. and P.L. Vidale, 2004b: Modeling seasonal water and heat exchanges at European Fluxnet sites. Theor. Appl. Climatol., in press

Van den Hurk, B., M. Hirschi, C. Schär, G. Lenderink, E. van Meijgaard, A. van Ulden, B. Röckel, S. Hagemann, P. Graham, E. Kjellström and R. Jones, 2004: Soil control on runoff response to climate change in regional climate model simulations. J. Climate, conditionally accepted

Vidale, P.L., D. Lüthi, C. Frei, S. Seneviratne, and C. Schär, 2003: Predictability and uncertainty in a Regional Climate Model, J. Geophys. Res., 108 (D18), 4586 , doi: 10.1029/2002JD002810.

Vidale P.L., D. Lüthi, R. Wegmann, C. Schär, 2005: Variability of European climate in a heterogeneous multi-model ensemble. In preparation

EMPLOYEES:
Name: P.L. Vidale, J. Kleinn, S. Jaun, M. Hirschi, R. Wegmann, R. Stöckli

PUBLICATION PLAN:

Several papers are in the last phase of drafting (e.g. Frei et al 2005, Vidale et al. 2005)

Partner no.: 7

Institution: GKSS Research Centre
Acronym: **GKSS**
Responsibility: GKSS applies the LM model at 50km resolution to the 2071-2000 SRESA2 simulations by the Hadley Centres AGCM. GKSS applies the TRIM3D model to the RCM simulations.

RESPONSIBLE FOR TASK: D5B1
WORK: Quality assessment of surface wind and pressure in the RCM control simulations
ALLOCATED PERSON MONTH THIS PERIOD: 2
RESULTS: Expansion of the comparisons of differences in the control climate between percentiles for wind speed and SLP derived from four RCMs HIRHAM, RCAO, CLM and REMO) and the REMO hindcast.
PRESENTATIONS: (combined with D5B2)
DELIVERABLES:

RESPONSIBLE FOR TASK: D5B2
WORK: Assessment of storm surges from TRIM3D simulations driven by RCM simulations
ALLOCATED PERSON MONTH THIS PERIOD: 2.6
RESULTS: Two more experiments – driven by meteorological forcing from CLM (GKSS) and REMO (MPI) have been finished and their results have been analysed under consideration of the whole ensemble.
Presentations: Toledo, Spain, 06 Sep - 10 Sep 2004
Climate change and North Sea storm surge extremes - an ensemble study: final results. Final PRUDENCE project workshop
(combined with D5B1)
DELIVERABLES:

CONTRIBUTOR TO TASK: D1B1
WORK: RCM simulations at 50km
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS:
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D1B7
WORK: Analysis and assessment of reliability of simulations
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS:
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2A2
WORK: Supply results from RCM simulations at 50km
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS:
PRESENTATIONS:
DELIVERABLES: Daily, monthly, and seasonally data from RCM 50km simulations.

CONTRIBUTOR TO TASK: D2B1
WORK: Assessment of the quality of current RCM climate simulations
RESULTS:
ALLOCATED PERSON MONTH THIS PERIOD: 0
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B2
WORK: Assessment of climate change simulations
RESULTS: Assessment of change in near surface wind extremes (combined with D2B3)
ALLOCATED PERSON MONTH THIS PERIOD: 1
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: D2B3
WORK: Uncertainty assessment across all models
RESULTS: Assessment of change in near surface wind extremes across all models (combined with D2B2)
ALLOCATED PERSON MONTH THIS PERIOD: 3
PRESENTATIONS: Toledo, Spain, 06 Sep - 10 Sep 2004
Changes in near surface wind speed from an ensemble of regional model simulations.
DELIVERABLES:

GENERAL COMMENTS:
PUBLICATIONS:
Woth K, Weisse R, von Storch H. Dynamical modelling of North Sea storm surge extremes in a changed climate: an ensemble study. Submitted to Int. J. Clim.
EMPLOYEES:
Name: Katja Woth
PUBLICATION PLAN:
Rockel, B. and Woth K.: Future changes in near surface wind speed extremes over Europe from an ensemble of RCM simulations
PLANS FOR THE NEXT PHASE:
N/A

Contribution to WP1 (B. Rockel)

The task of GKSS in work packages WP1 and WP2 are simulations with the regional climate model CLM for a control run and the ScA2 scenario on a 50 km grid followed by an analysis of the results.
For the simulations we defined the following setup:
A rotated lat-lon grid with 101 x 107 grid points (including 8 boundary grid points). The horizontal grid width is 0.5° x 0.5° (~ 56 km x 56 km). There are 20 levels in the vertical direction on a hybrid sigma-pressure grid.
Both control and scenario simulations have been finished mid of 2003. Seasonal, monthly, and daily data sets have been produced. These data are now part of the PRUDENCE data archive at DMI.

Contribution to WP2 (B. Rockel)

In this study we assess the uncertainty in future change of near surface wind predicted by an ensemble of regional model simulations. The basic data sets are the daily maximum and mean wind speed fields from the PRUDENCE data archive at DMI.
Main focus is on the results from the standard 50km runs of eight regional models driven by the Hadley Centre global model results. In addition we also take into account the 20km runs and 50km runs driven by another GCM (ECHAM4).
From the given data sets the optimal parameter for determining future changes in extreme wind speeds and the change in number of storm events is the maximum daily wind speed. It turns out that the way maximum daily wind speed is calculated differs among the regional models. The calculation is done in three different ways: 1) maximum from three hourly instantaneous

values, 2) maximum values of each time step, 3) as the latter plus a gust parameterization. The effect of the different ways to determine the maximum wind speed on the storm prediction is investigated.
In order to get a homogeneous ensemble we also look at the 99-percentile of the daily mean wind speed. We divide Europe into eight sub-regions (e.g. British Isles, Iberian Peninsula, Scandinavia) and investigate the monthly variation of wind over these regions. Results show differences and similarities between the sub-regions in magnitude, spread, and seasonal tendencies.
It can be shown that daily mean and maximum wind velocities (without gust parameterization) are only useful for analyzing tendencies. These quantities give too low values over land as to be used for storm statistics. For quantitative measures like storm counts daily maximum wind velocities including gust parameterization have to be chosen.

Contribution to WP5 (K. Woth)

D5B2
Assessment of storm surges from TRIM 3D simulations driven by RCM simulations

The ensemble simulation of the tide-surge model TRIMGEO was extended, up to four different model simulations driven with atmospheric forcing coming from HIRHAM, CLM, REMO and RCAO. The surge results were analysed regarding the quality of the control runs as well as in respect to changes in a perturbed climate scenario (A2 SRES IPCC) relative to the control simulations. The focus for the statistical examinations was laid on extremes storm surge events.
A comparison between the statistics, derived from the tide-surge model simulations of the control climate and a tide surge model run, driven with reanalysis (hindcast) gave satisfactory results. This hindcast was prepared using meteorological forcing from a regional re-analysis of atmospheric conditions (Feser et al., 2001), representing the control climate. On the positive side, the spatial structure of extreme events, with highest storm surges in the German Bight and relatively small values along the UK coast, was found to be in good agreement with reconstructed conditions. But on the other side, with the exception of the simulation forced with CLM atmospheric data, the intensity is generally too weak leading to an underestimation of the storm surge 99.5%-tile, which is consistent with the findings from Flather’s and Smith’s (1998) results.
The overall structures of the changes between the scenario and the control simulations are rather similar for all ensemble members though differences in absolute values and statistical significance of the results occur. Larger changes are obtained for the continental coast while differences are generally smaller and not statistically different from zero along the UK coast. Within the German Bight the 99.5 storm surge percentile along the 10 m bathymetry line is increased significantly in all scenario simulations by 20 to 30 cm which corresponds to a plus of around 20% surge heights.
The difference in modeled surge statistics in the ‘control climate’, using the four different RCM meteorological forcings, is fully consistent with the analyzed high 10m wind speeds – which is larger in CLM, HIRHAM and REMO than in RCAO. In the future climate scenario all four RCMs show an increase of the 99%-ile. This is consistent with the positive trend in surge extremes around the North Sea coast.

D5B1
Quality assessment of surface wind and pressure in the RCM control simulations

For an assessment of surface wind and pressure (SLP) in the RCM control simulations, 10 m wind speed and SLP were compared with regional re-analysis of atmospheric conditions (Feser et al., 2001) in the tide surge model domain (North Sea area). This hindcast was preformed using the REMO model with spectral nudging. The reconstruction of marine winds and air pressure were found to be homogeneous and of satisfactory quality (e.g., Sotillo, 2003; Weisse et. al, 2004).
All four analysed RCM control simulations used in this experiment, namely HIRHAM, CLM, REMO and RCAO, driven with the same boundary conditions coming from the global circulation model HadAM3H, show an overestimation of the deepest sea level pressures in the control climate simulations compared to the hindcast. The largest deviations are found for the HIRHAM and RCAO runs and vary between about 3.5 and 6 hPa. CLM show smallest differences of about 0.5 hPa up to 4.5 hPa, REMO is varying in between.
Corresponding to the overestimation of the lowest surface pressures, extreme near-surface wind speeds are underestimated in three of four control simulations compared to the hindcast. Again, the CLM simulation is an exception. Compared to the hindcast, the 99%-ile is about 0.5 m/s higher in the southern and the south-western part of the analysed domain and the differences increase up to about 1.5 m/s in the north-eastern part. The spatial structure of difference in high wind speeds is quite similar for all other control simulations. While REMO underestimates severe wind speeds slightly by about -0.5 m/s in the Northern and about -1.5 m/s in the Southern North Sea, HIRHAM and RCAO show larger differences in the order of about -2.5 m/s over a large fraction of the North Sea.
Because of the deviations between hindcast and control simulations of both, the atmospheric forcing as well as the storm surge residuals, we interpret the differences between scenario and control climate projections as a relative shift of present day statistics in the projected future. This assumption is inherent in all climate change studies and represents the best possible option so far.

Literature cited

Feser F, Weisse R, von Storch H. 2001. Multidecadel atmosperic modelling for Europe yields multi purpose data. EOS 82: 305 + 310.
Flather R, Smith J. 1998. First estimates of changes in extreme storm surge elevation due to doubling CO_2. Global Atmos. Ocean Sys. 6: 193 – 208.
von Storch H, Langenberg H, Feser F. 2000. A spectral nudging technique for dynamical downscaling purposes. Mon. Wea. Rev. 128: 3664 – 3673.
Weisse R, von Storch H, Feser F. 2004. Northeast Atlantic and North Sea storminess as simulated by a regional climate model 1958-2001 and comparison with observations. J. Climate, in press.

Partner no.: 8

Institution: Max-Planck-Institute for Meteorology
Acronym: **MPI**
Responsibility: MPI is partner in WP 1, 2, 3 and 7. MPI is the coordinator of WP 1. MPI performs two SRES-A2-scenario simulations with the AGCM ECHAM5, one driven by HadCM3, the other driven by ECHAM4/OPYC3. Further on MPI applies the regional climate model REMO in a resolution of 1/2 degree to the European region using the boundary forcing from HadAM3H.

MPI is responsible for tasks: D1A1, D1A2, D1A3, D1A4, D1A5, D1A6, D1B1, D1B2, D1B3, D1B4, D1B5, D1B6, D1B7
MPI participates in tasks: D1A1, D1A5, D1A6, D1B1, D1B4, D1B5, D1B6, D1B7, D2A1, D2A2, D2B1, D2B2, D2B3, D2C1, D2C2, D3A2, D3A3, D3B2, D3B5, D7A3.

RESPONSIBLE FOR TASK: D1A1
WORK: High-resolution SRES-A2-realisations of global climate for 2071-2100
RESULTS: Completed, ECHAM5 completed
PRESENTATIONS:
DELIVERABLES: Expected until month 12, ECHAM5 until month 30

RESPONSIBLE FOR TASK: D1A2
WORK: High-resolution SRES-B2-realisations of global climate for 2071-2100
RESULTS: Completed, ECHAM5 running
PRESENTATIONS:
DELIVERABLES: Expected until month 12, ECHAM5 until month 30

RESPONSIBLE FOR TASK: D1A3
WORK: B2 scenario with different sea-surface conditions
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 18

RESPONSIBLE FOR TASK: D1A4
WORK: Additional control and A2 scenarios
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 12

RESPONSIBLE FOR TASK: D1A5
WORK: Analysis of simulations and assessment of reliability
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

RESPONSIBLE FOR TASK: D1A6
WORK: Set of boundary data for driving regional climate models
RESULTS: Completed, all boundary data available
PRESENTATIONS:
DELIVERABLES: Expected until month 12

RESPONSIBLE FOR TASK: D1B1
WORK: 8 SRES-A2-RCM realizations of European climate for 2071 - 2100
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

RESPONSIBLE FOR TASK: D1B2
WORK: 2 three-member ensemble European climate SRES-A2-scenarios 2071 - 2100
RESULTS: Completed

PRESENTATIONS:
DELIVERABLES: Expected until month 24

RESPONSIBLE FOR TASK: D1B3
WORK: 3 SRES-B2-RCM realizations of European climate for 2071 - 2100
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

RESPONSIBLE FOR TASK: D1B4
WORK: 3 RCM realizations of European climate for 2071 - 2100 from one AGCM-SRES-A2-scenario
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

RESPONSIBLE FOR TASK: D1B5
WORK: Like D1B2, but 1 two-member ensemble with a different driving AGCM
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

RESPONSIBLE FOR TASK: D1B6
WORK: A four-member ensemble European climate SRES-A2-scenario with very high resolution
RESULTS: Completed, but one member substituted by SRES-B2-scenario
PRESENTATIONS:
DELIVERABLES: Expected until month 33

RESPONSIBLE FOR TASK: D1B7
WORK: Analysis of the simulations and assessment of the reliability
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D1A1
WORK: High-resolution SRES-A2-realisations of global climate for 2071-2100
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed, ECHAM5 running
PRESENTATIONS:
DELIVERABLES: Expected until month 12, ECHAM5 until month 24

CONTRIBUTOR TO TASK: D1A5
WORK: Analysis of simulations and assessment of reliability
ALLOCATED PERSON MONTH THIS PERIOD: 3
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D1A6
WORK: Set of boundary data for driving regional climate models
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: All boundary data available
PRESENTATIONS:
DELIVERABLES: Expected until month 12

CONTRIBUTOR TO TASK: D1B1

WORK: 8 SRES-A2-RCM realisations of European climate for 2071 - 2100
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed
PRESENTATIONS:

CONTRIBUTOR TO TASK: D1B4
WORK: 3 RCM realisations of European climate for 2071 - 2100 from one AGCM-SRES-A2-scenario
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

CONTRIBUTOR TO TASK: D1B5
WORK: Like D1B2, but 1 two-member ensemble with a different driving AGCM
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 24

CONTRIBUTOR TO TASK: D1B6
WORK: A four-member ensemble European climate SRES-A2-scenario with very high resolution
ALLOCATED PERSON MONTH THIS PERIOD: 2
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D1B7
WORK: Analysis of the simulations and assessment of the reliability
ALLOCATED PERSON MONTH THIS PERIOD: 2
RESULTS: In progress
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D2A1
WORK: Assessment of the uncertainty in high-resolution global climate scenarios
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D2A2
WORK: Authoritative A2 emissions-driven high-resolution global climate scenario for 2071 - 2100
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 18

CONTRIBUTOR TO TASK: D2B1
WORK: Assessment of the quality of simulations of current climate by European RCMs
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D2B2
WORK: Assessment of the regional interpretation by eight European RCMs

ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 36

CONTRIBUTOR TO TASK: D2B3
WORK: Assessment of the uncertainty in European regional climate scenarios
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 36

CONTRIBUTOR TO TASK: D2C1
WORK: Assessment of the reliability of three SRES-A2 ensemble realisations of European regional climate
ALLOCATED PERSON MONTH THIS PERIOD: 0.5
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 30

CONTRIBUTOR TO TASK: D2C2
WORK: Assessment of the reliability of three SRES-B2 ensemble realisations of European regional climate
ALLOCATED PERSON MONTH THIS PERIOD: 0.5
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D3A2
WORK: Hydrological models of a specific North European river basin
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 12

CONTRIBUTOR TO TASK: D3A3
WORK: Validation of the hydrological components of control simulations
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: completed
PRESENTATIONS:
DELIVERABLES: Expected until month 30

CONTRIBUTOR TO TASK: D3B2
WORK: Assessment of the potential impact of future climates on river flows and flooding
ALLOCATED PERSON MONTH THIS PERIOD: 3
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D3B5
WORK: Validation of the hydrological components of the climate models
ALLOCATED PERSON MONTH THIS PERIOD: 3
RESULTS: Completed
PRESENTATIONS:
DELIVERABLES: Expected until month 33

CONTRIBUTOR TO TASK: D7A3
WORK: Presentation summarising the climate scenarios
ALLOCATED PERSON MONTH THIS PERIOD: 2
RESULTS: Completed

PRESENTATIONS:
DELIVERABLES: Expected until month 36

GENERAL COMMENTS:

The coupling of REMO with the hydrological model HD is finished and tested. The data of the different regional climate models have been retrieved from the DMI server and have been interpolated to a common grid.

The data from 10 different regional climate models were considered. The RCMs comprise the ARPEGE model (Déqué et al. 1998) of Météo-France (CNRM), a modified version of the German Weather Service $B!G (Bs forecast Europa model (CHRM; Lüthi et al. 1996) used by the Institute for Climate Research of the ETH Zurich, the climate version of the Lokal-Modell (Doms et al. 2002) used by the GKSS Forschungszentrum Geesthacht, the HadRM3H model (Jones et al. 1995) of the Hadley Centre (HC), the HIRHAM4 model (Christensen et al. 1996) of the Danish Meteorological Institute (DMI), the PROMES model (Gaertner et al. 2001) of the Universidad Computense de Madrid (UCM), the RACMO model (Lenderink et al. 2003) of the Royal Netherlands Meteorological Institute (KNMI), the RCAO model (Räisänen et al. 2002) of the Swedish Meteorological and Hydrological Institute (SMHI), the REMO model (Jacob 2001) of the Max-Planck-Institute for Meteorology (MPI-M) and the RegCM model (Giorgi et al. 1993a; Giorgi et al. 1993b) used by the Abdus Salam International Centre for Theoretical Physics (ICTP). Within PRUDENCE two RCM simulations were performed by each participating RCM. A control simulation representing current climate conditions for the period 1961-1990, and a scenario simulation representing climate change conditions according to the IPCC scenario A2 for the period 2071-2100.

MPI-M has performed hydrological studies that include both their own RCM simulations and those from the other RCMs. A special focus is put on the discharge from large European rivers. The discharge was simulated with the Hydrological Discharge (HD) Model (Hagemann and Dümenil Gates 2001). The HD model uses daily fields of surface runoff and drainage from the soil as input to represent fast and slow runoff responses. Practically, only total runoff has been delivered to the PRUDENCE database located at DMI. Thus, it was necessary to perform additional analyses to partition total runoff into components that represent fast and slow responses. This was done with a simplified land surface (SL) scheme (Hagemann and Dümenil Gates 2003) which uses daily fields of precipitation and 2m temperature to simulate the hydrological processes at the land surface. In order to be more consistent with the hydrological cycle of the different RCMs, a special version of the SL scheme was used which additionally uses RCM evapotranspiration as input. The discharge was simulated for the RCM control and A2 scenario simulations.

Results
In order to evaluate the simulated discharge, a validation of the simulated hydrological cycle was also performed. Here, several large European catchments were considered, i.e. the Baltic Sea catchment and the catchments of the rivers Danube, Elbe and Rhine, where the validation focused on common RCM model problems, such as investigated by Hagemann et al. (2004) for several RCM simulations driven by ERA15 data [CNRM (using the same simulation as in the present study that is driven only by observed SST) DMI, ETH, HC, MPI]. These problems comprise the overestimated precipitation in the winter and spring over the Baltic Sea catchment and the summer drying problem over the Danube catchment.

It was shown that both problems still exists for most of the RCMs, and they also become visible in the multi-model ensemble mean. The validation of the simulated discharges into the Baltic Sea and for the Danube river has shown that a large spread exists between the different model simulations. The multi-model ensemble mean is usually closer to the observations than each of the models, especially if several catchments and variables are considered.

The multi-model ensemble mean yielded the following results for the climate change simulations:
For the Baltic Sea catchment, there is a precipitation increase in winter, an evaporation increase in the whole year with a maximum increase in the winter. The discharge increases (>20%) only in the winter and early spring. For the Danube and the Rhine rivers, there is a precipitation increase in the late winter (JAM), but a decrease in the summer. The evaporation is generally increasing except for the summer (Here, over the Danube catchment even a decrease takes place in the summer), with a maximum in the winter. There is a large reduction (>20%) in discharge throughout the year except in the late winter. Here the simulated discharge increases about 10%. It seems that the large summer warming intensifies the drying of the area.

PUBLICATIONS:

S. Hagemann and D. Jacob, 2005: Gradient in the climate change signal of European discharge predicted by a multi-model ensemble, Climatic Change (Prudence Special Issue - Part 2), submitted

Semmler, T. and D. Jacob (2004): Modeling extreme precipitation events - a climate change simulation for Europe. Global and Planetary Change, 44, 119-127.

EMPLOYEES:
Name: Daniela Jacob, Tido Semmler, Stefan Hagemann, Philip Lorenz, Lola Kotova

PUBLICATION PLAN:

Leading authorship:
Jacob et al.: An intercomparison of regional climate models for Europe: design of the experiments and model performance. (WP1 contribution), Special Issue of Climatic Change, in preparation

Contributing:
Déqué et al.: An intercomparison of regional climate models for Europe: assessing uncertainties in model projections. (WP2 contribution), Special Issue of Climatic Change, in preparation

Graham et al.: On interpreting hydrological change from regional climate models. (WP3 contribution), Special Issue of Climatic Change, in preparation

van den Hurk, Hirschi, Lenderink, van Meijgaard, van Ulden, Rockel, Hagemann, Graham, Kjellström 2004:
Soil control on runoff response to climate change in regional climate model simulations, submitted to J. Climate

PLANS FOR THE NEXT PHASE:
No further plans

Summary

The last year of the project duration was mainly dedicated to work within WP3. An intense investigation of the hydrological cycle and the analyses of the simulated river run-off data

from all RCMs participating in PRUDENCE were carried out and further details are given below.

In addition the validation of the RCM results under current climate conditions had to be finalized. This work, which was done within WP1 and WP2, is summarised in a paper in the special issue of Climatic Change, which will be submitted during the next months.

European discharge under climate change conditions simulated by a multi-model ensemble

Ten regional climate models (RCMs) participated in the European project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects; http://prudence.dmi.dk/index.html), which aim was to predict uncertainties in RCM simulations over Europe (Christensen et al., 2005).

Within PRUDENCE two major climate simulations were performed by each participating RCM. A control simulation representing current climate conditions for the period 1961-1990, and a scenario simulation representing climate change conditions according to the IPCC scenario A2 for the period 2071-2100. Lateral boundary conditions were provided by the atmospheric general circulation model (GCM) HadAM3H (Pope et al., 2000) for both simulations.

In order to perform hydrological studies on these RCM simulations, a special focus was put on the discharge from large river catchments located in northern and central Europe. The discharge was simulated with a simplified land surface (SL) scheme (Hagemann and Dümenil Gates, 2003) and the Hydrological Discharge (HD) model (Hagemann and Dümenil Gates, 2001). The daily fields of precipitation, 2m temperature and evapotranspiration from the RCM simulations were used as forcing. Therefore the total catchment water balances are constrained by the hydrological cycle of the different RCMs.

The validation of the simulated hydrological cycle in the current climate has shown that a large spread exists between the models, but that the multi-model ensemble mean can be used to reduce uncertainty introduced by the use of a single RCM. This reduction can be achieved since the multi-model ensemble mean is usually closer to the observations than each of the models, especially if several catchments and hydrological variables are considered.

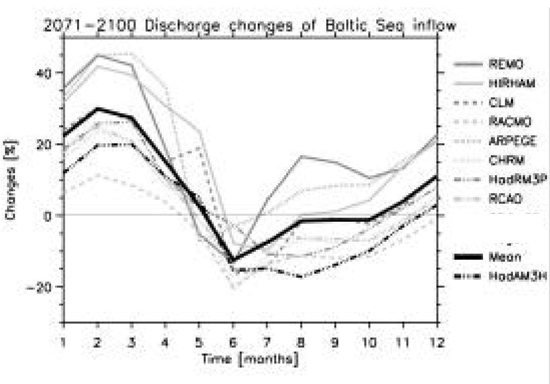
Significant deviations of the ensemble mean to the observations point to common model problems, such as the prominent summer drying problem over Central Europe (Hagemann et al., 2004). Despite of the large differences in the control simulations of the RCMs, where the performance of the RCMs is different over the diverse catchments, the A2 climate change signal is very much confined and similar for almost all of the models. And even those RCMs who particularly disagree with regard to P and E in the control simulations, the A2 signal in the discharge is largely constrained by each of the models. This provides some confidence in the future projections even if only a few of the 10 RCMs may be considered. The results also indicate that the changes over the maritime Baltic Sea catchment are mainly related to changes in the large-scale circulation, while over the more continental Danube catchment the effect of local scale processes seems to be more important.

The following changes are predicted by the multi-model ensemble mean.For the Baltic Sea catchment, the precipitation will increase in the winter half of the year (October-March), and evapotranspiration will increase during the whole year with a maximum increase in the winter. These rises in precipitation and evapotranspiration will lead to an increase in discharge (>20%) only in the winter and early spring (Fig. 1). For the Danube, the precipitation will increase in the late winter (January-March) and decrease in the summer. The evapotranspiration will rise during the whole year, except for the summer, with a maximum increase in the winter. In the summer, a decrease is predicted. These changes lead to a large reduction (>20%) in the discharge throughout the year except in the late winter (Fig. 2). Here increases of about 10% are predicted. It seems that the large summer warming intensifies the drying of the Central European area represented by the Danube catchment. These results show that a strong gradient in the climate change signal is predicted by the RCMs. The future warming is intensifying the hydrological cycle in the north of Europe while over Central Europe the warming causes a weakening.

During the summer, the predicted changes by the GCM HadAM3H and the RCM HadRM3P deviate significantly from the RCM multi-model ensemble mean, especially for temperature, precipitation and evapotranspiration. As this common model behavior of the HadM3 model family seems to be independent of resolution, it is probably related to problems in representing certain local effects that are simulated differently than by the other RCMs. Despite of these problems of the driving GCM, almost all RCMs predict consistent changes in the hydrological cycle for all catchments. This indicates that the use of RCMs can compensate problems that a driving GCM might have with the representation of local scale processes or parameterizations. Thus, in addition to the higher resolution, a further added value is obtained by the use of the RCM multi-model ensemble mean compared to the GCM.

It has to be noted that in this study only one scenario was considered, and only forcing from one GCM simulation was used. Results of Déqué et al. (2005) indicated that regarding uncertainty based on several models, the number of GCM forcings involved is at least as important as the number of RCMs, and that it is also necessary to consider several scenarios in the case of southern Europe summer warming.

How RCM predictions behave using different scenarios and different GCM forcing will be investigated within the forthcoming European Union project ENSEMBLES that started in September 2004. First results considering two different scenarios and two different GCM forcings were obtained with RCAO (Räisänen et al., 2004) within the PRUDENCE project. Here, the four simulations agree on a general increase in precipitation in northern Europe especially in winter and on a general decrease in precipitation in southern and central Europe in summer, but the magnitude and the geographical patterns of the change differ markedly between the two GCM forcings.



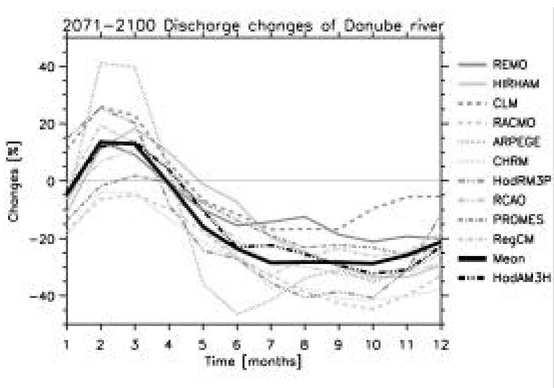


Figure 1 *Left*: Mean monthly discharge Baltic Sea catchment. Mean designates the multi-model ensemble mean change of 8 RCMs (The other 2 RCMs did not cover the whole area). *Right*: Mean monthly discharge changes in the Danube catchment. Mean designates the multi-model ensemble mean change of the 10 RCMs.

References

Christensen, J.H., Christensen, O.B., and al.: 2005, 'PRUDENCE special issue introduction paper (title and co-authors to be finalized)', *Climatic Change*, submitted.

Déqué, M., Rowell, D., Schär, C., Giorgi, F., Christensen, J. H., Rockel, B., Jacob, D., Kjellstrom, E., de Castro, M., and van den Hurk, B.: 2005, 'An intercomparison of regional climate models for Europe: assessing uncertainties in model projections', *Climatic Change*, submitted.

Hagemann, S. and Dümenil Gates, L.: 2001, 'Validation of the hydrological cycle of ECMWF and NCEP reanalyses using the MPI hydrological discharge model', *J Geophys Res* **106**, 1503-1510.

Hagemann, S. and Dümenil Gates, L.: 2003, 'Improving a subgrid runoff parameterization scheme for climate models by the use of high resolution data derived from satellite observations', *Clim. Dyn.* **21**, 349-359.

Hagemann, S., Machenhauer, B., Jones, R., Christensen, O.B., Déqué, M., Jacob, D., and Vidale, P.L.: 2004, 'Evaluation of Water and Energy Budgets in Regional Climate Models Applied Over Europe', *Clim. Dyn.* **23**, 547-567.

Pope, V.D., Gallani, M.L., Rowntree, P.R., and Stratton, R.A.: 2000, 'The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3', *Clim Dyn* **16**, 123-146.

Räisänen .J, Hansson, U., Ullerstig, A., Döscher, R., Graham, L.P., Jones, C., Meier, H.E.M., Samuelsson, P., and Willén, U.: 2004, 'European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios', *Clim. Dyn.* **22**, 13-31.

Partner no.: 9

Institution: Swedish Meteorological and Hydrological Institute
Acronym: **SMHI**
Responsibility: SMHI contributes to WPs 1, 2, 3 and 7. Of these, SMHI has the lead in WP3.

In WP1, SMHI applies the RCAO-model at approximately 50 km resolution to HadAM3 control, one A2 and one B2 realisation. A simulation at approximately 25 km has also been performed, with the HadAM2 control and one A2-realization. Simulations are also performed/planned with ERA and ECHAM4. These do not belong to PRUDENCE but will be delivered as is felt relevant and possible.

In WP2, SMHI participates in the analysis of model simulations and the studies of uncertainty aspects.

In WP3, SMHI leads and contributes to the water resources impact studies. At SMHI, studies are conducted for the entire Baltic drainage basin and for the Lule River basin in northern Sweden.

In WP7, SMHI contributes to the management, data, reporting and dissemination topics as requested. Specifically, a contribution is foreseen as concerns the water resources studies.

CONTRIBUTOR TO TASK: D1B1
WORK: ~50 km RCAO simulation based on the HadAM3 control 1961-1990 time slice and one of the SRES/A2-based scenario time slices for 2071-2100.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Both simulations are complete and delivered.
PRESENTATIONS: The simulation/scenario results continue to be used in talks on regional climate change in Sweden, including representatives of local and national authorities.
DELIVERABLES: month 24, DELIVERED.

CONTRIBUTOR TO TASK: D1B3
WORK: ~50 km RCAO simulation based on the HadAM3 SRES/B2-based scenario time slice for 2071-2100.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Both simulations are complete and delivered.
PRESENTATIONS: The simulation/scenario results continue to be used in talks on regional climate change in Sweden, including representatives of local and national authorities.
DELIVERABLES: month 24, DELIVERED.

CONTRIBUTOR TO TASK: D1B6
WORK: ~25 km RCA simulation based on the HadAM3 control 1961-1990 time slice and one of the SRES/A2-based scenario time slices for 2071-2100.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: Both simulations are complete and delivered.
PRESENTATIONS:
DELIVERABLES: month 33, DELIVERED.

CONTRIBUTOR TO TASK: D2B1
WORK: assessment of RCM control simulations
ALLOCATED PERSON MONTH THIS PERIOD: 0.4

RESULTS: Additional analysis of the RCAO/HadAM3 control and ECHAM4/OPYC3 control have been performed, including the 25 km high resolution control.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 33, DELIVERED

CONTRIBUTOR TO TASK: D2B2
WORK: assessment of RCM scenarios with HadAM3/A2
ALLOCATED PERSON MONTH THIS PERIOD: 0.4
RESULTS: Further analysis has been conducted, including the 25 km high resolution A2.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 36, DELIVERED

CONTRIBUTOR TO TASK: D2B3
WORK: uncertainty analysis across all RCM simulations
ALLOCATED PERSON MONTH THIS PERIOD: 0.4
RESULTS: Work on the common analysis has continued, both on temperature and precipitation.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 36, DELIVERED

CONTRIBUTOR TO TASK: D2C2
WORK: assessment of RCM scenarios with HadAM3/B2
ALLOCATED PERSON MONTH THIS PERIOD: 0.2
RESULTS: Further analysis has been conducted, both on temperature and precipitation.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 36, DELIVERED

RESPONSIBLE FOR TASK: D3A1
WORK: Interfacing a hydrological model of the Baltic Sea drainage basin with regional and global models.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: This work is complete.
PRESENTATIONS:
DELIVERABLES: month 12, DELIVERED

RESPONSIBLE FOR TASK: D3A2
WORK: Interfacing a hydrological model of the Lule River basin with regional and global models.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: This work is complete.
PRESENTATIONS:
DELIVERABLES: month 12, DELIVERED

RESPONSIBLE FOR TASK: D3A3

WORK: Validation of hydrological components of global/regional climate models, of control simulations (cf. D2C1, D2C2), for the Baltic Sea drainage basin.
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS: This work is complete.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 24, DELIVERED

RESPONSIBLE FOR TASK: D3A4
WORK: Water resources impact studies for the Baltic Sea drainage basin (cf. D3A1) and the Lule River basin (cf. D3A2) based on PRUDENCE-scenarios.
ALLOCATED PERSON MONTH THIS PERIOD: 4.8
RESULTS: Hydrological simulations for a total of 17 climate change scenarios using 9 different RCMs have been completed for the Baltic and Lule River basins.
PRESENTATIONS: Results were presented at the 4th Study Conference on BALTEX in Gudhjem, Denmark 24-28 May 2004, and at the final PRUDENCE meeting in Toledo, Spain 6-10 September 2004.
DELIVERABLES: month 33, DELIVERED

CONTRIBUTOR TO TASK: D7A3
ALLOCATED PERSON MONTH THIS PERIOD: 0.2
WORK: Contribute to the PRUDENCE-presentation of simulations, scenarios and impact studies.
RESULTS:
PRESENTATIONS:
DELIVERABLES: month 36, DELIVERED

GENERAL COMMENTS: Work in all WPs is now complete. Remaining post-project work concentrates on publishing results.

PUBLICATIONS: The following publications are now finalised:

Andréasson, J., Bergström, S., Carlsson, B., Graham, L.P. and Lindström, G., 2004. Hydrological change - climate change impact simulations for Sweden. *Ambio* **33**, 228-234.

Graham, L.P., 2004. Climate change effects on river flow to the Baltic Sea. *Ambio* **33**, 235-241.

Kjellström, E., 2004. Recent and future signatures of climate change in Europe. *Ambio* **33**, 193-198.

PUBLICATIONS: The following article is submitted:

Kjellström, E., Döscher, R., Meier, M., and Banks, H., 2004. Atmospheric response to different sea surface temperatures in the Baltic Sea: Coupled versus uncoupled regional climate model experiments. *Nordic Hydrology*, (submitted).

PUBLICATIONS: The following articles appear in conference proceedings:

Graham, L.P., 2004. Using multiple RCM simulations to investigate climate change effects on river flow to the Baltic Sea. In: H.-J. Isemer (ed.) *Proceedings from Fourth Study Conference on BALTEX*.

Gudhjem, Bornholm, Denmark, 24-28 May 2004. International BALTEX Secretariat 164-165.

Kjellström, E., 2004. Daily variability in temperature and precipitation: recent and future changes over Europe. In: L. Bärring (ed.) *Proceedings from Regional-scale climate modeling WORKSHOP. High-resolution climate modeling: Assessment, added value and applications*. Lund, Sweden, 29 March - 2 April 2004. International BALTEX Secretariat (in press).

Kjellström, E., 2004. Present-day and future precipitation in the Baltic Region as simulated in regional climate models. In: H.-J. Isemer (ed.) *Proceedings from Fourth Study Conference on BALTEX*. Gudhjem, Bornholm, Denmark, 24-28 May 2004. International BALTEX Secretariat 167-168.

Rummukainen, M., 2004. Recent development of a regional air/land surface/sea/ice coupling modeling system, "the RCAO experience". In: H.-J. Isemer (ed.) *Proceedings from Fourth Study Conference on BALTEX*. Gudhjem, Bornholm, Denmark, 24-28 May 2004. International BALTEX Secretariat 148-149.

EMPLOYEES: Active during the period of May 2004 - October 2004: Phil Graham, Erik Kjellström, Anders Ullerstig, Markku Rummukainen, Bengt Carlsson, Johan Andréasson and Sofia Fogelberg, Lars Bärring.

PUBLICATION PLAN: SMHI is lead author for the following articles that will be submitted to the PRUDENCE special issue in Climatic Change:

Graham, L.P., Andréasson, J. and Carlsson, B., 2005a. Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods - a case study on the Lule River Basin. *Climatic Change*, (to be submitted, PSICC).

Graham, L.P., Hagemann, S., Jaun, S. and Beniston, M., 2005b. On interpreting hydrological change from regional climate models. *Climatic Change*, (to be submitted, PSICC).

Kjellström, E., 2005. Present-day and future precipitation in the Baltic Sea region as simulated in a suite of regional climate models. *Climatic Change*, (to be submitted, PSICC).

Kjellström, E. and Bärring, L., 2005. Variability in daily maximum and minimum temperatures: recent and future changes over Europe. *Climatic Change*, (to be submitted, PSICC).

PUBLICATION PLAN: SMHI is a co-author in the following articles that will be submitted to the PRUDENCE special issue in Climatic Change:

Déqué, M., Rowell, D., Lüthi, D., Giorgi, F., Christensen, J.H., Rockel, B., Jacob, D., Kjellström, E., de Castro, M. and van den Hurk, B., 2005b. An intercomparison of regional climate simulations for Europe: assessing uncertainties in model projections. *Climatic Change*, (to be submitted, PSICC).

Jacob, D. et al., 2005. An intercomparison of regional climate models for Europe: design of the experiments and model performance (title and co-authors to be finalized). *Climatic Change*, (to be submitted, PSICC).

PUBLICATION PLAN: SMHI is a co-author in the following articles that have been submitted to other journals:

Déqué, M., Jones, R.G., Wild, M., Giorgi, F., Christensen, J.H., Hassell, D.C., Vidale, P.L., Rockel, B., Jacob, D., Kjellström, E., de Castro, M., Kucharski, F. and van den Hurk, B., 2005a. Global high resolution versus limited area model scenarios over Europe: results from the PRUDENCE project. *Clim. Dynamics*, (submitted).

van den Hurk, B.J.J.M., Hirschi, M., Schär, C., Lenderink, G., van Meijgaard, E., Rockel, B., Hagemann, S., Graham, L.P., Kjellström, E. and Jones, R.G., 2005. Soil control on runoff response to climate change in regional climate model simulations. *J. Climate*, (submitted).

Partner no.: 10

Institution: Universidad Complutense Madrid

Acronym: UCM

Responsibility: UCM is partner in WP 1 and 2 . UCM applies the PROMES model at 50km resolution to 3 sets of Hadley Centre AGCM simulations.

UCM participates in tasks: D1B1, D1B3, D1B7, D2A2, D2B1, D2B2, D2C2.

CONTRIBUTOR TO TASK D1B3
WORK: B2 scenario simulation
ALLOCATED PERSON MONTH THIS PERIOD: 3.4
RESULTS: A new B2 scenario run was finished by February 2004 in order to correct an error in soil physical parameters included in the former one. Furthermore, two 30-years 25km runs (control + A2) with PROMES RCM covering a domain centred in the Iberian Peninsula were accomplished, despite of our group was not committed with this task. A study of precipitation extremes statistics differences between 50km and 25km resolution runs is currently being carried out.
PRESENTATIONS: Results were used in talks on regional climate modelling in Spain, including representatives of national authorities.
DELIVERABLES: Output sent to data base.

CONTRIBUTOR TO TASK: D1B6
WORK: A2 high-resolution simulation
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Despite of our group was not committed with this task in the project's contract, two 30-years 25km runs (control + A2) with PROMES RCM covering a domain centred in the Iberian Peninsula, instead of the whole Europe, were accomplished. A study of precipitation extremes statistics differences between 50km and 25km resolution runs is currently being carried out.
PRESENTATIONS: Results were used in talks on regional climate modelling in Spain, including representatives of national authorities.
DELIVERABLES: Output sent to data base.

CONTRIBUTOR TO TASK: D2B1
WORK: Assessment of the quality of current climate simulation
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: PROMES-RCM present climate summer precipitation results sensitivity to soil parameter values is a specific topic of our analysis. This study is performed by means of two 30 year control simulations with very different land-cover type distributions. A comparison with CRU climatology allowed us to assess the importance of a better representation of land-atmosphere water exchanges for the improvement of summer precipitation simulation in Europe.
PRESENTATIONS: Poster at the EGU Assembly in Nice (April-04). Results were also used in talks on regional climate modelling in Spain, including representatives of national authorities.
DELIVERABLES: Months 25-36

CONTRIBUTOR TO TASKS: D1B7, D2B2, D2B3, D2C1, D2C2

WORK: Assessment of reliability of simulations of current climate and SRES scenarios
ALLOCATED PERSON MONTH THIS PERIOD: 7
RESULTS: The following studies have been carried out related to these tasks, some with PROMES-RCM results only, but most with results from the ensemble of Prudence RCMs: (1) Influence of Soil-Vegetation description in PROMES RCM on future climate conditions. This study is a continuation of the above mentioned TASK D2B1, but looking now at the sensitivity of future scenario summer precipitation changes relative to current climate to soil parameters. (2) A first analysis of a tropical-like cyclonic event simulated in the Mediterranean by PROMES RCM in A2 scenario run has been done, and further detailed analysis of similar processes simulated by other Prudence RCMs A2 scenario run is being made. (3) A modified Köppen climate classification was applied to the results from all of Prudence RCMs present and scenario climate run in order to assess the climate change impact on natural vegetation in Europe. (4) Results from an ensemble of Prudence RCMs have been used to analyse changes in the length and starting of the four year seasons in the A2 scenario relative to control run.
PRESENTATIONS: In Lund and Toledo Prudence project workshops. Results were also used in talks on regional climate modelling in Spain, including representatives of national authorities.
DELIVERABLES: Months 25-36

EMPLOYEES:
Name: Manuel de Castro, Miguel A. Gaertner, Clemente Gallardo, Enrique Sánchez and Elena Padorno

PUBLICATION PLAN:

1. E. Sanchez, C. Gallardo, M.A. Gaertner, A. Arribas and M. Castro. Already published in Global and Planetary Change, 44, 163-180 (2004) “Future climate extreme events in the Mediterranean simulated by a regional climate model: a first approach”.

2. M.Castro, J. Martin-Vide and S. Alonso (it has been edited in 2005) “Current and future climate in Spain”. First Chapter of the “Assessment Report on Climate Change and its Impacts in Spain”, edited by the Spain’s Ministry of Environment.

3. E. Sanchez, C. Gallardo and M.A. Gaertner (to be submitted in February 2005) “Impact of soil parameters in present and future climate”. To be submitted to Climate Dynamics in January 2005.

4. M.Castro, C. Gallardo, K. Jhyla and H. Tournavirta “The use of a climate-type classification for assessing climate change effects in Europe from an ensemble of nine regional climate models”. Submitted to Climate Change special issue.

5. M.A. Gaertner, E. Sanchez, C. Gallardo and M. Castro “A tropical cyclone over the Mediterranean Sea in a climate change scenario simulation with an RCM”. Submitted to Atmospheric Science Letters in November 2004.

6. C. Gallardo, E. Sanchez, M.A. Gaertner and M. Castro (to be submitted in February-March 2005) “Seasonality changes for a future climate scenario in Europe from an ensemble of nine regional climate models”. To be submitted to Climate Research in February 2005.

Partner no.: 11

Institution: Escuela Técnica Superior de Ingenieros Agrónomos, Universidad Politécnica de Madrid
Acronym: ETSIA-UPM
Responsibility:
RESPONSIBLE FOR TASK:
WORK:
ALLOCATED PERSON MONTH THIS PERIOD:
RESULTS:
PRESENTATIONS:
DELIVERABLES:

CONTRIBUTOR TO TASK: WP4 and WP7
WORK: Report on effectiveness of adaptive management options for a restricted range of climate change scenarios. Report on the uncertainty in climate model+crop model outputs related to yield and soil water balance parameters in the Mediterranean region. Dissemination work that will also continue after the end of PRUDENCE.

ALLOCATED PERSON MONTH THIS PERIOD : WP4: 4.75 (third year 9.5) and WP7: 0.67 (third year: 1.34)
RESULTS: expected for month 36 (see comments)
PRESENTATIONS: see below
DELIVERABLES: D4 A4

GENERAL COMMENTS:

1- Applied methodology for impact assessment

The methodology developed and applied for impact assessment in PRUDENCE connects GCM/RCMs to crop simulation models with a geographical information system as organiser for the generation of impact data and map development.
Crop simulation models have proved to be powerful tools for analysing the non-linear effects of climate change in the Iberian Peninsula. Weather data from the RCM climate models and from HadCM3 were the input weather data for the crop models.

There are several ways to introduce climate outputs into the crop models: Method 1 (M1) direct use of outputs from RCMs for both control and future climate scenarios, M2: use of observed current climate or re-analysis climate from ERA-15 (when daily weather data were missing) and for future climate, use of data built with (current or baseline + Δ), Δ being the differences or ratios between future (A2, B2, etc.) and control scenarios, generated by the climate models, and M3: RCM outputs adjusted for observed baseline climate (for both baseline and future conditions).

Although we have explored all these methodologies, we have relied most on the first method because it allowed us to systematise the analysis, maintain the difference in variability between control and future climate and avoid failures in the simulation runs. In the other methods, simulations could not be performed (unless adapted) for all years because of anomalies in the weather data. For example, some days would have daily maximum temperatures lower than the minimum temperatures, others a negative value for rainfall.

2- Yield and other crop model outputs as indicators of climate change impact and sustainability

Yield generated by crop simulation models summarises the effects of the environment during the entire crop cycle. It is accumulated from daily intercepted solar radiation that determines potential growth that is then modulated for the effects of CO_2 concentration, temperature and water availability in the soil. In this way it integrates the non-linear effects of climate change.

Yield is a useful indicator for economic analysis and land use planning. Shoot biomass is a broader indicator for canopy photosynthesis, more closely related to water use or water availability of the crop under rain-fed conditions, and can be used to determine water requirements for irrigated crops. Several crop model outputs, such as the above, are needed for impact assessment, water and land use planning, and in establishing mitigation and adaptation strategies.

Our work has revealed that trends in the responses of these indicators can be more valuable for assessing the impacts than the absolute values themselves.

3- Impacts on a regional scale

It is useful to describe the predicted effects without biological or managerial adaptation in order to present an overview of the uncertainties that arise when various RCMs are linked to the same crop model. Such an analysis shows that effects of climate change vary among regions and crops. Figures 1 and 2 present maps generated using the outputs from the climate models directly into the crop models. Relative yield (future yield A2/control yield) of winter (Figure 1) and spring (Figure 2) wheat are shown for all regions. The climate models included in Figure 1, REMO, RegCM and CHRM RCM, were selected because the range of impacts is representative of all of the RCM + winter wheat simulations that were studied.

The comparison reveals substantially different responses of crops to the climate models, but with some consistent trends. Thus, winter wheat that requires low temperatures to induce flowering (vernalisation) fails to yield if temperatures are mild or rise during the winter. In Figure 1, in the south western regions of Iberia, RCMs + CERES winter wheat predicted crop failure. This response does occur now in some years and will be aggravated under future climate conditions. In fact, farmers are nowadays avoiding this problem by using autumn-sown spring wheat that does not need vernalisation. The RCMs + crop model do reflect this phenomenon either under current or under future climate. This allows for checking the quality of the RCM + model simulations. Effects of climate change in the other regions differ between the RCM + crop model and the three examples chosen represent the three groups of responses found for Iberia. In northern areas, relative yields present variable changes for REMO and RegCM but a general decrease for the CHRM climate scenario (Figure 1). This shows how different projected changes of temperature, rainfall and CO_2 can have compensating effects on crop production.

In the case of spring wheat (Figure 2) similarities are found in the Central Plateau (circle) but other regions with complex orography, enhance the differences among RCMs. Again the examples chosen represent the trends found with all RCMs combined with the same CERES-spring wheat model. Results indicate the possibility of increased yields in regions currently limited by low winter temperatures, such as shown in the maps. The big relative increases occur because simulated yields are small under control climate (some are under 1 t/ha) and small absolute increases in yield are obtained under future A2 scenario.

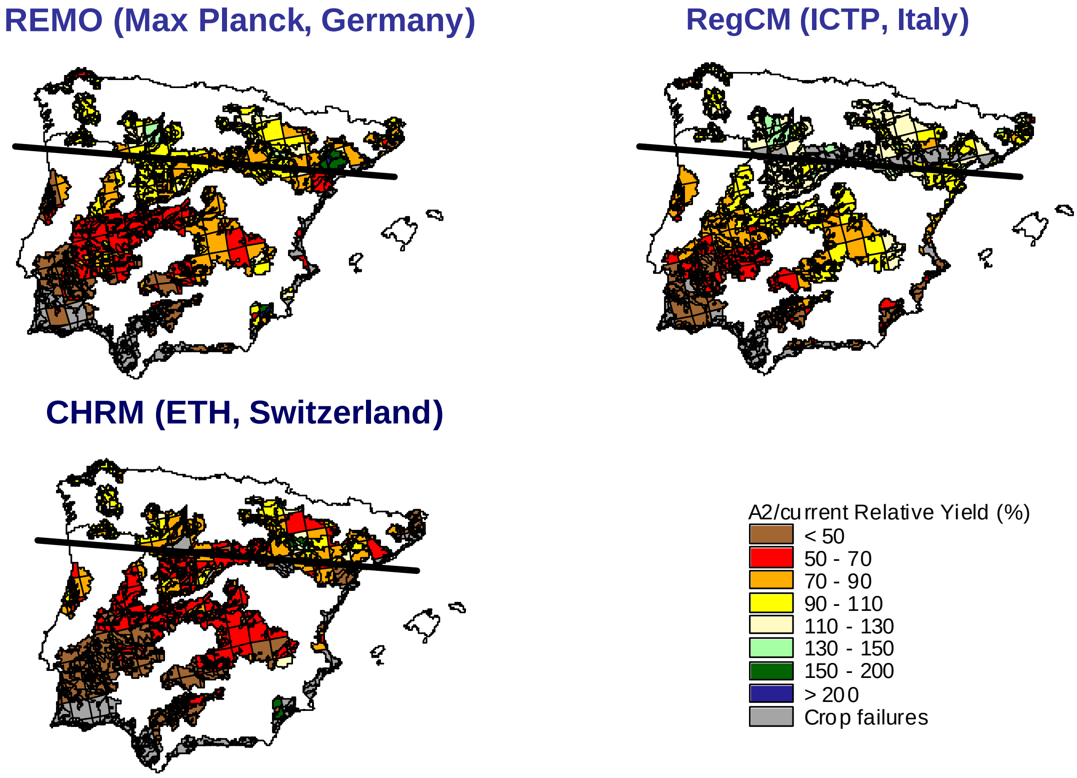


Figure 1. Relative yield of winter wheat sown in autumn obtained using weathe outputs from three RCMs. Vernalisation (low temperature) requirements are not met in current and A2 climate scenarios in south western areas.

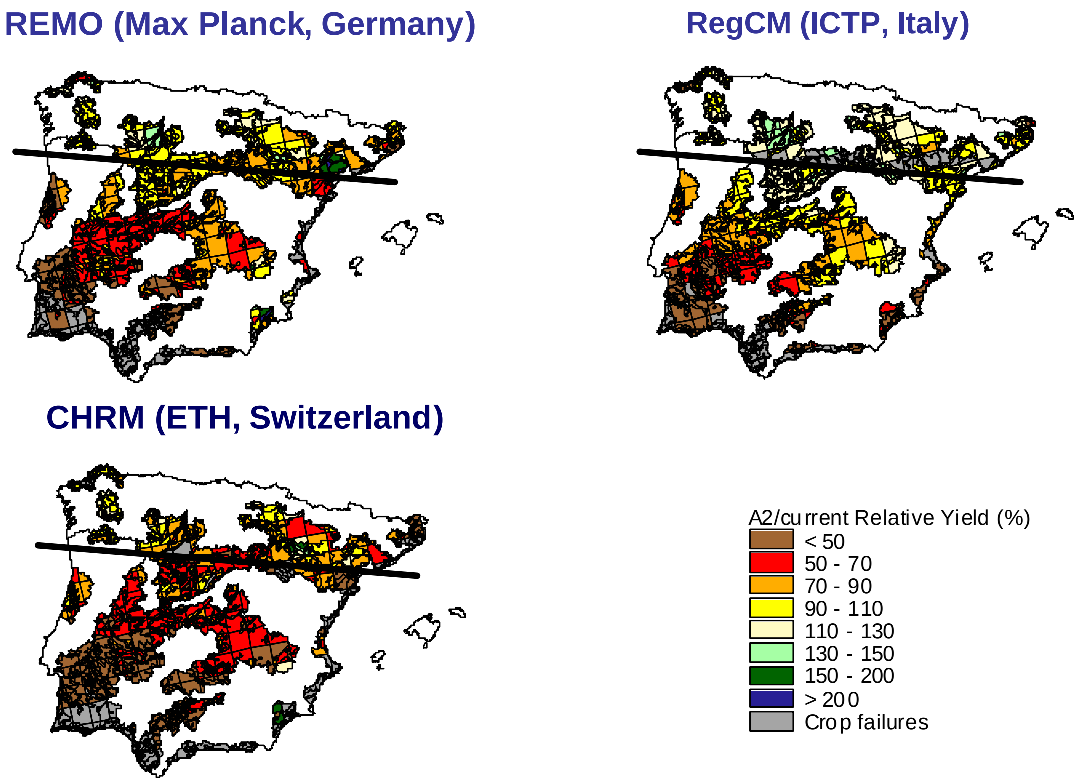


Figure 5. Relative yield of spring wheat sown in autumn obtained using weather outputs from three RCMs. Similar trends are observed in the Central Plateau but other areas reflect the differences among RCMs.

Extended analysis of these results will be presented in papers now being prepared, and will be disseminated to governmental agencies.

4- Uncertainties

Uncertainties are related to all steps in the procedure from climate scenario generation to impact analysis. They are linked to both climate and crop modelling formulations. In the former case, uncertainties are derived from climate variability and future atmospheric emissions; the combination of a single climate model and a single simulation is therefore insufficient to provide the information required for impact assessment. For this reason, several emission scenarios and climate models have been considered in this project to establish the range of uncertainties.

Crop models add additional uncertainties of two types. First, the difference in model response to observed behaviour at those sites where calibration with actual weather data has been made. Second, the use of the models outside the climatic domain in which calibration has been made.

The need for standardising the process and maintaining an equilibrium between spatial scale and quality of the data makes it necessary to synthesise the main processes involved at the crop and cropping systems level. Although the impact models used were crop simulation models that are accepted tools for climate impact evaluation, they do have some shortcomings. Although they are able to reflect, under specified assumptions, the effects of CO_2 increase on photosynthesis and transpiration rates, possible changes in assimilate partitioning are not usually included and the models cannot be calibrated for future projected conditions.

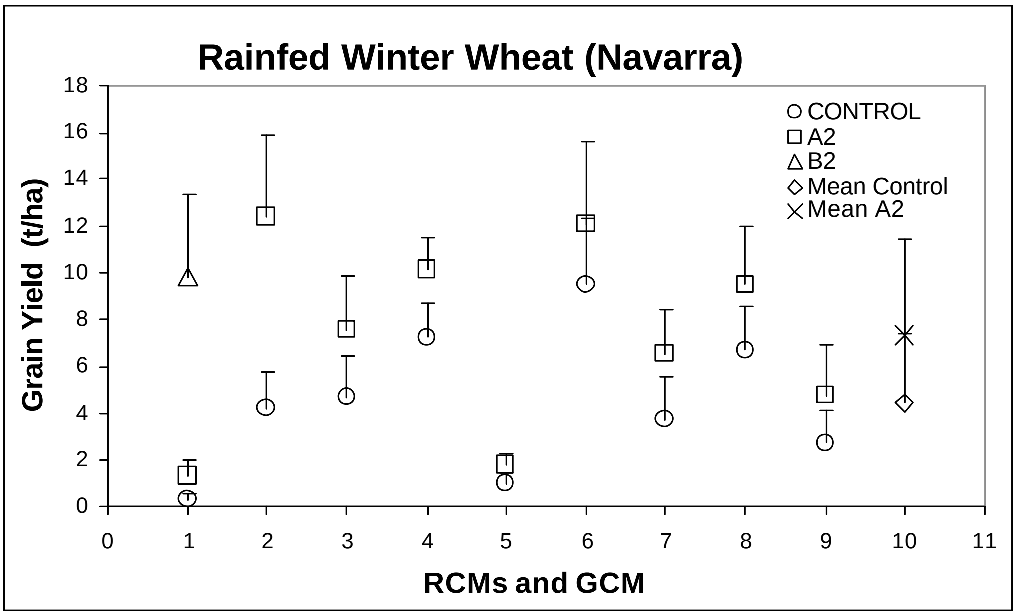


Figure 3. Grain yield of winter wheat simulated with nine RCMs linked to a single crop model, CERES-Wheat. Simulation were done for control (current climate) and A2 scenarios. B2 scenario is shown for climate model 1.
RCMs are: 1: PROMES; 2: HIRHAM; 3: HadRM3H; 4: CLM; 5: CHRM; 6: RegCM; 7: RACMO; 8: ARPÈGE; and 9: AGCM, HadAM3H. Means of all control and A2 simulations are presented as number 10. Standard deviations are represented by one-sided bars.

In order to show some of the uncertainties linked to the overall process of impact evaluation, the yields of winter wheat obtained with one crop model linked to several RCMs are shown in Figure 3. The data correspond to a specific location, Navarra, where CERES-winter wheat had been calibrated and validated with field experiments.

Autumn sown winter wheat in Navarra could be expected to increase yield under the A2 scenario. Low temperatures currently limit biomass accumulation during winter months, so greater CO_2 concentration and temperature in the A2 scenario, together with the less frequent occurrence of frosts at flowering time, is reflected in greater average yields. Absolute values from each of the RCM + crop model simulations vary considerably although the control mean is not significantly different from current yields (4.5-5.0 t/ha). B2 scenario with model (1) predicts an increase in yield that can be interpreted as the consequences of the overriding effect of CO_2, and near optimum temperatures and adequate rainfall, but further analysis is warranted.
Uncertainties are quantified by the standard deviations of control and A2 means from all the RCM + crop model combinations. In the case of this location there is a significant increase of rainfed winter wheat in the A2 scenario.

5- Mitigation and adaptation

It is necessary to distinguish between easy adaptation measures that can be applied gradually by farmers, as change progresses, from those more complex adaptations that are linked to changes in land use, cropping systems management and agricultural policy. Here we will present some of the former measures that can be analysed with the methodology described in this chapter.

The general increase in temperature will have a direct effect on crop growth and development. Crops will develop faster, thus shortening the duration of their growth cycle. If farmers' objectives are to maintain the same growth duration, change to a longer-cycle commercial cultivar can compensate for the faster development rate. Many individual cultivars are already available for grain and other crops. Alternatively, higher temperature may allow earlier sowing, e.g. in the case of maize presented above (Table 1). Under those conditions, a farmer would sensibly seek a longer season cultivar to take advantage of a longer season and a greater yield potential. Choices of crop, cultivar and sowing time provide many management options to new temperature regimes that may increase yield.

Seasonal and annual rainfall variation and change in rainfall intensity will affect the management of rain-fed and irrigated systems. As seen in Figures 1 and 2, the northern, high altitude areas, may have no difficulties in adapting as some projections indicate areas where yields are greater even without adaptation measures. It is mainly in the southern regions where yields are reduced by supra-optimal temperatures that the availability of water will be crucial. Greater temperatures in those areas increase daily evaporative demand and heat stress.

The introduction of fallows, or the need for strategic irrigations, to stabilise crop yields will have to be analysed within an economic perspective. Strategic irrigation may not be economically viable, even in high value crops, and competition from water from other sectors can be expected to increase.
Impact was assessed here with studies on a few reference crops but extrapolation to other crops is possible. In southern areas, fruit trees that currently need low temperatures to induce flowering, will have to be replaced with cultivars with little, or no vernalisation requirements. Experience with maize, a crop with large irrigation requirement, can be readily extended to vegetable crops of similar water use characteristics.

The interdependence of agriculture with other sectors of society such as hydrological resources, production of hydroelectric power (that compete with irrigation), insurance, and, the need to maintain non-agricultural areas for current ecosystems, will induce changes at the cropping system level and the need for more complex analyses.

Table 1. Maize in south western Iberia (Córdoba) cultivated in a Xerorthent soil with irrigation. Direct use of outputs from RCMs is compared with the use of baseline data with Δ values from monthly RCM means. Relative future/control yield is also included. Simulations were done for 30 years for the direct outputs and 15 years when using Δ values.

Irrigated Maize (kg/ha)	PROMES		HIRHAM		RegCM	
	Avge	CV	Avge	CV	Avge	CV
Control	8093	14	9846	10	8883	10
A2	6670	16	6729	9	8208	15
Rel (%)	82		60		78	
Baseline	8595	11	8595	11	8595	11
Baseline+Δ	4882	46	6437	12	6956	25
Rel (%)	57		75		81	

Avge: mean yield ; CV: coefficient of variation (%)

5- Discussion and conclusions

The use of several high-resolution climate models linked to impact or crop models enabled us to quantify crop parameters that can be used as indicators for impact analysis. Trends can be established for some regions of the Peninsula but divergences arise among RCM + crop model combinations.

In general, the main positive effects are linked to milder temperatures in winter that can be offset by seasonal and annual changes in rainfall. Together these changes can generate important impacts on the productivity of agricultural systems. Southern parts of the Peninsula that present contradictory impacts depending on the climate models used will need further study. It is a complex region for climate simulation because it is surrounded by the sea, and has several mountain ranges within a small area.

The uncertainties quantified here, arise from both the RCMs and the extrapolation of the crop model into agricultural areas for which it has not been calibrated. Uncertainties evaluated through the standard deviations of means of RCM + crop model (Figure 3), with a wide range of RCMs, varied among regions.

The impact study was centred on reference crops that represent chemically and anatomically different photosynthetic systems, (C3 for wheat and C4 for maize), enabling a first step quantitative evaluation of impact trends of the productivity across seasons of main agricultural crops. This is a preliminary step required before considering cropping systems and economic conditions. Finally, more regional detail is necessary for the Iberian Peninsula because its orography, latitude and being almost an island, increase the uncertainties not only of current climate simulations but also of future projections.

DISSEMINATION

WMO/COST Action Expert Meeting on Weather, Climate and Farmers held in Geneva from 15 to 18 November 2004.

Mínguez, M.I., Ruiz-Ramos, M., Díaz-Ambrona, C., Quemada, M. and Sau, F. 2004. The need for high resolution climate models in the Iberian Peninsula for agricultural impact studies.

Oficina Española de Cambio Climático (MIMAM)
Governmental agency for Climate Change

Mínguez Tudela, M.I., Ruíz Mantecón, A., Estrada Peña, A., Ruiz-Ramos, M., Hernández Díaz-Ambrona, C., Quemada Sainz-Badillos, M., Sau Sau, F. and Lavín González, P. (in press). Impactos sobre el sector agrario. In: Evaluación de los Impactos del Cambio Climático en España (ECCE) Chapter 10. Oficina Española de Cambio Climático (MIMAM)

PUBLICATIONS:

<u>Scientific papers:</u>

Related with crop models:

Boote, J., Mínguez, M.I. and Sau, F. 2002. Adapting the CROPGRO-legume model to simulate growth of faba bean. Agronomy Journal 94: 743-756.

Díaz-Ambrona, C.G.H., Mínguez, M.I. (under revision). Rotation modelling for generating sustainability indicators in a Mediterranean rain-fed cropping system. Agricultural Systems.

Sau, F., Boote, K.J., McNair Bostick, W., Jones, J.W. and Mínguez, M.I. 2004. Testing and improving evapotranspiration and soil water balance of the DSSAT crop models. Agronomy Journal 96: 1243-1257.

Related to climate change impacts:

Mínguez, M. I., Ruiz-Ramos, M., Díaz-Ambrona C.H. and Quemada M. (in press). Productivity in agricultural systems under climate change scenarios. Evaluation and adaptation. Journal de Physique. ERCA lectures. (*)

Mínguez, M.I., Ruiz-Ramos, M., Díaz-Ambrona, C., Quemada, M. and Sau, F. (in preparation). Impact studies in areas with complex orography and highly variable rainfall. the need for high-resolution climate models in the Iberian Peninsula. Climatic Change (*)

Mínguez, M.I., Ruiz-Ramos, M., Díaz-Ambrona, C., Quemada, M. and Sau, F. (in preparation). Regionalisation studies of impacts of climate change in areas with complex orography. Field Crops Research(*)

<u>Congresses:</u>

Quemada, M. and Tajadura, N. 2001. Validation of CERES-wheat and CERES-barley under Mediterranean conditions. II International Symposium on modelling Cropping Systems. Florencia, Italia. July 2001. European Society for Agronomy. Poster. Book of abstracts pp: 77-78

Sau, F., Boote, K.J., Bostick, W. McN., Jones, J.W. and Mínguez, M.I. 2002. Testing and improving soil water balance of DSSAT 3.5 models. ESA VII Congress, 15-18 July, Córdoba, Spain.

Mínguez, M. I., Ruiz-Ramos, M., Díaz-Ambrona, C.H., Quemada, M. and Sau, F. 2004. PRUDENCE: a project seeking to minimise uncertainties in the evaluation of climate-change impacts on agriculture in Mediterranean areas. 4th International Crop Science Congress, 26 September- 1 October, Brisbane, Australia.(*)

Invited conferences:

Mínguez, M.I., Díaz-Ambrona, C.H. and Quemada, M. 2003. Climate Change Impacts on Spanish Farming Systems.
Faculty of Agriculture, University of Hebei. Academy of Agricultural Sciences. Shanghai.

Dissemination:

WMO/COST Action Expert Meeting on Weather, Climate and Farmers held in Geneva from 15 to 18 November 2004.

Mínguez, M.I., Ruiz-Ramos, M., Díaz-Ambrona, C., Quemada, M. and Sau, F. 2004. The need for high resolution climate models in the Iberian Peninsula for agricultural impact studies

Mínguez Tudela, M.I., Ruíz Mantecón, A., Estrada Peña, A., Ruiz-Ramos, M., Hernández Díaz-Ambrona, C., Quemada Sainz-Badillos, M., Sau Sau, F. and Lavín González, P. (in press). Impactos sobre el sector agrario. In: Evaluación de los Impactos del Cambio Climático en España (ECCE) Chapter 10. Oficina Española de Cambio Climático (MIMAM)

(*) last semester

EMPLOYEES (Drs):

M. Inés Mínguez Tudela
Carlos Hernández Díaz Ambrona
Miguel Quemada Sainz-Badillos
Federico Sau Sau (Universidad de Santiago de Compostela)
Margarita Ruiz-Ramos

Students:
Elena Parras Castrillo (supported by the Ministry of Education and Science)
Rodrigo González Lera (Ministry of Education and Science)

PUBLICATION PLAN:

Impact studies being the last step in the project, our publication plan will extend to the next years.

Impact analysis will enable us to prepare scientific papers for specialised scientific journals (Climate Change, Field Crops Research, Agronomy Journal, etc.).

Dissemination: A Report for a Governmental Agency (Spanish Office of Climate Change (MIMAM) will also be prepared for September 2004. “Evaluación de los Impactos del Cambio Climático en España” (ECCE). It is a review on the state of impact analysis on Spanish Agriculture. The aim of the report is to present to this Governmental Agency what has been accomplished, what are the main uncertainties and what should be the future work. This will lead to future applied research in the area.

DISSEMINATION AND DEVELOPMENT AFTER PRUDENCE:

Our objective is to establish a development project with the “Centro de Estudios y Desarrollo Experimental de Obras Públicas” CEDEX (www.cedex.es) linked to the Ministry of Fomento, for irrigation planning. We have collaborated on studies on climate change impact on irrigation requirement and plan to renew collaboration with the Department of Irrigation.
We will supply methodology and information on the evaluation of changes and optimisation of irrigation requirements.

Partner no.: 13

Institution: Danish Institute of Agricultural Sciences
Acronym: **DIAS**
Responsibility: DIAS is partner in WP 4 and 7. DIAS is the PI on WP4.

DIAS applies 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 model will be applied to a crop rotation typical for arable farming in Denmark and for a range of typical Danish soil types using regional climate data for Denmark.

DIAS is responsible for tasks: D4B1, D4B2, D4B3
DIAS participates in tasks: D7A4

RESPONSIBLE FOR TASK: D4B1
WORK: Soil-plant-atmosphere model for the North European region verified for adaptive responses under current climate
RESULTS:
The DAISY soil-plant-atmosphere model was used to simulate crop production and soil carbon (C) and nitrogen (N) turnover for three arable crop rotations (Table 1) on a loamy sand in Denmark under varying temperature, rainfall, atmospheric CO_2 concentration and N fertilization. The crop rotations varied in proportion of spring sown crops and use of N catch crops (ryegrass). The effects on CO_2 emissions were estimated from simulated changes in soil C. The effects on N_2O emissions were estimated using the IPCC methodology from simulated amounts of N in crop residues and N leaching. Simulations were carried out using the original and a revised parameterization of the soil C turnover. The use of the revised model parameterization increased the soil C and N turnover in the topsoil under baseline conditions resulting in an increase in crop N uptake of 11 kg N ha^{-1} y^{-1} in a crop rotation with winter cereals and a reduction of 16 kg N ha^{-1} y^{-1} in a crop rotation with spring cereals and catch crops. The effect of increased temperature, rainfall and CO_2 concentration on N flows was of the same magnitude for both model parameterizations. Higher temperature and rainfall increased N leaching in all crop rotations, whereas effects on N in crop residues depended on use of catch crops. The total greenhouse gas (GHG) emission increased with increasing temperature.

Table 1. Arable crop rotations used in the simulations. Undersown ryegrass is used as catch crop in rotation 3. The straw from fields 1 and 2 were incorporated, whereas the straw from fields 3 and 4 were removed. The standard nitrogen fertiliser rates (kg N ha^{-1} yr^{-1}) are shown in brackets.

Field	Rotation 1		Rotation 2		Rotation 3	
1	Winter barley	(142)	Spring barley	(115)	S.barley/grass	(115)
2	Winter rape	(167)	Spring rape	(112)	Spring rape	(112)
3	Winter wheat	(116)	Winter wheat	(124)	Winter wheat/grass	(124)
4	Spring barley	(110)	Spring barley	(110)	S.barley/grass	(110)

The increase in total GHG emission was 66-234 kg CO_2-eq ha^{-1} y^{-1} for a temperature increase of 4°C. Higher rainfall increased total GHG emissions most in the winter cereal dominated rotation. An increase in rainfall of 20% increased total GHG emissions by 11-53 kg CO_2-eq ha^{-1} y^{-1}, and a 50% increase in atmospheric CO_2 concentration decreased emissions by 180-269 kg CO_2-eq ha^{-1} y^{-1}. The total GHG emissions increased considerably with increasing N fertilizer rate for a crop rotation with winter cereals, but remained unchanged for a crop rotation with spring cereals and catch crops. The simulated increase in GHG emissions with global warming can be effectively mitigated by including more spring cereals and catch crops in the rotation.

The effect of climate change on productivity and N-losses as influenced by N-fertilisation were analysed for continuous winter wheat cropping for a loamy sand soil in Denmark. However, baseline climate was taken from two sites in Denmark (Fig. 1). Jyndevad represents a site in Western Denmark with high rainfall, whereas Roskilde represents a site in Eastern Denmark with lower rainfall. The DAISY model was run for 40-year period using climate data from 1961 to 2000. However, results were taken from the last 32 years of the run.

Increasing atmospheric CO_2 concentration increases crop productivity, yield and also the optimal N fertilisation level. This results in a reduction in grain N concentration, which cannot be compensated for by increasing N fertiliser. An increase in rainfall increases yield more at Roskilde than at Jyndevad due to the higher baseline rainfall at Jyndevad. This has a small effect on optimal N fertilisation rate. A temperature increase of 4°C reduces N yield, but without major effects on optimal N-yield.

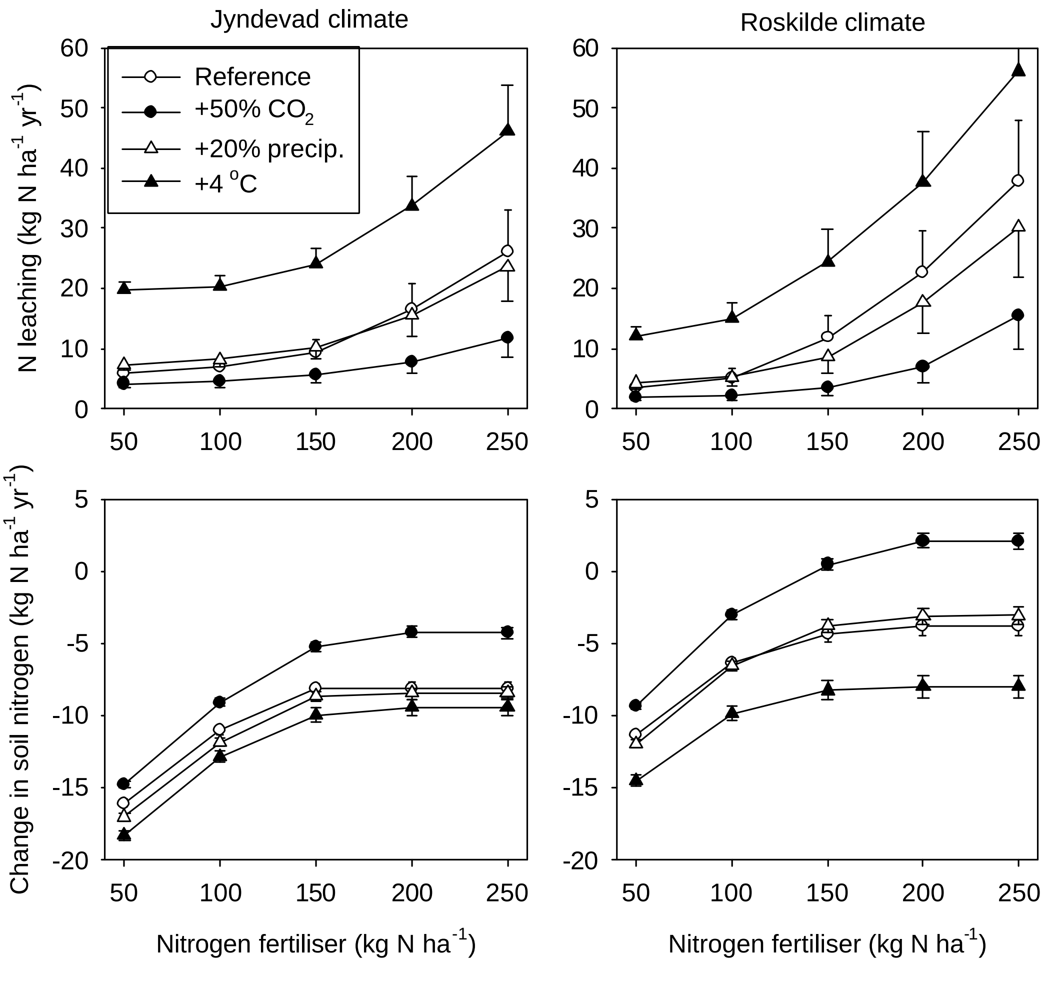


Figure 1. Response of simulated mean N leaching and change in soil N content of a winter wheat cropping system on a loamy sand soil for two climates in Denmark (Jyndevad and Roskilde) to changes in atmospheric CO_2 concentration, precipitation and temperature. Straw was removed from the field, and sowing was delayed with higher temperatures. The vertical lines show the standard errors.

Simulated N-leaching was found to increase with increasing N-fertiliser rate, but there was also large effects of changes in CO_2 concentration and temperature on N-leaching (Fig. 1). The effect of change in rainfall was considerably smaller, and at high N-fertiliser rate there was even a small reduction in N-leaching due to increased N-uptake with increasing rainfall.

ALLOCATED PERSON MONTH THIS PERIOD (Nov 2003-Oct 2004): 0.0
PRESENTATIONS:

Christensen, B.T. & Olesen, J.E. (2003). Klimaændringer og landbrugets planteproduktion. *Naturens Verden* **86**, 2-11.

Olesen, J.E. (2004). Climate change and CO_2 effects on productivity of Danish agricultural systems. *Journal of Crop Improvement* **13**, 257-274.

Olesen, J.E., Rubæk, G., Heidmann, T., Børgesen, C.D. & S. Hansen (in press). Effect of climate change on greenhouse gas emission from arable crop rotations. *Nutrient Cycling in Agroecosystems* **70**, 147-160.

Olesen, J.E., Rubæk, G. & Heidmann, T. (2003). Effects of climate change and CO_2 on productivity and nitrogen cycling of arable crop rotations. In: Braun, P. (ed.) Agriculture, climate change and economic consequences - from description to mitigation. Proceedings of EC-sponsored workshop under the European Phenological Network, Royal Veterinary and Agricultural University. p. 8.

DELIVERABLES:
The model has been successfully validated and set up for the further analyses.

RESPONSIBLE FOR TASK: D4B2
WORK: Report on response of nitrogen cycling for a wide range of climate change scenarios.
RESULTS:
A methodology for importing climate model output data has been designed. The Daisy model has been applied to climate data from nine sites across Europe and a simple/empirical function of climate effects on nitrate leaching has been derived for use in European mapping studies together with FEI.

Different methods of downscaling the GCM/RCM outputs have been tested. These tests include applying the impact (crop) model to the following combinations of data:

1. The observed baseline climate data, which for some areas (e.g. Spain) may be based on reanalysis data.
2. The simulated GCM/RCM outputs directly (for both baseline and future conditions).
3. The observed baseline climate data adjusted for the mean monthly differences or ratios between simulated GCM/RCM outputs for the future and baseline climates (anomalies).
4. The simulated GCM/RCM outputs adjusted for observed baseline climate (for both baseline and future conditions).

The methods were tested using climate from two sites in Denmark; Jyndevad in western Denmark and Roskilde in eastern Denmark. All tests were performed for a loamy sand soil and for continuous winter wheat cropping. The simulation model was run for 40 years, but results were taken for the last 32 years only. All simulations were run for five different N fertilisation rates from 0 to 250 kg N/ha. This was used to estimate optimal N fertiliser rate and the yield and N-leaching at optimal fertiliser rate. The simulated results for the observed series showed a skewed distribution with the largest number of years giving yields of about 10 t/ha (Figure 2). The use of the RCM control run gave a much more uniform distribution of yields, and on average too low yields. When the RCM-control data was adjusted to the absolute level of temperature and precipitation in the observed series, grain yields were generally increased, but not to the level of the observed series. The results of the different downscaling methods for the scenario runs showed similar tendencies, and in conclusion the output of the RCM models are not yet a stage where they can be used directly for feeding the Daisy simulation model. In stead the RCM scenario results were downscaled by adjusting the observed climate series.

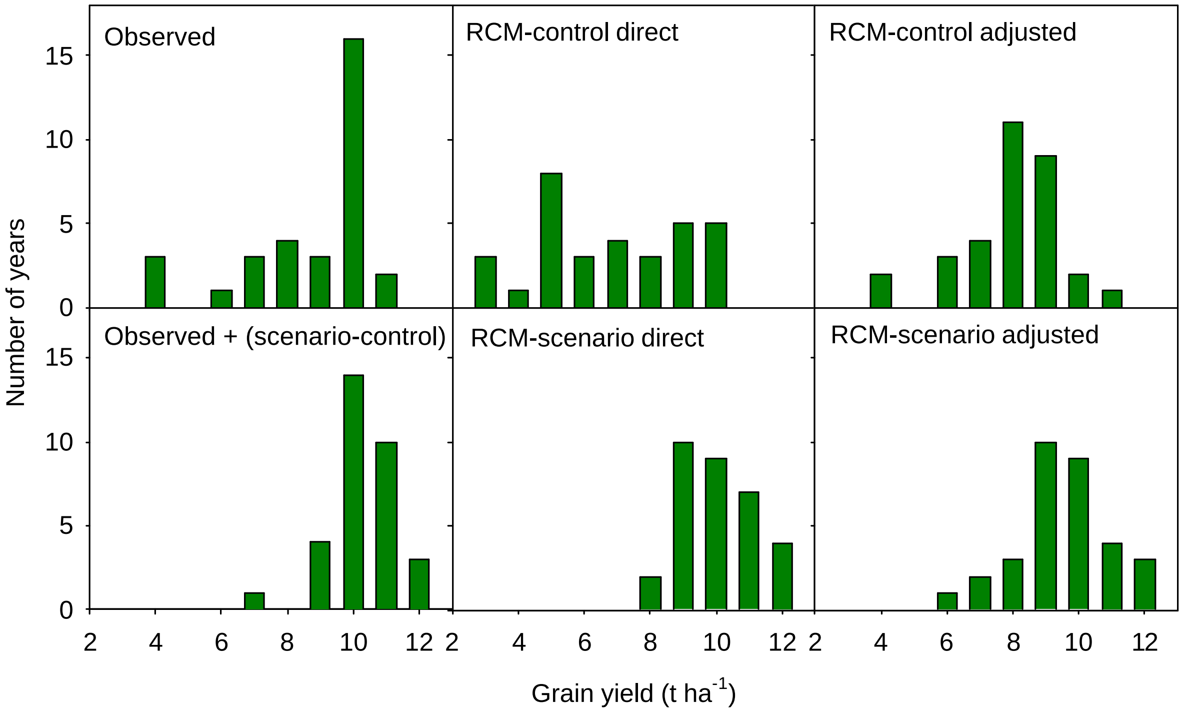


Figure 2. Simulated frequency distribution of annual yields of winter wheat at Jyndevad for a loamy sand soil for observed data and control and scenario runs of the HIRHAM (50 km) RCM for different downscaling methodologies.

Table 2. Simulated mean increase in grain yield of winter wheat and nitrate leaching from continuous winter wheat at optimal fertiliser rate for different model for the A2 scenario for 2071-2100.

		Yield increase (t/ha)		Increased N leaching (kg N/ha)	
Driving data	Model	Jyndevad	Roskilde	Jyndevad	Roskilde
-	HadAM3H	1.8	2.4	10	-5
HadCM3 A2	Arpège	1.2	3.0	10	-2
HadAM3H A2	HadRM3H	1.7	2.8	7	-3
HadAM3H A2	CLM	0.8	2.9	11	1
HadAM3H A2	CHRM	2.0	3.5	1	-9
HadAM3H A2	RegCM	1.7	3.0	9	-2
HadAM3H A2	RACMO	1.1	2.6	11	-0
HadAM3H A2	REMO	1.3	2.7	6	-4
HadAM3H A2	RCAO	1.2	2.9	7	-4
HadAM3H A2	RCAO, high res.	1.1	2.6	9	-3
HadAM3H A2	HIRHAM	1.0	2.3	9	-1
HadAM3H A2	HIRHAM, high	0.9	2.2	10	1

	res.				
HadAM3H A2	HIRHAM	0.7	1.9	8	3
HadAM3H A2	HIRHAM	0.6	2.0	11	0
HadAM3H A2	PROMES	2.4	3.6	5	-4
HadAM3H sst	HIRHAM	1.0	2.6	10	3
ECHAM/OPYC A2	HIRHAM	1.2	2.3	13	1
HadAM3P	HadRM3P	1.7	2.9	5	-5
HadAM3P	HadRM3P	1.6	2.7	8	-2
HadAM3P	HadRM3P	1.5	2.7	7	-2

The results of applying the model to a range of different RCM shows a general consistency in results between different RCMs and a larger variation between results caused effect of current climatic differences than of the variation between RCMs (Table 2). The grain yield increases were thus considerably larger for the Roskilde compared with the Jyndevad climate, and the increases in N leaching correspondingly lower. This probably primarily reflects differences in the precipitation climate.

ALLOCATED PERSON MONTH THIS PERIOD (Nov 2003-Oct 2004): 5.5

PRESENTATIONS:

Olesen, J.E. & Heidmann, T. (submitted). Nitrogen cycling of a winter wheat cropping system under climate change in Denmark. *European Journal of Agronomy*

Olesen, J.E., Rubæk, G. & Heidmann, T. (2004). Impacts of climate change on nitrogen cycling in winter wheat in Denmark using different regional climate models. Danish Institute of Agricultural Sciences. Internal report.

Olesen, J.E., Rubæk, G. & Heidmann, T. (in prep). Climate change and CO_2 affect crop productivity and nitrogen cycling in arable crop rotations. *Global Change Biology*

DELIVERABLES:

A report on the response of nitrogen cycling to climate change scenarios has been produced, and a paper in an international journal is in preparation.

RESPONSIBLE FOR TASK: D4B3

WORK: Report on effectiveness of adaptive management options and effect on mitigation strategies for a restricted range of climate change scenarios.

RESULTS:

The model was applied to three different crop rotations varying in proportion of winter crops and catch crops (Table 1). The model was applied to climate data from two sites in Denmark and to two different soil types (Table 3). In all cases the simulated increased in N leaching under the A2 scenario could the reduced considerably by changing the crop rotation from being dominated by winter cereals to spring cereals, in particular in combination with the use of catch crops. However, for the Roskilde climate this resulted in a smaller increase in grain yields compared with the winter cereal dominated crop rotation.

Table 3. Simulated mean increase in grain yield and nitrate leaching of three different rotations (Table 1) as average of 12 RCM models for the A2 scenario for 2071-2100.

Climate station	Soil type	Crop rotation	Yield increase (t/ha)	N leaching increase (kg N/ha)
Jyndevad	Loamy sand	R1	-0.24	36

		R2	0.12	20
		R3	-0.14	14
	Sandy loam	R1	-0.06	33
		R2	0.07	12
		R3	-0.15	6
Roskilde	Loamy sand	R1	0.66	25
		R2	0.74	10
		R3	0.31	7
	Sandy loam	R1	0.69	22
		R2	0.67	8
		R3	0.16	3

ALLOCATED PERSON MONTH THIS PERIOD (Nov 2003-Oct 2004): 5.0
PRESENTATIONS:
Olesen, J.E., Rubæk, G. & Heidmann, T. (2004). Impacts of climate change on nitrogen cycling in cereal crop rotations in Denmark using different regional climate models. Danish Institute of Agricultural Sciences. Internal report.
Olesen, J.E. et al. (in prep). Uncertainties in projected impacts of climate change on European agriculture, forestry and ecosystems based on scenarios from regional climate models. *Climatic Change*

DELIVERABLES:
A report on the adaptive management strategies and effect on mitigation strategies has been produced, and a paper in an international journal is in preparation.

CONTRIBUTOR TO TASK: D7A4
WORK: A summary presentation of results.
RESULTS:
The results of the project have been presented broadly in Denmark and also formed the basis for an entry in an international Encyclopedia. During the preparation of a new Aquatic Action Plan in Denmark, the results of PRUDENCE was included in a report on the interaction of climate change and agricultural effect on the aquatic environment as a basis for policy decisions on further regulations of agriculture to reduce environmental impacts.

A Nordic seminar on "Adaptation of crops and cropping systems to climate change" is being organised in November 2005, and this will form the basis for a wider communication of PRUDENCE impacts results among agricultural researchers and advisors.

ALLOCATED PERSON MONTH THIS PERIOD (Nov 2003-Oct 2004): 2.0
PRESENTATIONS:
Olesen, J.E. (2004). Crops and environmental change. In R.M. Goodman (Ed.) Encyclopedia of Plant and Crop Science, p. 370-373.
Olesen, J.E., Petersen, S.O., Gyldenkærne, S., Mikkelsen, M.H., Jacobsen, B.H., Vesterdal, L., Jørgensen, A.M.K., Christensen, B.T., Abildtrup, J., Heidmann, T. & Rubæk, G. (2004). Jordbrug og klimaændringer - samspil til vandmiljøplaner. *DJF rapport Markbrug* nr. 109.

DELIVERABLES:
The deliverables include the presentations and reports as listed above including discussions with journalists and policy makers.

GENERAL COMMENTS:
The DAISY modelling system has been tested with different parameterisations of the soil organic matter model and a new crop model including effects of CO_2 response to crop growth has been

implemented. The model has been used to analyse the effect of changes in individual climate variables (temperature, rainfall and CO_2 concentration) for two sites in Denmark and for four different soil types. The results for effects on crop yield were in general agreement with results reported in literature. Temperature and CO_2 had very contrasting effects on nitrate leaching, and some of the effect of temperature was due to adaptation in sowing time of winter cereals to increases in temperature.

The model was applied to the HIRHAM RCM output to test different downscaling methods. The results show a considerably bias in simulated yields and N leaching when the outputs of the RCM were applied directly to the Daisy model. There is therefore a need to downscale the RCM output using an appropriate methodology.

Results of applying results of a range of RCM model output show a smaller variation in simulated yields and N leaching between different RCM's than between application at different sites with variation in current precipitation climate. It is therefore very important to consider not only variation between different RCMs, but also the regional variation in current climate and soils.

PUBLICATIONS:

Olesen, J.E. (2004). Climate change and CO_2 effects on productivity of Danish agricultural systems. *Journal of Crop Improvement* **13**, 257-274.
Olesen, J.E. (2004). Crops and environmental change. In R.M. Goodman (Ed.) Encyclopedia of Plant and Crop Science, p. 370-373.
Olesen, J.E., Rubæk, G., Heidmann, T., Børgesen, C.D. & S. Hansen (in press). Effect of climate change on greenhouse gas emission from arable crop rotations. *Nutrient Cycling in Agroecosystems* **70**, 147-160.
Olesen, J.E., Rubæk, G. & Heidmann, T. (2003). Effects of climate change and CO_2 on productivity and nitrogen cycling of arable crop rotations. In: Braun, P. (ed.) Agriculture, climate change and economic consequences - from description to mitigation. Proceedings of EC-sponsored workshop under the European Phenological Network, Royal Veterinary and Agricultural University. p. 8.
Christensen, B.T. & Olesen, J.E. (2003). Klimaændringer og landbrugets planteproduktion. *Naturens Verden* **86**, 2-11.
Olesen, J.E., Petersen, S.O., Gyldenkærne, S., Mikkelsen, M.H., Jacobsen, B.H., Vesterdal, L., Jørgensen, A.M.K., Christensen, B.T., Abildtrup, J., Heidmann, T. & Rubæk, G. (2004). Jordbrug og klimaændringer - samspil til vandmiljøplaner. *DJF rapport Markbrug* nr. 109.
Olesen, J.E., Rubæk, G. & Heidmann, T. (2004). Impacts of climate change on nitrogen cycling in winter wheat in Denmark using different regional climate models. Danish Institute of Agricultural Sciences. Internal report.
Olesen, J.E., Rubæk, G. & Heidmann, T. (2004). Impacts of climate change on nitrogen cycling in cereal crop rotations in Denmark using different regional climate models. Danish Institute of Agricultural Sciences. Internal report.
Olesen, J.E. & Heidmann, T. (submitted). Nitrogen cycling of a winter wheat cropping system under climate change in Denmark. *European Journal of Agronomy*

EMPLOYEES:

Name: Jørgen E. Olesen, Tove Heidmann, Christen D. Børgensen, Gitte Rubæk, Mette B. Greve.

PUBLICATION PLAN:

Olesen, J.E. et al. (in prep). Uncertainties in projected impacts of climate change on European agriculture, forestry and ecosystems based on scenarios from regional climate models. *Climatic Change*

Olesen, J.E., Rubæk, G. & Heidmann, T. (in prep). Climate change and CO_2 affect crop productivity and nitrogen cycling in arable crop rotations. *Global Change Biology*

PLANS FOR THE NEXT PHASE:

The remaining papers for international journals will be completed and submitted.

Partner no.: 14

Institution: Risø national Laboratory
Acronym: **Risoe**
Responsibility: WP6

Contributor to D6A1, D6A2, D6A3, and D6A4

During the period Risoe has developed a conceptual framework for linking detailed climate change modelling results provided by PRUDENCE partners with socio-economic analysis, and has based on this conducted a micro-level and a macro-level assessment of the economic consequences of climate change for European agriculture. More details about these activities are given in the following. Finally Risoe has worked on two journal papers to a special issue of climate change with joint authorships with WP4 and WP5.

Development of a conceptual framework

Risoe has developed a working paper titled Climate Change Impacts and Adaptation Analysis – How to Link Physical Climate Data and Economic Studies.

The paper recognises that there are a number of structural and conceptual differences between the information provided by climate change models and the inputs that are needed in economic policy analysis, and this implies that physical climate modelling and economic analysis not fully benefit from work from other disciplines. In this way, some of the detailed information generated by climate modelling studies are not well defined and targeted seen from a policy perspective, and economic studies tend to draw conclusions based on too general and aggregate climate information.

Based on these observations the paper presents a framework for the establishment of a link between studies conducted by different disciplines, in order to increase the quality and relevance of climate modelling and economic assessments and in this way to guide future research efforts. This is done through a short introduction of economic concepts applied to climate change impact and adaptation policy assessment, and to illustrate how these concepts can be used in relation to case study material that has been considered by various project partners in the PRUDENCE project. This leads up to a number of conclusions about how climate change information and economic analysis can be coupled. The case material reviewed here includes climate change impacts of the profitability of agricultural investment decisions, health impacts of heat waves, and climate change impacts on hydrological systems and hydropower production in Scandinavia.

Microlevel study of climate change impacts on European agriculture

Risoe has conducted a detailed assessment of climate change impacts on wheat production distribution in Danish regions. An econometric model based on farm enterprise surveys have been linked with Prudence DMI HIRHAM High resolution-model/Hadleys HadAM3H A2 scenarios for Europe.

The model has been used to estimate the relationship between production inputs, soil conditions, management practices, and temperature and precipitation and wheat yields, and it shows up that regional and time specific climate variations are major factors behind production outputs. In this way linking detailed farm surveys and climate data provides key information to the assessment of vulnerabilities and adaptation strategies.

The wheat yield has been modeled with an econometric model based on farm level information on production inputs, management practices, soil quality, and climate conditions. The crop yield y is modeled as

$$y = f\left[f_1\left(x^1, y_0, e^1\right), \ldots, f_m\left(x^m, y_{m-1}, e^m\right)\right]$$

where
y is the yield
x is production inputs
e represent weather impacts on the production process f
and subscript 1,…,m indicate production steps up to the harvest at m

The model has been verified through a comparison of actual yield distribution in the period 1992 to 2003 and simulated yield distribution based on actual agricultural and meteorological data. The estimated results for 1992 to 2003 seem to fit the actual wheat production reasonably well despite that the estimated distribution is a little bit more centered than the actual.

It is seen that the mean of the forecasted yields is lower than the mean of the presently observed yields. The mean of the forecasted distribution is approximately 13% lower than the mean of the current wheat yields. This is in line with other findings for wheat yields in a Danish climate.

Macro-level study of climate change impacts on European agriculture

Climate Change Impacts on Agricultural outputs in Europe and Economic Feedbacks from the World Market has been studied in a collaboration between Risoe and International Institute of Applied System Analysis, IIASA.

The interaction between climate change, agricultural production, agricultural policy and economic feedbacks from agricultural markets are examined in a scenario study for Europe. The economic analysis consists of a base case, business as usual scenario, and two counterfactual scenarios, a liberal market-oriented scenario and an environment-oriented scenario. In addition, the study allows for a comparative analysis of different scales of climate information, from a meso and a higher resolution scale climate model. The exercise gives insight into whether the use of finer scale climate information in climate change assessments will lead to different economic impact estimates relative to assessments done based on larger scale data.

The sensitivity of agro-ecosystems to climate change has been assessed with the FAO/IIASA Agro-ecological Zones (AEZ) model in conjunction with IIASA's modeling framework for analyzing regional and world food systems, referred to as the Basic Linked System (BLS). The BLS comprises a representation of all major economic sectors, and views national agricultural systems as embedded in national economies, which in turn interact with each other at the international level. The agro-ecological effects of climate change on food production systems are introduced to the BLS model as changes in the national or regional production relationships per commodity.

Allocated person months this period:

Deliverables: D6A2, and contributions to D6A3 and D6A4

Employees: Kirsten Halsnæs, Molly Hellmuth, Jesper Kühl, subcontract with IIASA.

Publication plan: Two papers submitted to Climatic Change

Partner no.: 15

Institution: University of Fribourg
Acronym: **Uni FR**
Responsibility: Responsible for D3B4, D5A3, D5A5. Contributor to D5A4

RESPONSIBLE FOR TASK: D5A3
WORK: Assessing changes in frequency and intensity of wind-storms
ALLOCATED PERSON MONTH THIS PERIOD: **2.5**
RESULTS:

- Changes in extreme wind speeds between the 20th(1961-90) and the 21st(2071-2100) centuries have been investigated over Europe on the basis of climate simulations from five different GCM-RCM model chains. Relative changes in both intensity and frequency indices of extreme winds have been studied and the related uncertainties assessed over Europe for the half-winter months.
- The investigations for the development of a high resolution extreme windstorm climatology over Switzerland for the 1961-1990 period have been pursued and completed.

PRESENTATIONS (last 6 months):
Koffi B (2004a) Heat waves and extreme wind speeds over Europe by the end of the 21st century: Analysis of multi regional climate simulations. 4th PRUDENCE meeting. Toledo. Spain. 6-10 September.

DELIVERABLES: two papers in preparation to be submitted end of 2004 or beginning 2005 (Goyette, 2004; Leckebusch and Koffi, 2004).

CONTRIBUTOR TO TASK: D5A4
WORK: Assessing changes in frequency and intensity of heat waves and cold spells
ALLOCATED PERSON MONTH THIS PERIOD: **2**
RESULTS: The study based on HIRHAM4 simulations (Beniston et al., 2004) has been extended to four different global/regional models chains and two IPCC scenarios so as to get a good appreciation of the variability and level of confidence in these results as a function of uncertainties in model formulation, climate variability and radiation forcing. Based on calendar day thresholds of the daily maximum temperature, the selected Heat Wave indices allowed a consistent analysis over the European continent and throughout the year. Heat wave events are shown to become very commonplace at the end of this century, with highly differing patterns according to season and location.

PRESENTATIONS (last 6 months):
Koffi B, 2004a, Heat waves and extreme wind speeds over Europe by the end of the 21st century: Analysis of multi regional climate simulations. 4th PRUDENCE meeting. Toledo. Spain. 6-10 September.

DELIVERABLES: A paper submitted to Climate Dynamics (Koffi, 2004b)

RESPONSIBLE FOR TASK: D5A5
WORK: Sensitivity of hydro-power supply to changing temperature and precipitation patterns.
ALLOCATED PERSON MONTH THIS PERIOD: **0**
RESULTS:
PRESENTATIONS:
DELIVERABLES: Expected in months 30. **Cancelled** (see previous report)

RESPONSIBLE FOR TASK: D3B4
WORK: Assessing the reduction of snow and ice in the Alps
ALLOCATED PERSON MONTH THIS PERIOD: **0**

RESULTS: (see previous reports)
PRESENTATIONS:
DELIVERABLES: Initially expected in months 30-33. **Completed**

GENERAL COMMENTS:
This 6 last months have been mainly devoted to:
- the preparation of the paper on windstorms climatology in Switzerland (Goyette, 2004)
- the finalization of the paper on heat waves in Europe (Koffi, 2004)
- the preparation of a paper on wind storms in Europe (Leckebusch and Koffi, 2004)
- the WP5 joint paper (final draft): UniFR contributions and coordination of the preparation (Beniston et al., 2004)

PUBLICATIONS (last 6 months):
Beniston M, DB Stephenson, OB Christensen, CAT Ferro, C Frei, S Goyette, K Halsnaes, T Holt, K Jylhä, B Koffi, J Palutikof, R Schöll, T Semmler, K Woth (2004) Future Extreme Events in European Climate: An Exploration of Regional Climate Model Projections. Clim Change. Special issue on PRUDENCE. in preparation.

Goyette, S (2004), Towards the development of a model-based high resolution extreme wind climatology for Switzerland using RCM multiple self-nesting methodology. In preparation.

Koffi, B (2004b) Heat waves in Europe by the end of the 21st century: Analysis of multi regional climate simulations. Submitted to Clim. Dyn.

Leckebusch, G and B Koffi (2004) Analysis of frequency and intensity of winter storm events from a multi-model perspective on synoptic and regional scales based on climate simulations, *in preparation*.

EMPLOYEES:
Name: Martin Beniston, Stephane Goyette, Brigitte Koffi

1. Responsibility

The University of Fribourg (Uni FR) is partner in Work Package 3 '*Impacts of future climate scenarios on hydrology*') and Work Package 5 ('*Risk assessment of European weather and climate extremes in future regional forecast scenarios'*), in which it is responsible for (in bold characters) or contributes to the 4 following research tasks:

Table 1: Deliverables of the University of Fribourg

D3B4 : Assessing the reduction of snow and ice in the Alps
D5A3 : Assessing changes in frequency / intensity of wind storms
D5A4 : Assessing changes in frequency / intensity of heat waves and cold spells
D5A5 : Sensitivity of hydro-power supply to changing temperatures and precipitation patterns

2. Main results

The assessment of changes in the frequency and intensity of extreme climatic events, in particular wind storms and heat waves, has been undertaken from the analysis of RCM control (1961-1990) and prediction (2071-2100) experiments performed in the framework of PRUDENCE WP1. In addition, high-resolution simulations to investigate specific occurrences of extreme events, during both periods have been made at the University of Fribourg (quoted Unifr, hereafter) with the Canadian Regional Climate Model (CRCM2).

3. Progress report of Workpackage 3

Task D3B4 already completed in 2003 (see 2nd annual report)

4. Progress report of Workpackage 5

Task D5A3: Changes between the 20th (1961-90) and the 21st (2071-2100) centuries, in extreme wind speed indicators have been investigated over Europe on the basis of climate simulations from five different GCM-RCM model chains. Based on percentile rather than on absolute thresholds, the developed wind speed indices allow a consistent analysis over Europe and better avoid for model discrepancies. Relative changes in both intensity and frequency indices of extreme winds have been studied and the related uncertainties assessed for the half-winter months. Significant positive changes are obtained over at least 20% and 10% of the European study area (15°W-43°E; 35°-72°N), respectively. Higher changes are obtained for the only December, January and February (DJF) winter months (see Figure 1 as illustration). Differences between models and relationships between storm tracks and wind storminess have also been investigated. Results will be soon submitted for publication as a collaborative paper between the University of Fribourg and the University of Cologne (Germany), i.e., putting together PRUDENCE and MICE wind storm relevant studies, respectively (Koffi, 2004b, Koffi, 2004c, Leckebusch and Koffi, 2004). In addition, investigations at higher resolution have been made at the Uni FR, using the CRCM2 model to downscale the HADLEY simulations. It allowed the development of a high resolution extreme windstorm climatology over Switzerland for the past (1961-90) climate (Goyette, 2004a; Goyette, 2004b; Goyette, 2004c).

Task D5A4: The analysis of changes in the occurrence of heat waves previously performed on the basis of HIRHAM model outputs for the A2 IPCC scenario (Beniston *et a*l., 2004), has been completed for 3 other model chains and 1 more scenario (B2), in order to assess the uncertainties due to model formulation, natural climate variability, and radiation forcing. Based on calendar day percentile thresholds of the daily maximum temperature, the selected Heat Wave indices provide a consistent analysis Europe-wide and throughout the year, i.e., also accounting for episodes with anomalously warm temperature other than during the summer season. As a result of changes in both the mean and the variability of temperature, Heat wave events as predicted from all the selected models are shown to become very commonplace at the end of this century (e.g., **Figure 2**), but with highly differing patterns according to season and location (Koffi, 2004a; Koffi, 2004b; Koffi, 2004c).

Task D5A5: Revisited. Another EU project, called SWURVE (Sustainable Water: Uncertainty, Risk and Vulnerability in Europe), which involves several research teams in Europe is also currently dealing with this particular topic, (http://www.ncl.ac.uk/swurve), by partly making use of PRUDENCE datasets. Therefore, it has been commonly agreed and decided by all PRUDENCE WP5 partners to rather allocate the D5A5 person month to the coordination and preparation of the WP5 joint paper (see section 5).

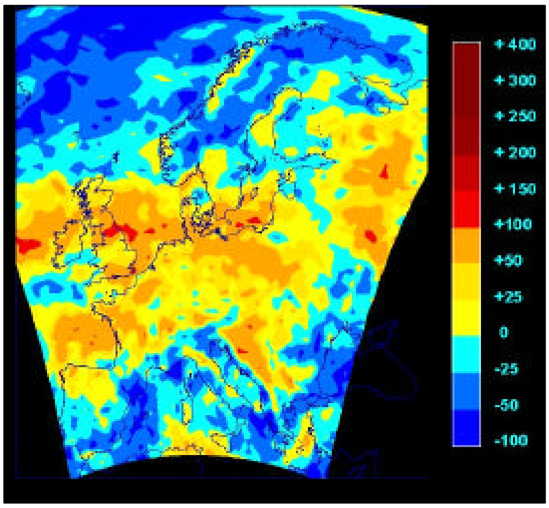


Figure 1: HadAM3H-RCAO model chain: Change (%) in the number of days above 1961-90 DJF 99th percentile of the daily maximum wind speed between the 20th (1961-90) and 21st (2071-2100) centuries, based on A2 scenario (Koffi, 2004c

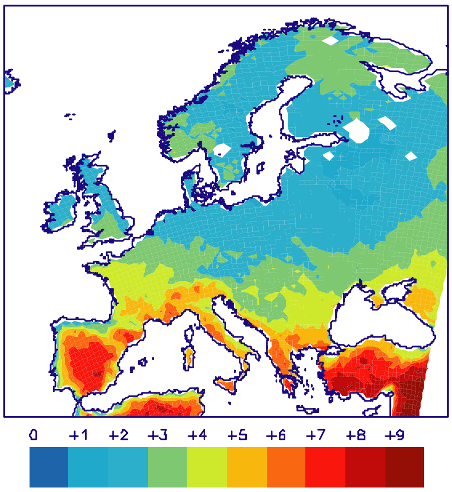


Figure 2: HadAM3H-RCAO model chain: Increase (days/decade) in the number of heat wave days for the half-summer months between the 20th (1961-90) and 21st (2071-2100) centuries, based on A2 scenario (Koffi, 2004a)

5. Other PRUDENCE relevant activities

- Local organization of PRUDENCE WP5 scientific coordination meeting (6-9 March 2004, Château d’Oex, Switzerland).
- Co-coordination of the preparation of the WP5 joint paper (Beniston *et al.*, 2004)

6. Publications and presentations

The list is accumulating information from the project start. Work written in red represents new material (or indicates that the status of the paper has been updated) since the 2nd annual report.

Publications

Beniston, M. and D.B. Stephenson (Eds), 2004, “Extreme Climatic Events”, Special issue of “Global and Planetary Change”, on the 2003 EGS-AGU meeting (Nice, 2003), in production process.

Beniston, M., D.B. Stephenson, O.B. Christensen, C.A.T Ferro, C. Frei, S. Goyette, K. Halsnaes, T. Holt, K. Jylhä, B. Koffi, J. Palutikof, R. Schöll, T. Semmler, K. Woth, 2004, Future Extreme Events in European Climate: An Exploration of Regional Climate Model Projections. Clim Change. Special issue on PRUDENCE. in preparation.

Beniston, M., F. Keller and S. Goyette, 2003, Snow pack in the Swiss Alps under changing climatic conditions: an empirical approach for climate impacts studies, Theoretical Applied Climatology, 74, 19-31.

Beniston M, F Keller, B Koffi, and S Goyette, 2003, Estimates of snow accumulation and volume in the Swiss Alps under changing climatic conditions. Theor and Appl Clim 76: 125-140.

Goyette, S., 2004a, Towards the development of a model-based high resolution extreme wind climatology for Switzerland using RCM multiple self-nesting methodology, in preparation.

Koffi, B., 2004a, Heat waves in Europe by the end of the 21st century: Analysis of multi regional climate simulations, submitted to Clim. Dyn.

Leckebusch, G. and B. Koffi, 2004, Analysis of frequency and intensity of winter storm events from a multi-model perspective on synoptic and regional scales based on climate simulations, in preparation.

Presentations

Beniston, M. et al, 2002, Presentation on work progress, 2nd PRUDENCE meeting (04/10/02).

Beniston, M., 2003, Opening talk, Session CL13 on ’Extreme Climatic Events, their Evolution and their Impacts’, EGS-AGU-EUG Joint General Assembly Meeting (07/04/03).

Beniston, M., F. Keller, B. Koffi, and S. Goyette, (2003c), Sensitivity of the alpine snow pack to climatic change, National Centres of Competence in Research (NCCR), Review Panel Meeting, Zürich, poster presentation (22/05/03).

Goyette, S., 2004b: Towards the development of a high resolution extreme wind climatology for Switzerland. Regional-Scale climate modelling workshop. High-resolution climate modelling: Assessment, added value and applications. WCRP-sponsored, Lund, Sweden, 29 March - 2 April, 2004.

Goyette, S., 2004c: On the use of RCM self-nesting methodology for the development of a high resolution extreme windstorm climatology for Switzerland. EGU Ist General Assembly, Nice (France), April 2004.

Koffi B., 2003: WP5 Work progress of Partner 15, PRUDENCE WP5 meeting, Chateau d’Oex, Switzerland, March 15-18, 2003.

Koffi, B., 2003, ’Heatwaves in Europe under Climate Change’, Wengen 2003 Workshop on ‘Regional Climatic Change in Europe: processes and Impacts’, September 29 to October 3, 2003,Wengen, Switzerland, oral presentation (01/10/03).

Koffi B., 2004b: WP5 Work progress of Partner 15, PRUDENCE WP5 meeting, Chateau d’Oex, Switzerland, March 6-9, 2004.

Koffi B., 2004c: Heat waves and extreme wind speeds over Europe by the end of the 21st century: Analysis of multi regional climate simulations. 4th PRUDENCE meeting. Toledo. Spain. 6-10 September.

Koffi, B., S. Goyette and M.Beniston, 2003, ’Heatwaves and wind storms in a changing climate’, EGS Conference, 7-11 April 2003, Nice, France, poster presentation.

Koffi B., S. Goyette and M. Beniston, 2003, Assessment of changes in the occurrence of heatwaves and wind storms, NCCR Review Panel Meeting, Zürich, 22 may 2003, poster presentation (22/05/03).

Partner no.: 16

Institution: Finnish Environment Institute
Acronym: **FEI** (now officially **SYKE**)
Responsibility: FEI is partner in WP 2, 4, 5 and 7. It is working closely with Associate Partner 21 (Finnish Meteorological Institute – FMI). FEI is using impact indicators to analyse and map different sources of uncertainty in resource potential across Europe (requiring mean annual, seasonal or monthly climatological information). FEI also supports FMI in assessing the "full" uncertainty range of regional climate change in Europe, using pattern scaling methods, and in mapping indices of resource risk (requiring daily climatological data).

FEI is responsible for tasks: D4C5, D4C6, D5A8
FEI participates in tasks: D2A3, D5A7, D7A3, D7A4

RESPONSIBLE FOR TASK: D4C5
WORK: Analysis, interpretation and presentation of present and future resource potential (simple impact models and indices) in GIS
ALLOCATED PERSON MONTH THIS PERIOD: 0
RESULTS:
PRESENTATIONS:
DELIVERABLES: Month 12 DELIVERED

RESPONSIBLE FOR TASK: D4C6
WORK: Analysis, interpretation and presentation of uncertainties in impacts in GIS (with FMI)
ALLOCATED PERSON MONTH THIS PERIOD: 6.5
RESULTS:
Abstract. An analysis was conducted of the estimated impacts of climate change on different aspects of the natural environment, agriculture and energy demand in Europe under a wide range of RCM- and AOGCM-based climate scenarios. A suite of simple models and indices were used to assess impacts on the growing season, potential biomass, thermal suitability for the cultivation of crops, nitrate leaching from winter wheat, and potential energy demand for indoor cooling and heating.

Impacts were estimated for observed climate in the 1961-1990 baseline period and projected climate during 2070-2099 based on outputs from a range of RCMs using SRES emission scenarios A2 and B2 and from seven GCMs using a wider range of emission scenarios. All analyses were conducted on a regular 0.5 x 0.5° grid across Europe.

Uncertainties in the projected impacts of climate change were assessed with respect to: 1) the direct model output vs. delta change approach, 2) differences in the driving GCMs and the RCM runs, 3) the model range vs. a range of emission scenarios, 4) changes in long-term mean climate, and 5) changes in inter-annual climate variability.
PRESENTATIONS: Fronzek, S. "Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from climate models". Research seminar in environmental sciences, University of Helsinki (Helsinki, Finland, 11/2004)
Fronzek, S., T.R. Carter and K. Jylhä, "Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs". PRUDENCE Final Workshop (Toledo, Spain, 9/2004)
DELIVERABLES: Month 34 DELIVERED (abstract) Full paper is in preparation for Climatic Change (Fronzek et al.). FEI is also contributing to the WP 4 paper in Climatic Change (Olesen et al.)

RESPONSIBLE FOR TASK: D5A8
WORK: Analysis of uncertainties in estimated changes in resource risk in co-operation with FMI
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS:
Abstract. Projected changes in indices related to low temperatures were analysed, including the annual number of frost days, first and last dates of the frost season, number of days crossing the 0ºC threshold, number of days with snow cover, and annual maximum ice cover over the Baltic Sea. To assess the maximum ice cover, we used a modified regression method based on monthly mean temperature. Seasonal and annual means of the remaining indices were calculated using daily data from an extensive suite of RCM runs. Interpolation of the indices onto a common grid across Europe enabled us to assess the uncertainties in the estimated changes due to differences in RCM formulation, GCM boundary conditions and future emissions. The results are presented as maps and domain-averages.
PRESENTATIONS: Jylhä, K. (FMI) "Projected changes in indices related to low air temperatures and extreme precipitation". PRUDENCE Final Meeting, Toledo, 6-10 September 2004
DELIVERABLES: Month 34 DELIVERED (abstract) Full paper is under preparation for Climatic Change (Jylhä et al.)

CONTRIBUTOR TO TASK: D2A3
WORK: Upper and lower estimates of regional temperature change across Europe based on pattern scaling methods for the SRES emissions range and the IPCC range of climate sensitivities
ALLOCATED PERSON MONTH THIS PERIOD: 2.33
RESULTS:
Abstract. Seasonal temperature and precipitation change projections for the end of the 21st century were analysed for five regions covering continental Europe. Projections are based on simulations made with six global coupled GCMs. For most of the GCMs, only responses to the SRES A2 and B2 forcing scenarios have been simulated. In order to formulate projections for the highest (A1FI) and lowest (B1) forcing scenarios, a super-ensemble pattern-scaling technique has been elaborated. This method uses linear regression to represent the relationship between the local GCM-simulated temperature/ precipitation response and the global mean temperature change simulated by a simple climate model. The method has several advantages: e.g., the noise caused by natural variability is reduced, and the method effectively utilizes the information given by GCM runs performed with various forcing scenarios. Compared with the simple time slice method, the super-ensemble method proved especially useful in a situation with only one A2 and one B2 simulation available for an individual GCM.

95% probability intervals for seasonal temperature and precipitation change for each region are derived by fitting a normal distribution to the set of projections given by various GCMs; this approximation appeared to work quite well. The highest estimates of temperature response to A1FI scenario are close to 10ºC in the southern Europe summer and northern Europe winter. In contrast, the lowest B1 estimates for some individual seasons and regions are ~1ºC. The upper and lower estimates of precipitation change are generally of opposite sign, but the mean estimate is of a marked increase in the north in winter and a drastic reduction in the southern Europe in summer.

Ranges of GCM-based temperature and precipitation change were compared with corresponding estimates given by nine regional climate models (RCMs) participating in the PRUDENCE project. There is generally no major systematic difference in the estimates of mean change, but the total range of GCM responses is distinctly wider than the RCM range.

PRESENTATIONS: Tuomenvirta, H. (FMI) "Regional temperature and precipitation change estimates for Europe under four SRES scenarios", PRUDENCE Final Meeting, Toledo, 6-10 September 2004
DELIVERABLES: Month 34 DELIVERED (abstract) Full paper is under preparation for Climatic Change. (Ruosteenoja et al.)

CONTRIBUTOR TO TASK: D5A7
WORK: Mapping present-day and future resource risk for Europe or for sub-regions of Europe, based on gridded or site-based information. Estimates to be provided by FMI and mapped by FEI.
ALLOCATED PERSON MONTH THIS PERIOD: 2.67
RESULTS: See results described under D5A8. FMI also contributed to the WP 5 paper (Beniston et al.) and FEI assisted with some background analysis.
PRESENTATIONS: Jylhä, K. (FMI) "Projected changes in indices related to low air temperatures and extreme precipitation". PRUDENCE Final Meeting, Toledo, 6-10 September 2004
DELIVERABLES: Month 34 DELIVERED (abstract) Full paper is under preparation for Climatic Change (Jylhä et al.)

CONTRIBUTOR TO TASK: D7A3
WORK: Presentation of climate scenarios and their uncertainties
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Outputs from selected PRUDENCE RCM-based simulations have been adopted as scenarios in the FP 6 Integrated Project ALARM (Assessing LArge-scale environmental Risks with tested Methods).
PRESENTATIONS: Carter et al.: "Climate scenarios for ALARM", First General ALARM Project Meeting, 6-12 November 2004, Mallorca.
DELIVERABLES: Month 36 DELIVERED
There are tentative plans to host a press briefing on PRUDENCE in early 2005 in Helsinki.

CONTRIBUTOR TO TASK: D7A4
WORK: Final presentation of PRUDENCE, particularly summarising the impacts of climate change and their uncertainties
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS:
PRESENTATIONS: Fronzek, S. "SYKE activities during the EC FP5 project PRUDENCE". Seminar at the Research Programme for Global Change, Finnish Environment Institute (Helsinki, Finland, 10/2004)
Fronzek, S. "Climate change and its impacts on agriculture and the natural environment". Presentation at the sauna evening of luomuruokayhdistys POTAatti and Otaniemen Ympäristöseura, Helsinki University of Technology (Espoo, Finland, 4/2004)
DELIVERABLES: Month 36 DELIVERED
There are tentative plans to host a press briefing on PRUDENCE in early 2005 in Helsinki.

GENERAL COMMENTS:

PUBLICATIONS:

Carter, T.R. and 24 others. 2004. Characterizing the 21st Century and Beyond: Guidance on Scenarios for Authors of the Working Group II Fourth Assessment Report. Draft documents in support of the writing process for the IPCC Working Group II Fourth Assessment Report. Working Group II Technical Support Unit, Hadley Centre, Exeter, UK, 52 pp. plus appendices.

Luoto, M., S. Fronzek and F.S. Zuidhoff (2004). Spatial modelling of palsa mires in relation to climate in Northern Europe. Earth Surface Processes and Landforms, 29, 1373-1387.

EMPLOYEES:
Name: Timothy Carter, Stefan Fronzek

PUBLICATION PLAN:

Olesen, J.E., Carter, T.R., Fronzek, S., Holt, T., Minguez-Tudela, M.I., Morales, P., Palutikov, J., Sykes, M. and others. "Uncertainties in projected impacts of climate change on European agriculture, forestry and ecosystems based on scenarios from regional climate models". In preparation for Climatic Change

Jylhä, K., Fronzek, S., Tuomenvirta, H. and Carter, T.R. "Changes in frost and snow in Europe and sea ice in the Baltic Sea by the end of the 21st century" In preparation for Climatic Change

Fronzek, S., Carter, T.R. and Jylhä, K. "Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs" In preparation for Climatic Change

PLANS FOR THE NEXT PHASE:
Project completed

Partner no.: 17

Institution: University of Reading
Acronym: **UREADMY**
Responsibility: UREADMY is partner in WP5 with the specific responsibility of developing statistical methods for diagnosing risk/extremes. In addition, UREADMY is management coordinator for WP5.

Responsible for tasks: D5A1, D5A2
Participates in tasks: D5A1-8, D5B1-2

RESPONSIBLE FOR TASK: D5A1
WORK: Develop statistical tools for the estimation of risk due to weather/climate extremes (months 3-15)
RESULTS: Methods for estimating return levels that exploit the spatial structure of model simulations and for constructing confidence intervals for such estimates were investigated further. Local-likelihood, latent process, multivariate and max-stable process models were implemented and assessed. Resampling methods for calibrating profile-likelihood confidence intervals were developed. In response to a J. Climate a reviewer's comments on power testing in Ferro et al. (2005), more work has also been performed on developing suitable statistical tests for location-scale changes. A summary of the different approaches will appear in the revised paper.

PRESENTATIONS: David Stephenson and Chris Ferro organised a very successful and well-attended Royal Meteorological Society afternoon meeting on extremes in weather and climate in London, UK, on 21 January 2004. They both gave presentations on extremes and presented PRUDENCE results. Chris Ferro presented the statistical methods described above at a local group meeting of the Royal Statistical Society in Birmingham, UK, on 11 December 2003, at a meeting of the UK Extremists Group in Lancaster, UK, on 3 February 2004, at a PRUDENCE workshop in Chateau d'Oex, Switzerland, on 6 March 2004. David Stephenson and Chris Ferro both gave invited talks at the 9th International Meeting on Statistical Climatology in Cape Town, South Africa, on 26 May 2004. Chris presented an excellent overview of possible statistical methodologies for modelling spatial extremes and illustrated these methods using PRUDENCE data.

DELIVERABLES: The revised version of Ferro et al. (2005) will be submitted shortly to the J. Climate.

RESPONSIBLE FOR TASK: D5A2
WORK: Analysis of extremes in observations and model output using methods developed in D5A1 (months 3-39)
RESULTS: The methods developed for D5A1 were applied to subsets of temperature and precipitation data simulated by HIRHAM in order to assess their efficacy ahead of wider application. Models from extreme-value theory were used to investigate the form of distributional change in precipitation extremes from the control to scenario in the HIRHAM simulations. Changes were well approximated by a simple change in scale of the distribution.

In addition, work designed to help synthesise the uncertainties in the PRUDENCE simulations was completed. Linear statistical models amenable to 'analysis of variance' techniques were constructed to attribute the amount of variation in the PRUDENCE experiments due to the driving GCM, RCM and emissions scenario. A report illustrating the approach for eight PRUDENCE experiments was distributed to PRUDENCE partners and was well received. Rather than summarise each model simulation individually, a general linear model can be fitted simultaneously to all the model simulations in order to provide an overall summary of the variations in the simulations. Careful examination of the model can then reveal which factors are most important (e.g. RCM or GCM) and the magnitude of interaction terms (e.g. RCM-GCM effects on the doubled CO2 response). This work has helped advise PRUDENCE partners making syntheses at DMI. It also clearly shows that careful design of experiments would be advantageous in future projects (e.g. ENSEMBLES). In addition, both Chris Ferro and David Stephenson have spent substantial time revising and rewriting large parts of the WP5 joint paper Beniston et al. (2005) to make it suitable for publication in the PRUDENCE Special Issue of Climatic Change.

PRESENTATIONS: Chris Ferro presented preliminary results in a talk at the PRUDENCE conference in Toledo 6-10 September 2004. He has since presented a more comprehensive approach capable of dealing with time trends and inter-model dependencies in a recent Centre for Global Atmospheric Modelling seminar on 3 December 2004. David Stephenson prepared an overview talk of highlights from WP5 and presented this at the PRUDENCE conference in Toledo 6-10 September 2004. The talk has since been used by Ole Christensen for an extremes meeting in Beijing.

DELIVERABLES: Beniston et al. (2005) has been submitted to Climatic Change in November 2004.

CONTRIBUTOR TO TASKS: D5A3-8, D5B1-2
WORK: Other tasks in WP5
RESULTS: Statistical issues relating to these deliverables were discussed further with the relevant partners.
PRESENTATIONS:
DELIVERABLES:

GENERAL COMMENTS:

The Beniston et al. (2005) joint paper has managed to achieve a fine synthesis of the highlights of the WP5 work – it is likely to become a highly cited publication for future studies on regional changes in weather and climate extremes.

A second workshop was held in Chateau d'Oex, Switzerland, on 6 – 9 March 2004 for WP5 and other invited PRUDENCE partners. This proved again to be a very valuable opportunity to exchange ideas and discuss future work.

PUBLICATIONS: Completed and in progress – see below.

EMPLOYEES:

Dr David B. Stephenson	1 December 2001 – onwards
Dr Christopher Ferro	1 October 2002 – onwards
Dr Abdel Hannachi	1 April 2002 – 30 September 2002
	1 April 2004 – 30 September 2004

PUBLICATION PLAN:

See above and updated list of references below.

PLANS FOR THE NEXT PHASE:

None. All project work was satisfactorily completed.

Publications

Beniston, M., and D.B. Stephenson, 2004: Extreme climatic events and their evolution under changing climatic conditions, Global and Planetary Change, Vol. 44/1-4, 1-9.

Ferro, C.A.T., D.B. Stephenson, and A. Hannachi, 2005: Simple non-parametric techniques for exploring changing probability distributions of weather and climate, J. Climate, (accepted subject to minor revisions).

McGregor, G., D.B. Stephenson, and C.A.T. Ferro, 2005: Projected changes in extreme weather and climate events, Chapter in: Proceedings of World Health Organisation Conference on Extreme weather events and Public Health responses, 9-10 Feb 2004, Bratislava, Slovakia.

Beniston, M, D. B. Stephenson, O. B. Christensen, C. A.T. Ferro, C. Frei, S. Goyette, K. Halsnaes, T. Holt, K. Jylhä, B. Koffi, J. Palutikof, R. Schöll, T. Semmler, and K. Woth, 2005: Future Extreme Events in European Climate: An Exploration of Regional Climate Model Projections, Climatic Change, PRUDENCE special issue (submitted).

Partner no.: 18

Institution: Lund University
Acronym: **LU**
Responsibility: Workpackage 4

RESPONSIBLE FOR TASKS: Martin Sykes, Pablo Morales, Thomas Hickler, Ben Smith

1) CONTRIBUTOR TO TASK: **D4C2, D4C3,**
2nd and 3rd deliverables (18 months):

DESCRIPTION OFTASK D4C2

WORK: Validation of model outputs under current climate against forest inventory data at selected sites.

RESULTS: Finished. We performed an experiment validating LPJ-GUESS predictions of forest growth on a geographically extensive basis across Europe. This experiment compared output from the model to observations of forest age structure and standing biomass from the European Forest Institute's EFISCEN database provided by The Potsdam Institute of Climate Impacts Research (PIK).
Additionally, we made a validation of the model outputs for Sweden by comparing actual land use from the National Forest Inventory against simulated vegetation by LPJ-GUESS.

PRESENTATIONS:

PRUDENCE WP4 meeting. Copenhagen , Denmark 3-4 april 2003.
PRUDENCE annual meeting. Wengen , Switzerland October 2003.

DELIVERABLES: Validation of the model outputs against forest inventory data at Swedish forest ecosystems. Validation of model outputs using measurements over fifteen sites within the EUROFLUX project.

DESCRIPTION OFTASK D4C3

WORK: Simulations of ecosystem processes at selected EUROFLUX sites from 1996.
For this task, the LPJ-GUESS [Smith et al 2001] dynamic ecosystem model was run using present day climatology (and forest management history) for each of 15 sites in Europe within the EUROFLUX project in order to simulate carbon and water fluxes over a three-year period. Subsequently, the model was evaluated using the flux measurements collected by the EUROFLUX project (3 years of eddy covariance data from 1996 to 1998).
Additionally, preliminary simulations were completed with output from one RCM (SWECLIM) to predict potential natural vegetation distributions within Swedish forests. First simulations with the RCM model output was done for 200 years using time series data and including as historical climate data the CRU05 (1901-1998) dataset and SWECLIM regional climate model outputs for (2071-2100) based on HadCM3/AM3 & ECHAM4/OPYC3. LPJ-GUESS was also used to simulate changes in tree species diversity and ecosystem productivity using the 30 years of SWECLIM (2071-2100) model output.

RESULTS: Finished. Simulations of Carbon and water fluxes for all the sites within the EUROFLUX project were completed. An analysis of the monthly model outputs and field data showed that, in general, the model accurately predict the seasonal patterns in Net Ecosystem Exchange (NEE) and Actual EvapoTranspiration (AET) for most EUROFLUX sites except for some Mediterranean and Maritime Evergreen forest sites.
Using the SWECLIM RCM, the ecosystem model predicted changing species composition in existing forests, increasing productivity in Swedish forest ecosystems and therefore increased sequestration of carbon into the future.

PRESENTATIONS:
PRUDENCE annual meeting. Wengen , Switzerland October 2003.

DELIVERABLES: Validation of model outputs using measurements over fifteen sites within the EUROFLUX project. Full set of simulations of ecosystem processes (Carbon and Water fluxes) over 15 EUROFLUX sites from 1996 to 1998.

2) CONTRIBUTOR TO TASK: D4C4

4th deliverable (33 months)
DESCRIPTION OF TASK D4C4

WORK: Simulations of vegetation and ecosystem processes for European regions for the period 2071-2100 using the Regional Climate model outputs and selected SRES scenarios.

For this task we used the LPJ-GUESS ecosystem model to assess the impacts of RCM-modelled climate changes and associated changes in atmospheric CO_2 concentrations on vegetation, net primary production (NPP) and terrestrial ecosystem carbon stocks in Europe. All analyses were conducted on 0.5 x 0.5° grid across Europe.

The simulations performed in this study were of the potential natural vegetation; anthropogenic land use and land management were not taken into account. Simulations began from bare ground (no plant biomass present) and were then "spun up" for a 300 model years to achieve equilibrium with respect to carbon pools (i.e. a balance between ecosystem release and uptake of CO_2, averaged over a few years). The model was then driven using transient climatology for the period 1901-1998 from CRU05 monthly dataset (New *et al.* 1999). A 100-year mean disturbance interval, corresponding to typical disturbance regimes for natural vegetation in Europe, was implemented over the entire model domain and simulation period.

Climate data for the gap between the observed data and climate input for the scenario period (1991-2070) was derived by linear interpolation between means for the final 30 years of the historical data and rescaled data for the scenario period (2071-2100). The detrended interannual variability for the last 30 years of the historical record was superimposed on the trend line. The climate data for the scenario period was rescaled in order that mean values and standard deviations for the control period (1961-1990) corresponded with the observed data from CRU05.

For the scenario period the RCM outputs for 2071-2100, rescaled to the 0.5 x 0.5° grid, were taken from the PRUDENCE experiments. The PRUDENCE RCMs climate outputs used to drive LPJ-GUESS are listed in Table1. Global atmospheric concentrations from 1901 to 1998 were obtained from the Carbon Cycle Model Linkage Project (Kicklighter et al. 1999; McGuire et al. 2001). CO_2 concentrations for the scenario period were consistent with the GCMs boundary conditions used to drive the Regional Climate models (RCMs).

RESULTS: Finished.

LPJ-GUESS outputs included net primary production (NPP), net ecosystem exchange (NEE), leaf area index (LAI) and AET (actual evapotranspiration). Here we present results for NPP and changes in carbon stocks as an example.

For Europe as a whole, net primary production (NPP) increased in both scenarios, slightly more under the A2 scenario compared to the B2 (Figure 1). At higher elevations (in the Alps) and latitudes (in Scandinavia) NPP increases and the magnitude of the increase is greater under A2 scenario. In some mediterranean and southern European areas, NPP declines.
The differences among simulations is more prominent in northern than in southern Europe. In the north increases in atmospheric CO_2 and temperatures interact positively to enhance growing season length and NPP, and lead to a shift in dominance from coniferous forest to a deciduous forest in some areas and to an advance in the
tree-line especially in the Fennoscandian Alps.

Decreases in NPP in the Mediterranean are particularly pronounced under scenario A2. This is likely related to the fact that the RCAO RCM predicts decreases in precipitation in this region and this coupled with increased evapotranspiration, leads to soil water deficits and reduced plant productivity.

The greatest proportional changes in NPP were predicted to occur in Northern Europe, while the smallest changes were predicted for SW Europe, and this was consistent across all scenarios (Table 2). In general, the A2 scenarios are associated with larger changes than B2 scenarios, both because the emission driven climatic changes are generally greater, and because of higher atmospheric CO2 levels in the A2 scenario, both of which have consequences for vegetation processes.

The smaller increases in NPP projected for SW Europe in comparison to the other sub-regions are mainly determined by water limitations and their effects on vegetation. Differences between the emissions scenarios are not pronounced in this region, indicating that variations in precipitation and temperatures between RCM scenarios are more relevant than CO_2 levels in explaining the NPP changes predicted for this region.
Differences between the HadAM3H and ECHAM-OPYC based scenarios may be explained in part by differences in heterotrophic respiration rates in southern areas of Europe. Higher temperatures generally predicted by ECHAM-OPYC in comparison to HadAM3H lead to increased carbon losses through respiration in the ecosystem model. In addition, ECHAM-OPYC is generally associated with strong regional precipitation reductions, leading to reduced carbon uptake through primary production. Counteracting these effects, productivity is enhanced particularly in central and northern Europe by an increased vegetation period resulting from higher temperatures, as well as the fertilization effect of increased atmospheric CO_2 concentrations on photosynthesis.

Figure 1. Net primary production (NPP) changes for (2071-2100)-(1961-1990), in kgC m^{-2} yr^{-1}, simulated by LPJ-GUESS, driven by the RCM RCAO with boundary conditions derived from two AGCMs and two emissions scenarios.

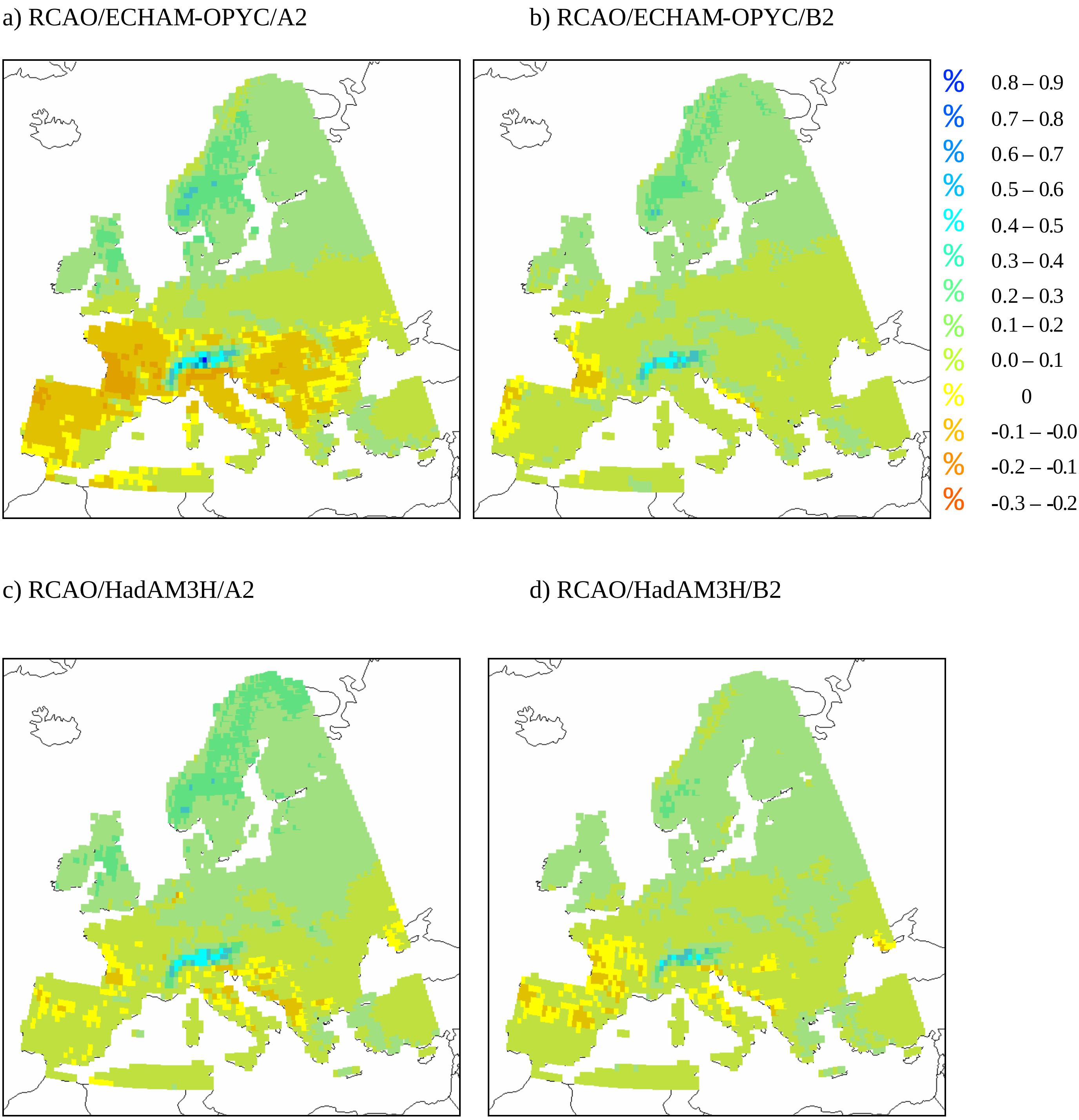


Table 2. Changes in NPP (%) (2071-2100)-(1961-1990) across five European sub-regions simulated by LPJ-GUESS driven by different RCM-generated climate scenarios. (SW: South-Western Europe; SE: South-Eastern Europe; E: Eastern Europe; W: Western Europe; N: Northern Europe).

			European sub-regions				
RCM	***GCM***	***Emission Scenario***	***SW***	***SE***	***E***	***W***	***N***
RCAO	HadAM3H	A2	8.4	13.6	19.3	27.0	48.3
RCAO	"	B2	7.9	15.3	17.7	20.1	35.4 *
RCAO	ECHAM/OPYC	A2	-4.8 *	10.0 *	9.7 *	16.8 *	44.3
RCAO	"	B2	11.2	16.5	14.5	25.4	54.2
HIRHAM	HadAM3H	A2	17.4	24.2	22.7	30.8	48.9
HIRHAM	ECHAM/OPYC	A2	11.3	15.8	14.9	23.2	48.5
HIRHAM	ECHAM/OPYC	B2	11.2	16.5	14.5	22.1	41.1
HadRM3H	HadAM3H	A2	8.9	16.3	14.5	25.4	54.3 **
CLM	"	A2	17.5 **	24.8	26.4	34.0 **	52.1
REMO	"	A2	13.0	26.4 **	28.0 **	29.2	44.3
		Mean	***10.20***	***17.93***	***18.20***	***25.08***	***45.71***

* =Lowest value for each sub-region; ** =Highest value for each sub-region.

Changes in Carbon stocks

LPJ-GUESS predicted using the RCM based scenarios, on average for Europe, a mean sink of up to 2.04 GtC for the 110 year period 1991-2100s, although the level of uncertainty is large, ranging from 0.94 to 3.22 GtC across all scenarios (Figure 2).

When driven by the RCM scenarios based on HadAM3H, LPJ-GUESS predicted on average for Europe, a sink of up to 2.35 GtC for the 110 year period 1991-2100. The RCM scenarios based on ECHAM-OPYC climate model, on the other hand, lead to an average net carbon uptake from ecosystems in the order of 1.57 GtC during the period 1991-2100, according to the model.
The level of greenhouse gas emissions underlying the climate scenarios likewise affects the predicted changes in carbon stocks. Sinks of up to 2.0 GtC, under A2 emissions, and 2.1 GtC, for B2 emissions, are simulated for the period 1991-2100.

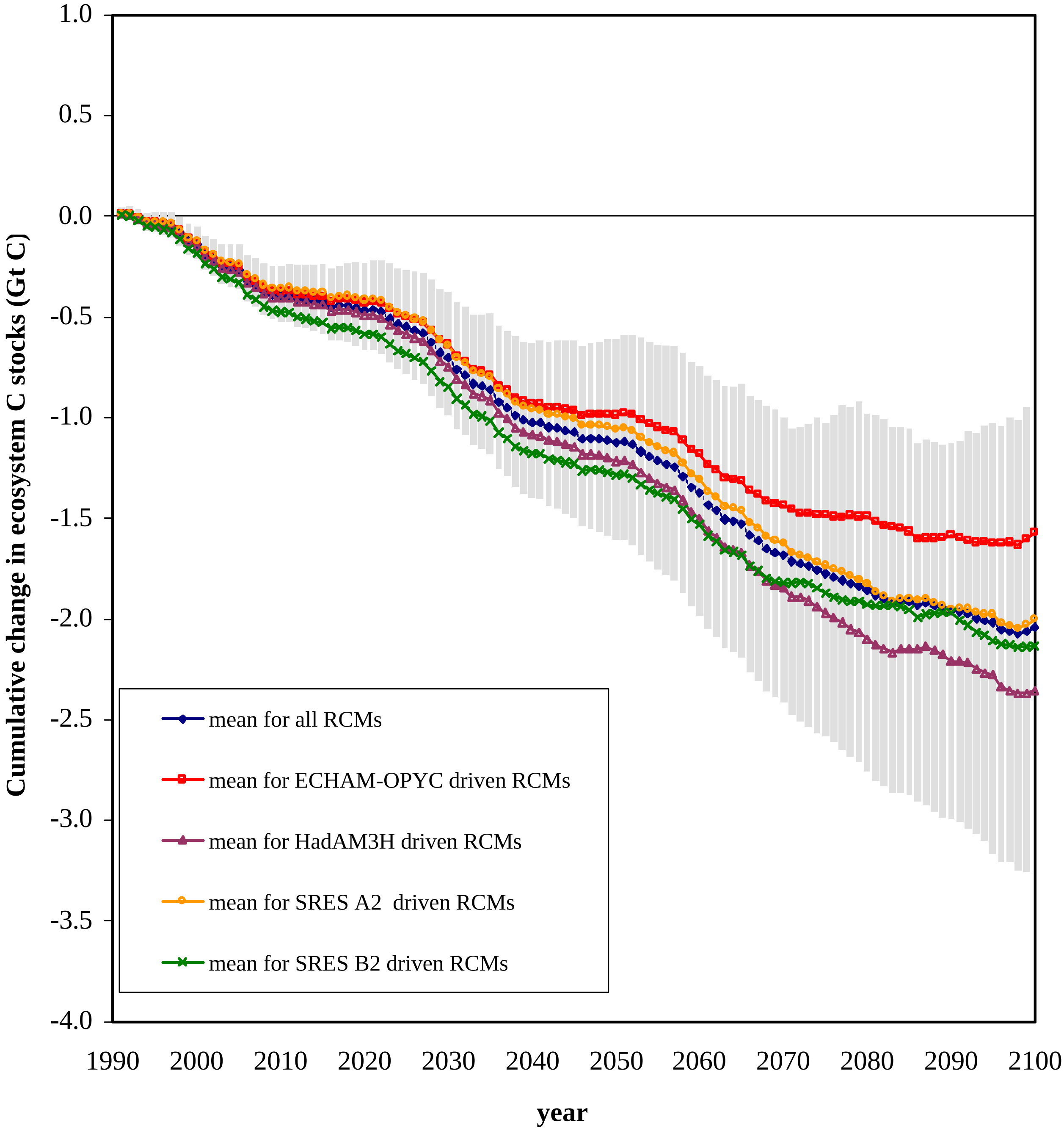


Figure 2. Cumulative change in ecosystem carbon stocks over Europe during the period 1991-2100 simulated by LPJ-GUESS driven by different RCM-generated climate scenarios. Error bars show range from all simulations

DELIVERABLE: 4th deliverable (33 months): Modelled predictions of vegetation (LAI) and ecosystem processes (NPP, NEE and AET) for European regions for the period 2071-2100 using the Regional Climate model outputs and their various SRES scenarios.

GENERAL COMMENTS:

All activities have been completed according to schedule.

PRESENTATIONS:

-2004-04-15. Lund University. Department of Physical Geography & Ecosystems Current Research Seminars. “Fluxes of carbon and water on European forests: Modelling the current spatial and temporal patterns and the future impacts of a changing climate"

-2004-09-09. PRUDENCE final meeting in Toledo Spain. “Assessing PRUDENCE RCM scenarios using the LPJ-GUESS ecosystem model” .

PUBLICATIONS:

-Comparing and evaluating process-based ecosystem model predictions of carbon and water fluxes in major European forest biomes. Pablo Morales, Martin T. Sykes, I. Colin Prentice, Pete Smith, Benjamin Smith, Harald Bugmann, Bärbel Zierl, Pierre Friedlingstein, Nicolas Viovy, Santi Sabaté, Anabel Sánchez, Eduard Pla, Carlos A. Gracia, Stephen Sitch, Almut Arneth, Jerome Ogee. Submitted to Global Change Biology.

- Certainties and uncertainties in projected impacts of climate change on European agriculture, forestry and ecosystems. Olesen, J.E., Carter, T.R., Fronzek, S., Holt, T., Minguez-Tudela, M.I., Morales, P., Palutikov, J., Sykes, M.T., Hickler T., Smith B. and others. In preparation to be submitted to Climatic Change.

- Impacts of climate change on vegetation distribution, net primary production (NPP) and terrestrial ecosystem carbon stocks in Europe. An assessment using the LPJ-GUESS ecosystem model and high-resolution climate change scenarios. Morales, P., Sykes M.T., Smith B., Hickler, T. In prep.

Partner no.: 19

Institution: Centre International de Recherche sur l'Environnement et le Développement
Acronym: **CIRED**
Responsibility: Jean-Charles Hourcade

CONTRIBUTOR TO TASK: D6A2 (continuing) and D6A3.

WORK: During the last year of the PRUDENCE project, CIRED contribution to WP6 has explored two main directions:

How to derive information regarding climate change risks from climate scenarios?
What are the interest and value-added to produce climate change projections on a finer spatial and temporal scale ?

1-Defining a dangerous climate change through successive indicators of climate risks.

The starting point is the following: to date monetary estimates of climate change damages are much too uncertain and controversial, since even the definition of a damage is unclear. However to design climate policies (mitigation and sequestration measures and adaptation options) and to assess their relative benefits, we need some information about climate risks. In this context, we show how indicators developed within the project on the basis of the data obtained from GCMs experiments may help actually to bridge the gap between science and decision-making. A first part is devoted to a discussion about the key-properties these indicators must exhibit to contribute in quantifying and communicating between the integrated assessment community and between science and decision:

• describing our vulnerability, showing trends and predicting future evolutions,
• conveying information about the amount of climate change and how it might affect human settlements, ecosystems and economic activities (direct vulnerability) to decision maker and a large public
• assessing the (marginal) benefits of mitigation and adaptation policies
• linking climate change multi-fold issue and human welfare and development issue.

Several examples are given and discussed. Especially, one examines how they meet such requirements and hence are actually helpful in clarifying the risks, in assessing the associated uncertainties and informing in a meaningful way decision-makers and the civil society.

In the second section, we explore in depth how such indicators might be useful to plan adaptation strategies in urban areas in an uncertain context, on the basis of climate analogues – another kind of climate change vulnerability indicators. One must indeed keep in mind that a) the majority of the population is nowadays urban and may be sensitive to the evolution of its living conditions; b) urban areas concentrate the vast majority of capital stocks (housing and transportation infrastructures); c) energy systems are planned to respond primarily to urban demands; d) the technical content of infrastructures will be sensitive to changes in living conditions and water and energy supply; e) costs of climate change will come primarily from transition costs due to the inertia of economic systems (decommissioning of long lived capital stocks, replacement by new technologies and infrastructures).

The main motivation of this work is to check whether it is possible to avoid the main deadlocks of applying to urban areas the conventional approach of economic assessment of climate change impacts (difficult definitions of a counterfactual scenario and of internally consistent adaptation strategies). An alternative methodology can be defined and applied on cities, which predicted future climate can be considered as analogous to the present climate of some another city. We use the simulations of the ARPEGE-Climat model (CNRM/Météo-France) and the HadRM3H model (Hadley Centre) to determine such analogues for a number of European capitals. We furthermore concentrate on the example of Paris to illustrate how adaptation planning in this area benefits from the availability of several analogues, namely Bordeaux and Malaga, to account for uncertainty and provide an aggregate picture of the implications of climate change.

2- The second part focuses on regional/sectoral disaggregation and their potential masking effect.

In this task, we have concentrated on local non-linearities in climate change damages valuation and the potential masking effects of aggregation to a more global level. So far, no study has indeed explicitly considered uncertainty when assessing welfare costs of climate change impacts for populations at risk. They will yet be given very different values depending on the characteristics of risk (what’s at stake: marginal loss of income, threat on supports of human livelihood, i.e. threat on the basic needs; the available information) and on the degree of risk aversion (related to personal motivations, amount of income, extent of risk).

Here we have investigated how explicitly taking into account risk aversion and uncertainty in regional projections of climate change and future impacts leads to significant differences with expected (or central) resulting damage. The multi-model regional projections of the PRUDENCE project has allowed for an assessment of the regional uncertainties and an evaluation of the consequences of risk aversion on policy decisions. We have here considered two specific uncertainties: uncertainty regarding climate change scenario and uncertainty regarding impact function specifications.

ALLOCATED PERSON MONTH THIS PERIOD: 9

DELIVERABLES: D6A2 and D6A3 (merged)

GENERAL COMMENTS:

PUBLICATIONS:

EMPLOYEES:
Name: Jean-Charles Hourcade, Philippe Ambrosi, Stéphane Hallegatte, Christophe Wendling, Patrice Dumas.

PUBLICATION PLAN: A section of the final report (climate analogues) is intended to be submitted for PRUDENCE Special Issue in Climatic Change. The same goes for the section concerning regional risk-premium in an integrated assessment journal.

Partner no.: 20

Institution: University of East Anglia, Climatic Research Unit
Acronym: **UEA**
Responsibility: UEA is a partner in WP 4, 5 and 7. UEA is to carry out impacts analyses, primarily in Mediterranean countries, using the regional climate model outputs as a basis. The sectors of interest are water resources (soil moisture, droughts and high-intensity rainfall) and thermal stress (heat waves and cold spells).

UEA is responsible for task D5A6

UEA participates in tasks D4A4 and D5A4

RESPONSIBLE FOR TASK: D5A6

WORK: Assessments of the change in frequency and severity of droughts and high-intensity rainfall events in the Mediterranean region.
RESULTS: Report Completed.
PRESENTATIONS:
DELIVERABLES: Report delivered in Month 24
PERSON MONTHS: 3.5

Several annual indices of precipitation extremes were created for four PRUDENCE models and analyses presented of projected change in the mean between the climate normal period 1961-1990 and 2070-2099. To further consider the properties of extreme values, we estimated 50 and 100-year return levels. Both analyses considered the A2a emissions scenario and the less severe B2a scenario. Using the four RCMs as an ensemble, bootstrapped confidence levels indicated that, generally, uncertainty at the 95% level is within ±20% of the projected change in ensemble mean climate extreme.

The comparison of means indicated that the Mediterranean, under the A2a scenario, can expect considerable drying with reduced intensity rainfall, earlier start of drought, and longer periods of drought. The spatial pattern of change is essentially the same under the B2a scenario, but the overall drying is reduced.

An important finding of this study is that changing the forcing model for the RCM has a comparable effect on climate extremes as changing the emissions scenario.

As an example, the figure below shows, for the A2a and B2a scenarios, the change in ensemble mean maximum 3-day running total rainfall in a year (mm), together with the confidence range (mm) at the 95% level. The annual maximum running total rainfall over three days is expected to fall over most of the southern Mediterranean, particularly southern Spain and Portugal, and increase over parts of the northern Mediterranean under the A2a scenario (Figure 1a). Under the B2a scenario (Figure 1c), rainfall will increase over southern Italy, the Alps, and northern Portugal. The greatest uncertainty (about ±60%) is associated with the prediction over the Alps under the B2a scenario (Figure 1d).

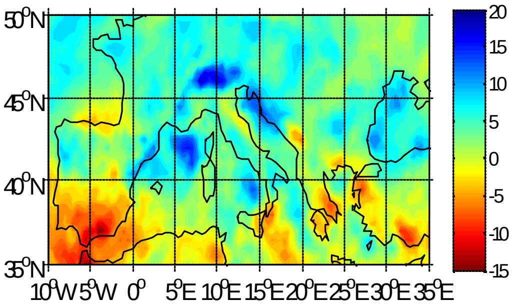


Figure 1a A2a – MaxRunSum3

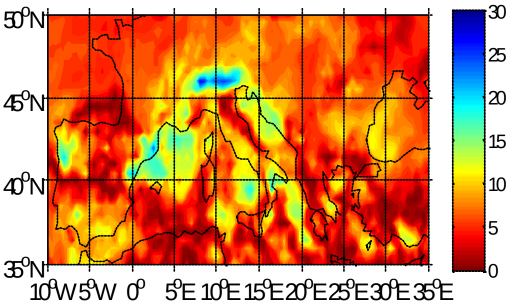


Figure 1b A2a confidence range (days)

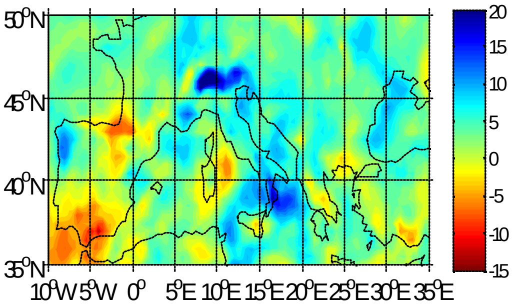


Figure 1c B2a – MaxRunSum3

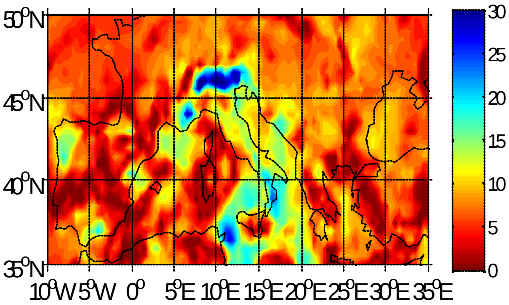


Figure 1d B2a confidence range (days)

CONTRIBUTOR TO TASK: D4A4

WORK: Evaluation of uncertainty in climate model estimation of soil water balance parameters in the Mediterranean
RESULTS: Report completed
PRESENTATIONS:
DELIVERABLES: Report delivered in Month 33
PERSON MONTHS: 1.0

Work completed:

Using data from three PRUDENCE RCMs, monthly potential evapotranspiration was calculated from temperatures for the periods 1961-1990 and 2070-2099. The method of calculation is the modified Blaney & Criddle method which adjusts for latitude and contains an empirical parameter to approximate the effects of relative humidity, wind speed, and sunshine. A monthly index of soil moisture availability (smam) was then derived by subtracting the monthly potential evapotranspiration from the monthly total rainfall.

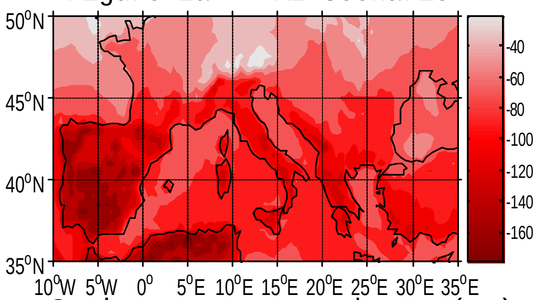
Changes in mean seasonal soil water availability were than examined for the A2a and B2a emissions scenarios between the periods 1961-1990 and 2070-2099. Bootstrapping was used to estimate the uncertainty in the ensemble mean change in seasonal soil moisture availability. To complete the examination of physics, similar analyses were also presented for seasonal changes in temperature and rainfall.

Under the A2 emissions scenario, the consensus of the models is that seasonal temperatures are expected to rise by 3-5°C, and rainfall to decline by up to 50 mm in winter (the main wet season) and by 50-100 mm in the other seasons. There will be an attendant fall in soil moisture availability of 50-100 mm in winter and 100-160 mm in spring and autumn. The uncertainty in the projected changes in soil moisture amount ranges from ±5% to ±35%.

Generally, the spatial distribution of changes under the B2 scenario mirrors the distribution under the A2 scenario. However, the intensity of the change is reduced by 40-50%. Even under the relatively modest B2 emissions scenario, therefore, the Mediterranean is projected to experience considerable depletion of soil moisture by the end of the century, even in the wet seasons.

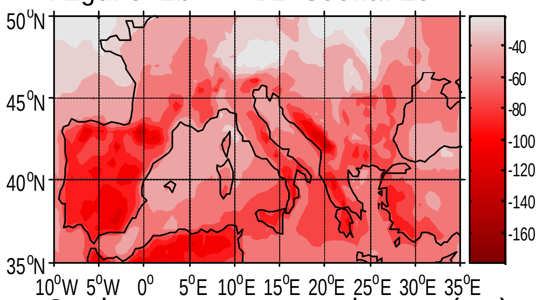
The example below shows the plots of the ensemble mean soil moisture changes (mm) in Spring and Summer under the A2a and B2a scenarios. In both seasons Iberia and North Africa are expected to suffer particularly severe soil moisture deficits under the A2a scenario.

Figure 2a A2 Scenario



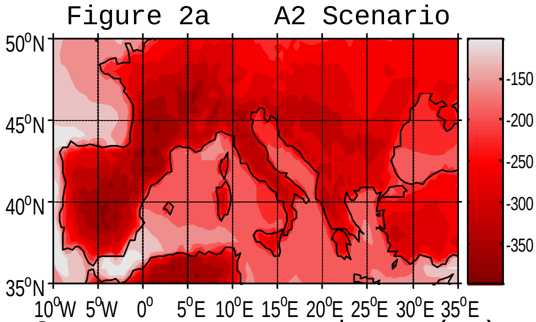
Spring smam, mean change (mm)

Figure 2b B2 Scenario



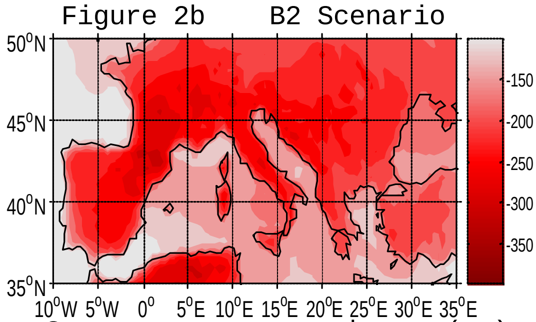
Spring smam, mean change (mm)

Figure 2a A2 Scenario



Summer smam, mean change (mm)

Figure 2b B2 Scenario



Summer smam, mean change (mm)

CONTRIBUTOR TO TASK: D5A4

WORK: Assessment of the general change in heat waves and cold spells as related to human health, agricultural risk and energy demand.
RESULTS: Report completed
PRESENTATIONS:
DELIVERABLES: Report is due in Month 33
PERSON MONTHS: 0.5

It would have been ideal to calculate a heat wave index for this study, combining the effects of temperature and humidity. However, relative humidity was only available for one model, therefore the report discusses heat waves in terms of the longest period in days per year with temperatures persistently above 30 degrees. For cold spells, we chose period per year with temperatures below freezing. Although this may not seem appropriate for the Mediterranean, it was considered a useful parameter because of the effect of persistent frosts on agriculture. The models used in the analysis are the DMI, HadRM3, and SMHI models, comparing spells between the present and the projections under the A2a scenario.

Figure 3 show the example of the change in hot spells between 1961-1990 and 2070-2099, in terms of the average for each period from the DMI model. The future extension of hot spells by up to 70 days over Africa, Iberia, and parts of Italy, Turkey, and Greece threatens the huge tourist industry in those countries. The picture for agriculture in terms of length of cold spells is much more reassuring (Figure 4). Winters in Turkey, particularly, are indicated to become much warmer with a future reduction in the length of cold spells by up to 60 days.

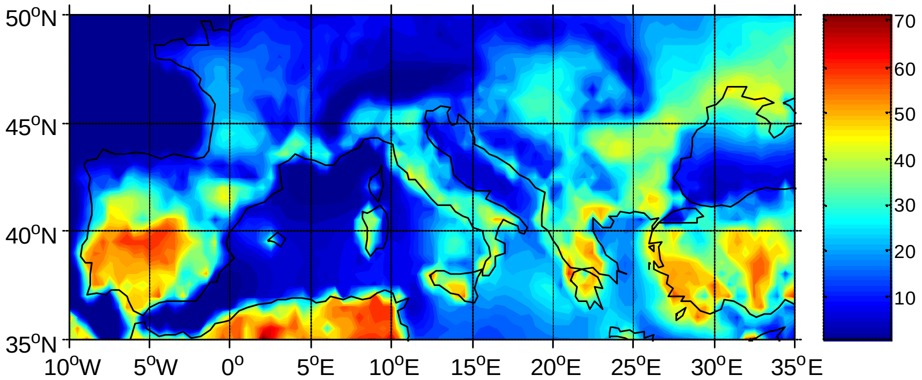


Figure 3 Change in the length of Hot Spells (days/year with t>30 deg. C) between 1961-1990 and 2070-2099 under the A2a scenario.

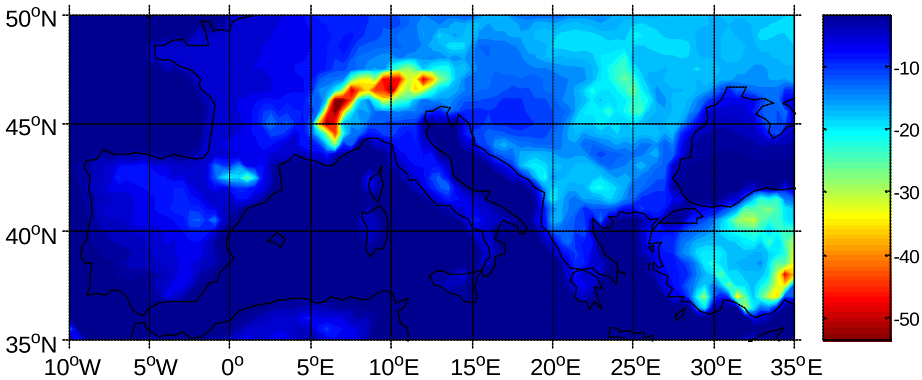


Figure 4 Change in the length of Cold Spells (days/year with t<0 deg. C) between 1961-1990 and 2070-2099 under the A2a scenario.

GENERAL COMMENTS:

PUBLICATIONS:
Contributions to the PRUDENCE joint papers on likely changes in Mediterranean droughts and soil moisture conditions (based on D5A6 and D4A4 above, respectively)

EMPLOYEES:
Name: Jean Patricia Palutikof; Tom Holt

PUBLICATION PLAN: At least one paper on the impacts of climate change in the Mediterranean as indicated by the Regional Climate Models employed in

PRUDENCE, to be delivered within two years. It may be possible to produce two papers – one on extremes in rainfall, one on extremes in temperature.
PLANS FOR THE NEXT PHASE: Project completed

Partner no.: 21

Institution: Finnish Meteorological Institute
Acronym: FMI
Responsibility: FMI is associated to Partner 16 (Finnish Environmental Institute - FEI) and participates to WP 2, 4, 5 and 7.

RESPONSIBLE FOR TASK: D2A3, D5A7
FMI PARTICIPATES IN TASKS: D4C5, D4C6, D5A8, D7A3, D7A4

RESPONSIBLE FOR TASK: D2A3
WORK: Upper and lower estimates of regional temperature change across Europe based on pattern scaling methods for the SRES emissions range and the IPCC range of climate sensitivities.
ALLOCATED PERSON MONTH THIS PERIOD: 0.5
RESULTS: Together with FEI (Partner 16), a pattern scaling methodology to approximate climate responses to emissions scenarios not actually simulated by the AOGCMs has been developed and applied. In collaboration with UCM, Spain (Partner 10) a method has been developed to compute (Köppen) climate classification from gridded observed and model data.
PRESENTATIONS: An oral presentation: Ruosteenoja, K., Tuomenvirta, H. and, Jylhä K., 2004: Regional temperature and precipitation change estimates for Europe under four SRES scenarios. PRUDENCE Final meeting, Toledo, Spain, 6-10 September 2004.
DELIVERABLES: Ruosteenoja, K., Tuomenvirta, H. and, Jylhä K.: GCM-based regional temperature and precipitation change estimates for Europe under four SRES scenarios applying a super-ensemble pattern-scaling method. To be submitted to PSICC.
de Castro M., C. Gallardo, K. Jylhä and H. Tuomenvirta, 2004: The use of a climate-type classification for assessing climate change effects in Europe from an ensemble of regional climate models. To be submitted to PSICC.

RESPONSIBLE FOR TASK: D5A7
WORK: Mapping present-day and future resource risk for Europe or for sub-regions of Europe, based on gridded or site-based information. Estimates to be provided by FMI and mapped by FEI.
ALLOCATED PERSON MONTH THIS PERIOD: 2.5
RESULTS: Calculation and analysis of resource risk indices based on PRUDENCE simulations at daily time resolution.
PRESENTATIONS: Jylhä K., Fronzek S., Ruosteenoja K., Tuomenvirta H. and T.R. Carter, 2004: Projected changes in indices related to low air temperatures and extreme precipitation. PRUDENCE Final meeting, Toledo, Spain, 6-10 September 2004.
DELIVERABLES: Jylhä K., Fronzek S., Ruosteenoja K., Tuomenvirta H. and T.R. Carter: Changes in frost and snow in Europe and sea ice in the Baltic Sea by the end of the 21st century. To be submitted to PSICC.

CONTRIBUTOR TO TASK: D4C6
WORK: Analysis, interpretation and presentation of uncertainties in impacts in GIS (with FEI)
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Assistance in the use of observational data from ECA&D and NORDKLIM data sources.
PRESENTATIONS: see Partner 16 (FEI)
DELIVERABLES: see Partner 16 (FEI)

CONTRIBUTOR TO TASK: D5A8
WORK: Analysis of uncertainties in estimated changes in resource risk in co-operation with FEI
ALLOCATED PERSON MONTH THIS PERIOD: 2
RESULTS: The sensitivity of the simulated changes in the 30-year means of the greatest summer and winter 1-day and 5-day precipitation totals to the emissions scenarios, differences in RCM formulation and GCM boundary conditions.
PRESENTATIONS: see Partner 16 (FEI)
DELIVERABLES: Beniston et al. 2004: Estimating the potential impacts of changes in climate variability and extremes in Europe derived from regional climate model information. To be submitted to PSICC.
See also Partner 16 (FEI)

CONTRIBUTOR TO TASK: D7A3
WORK: Presentation of climate scenarios and their uncertainties
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: In collaboration with the Finnish Science Centre, maps showing Köppen climate classification for selected SRES emission scenarios (B1, B2, A2 and A1FI) have been prepared to illustrate the range of climate scenarios and their uncertainties.
PRESENTATIONS:
DELIVERABLES: An animation describing climatic changes (Köppen climate classification) under four SRES scenarios and two climate models can be viewed at the web-site of the Finnish Science Centre (animation: http://194.137.146.17/ilmasto/ and Centres homepage: http://www.heureka.fi/portal/englanti/)

CONTRIBUTOR TO TASK: D7A4
WORK: Final presentation of PRUDENCE, particularly summarising the impacts of climate change and their uncertainties
ALLOCATED PERSON MONTH THIS PERIOD: 1
RESULTS: Dissemination of PRUDENCE results and guidance for data
PRESENTATIONS: Jylhä, K.: "Long-term trends of climate - towards greenhouse or ice age?" in a seminar titled "In our lifetimes deluge - and droughts? Finnish water environment and extreme phenomena", organized by the Association
of Finnish Civil Engineers. Helsinki, 26 Oct 2004 (in Finnish)
Jylhä, K., Tuomenvirta, H. and Ruosteenoja, K.: "Climate change scenarios for Finland" in a seminar titled "Climate changes - will the forests adapt?", organized by the Finnish Forest Research Institute.
Kuopio, 11 Nov 2004 (in Finnish)
DELIVERABLES: Assistance in use of PRUDENCE results in the Finnish research community dealing with impacts of and adaptation to climate change.
Contribution of PRUDENCE results to preparation of the National Adaptation Strategy of Finland (as a part of Finnish Climate Strategy).
(http://www.mmm.fi/sopeutumisstrategia/).

PUBLICATIONS:
Ruosteenoja, K., Tuomenvirta, H. and, Jylhä K., 2004: GCM-based regional temperature and precipitation change estimates for Europe under four SRES scenarios applying a super-ensemble pattern-scaling method. Submitted to Climatic Change.
Jylhä K., Fronzek S., Ruosteenoja K., Tuomenvirta H. and T.R. Carter: Changes in frost and snow in Europe and sea ice in the Baltic Sea by the end of the 21st century. Submitted to Climatic Change.

EMPLOYEES:
Name: Heikki Tuomenvirta, Kirsti Jylhä, Kimmo Ruosteenoja

RESULTS

WP 2

In most of the recent GCM and RCM experiments, only responses to the SRES A2 and B2 forcing scenarios have been simulated. In order to formulate projections for the highest (A1FI) and lowest (B1) forcing scenarios, a super-ensemble pattern-scaling technique has been developed. This method uses linear regression to represent the relationship between the local GCM or RCM simulated temperature/precipitation response and the global mean temperature change simulated by a simple climate model. Compared with the existing methods, the super-ensemble method proved especially useful in a situation with only one A2 and one B2 simulation available for an individual GCM.

For five regions covering continental Europe 95% probability intervals of GCM-based temperature and precipitation change were determined based on simulations made with six global coupled GCMs. The Normal distribution was used as an approximation to the seasonal temperature and precipitation changes. For the end of the 21st century, the highest estimates of temperature response to A1FI scenario are close to 10°C in the southern Europe summer and northern Europe winter. In contrast, the lowest B1 estimates for some individual seasons and regions are ~1°C. The upper and lower estimates of precipitation change are generally of opposite sign, but the mean estimate is of a noticeable increase in the north in winter and a strong reduction in the southern Europe in summer.

Ranges of GCM-based temperature and precipitation change were compared with corresponding estimates given by RCMs participating in the PRUDENCE project. Very rarely do the different approaches show large systematic difference in the estimates of mean change. However, the total range of GCM responses is distinctly wider than the RCM range.

WP5

We have analysed projected changes in 30-year means of indices related to low temperatures and extreme precipitation, including the number of frost days, first and last dates of the frost season, number of days crossing the 0°C threshold, number of days with snow cover, maximum 1-day and 5-day precipitation totals, and maximum length of dry spells. Seasonal and annual means of the indices were calculated using daily data from an extensive suite of RCM runs. Interpolation of the indices onto a common grid across Europe enabled us to assess the uncertainties in the estimated changes due to differences in RCM formulation, GCM boundary conditions and future emissions. The results have been presented as maps and domain-averages.

As an example of the results, the following figure shows the winter maximum 5-day and summer maximum 1-day precipitation totals for five regions covering continental Europe. The winter 5-day precipitation extreme increases in every model simulation for northern and central European domains, but the models disagree about the sign of the change in southern Europe. Heavy summer precipitation decreases in the south and increases in the north but for central European domains the results are somewhat controversial. For each sub-region, the projected increases (decreases) in summer heavy precipitation are slightly larger (smaller) than the changes in summer mean precipitation.

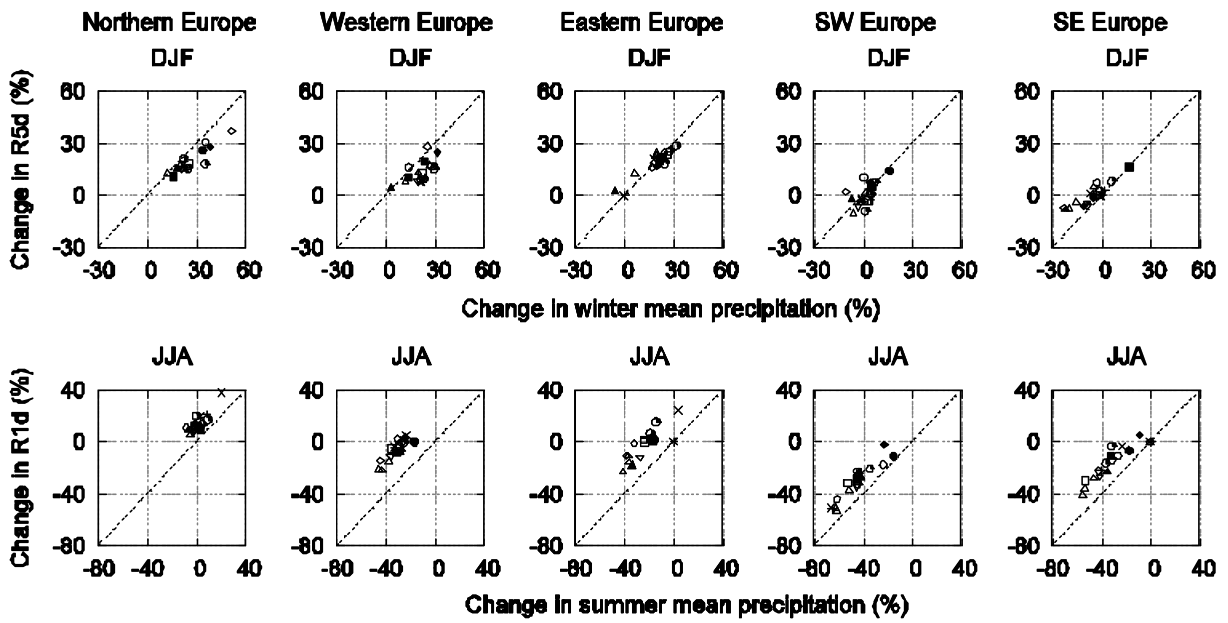


Fig. Projected area-averaged changes (%) in the 30-year means of the greatest 5-day precipitation total (R5d) in winter (top) and of the gratest 1-day precipitation total (R1d) in summer (bottom) in five European sub-regions in 2071-2100, relative to the baseline period 1961–1990. Both variables are given as a function of seasonal mean precipitation changes. Different symbols denote the different RCM experiments (solid symbols for SRES B2 forcing, the others for SRES A2 forcing).

Northern Europe: 55-75°N, 4-35°E
Western Europe: 45-55°N, 15W-15°E and 55-65°N, 10W-0°E
Eastern Europe: 45-55°N, 15-35°E
South-Western Europe: 35-45°N, 15W-18°E
South-Eastern Europe: 35-45°N, 18-35°E

WP7

Planning of cost-effective measures to mitigate climate change and to adapt to its impacts requires fluent communication between scientists and decision-makers. The mitigation and adaptation measures to be implemented successfully, it is also essential to influence the public opinion by creating awareness and strengthening knowledge of the general public about global change and sustainable development. A particularly important target group of dissemination of global change information consists of the schoolchildren, students and their teachers.

Maps illustrating projected shifts in the future of the Köppen climatic zones open up an efficient dissemination tool of climate change information. In March 2003 a one-year exhibition entitled “Open questions” was opened in Heureka, the Finnish Science Centre. The exhibition was aimed at the general public, particularly pupils and students, and was attended by 215 000 visitors. In an exhibit named as “Sunny tomorrow? --- Is our climate warming” a personal computer interactively displayed alternative animations of the spatial distribution of projected future climatic zones in Europe during a 110-year period (1975–2085). The animations were based on four alternative storylines of the future world (Nakicenovic *et al.* 2000) and on experiments by two global climate models (that have been directly (ECHAM4/OPYC) or indirectly (HadCM3) downscaled within PRUDENCE). Background information about creating climate change scenarios was also provided for the visitors of the exhibition.

The exhibit was popular and gained a lot of interest. Later, the animations have been made freely available via the internet in a climate change virtual web school.

Contribution from KNMI

In the last year of the PRUDENCE project, research at KNMI has been focussed on: 1) an analysis of the inter-annual temperature variability for summer, 2) runoff, water storage, and influence of soil control in the Rhine basin, and 3) an analysis of the circulation statistics in the PRUDENCE simulations. Results are shortly discussed below. A paper on the results of subject 2) by Van den Hurk et al. has been sent in to the Journal of Climate. Two other papers (about summertime temperature variability by Lenderink et al., and circulation statistics by Van Ulden et al.) will be considered for publication in the special PRUDENCE issue of Climate Change, or will be sent in elsewhere.

Summer temperature variability

The inter-annual variability in monthly mean summer temperatures in nine different regional climate model (RCM) integrations is investigated for both the control climate (1961-1990) and a future climate (2071-2100) with A2 emissions. All models are driven by the same boundaries of the HadAM3H global atmospheric model. Compared to the CRU TS 2.0 observational data set most RCMs over-predict the temperature variability significantly in their control simulation. In concert, results obtained with KNMI model RACMO2 using analyzed boundaries from the ERA40 project are discussed. The results using ERA40 boundaries are close to the results obtained using the HadAM3H boundaries, indicating that errors in the circulation statistics in the HadAM3H boundaries are not likely to be a major cause for the overestimation in temperature variability. The behaviour of the different regional climate models is analysed in terms of the surface energy budget, and the individual contributions of the different terms in the surface energy budget to the temperature variability are estimated. This analysis shows a clear relation in the model ensemble between temperature variability and the combined effects of downward long wave, net short wave radiation and evaporation.

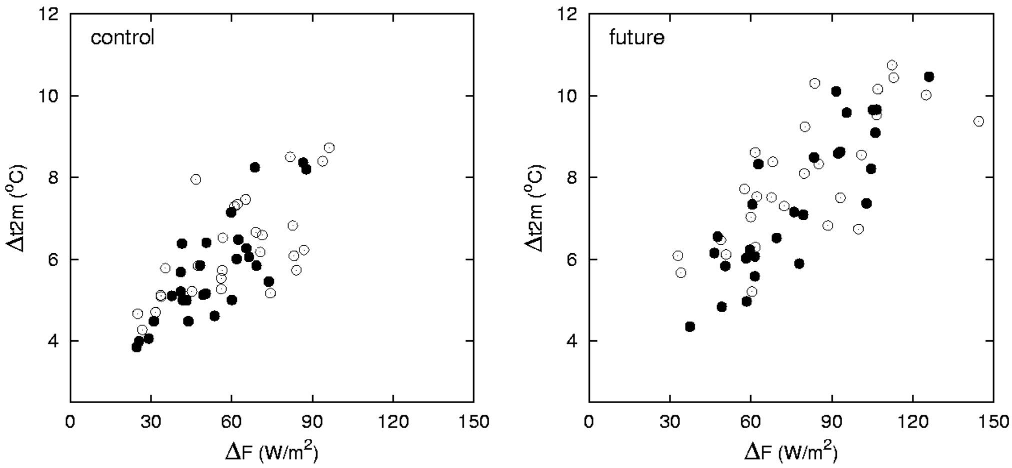


Fig.1. Relation between surface fluxes DF (defined as the flux difference of the sum of net short wave radiation, downward long wave radiation and latent heat flux between warm summer months and cold months) and temperature variability. Results are shown for all RCM simulations driven by HadAM3H boundaries (A2), for the months June, July, and

August, for two areas in Germany (solid) and France (open circles). Dt2m is a measure of the temperature variability, roughly 3.2 times the standard deviation.

Fig. 1 shows the relation between temperature variability and variability in the sum of downward long wave radiation, net short wave radiation and the latent heat flux. For the latter we used an "estimate" of the difference between the surface fluxes in warm months and those in cold months. The results of the multi-model ensemble show a clear relation between the surface fluxes and the temperature variability. However, the results also revealed that the overestimation of the temperature variability has no unique cause. The effect of shortwave radiation dominates in some RCMs, whereas in others the effect of evaporation dominates. In all models the temperature variability increases when imposing future climate boundary conditions, with particularly high values in central Europe. The surface energy budget analysis again shows a clear relation between the sum of the response in evaporation, net short wave radiation, and downward long wave radiation, on the one hand, and the change in temperature variability, on the other hand. Finally, it appears that the increased land-sea temperature contrast in the future climate has an impact on the surface energy budget such that the temperature variability increases.

Soil storage and runoff in the Rhine basin

Simulations with seven regional climate models driven by a common control climate simulation of a GCM carried out for Europe in the context of the PRUDENCE project were analysed with respect to land surface hydrology in the Rhine basin. In particular, the annual cycle of the terrestrial water storage was compared to analyses based on ERA40 atmospheric convergence and observed Rhine discharge data. In addition, an analysis was made of the partitioning of convergence anomalies over anomalies in runoff and storage. This analysis revealed that most models underestimate the size of the water storage and consequently overestimated the response of runoff to anomalies in net convergence (see Fig. 2). The partitioning of these anomalies over runoff and storage were indicative for the response of the simulated runoff to a projected climate change. In particular the depth of the annual cycle of runoff is affected largely by the terrestrial storage reservoir. Larger storage capacity leads to smaller changes in both wintertime and summertime monthly mean runoff. The sustained summertime evaporation resulting from larger storage reservoirs may have a noticeable impact on the summertime surface temperature projections.

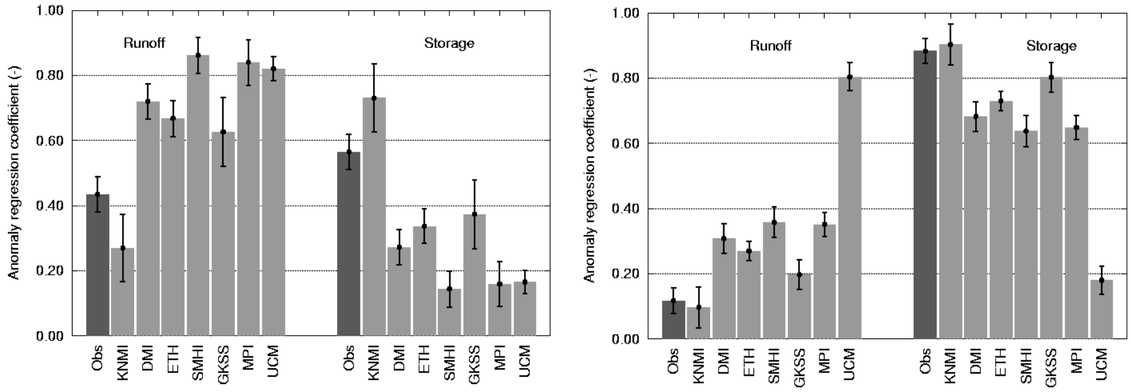


Fig 2. Regression coefficients between anomalies in moisture convergence into the Rhine area (precipitation minus evaporation) and runoff (left part of the plot) and soil storage (right part) for winter (left-hand side) and summer (right-hand side).

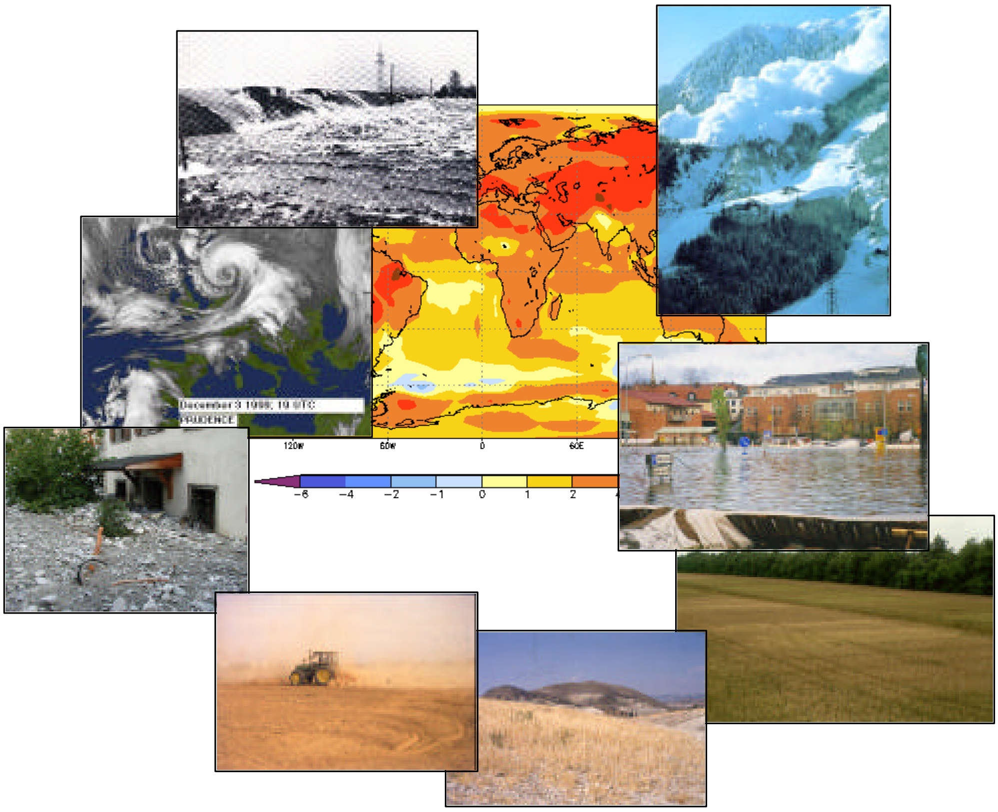
Circulation statistics

PRUDENCE simulations of monthly mean pressure and geostrophic wind over Central Europe are analysed. Model simulations are compared with observations over the period 1780–1995. This long record provides information on the mean circulation and on natural variability on inter-annual and inter-decadal timescales. The control simulations by the global models HadAM3H and ECHAM4/OPYC show biases, which fall outside the range of natural variability. In winter, both models have a pronounced positive bias in the west component of the geostrophic wind (Gw too strong). In summer, HadAM3H has a pronounced negative bias in Gw (Gw too weak), while ECHAM shows no significant bias in this variable. In the A2 scenario simulations the circulation statistics move further away from the observed statistics. The biases in Gw have a strong impact on the frequency of easterly and westerly flows. For winter months, the percentage of months with a mean easterly flow is 14% in the observations. In the control simulations this percentage is reduced to about 7%, while such easterly circulations are virtually absent in the scenario runs. Thus the simulated winter climate is far more maritime that the observed winter climate. For summer months, the HadAM3H simulation of the frequency distribution of Gw differs dramatically from the observations. In the observations about 8% of the summer months is characterised by a mean easterly flow. In the HadAM3H control run this percentage is 45% and in the HadAM3H scenario run even 75%. Thus the summer climate is far too continental in the HadAM3H simulations. The ECHAM simulations show fairly realistic circulation statistics for summer months.

We analysed nine regional climate models, which use lateral boundary conditions and SST's from HadAM3H. The correlations between monthly mean pressure and geostrophic wind components simulated by the regional models and those simulated by the driving model HadAM3H are quite high in winter (for DJF $r = 0.95$-0.99). Thus large-scale dynamics effectively control the circulation statistics in the domain of the regional models. In other months the situation is different, especially in summer. Some models show correlations around 0.7, while other models show correlations around 0.95 even in summer. Thus differences in boundary relaxation procedures are important when the large-scale dynamical forcing is weaker. The regional models show also important differences with HadAM3H and between each other in the simulated mean flow characteristics. Also the variability in the circulation components shows a wide range between the models. An interesting feature is that most regional models tend to reduce the easterly bias present in the HadAM3H simulations for the summer. This reduction is more pronounced for models that have a low sensitivity to summer drying. This points at a positive feedback between summer drying and the easterly flow bias. Also temperatures are involved in this feedback. This makes the models rather sensitive to the treatment of the soil moisture budget, leading to very warm extremes in the scenario simulations by some models. Also the impact of the westerly bias in winter is important. There is a lack of very cold months, due to a lack of easterly circulations. In general there is a warm circulation bias, which increases in the scenario simulations for winter.

The conclusion is that biases in the frequency distributions of the atmospheric circulation have to be taken into account when comparing model simulations of e.g. temperature and precipitation with observations. In the assessment of regional climate change, the role of changes in circulation statistics should also be included in the analysis.

Appendix A



Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects

PRUDENCE (http://prudence.dmi.dk)

Contract No. EVK2-2001-00156

A Side event at the
Tenth Session of the Conference of Parties (COP 10)
6 - 17 December 2004, Buenos Aires, Argentina

Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects – PRUDENCE

PRUDENCE was a project funded by the European Commission under its fifth framework programme. It had 21 participating institutions from a total of 9 European countries, with several additional international collaborators, who have contributed to the project from their own funding. The ideas and objectives giving the basis of the project can be summarised as follows:

Problem to be solved:
European decision-makers in government, non-governmental organisations, and industry, as well as the general public, need detailed information on estimates of the future climate. This would enable an evaluation of the risks of climate change due to anthropogenic emissions of greenhouse gases. Projections of future climate change already exist, but are insufficient, both in terms of the characterisation of their uncertainties and in terms of 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 Atmospheric-Ocean General Circulation Models (AOGCMs), neither capable of resolving spatial scales of less than about 300km. This coarse resolution precludes the simulation of realistic extreme events and the detailed spatial structure of variables like temperature and precipitation over heterogeneous surfaces like the Alps, the Mediterranean, or Scandinavia. Simple models include, at best, a limited physical representation of the climate system.

Scientific objectives and approach:
PRUDENCE is a European-scale investigation with the following objectives:

d) to address and reduce the above-mentioned deficiencies in projections of the future;
e) to quantify our confidence and the uncertainties in predictions of future climate and its impacts, using an array of climate models and impact models as well as expert judgement on their performance;
f) to interpret these 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, due to higher temperatures, an intensified hydrological cycle or more vigorous atmospheric motions. A major limitation in previous studies of extremes has been the lack of:

- appropriate computational resolution - obscures or precludes analysis of the events;
- long-term climate model integrations - drastically reduces their statistical significance;
- co-ordination between modelling groups - limits the ability to compare different studies.

These three issues are all thoroughly addressed in PRUDENCE, by using state-of-the-art high resolution global and regional climate models, by co-ordinating the project goals to address critical aspects of uncertainty, and by applying impact models and impact assessment methodologies to provide the link between the provision of climate information and its likely application to serve the needs of European society and economy.

Expected impacts:
PRUDENCE has provided a series of high-resolution climate change scenarios for 2071-2100 for Europe, characterising the variability and level of confidence in these scenarios as a function of uncertainties in model formulation, natural/internal climate variability, and alternative scenarios of future atmospheric composition. The project provides a quantitative assessment of the risks arising from changes in regional weather and climate in different parts of Europe, by estimating future changes in extreme events such as drought, flooding and wind storms and by providing a robust estimation of the likelihood and magnitude of such changes. The project also examines the uncertainties in potential impacts induced by the range of climate scenarios developed from the climate modelling results. This provides useful information for climate modellers on the levels of accuracy in climate scenarios required by impact analysts. Furthermore, a better appreciation of the uncertainty range in calculations of future impacts from climate change offer new insights into the scope for adaptation and mitigation responses to climate change

Project start and end:
PRUDENCE was formally accepted by the European Commission as contract No. EVK2-2001-00156, which was duly signed on 29 October 2001. The project thus accordingly officially started on 1 November 2001 with a duration of three years, so the formal end of the project was 30 October 2004. The final report and dissemination of results are expected by early 2005, while the scientific reporting of the project will not be in press before the end of 2005 or early 2006, when a special issue of the journal *Climatic Change* with PRUDENCE results will be ready. Meanwhile, the reader is referred to the project home page http://prudence.dmi.dk

About this document:

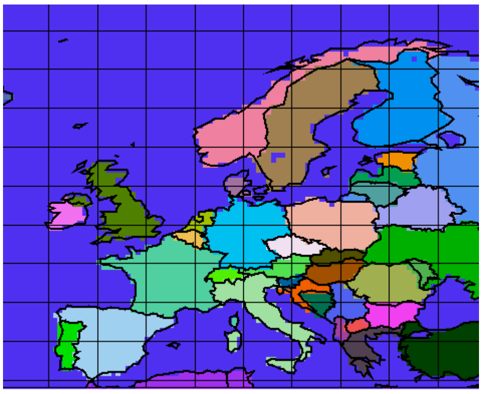
As a first attempt to generate a comprehensive assessment of expected changes in mean temperature and precipitation for Europe, an analysis based on all the PRUDENCE simulations has been conducted on a country-by-country basis. In order for this analysis to be independent of specific choices of emission scenario, a pattern scaling technique has been applied and the changes are expressed relative to a 1 °C global warming. Uncertainties in the estimates of projected changes still remain and are due to different formulations of the involved global and regional climate models as well as natural variability (inter-annual variations). A quantitative analysis of the role the different sources of uncertainty will become available with the planned special issue of *Climatic Change*. Here it is just noted that the uncertainty estimates are based on all sources of model spread.

Procedure:

For each country (some of the larger countries are split in two sections) all available simulation data for temperature and precipitation have been aggregated into one number per field representing this country for each simulation. This number is scaled according to the global temperature change using the underlying global climate model, which has been used as a driver for the regional climate model. This way, more than 25 estimates of the change in temperature and precipitation has be provided for each country. Hereafter, the resulting mean and standard deviation have been used to fit a normal probability distribution function for the projected change. Hence, estimates of the 5th, 50th and 95th percentiles of the projected changes can be provided as well as their associated 95% confidence intervals.

Results:

The following pages summarise the available information about annual and seasonally (Dec. – Jan. – Feb.), (Mar. –Apr. – May), (Jun. - Jul. – Aug.), and (Sep. – Oct. – Nov.) respectively, averaged temperature and precipitation for all European countries which are large enough to be represented by at least one grid point (50km times 50km) in the climate simulations on the geographical domain outlined below. The same scaling has been applied to all seasons.



Only countries which are completely within the domain are shown. The procedure previously described is illustrated by the example of Denmark.

The organisation of the figures are such that on the top of each page the projected changes in near surface air temperature per degree global warming is presented, below, projected relative change in precipitation per degree global warming is presented.

For each variable the results shown are as follows:

<x>: Estimate of mean from all models

<s>: Estimate of standard deviation from all models

<med>: Median values based on all models

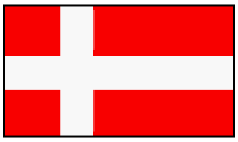
<p95>: 95th percentile value of projected change (with 95% confidence interval)

<p50>: 50th percentile value of projected change (with 95% confidence interval)

<p05>: 5th percentile value of projected change (with 95% confidence interval)

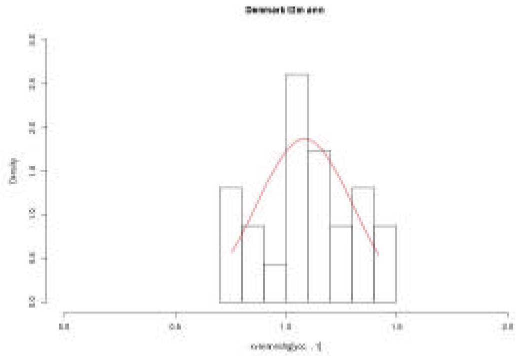
Acknowledgement:

The analysis and compilation of data country by country was carried out by Dr. Enrique Sanchez Sancez, UCLM in collaboration with Dr. Jens Hesselbjerg Christensen, DMI



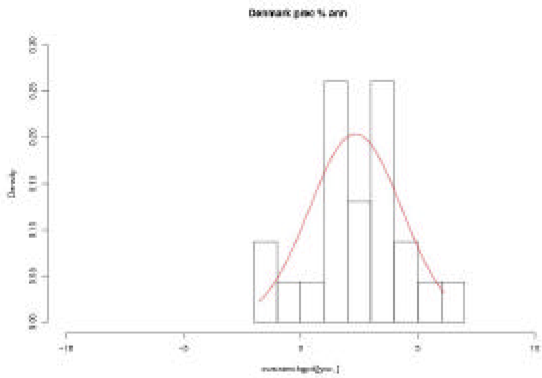
Denmark

Temperature[ºC] (ann)
<x>=1.1
<s>=0.2
<med>=1.1
<p95>=1.4(1.3,1.5)
<p50>=1.1(1.0,1.2)
<p05>=0.7(0.6,0.8)



Temperature[ºC] (DJF)	(MAM)	(JJA)	(SON)
1.0	1.0	1.1	1.2
0.2	0.2	0.2	0.2
1.1	1.0	1.0	1.2
1.4(1.3,1.6)	1.4(1.3,1.5)	1.4(1.3,1.5)	1.6(1.5,1.7)
1.0(1.0,1.1)	1.0(0.9,1.1)	1.1(1.0,1.1)	1.2(1.2,1.3)
0.6(0.5,0.8)	0.6(0.5,0.8)	0.7(0.6,0.8)	0.9(0.7,1.0)

Precipitation [%] (ann)
<x>=2.4
<s>=2.0
<med>=2.5
<p95>=5.6(4.5,6.6)
<p50>=2.4(1.7,3.0)
<p05>=-0.9(-1.9,0.2)

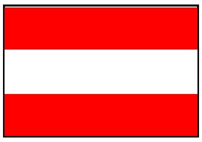


Precipitation [%] (DJF)	(MAM)	(JJA)	(SON)
9.8	3.6	-6.4	1.5
3.7	2.2	3.5	4.1
10.1	3.3	-7	1.7
15.9(13.8,17.9)	7.3(6.1,8.4)	-0.6(-2.3,1.2)	8.3(6.1,10.5)
9.8(8.5,11.1)	3.6(2.9,4.4)	-6.4(-7.5,-5.2)	1.5(0.0,2.9)
3.7(1.7,5.7)	-0.0(-1.2,1.1)	-12.2(-14.1,-10.3)	-5.3(-7.5,-3.0)

Albania

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.2	1.2	1.9	1.4
<s>=0.4	0.4	0.4	0.6	0.3
<med>=1.4	1.3	1.1	1.9	1.4
<p95>=2.1(1.9,2.3)	1.8(1.6,2.0)	1.8(1.6,2.0)	2.8(2.5,3.1)	2.0(1.8,2.2)
<p50>=1.4(1.3,1.6)	1.2(1.1,1.4)	1.2(1.0,1.3)	1.9(1.7,2.1)	1.4(1.3,1.5)
<p05>=0.8(0.6,1.0)	0.6(0.5,0.8)	0.6(0.4,0.8)	1.0(0.7,1.3)	0.8(0.7,1.0)

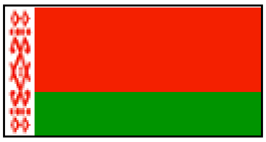
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-4.9	0.4	-5.3	-13.9	-5.8
<s>=3.1	3.9	4.6	7	3
<med>=-4.2	0.5	-4.9	-14	-6
<p95>=0.3(-1.4,1.9)	6.7(4.7,8.7)	2.2(-0.2,4.8)	-2.3(-6.0,1.4)	-0.8(-2.5,0.7)
<p50>=-4.9(-6.0,-3.8)	0.4(-1.0,1.6)	-5.3(-6.9,-3.7)	-13.9(-16.3,-11.5)	-5.8(-6.8,-4.8)
<p05>=-10.0(-11.7,-8.4)	-6.0(-7.9,-3.9)	-12.9(-15.5,-10.4)	-25.5(-29.2,-21.7)	-10.8(-12.4,-9.3)



Austria

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.2	1.2	1.6	1.4
<s>=0.4	0.4	0.4	0.5	0.4
<med>=1.3	1.2	1.2	1.5	1.3
<p95>=2.0(1.8,2.3)	1.9(1.7,2.1)	1.8(1.6,2.0)	2.5(2.2,2.8)	2.1(1.8,2.3)
<p50>=1.4(1.2,1.5)	1.2(1.1,1.4)	1.2(1.1,1.3)	1.6(1.4,1.8)	1.4(1.3,1.5)
<p05>=0.7(0.4,0.9)	0.6(0.4,0.8)	0.5(0.3,0.7)	0.7(0.4,1.0)	0.7(0.5,0.9)

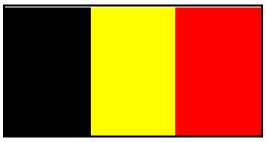
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.5	4.9	2.3	-5.6	-1.6
<s>=1.9	4.2	3.4	4.1	2.2
<med>=-0.1	5.3	2.9	-5.5	-1.6
<p95>=2.7(1.7,3.8)	11.9(9.6,14.1)	7.9(6.0,9.8)	1.2(-0.9,3.3)	2.1(0.9,3.3)
<p50>=-0.5(-1.1,0.2)	4.9(3.5,6.3)	2.3(1.1,3.4)	-5.6(-6.9,-4.2)	-1.6(-2.3,-0.8)
<p05>=-3.6(-4.7,-2.6)	-2.0(-4.3,0.2)	-3.4(-5.3,-1.5)	-12.3(-14.4,-10.1)	-5.2(-6.4,-4.1)



Belarus

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.6	1.3	1.3	1.4
<s>=0.3	0.3	0.3	0.4	0.2
<med>=1.4	1.6	1.3	1.3	1.4
<p95>=1.8(1.7,2.0)	2.1(1.9,2.2)	1.8(1.6,1.9)	1.9(1.7,2.1)	1.8(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.6(1.5,1.7)	1.3(1.3,1.4)	1.3(1.1,1.4)	1.4(1.3,1.5)
<p05>=1.0(0.9,1.1)	1.2(1.1,1.3)	0.9(0.8,1.0)	0.6(0.4,0.8)	1.0(0.9,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.3	8.8	2.5	-2.9	-2.4
<s>=2.0	3.6	2.8	5.3	3.1
<med>=1.2	10.3	2.5	-3.4	-3.5
<p95>=4.6(3.5,5.6)	14.7(12.6,16.6)	7.1(5.6,8.6)	5.8(3.0,8.6)	2.7(1.1,4.4)
<p50>=1.3(0.6,2.0)	8.8(7.6,10.0)	2.5(1.5,3.5)	-2.9(-4.6,-1.2)	-2.4(-3.5,-1.4)
<p05>=-2.0(-3.0,-0.9)	2.9(1.0,4.8)	-2.2(-3.7,-0.7)	-11.6(-14.4,-8.8)	-7.5(-9.1,-5.9)



Belgium

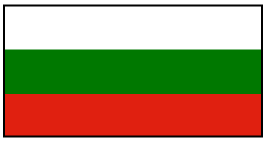
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.2	1.0	1.0	1.5	1.3
<s>=0.4	0.3	0.4	0.5	0.3
<med>=1.1	0.9	0.9	1.4	1.2
<p95>=1.8(1.6,2.0)	1.5(1.3,1.7)	1.5(1.4,1.7)	2.3(2.0,2.5)	1.8(1.6,2.0)
<p50>=1.2(1.0,1.3)	1.0(0.9,1.1)	1.0(0.8,1.1)	1.5(1.3,1.6)	1.3(1.2,1.4)
<p05>=0.6(0.4,0.8)	0.4(0.2,0.6)	0.4(0.2,0.6)	0.7(0.4,0.9)	0.7(0.6,0.9)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-1.1	6.5	0.0	-11.3	-2.3
<s>=1.1	3.1	2.6	4.4	3
<med>=-1.2	6.0	0.2	-10.3	-2.4
<p95>=0.6(0.1,1.2)	11.5(9.9,13.2)	4.3(2.9,5.7)	-4.1(-6.3,-1.7)	2.7(1.1,4.2)
<p50>=-1.1(-1.5,-0.8)	6.5(5.4,7.5)	-0.0(-0.9,0.8)	-11.3(-12.8,-9.8)	-2.3(-3.4,-1.3)
<p05>=-2.9(-3.5,-2.4)	1.4(-0.2,3.0)	-4.4(-5.8,-3.1)	-18.5(-20.8,-16.1)	-7.3(-8.9,-5.6)

Bosnia-Herzegovina

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.2	1.8	1.4
<s>=0.3	0.4	0.3	0.5	0.3
<med>=1.4	1.3	1.1	1.8	1.4
<p95>=2.0(1.8,2.2)	1.9(1.7,2.1)	1.6(1.5,1.8)	2.7(2.4,2.9)	1.9(1.7,2.1)
<p50>=1.4(1.3,1.5)	1.3(1.2,1.4)	1.2(1.0,1.2)	1.8(1.6,2.0)	1.4(1.3,1.5)
<p05>=0.9(0.7,1.0)	0.7(0.5,0.9)	0.7(0.5,0.8)	1.0(0.7,1.2)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-3.0	4.4	-3.2	-12.0	-3.1
<s>=2.3	3.9	3.6	6.6	2.2
<med>=-2.8	4.3	-3.3	-10.8	-3.2
<p95>=0.7(-0.5,1.9)	10.8(8.7,12.8)	2.7(0.8,4.6)	-1.1(-4.8,2.5)	0.6(-0.6,1.9)
<p50>=-3.0(-3.8,-2.2)	4.4(3.1,5.7)	-3.2(-4.5,-2.0)	-12.0(-14.2,-9.7)	-3.1(-3.8,-2.3)
<p05>=-6.7(-7.9,-5.6)	-2.1(-4.2,-0.0)	-9.1(-11.1,-7.2)	-22.8(-26.2,-19.2)	-6.7(-7.9,-5.5)



Bulgaria

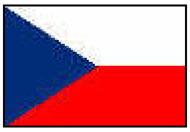
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.2	1.8	1.4
<s>=0.2	0.2	0.3	0.4	0.3
<med>=1.4	1.3	1.1	1.8	1.3
<p95>=1.8(1.7,2.0)	1.7(1.5,1.8)	1.6(1.5,1.7)	2.4(2.2,2.6)	1.8(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.3(1.3,1.4)	1.2(1.1,1.3)	1.8(1.7,1.9)	1.4(1.3,1.5)
<p05>=1.0(0.9,1.1)	1.0(0.9,1.1)	0.7(0.6,0.9)	1.2(1.0,1.4)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-3.9	-1.0	-2.5	-11.3	-2.5
<s>=2.9	3.7	3.2	5.6	4.4
<med>=-4.2	-1.1	-2.4	-12.1	-3.7
<p95>=0.9(-0.6,2.4)	5.0(3.1,6.8)	2.7(1.0,4.3)	-2.1(-5.1,0.8)	4.8(2.3,7.2)
<p50>=-3.9(-5.0,-2.9)	-1.0(-2.2,0.2)	-2.5(-3.6,-1.4)	-11.3(-13.2,-9.4)	-2.5(-4.0,-1.0)
<p05>=-8.7(-10.3,-7.1)	-7.0(-9.0,-5.1)	-7.7(-9.4,-6.1)	-20.5(-23.6,-17.5)	-9.8(-12.0,-7.5)

Croatia

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.1	1.8	1.4
<s>=0.4	0.3	0.3	0.5	0.4
<med>=1.4	1.3	1.1	1.8	1.3
<p95>=2.0(1.8,2.2)	1.9(1.7,2.1)	1.7(1.5,1.9)	2.7(2.4,2.9)	2.0(1.8,2.2)
<p50>=1.4(1.3,1.6)	1.3(1.2,1.4)	1.1(1.0,1.2)	1.8(1.6,2.0)	1.4(1.3,1.6)
<p05>=0.8(0.6,1.0)	0.7(0.5,0.9)	0.6(0.4,0.8)	1.0(0.7,1.2)	0.8(0.7,1.0)

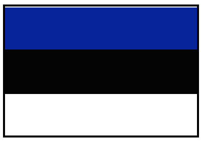
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-1.8	7.7	-2.1	-11.5	-2.1
<s>=2.1	4.2	4.0	5.5	1.6
<med>=-1.6	8.1	-2.3	-10.5	-1.9
<p95>=1.7(0.6,2.9)	14.5(12.3,16.7)	4.4(2.3,6.5)	-2.5(-5.3,0.4)	0.4(-0.4,1.3)
<p50>=-1.8(-2.5,-1.0)	7.7(6.3,9.0)	-2.1(-3.4,-0.7)	-11.5(-13.5,-9.7)	-2.1(-2.7,-1.6)
<p05>=-5.2(-6.3,-4.1)	0.8(-1.4,2.9)	-8.6(-10.5,-6.6)	-20.6(-23.6,-17.7)	-4.7(-5.5,-3.9)



Czech Republic

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.3	1.2	1.1	1.5	1.4
<s>=0.4	0.4	0.4	0.6	0.4
<med>=1.2	1.2	1.1	1.4	1.2
<p95>=2.0(1.8,2.3)	1.9(1.7,2.1)	1.8(1.6,2.1)	2.4(2.1,2.7)	2.1(1.9,2.3)
<p50>=1.3(1.2,1.5)	1.2(1.1,1.4)	1.1(1.0,1.3)	1.5(1.3,1.7)	1.4(1.3,1.5)
<p05>=0.6(0.4,0.8)	0.6(0.3,0.8)	0.5(0.2,0.7)	0.5(0.2,0.8)	0.7(0.5,0.9)

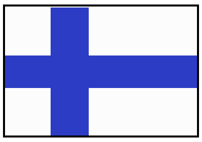
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.1	4.5	2.9	-4.9	-0.4
<s>=2.0	3.3	3.1	5.2	2.1
<med>=0.6	4.6	3.6	-5.2	-0.8
<p95>=3.5(2.5,4.6)	10.0(8.3,11.7)	7.9(6.4,9.6)	3.6(0.9,6.5)	3.1(1.9,4.2)
<p50>=0.1(-0.5,0.8)	4.5(3.4,5.7)	2.9(1.8,4.0)	-4.9(-6.7,-3.0)	-0.4(-1.1,0.3)
<p05>=-3.2(-4.3,-2.1)	-0.9(-2.6,0.9)	-2.2(-3.8,-0.5)	-13.4(-16.2,-10.7)	-3.9(-5.0,-2.8)



Estonia

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.6	1.4	1.2	1.4
<s>=0.4	0.4	0.3	0.4	0.4
<med>=1.3	1.6	1.3	1.1	1.4
<p95>=2.0(1.8,2.2)	2.3(2.1,2.5)	1.9(1.8,2.1)	1.9(1.6,2.1)	2.0(1.8,2.2)
<p50>=1.4(1.3,1.5)	1.6(1.5,1.8)	1.4(1.3,1.5)	1.2(1.0,1.3)	1.4(1.3,1.6)
<p05>=0.8(0.6,1.0)	1.0(0.7,1.2)	0.9(0.8,1.1)	0.4(0.2,0.7)	0.8(0.6,1.0)

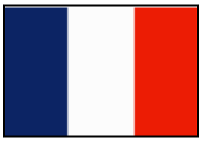
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=4.2	10.2	2.1	4.5	0.9
<s>=2.9	3.5	3.8	9.0	3.8
<med>=3.8	10.4	1.2	2.3	0.3
<p95>=9.0(7.5,10.)	16.0(14.1,17.8)	8.4(6.3,10.5)	19.3(14.8,24.1)	7.2(5.1,9.2)
<p50>=4.2(3.2,5.2)	10.2(9.0,11.4)	2.1(0.7,3.4)	4.5(1.5,7.5)	0.9(-.5,2.2)
<p05>=-0.6(-2.2,0.9)	4.4(2.4,6.2)	-4.2(-6.4,-2.1)	-10.3(-15.1,-5.6)	-5.5(-7.5,-3.5)



Finland

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.7	1.5	1.0	1.5
<s>=0.3	0.4	0.4	0.4	0.4
<med>=1.3	1.8	1.4	0.9	1.5
<p95>=2.0(1.8,2.2)	2.3(2.1,2.6)	2.2(1.9,2.4)	1.6(1.5,1.8)	2.1(1.9,2.3)
<p50>=1.4(1.3,1.5)	1.7(1.6,1.8)	1.5(1.3,1.6)	1.0(0.9,1.2)	1.5(1.4,1.6)
<p05>=0.9(0.7,1.0)	1.1(0.9,1.3)	0.8(0.5,1.0)	0.4(0.2,0.6)	0.9(0.7,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=5.8	10.9	4.6	4.6	4.5
<s>=1.8	3.6	3.5	4.9	3.1
<med>=5.4	10.1	5.0	3.1	3.7
<p95>=8.7(7.7,9.6)	16.9(15.0,18.7)	10.4(8.5,12.3)	12.6(9.9,15.2)	9.7(8.0,11.4)
<p50>=5.8(5.2,6.3)	10.9(9.7,12.2)	4.6(3.4,5.8)	4.6(2.9,6.2)	4.5(3.5,5.6)
<p05>=2.9(1.9,3.8)	5.0(3.0,7.0)	-1.2(-3.1,0.7)	-3.4(-6.0,-0.9)	-0.6(-2.3,1.0)



France

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
North				
<x>=1.2	1.0	1.0	1.7	1.3
<s>=0.4	0.4	0.4	0.6	0.4
<med>=1.1	0.9	0.8	1.6	1.2
<p95>=2.0(1.7,2.2)	1.6(1.4,1.8)	1.6(1.4,1.9)	2.8(2.4,3.1)	1.9(1.7,2.1)
<p50>=1.2(1.1,1.4)	1.0(0.9,1.1)	1.0(0.8,1.1)	1.7(1.5,1.9)	1.3(1.2,1.4)
<p05>=0.5(0.3,0.7)	0.4(0.2,0.6)	0.3(0.0,0.5)	0.7(0.3,1.0)	0.7(0.5,0.9)
South				
<x>=1.3	1.0	1.0	1.9	1.4
<s>=0.4	0.3	0.4	0.5	0.4
<med>=1.3	1.0	1.0	1.8	1.3
<p95>=2.0(1.8,2.2)	1.5(1.4,1.7)	1.7(1.5,1.9)	2.8(2.5,3.1)	2.0(1.8,2.2)
<p50>=1.3(1.2,1.5)	1.0(0.9,1.1)	1.0(0.9,1.2)	1.9(1.8,2.1)	1.4(1.2,1.5)
<p05>=0.7(0.5,0.9)	0.6(0.4,0.7)	0.4(0.2,0.6)	1.1(0.8,1.4)	0.8(0.6,1.0)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
North				
<x>=-1.5	7.4	-1.6	-13	-2.8
<s>=1.5	3.5	3.5	5.2	2.3
<med>=-1.3	7.6	-0.6	-11.6	-3.5
<p95>=1.0(0.2,1.8)	13.2(11.2,15.0)	4.1(2.3,6.0)	-4.5(-7.3,-1.6)	0.9(-0.3,2.1)
<p50>=-1.5(-2.0,-1.0)	7.4(6.2,8.7)	-1.6(-2.8,-0.4)	-13.0(-14.8,-1.3)	-2.8(-3.6,-2.0)
<p05>=-3.9(-4.7,-3.1)	1.7(-0.1,3.5)	-7.2(-9.1,-5.5)	-21.6(-24.2,-8.8)	-6.5(-7.8,-5.4)
South				
<x>=-3.3	4.9	-3.7	-13.8	-3.6
<s>=1.9	2.7	3.4	3.6	2
<med>=-3.0	5.3	-3.4	-14.9	-3.6
<p95>=-0.3(-1.2,0.8)	9.3(7.9,10.7)	2.0(0.0,3.8)	-7.8(-9.8,-5.8)	-0.4(-1.4,0.6)
<p50>=-3.3(-3.9,-2.6)	4.9(4.0,5.8)	-3.7(-4.9,-2.5)	-13.8(-5.1,12.5)	-3.6(-4.3,-3.0)
<p05>=-6.4(-7.3,-5.4)	0.5(-1.0,1.9)	-9.4(-11.4,-7.6)	-19.8(-21.7,-7.9)	-6.9(-8.0,-5.8)

FYR Macedonia

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.2	1.9	1.4
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.5	1.4	1.2	1.9	1.5
<p95>=1.9(1.8,2.1)	1.8(1.7,2.0)	1.6(1.5,1.8)	2.6(2.4,2.8)	1.8(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.3(1.2,1.4)	1.2(1.1,1.3)	1.9(1.7,2.0)	1.4(1.3,1.5)
<p05>=0.9(0.8,1.1)	0.7(0.6,0.9)	0.7(0.6,0.9)	1.1(0.9,1.4)	1.0(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-4.6	-1.1	-4	-11.8	-4.1
<s>=2.8	3.5	3.8	7.7	3.0
<med>=-4.4	-0.9	-4.3	-10.5	-3.5
<p95>=-0.1(-1.5,1.4)	4.6(2.8,6.5)	2.2(0.3,4.3)	0.9(-3.2,4.9)	0.8(-0.7,2.4)
<p50>=-4.6(-5.5,-3.6)	-1.1(-2.2,0.2)	-4.0(-5.2,-2.7)	-11.8(-14.3,-9.2)	-4.1(-5.1,-3.1)
<p05>=-9.2(-10.7,-7.6)	-6.8(-8.6,-5.0)	-10.2(-12.2,-8.2)	-24.5(-28.4,-20.4)	-8.9(-10.6,-7.3)

Germany

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=1.3	1.1	1.1	1.6	1.4
<s>=0.4	0.4	0.4	0.6	0.4
<med>=1.2	1.1	1.0	1.4	1.3
<p95>=2.0(1.8,2.2)	1.7(1.5,1.9)	1.7(1.5,1.9)	2.5(2.2,2.9)	1.9(1.7,2.1)
<p50>=1.3(1.2,1.4)	1.1(1.0,1.3)	1.1(1.0,1.2)	1.6(1.4,1.8)	1.4(1.2,1.5)
<p05>=0.6(0.4,0.8)	0.5(0.4,0.7)	0.4(0.2,0.6)	0.6(0.3,0.9)	0.8(0.6,1.0)
North				
<x>=1.2	1.1	1.0	1.3	1.3
<s>=0.4	0.4	0.4	0.5	0.3
<med>=1.1	1.0	1.0	1.1	1.3
<p95>=1.8(1.6,2.0)	1.8(1.6,2.0)	1.6(1.4,1.8)	2.0(1.8,2.3)	1.8(1.7,2.0)
<p50>=1.2(1.1,1.3)	1.1(1.0,1.2)	1.0(0.9,1.2)	1.3(1.1,1.5)	1.3(1.2,1.4)
<p05>=0.6(0.4,0.8)	0.5(0.2,0.7)	0.5(0.3,0.6)	0.6(0.3,0.8)	0.8(0.6,0.9)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=-0.3	5.1	2.0	-6.4	-1.7
<s>=1.6	2.9	3.3	4.7	2.3
<med>=0.2	4.8	2.2	-6.1	-2.4
<p95>=2.3(1.5,3.2)	9.9(8.3,11.5)	7.3(5.5,9.0)	1.3(-1.1,3.9)	2.1(0.9,3.3)
<p50>=-0.3(-0.8,0.3)	5.1(4.1,6.1)	2.0(0.8,3.1)	-6.4(-8.0,-4.8)	-1.7(-2.5,-0.9)
<p05>=-2.8(-3.7,-2.0)	0.3(-1.2,1.9)	-3.4(-5.2,-1.7)	-14.0(-16.6,-11.6)	-5.5(-6.7,-4.3)
North				
<x>=0.1	6.0	2.1	-7.3	-0.5
<s>=1.7	4.1	2.3	4.9	3.2
<med>=0.4	5.3	1.6	-7.2	-0.8
<p95>=2.9(2.0,3.8)	12.6(10.4,14.7)	6.0(4.7,7.2)	0.9(-1.8,3.6)	4.7(3.1,6.4)
<p50>=0.1(-0.5,0.7)	6.0(4.6,7.4)	2.1(1.3,2.9)	-7.3(-8.9,-5.6)	-0.5(-1.6,0.6)
<p05>=-2.7(-3.7,-1.8)	-0.7(-2.8,1.5)	-1.7(-2.9,-0.5)	-15.4(-18.0,-12.6)	-5.7(-7.4,-4.1)

Greece

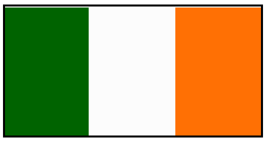
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.2	1.2	1.8	1.4
<s>=0.4	0.3	0.3	0.5	0.3
<med>=1.3	1.2	1.1	1.7	1.4
<p95>=2.0(1.8,2.2)	1.7(1.5,1.8)	1.7(1.5,1.9)	2.7(2.4,3.0)	2.0(1.8,2.1)
<p50>=1.4(1.3,1.5)	1.2(1.1,1.3)	1.2(1.0,1.3)	1.8(1.6,2.0)	1.4(1.3,1.5)
<p05>=0.8(0.6,1.0)	0.7(0.6,0.9)	0.6(0.4,0.8)	0.9(0.7,1.2)	0.8(0.6,1.0)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-5.8	-4.6	-5.6	-13.5	-4.4
<s>=3.7	3.9	5	7.8	4.2
<med>=-6.0	-4.2	-4.8	-12.7	-3.9
<p95>=0.2(-1.7,2.2)	1.8(-0.3,3.8)	2.6(-0.0,5.2)	-0.7(-5.0,3.4)	2.6(0.4,5.0)
<p50>=-5.8(-7.1,-4.5)	-4.6(-5.9,-3.3)	-5.6(-7.3,-3.9)	-13.5(-16.2,-10.8)	-4.4(-5.8,-2.8)
<p05>=-11.9(-13.8,-9.8)	-11.0(-13.1,-9.0)	-13.8(-16.5,-11.2)	-26.3(-30.3,-22.3)	-11.4(-13.6,-9.0)

Hungary

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.1	1.7	1.5
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.3	1.3	1.1	1.6	1.5
<p95>=1.9(1.8,2.1)	1.9(1.7,2.1)	1.6(1.5,1.8)	2.4(2.2,2.6)	2.0(1.8,2.1)
<p50>=1.4(1.3,1.5)	1.3(1.2,1.4)	1.1(1.0,1.2)	1.7(1.5,1.8)	1.5(1.4,1.6)
<p05>=0.9(0.7,1.0)	0.8(0.6,0.9)	0.6(0.5,0.8)	1.0(0.8,1.2)	1.0(0.8,1.1)

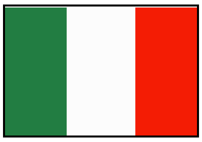
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.3	9.0	0.9	-8.2	-1.9
<s>=2.2	3.7	3.7	5.3	2.1
<med>=0.2	9.2	0.4	-7.5	-2.4
<p95>=3.4(2.2,4.6)	15.0(13.0,16.9)	7.0(5.0,9.0)	0.5(-2.3,3.2)	1.5(0.4,2.7)
<p50>=-0.3(-1.0,0.5)	9.0(7.7,10.3)	0.9(-0.4,2.1)	-8.2(-9.9,-6.4)	-1.9(-2.6,-1.2)
<p05>=-3.9(-5.1,-2.8)	3.0(1.0,5.0)	-5.2(-7.2,-3.3)	-16.9(-19.5,-14.1)	-5.3(-6.4,-4.2)



Ireland

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.8	0.6	0.7	1.0	1.0
<s>=0.3	0.3	0.3	0.4	0.3
<med>=0.7	0.5	0.6	0.9	0.9
<p95>=1.3(1.2,1.5)	1.1(0.9,1.2)	1.2(1.0,1.4)	1.6(1.4,1.8)	1.5(1.3,1.7)
<p50>=0.8(0.7,0.9)	0.6(0.5,0.7)	0.7(0.6,0.8)	1.0(0.9,1.1)	1.0(0.9,1.1)
<p05>=0.3(0.1,0.4)	0.1(-0.1,0.3)	0.2(-0.0,0.3)	0.4(0.2,0.6)	0.4(0.3,0.6)

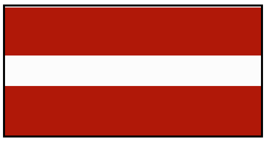
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.2	4.9	0.8	-9.7	0.6
<s>=1.8	2.2	1.4	4.4	3.1
<med>=-0.7	4.6	0.7	-9.7	-0.2
<p95>=2.7(1.8,3.7)	8.5(7.3,9.7)	3.0(2.3,3.8)	-2.5(-4.8,-0.2)	5.7(4.1,7.4)
<p50>=-0.2(-0.8,0.4)	4.9(4.1,5.7)	0.8(0.3,1.3)	-9.7(-11.2,-8.2)	0.6(-0.5,1.6)
<p05>=-3.1(-4.0,-2.1)	1.2(0.0,2.4)	-1.4(-2.2,-0.7)	-16.9(-19.3,-14.5)	-4.5(-6.2,-2.9)



Italy

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.1	1.1	1.8	1.4
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.4	1.1	1.1	1.9	1.4
<p95>=1.9(1.7,2.0)	1.6(1.5,1.8)	1.6(1.4,1.8)	2.5(2.3,2.7)	1.8(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.1(1.0,1.2)	1.1(1.0,1.2)	1.8(1.7,2.0)	1.4(1.3,1.5)
<p05>=0.9(0.7,1.0)	0.7(0.5,0.8)	0.7(0.5,0.8)	1.1(0.9,1.4)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-2.8	3.0	-3.6	-10.6	-0.9
<s>=2.1	2.6	4.1	5.1	2.8
<med>=-2.8	3.1	-3.2	-11	-1.2
<p95>=0.7(-0.4,1.8)	7.2(5.9,8.5)	3.2(1.0,5.4)	-2.2(-4.9,0.5)	3.6(2.3,5.0)
<p50>=-2.8(-3.5,-2.0)	3.0(2.2,3.8)	-3.6(-5.1,-2.2)	-10.6(-12.3,-8.9)	-0.9(-1.8,0.0)
<p05>=-6.2(-7.3,-5.1)	-1.2(-2.6,0.0)	-10.4(-12.7,-8.2)	-19.0(-21.6,-16.4)	-5.5(-6.9,-4.0)



Latvia

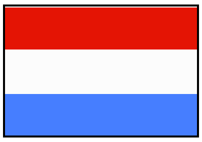
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.6	1.4	1.2	1.4
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.3	1.6	1.4	1.1	1.4
<p95>=1.8(1.7,2.0)	2.1(1.9,2.3)	1.8(1.6,1.9)	1.8(1.6,2.0)	1.9(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.6(1.5,1.7)	1.4(1.3,1.4)	1.2(1.0,1.3)	1.4(1.3,1.5)
<p05>=0.9(0.8,1.1)	1.0(0.8,1.2)	0.9(0.8,1.1)	0.6(0.4,0.7)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=3.2	9.7	2.5	1.8	-0.2
<s>=2.8	4.0	3.5	7.0	3.9
<med>=3.2	9.8	2.1	0.9	-0.1
<p95>=7.8(6.3,9.3)	16.2(14.0,18.3)	8.2(6.3,10.1)	13.2(9.4,16.9)	6.2(4.1,8.2)
<p50>=3.2(2.3,4.2)	9.7(8.3,11.1)	2.5(1.2,3.7)	1.8(-0.7,4.2)	-0.2(-1.5,1.2)
<p05>=-1.4(-2.8,0.1)	3.2(1.0,5.2)	-3.3(-5.2,-1.4)	-9.7(-13.4,-5.9)	-6.5(-8.6,-4.5)

Lithuania

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.5	1.3	1.2	1.4
<s>=0.3	0.4	0.3	0.4	0.3
<med>=1.4	1.6	1.3	1.2	1.5
<p95>=1.8(1.7,2.0)	2.1(1.9,2.3)	1.7(1.6,1.9)	1.8(1.6,2.0)	1.9(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.5(1.4,1.7)	1.3(1.2,1.4)	1.2(1.1,1.3)	1.4(1.3,1.5)
<p05>=0.9(0.7,1.0)	0.9(0.7,1.1)	0.9(0.7,1.0)	0.6(0.4,0.8)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=2.0	8.8	2.3	-1.1	-1.3
<s>=2.2	4.4	2.5	5.7	3.9
<med>=2.6	9.0	2.5	-1.9	-0.6
<p95>=5.7(4.5,6.9)	16.1(13.7,18.3)	6.5(5.1,7.9)	8.3(5.4,11.4)	5.1(3.0,7.1)
<p50>=2.0(1.3,2.8)	8.8(7.3,10.3)	2.3(1.5,3.2)	-1.1(-3.0,1.0)	-1.3(-2.6,-0.0)
<p05>=-1.6(-2.8,-0.5)	1.6(-0.8,3.9)	-1.8(-3.2,-0.5)	-10.5(-13.5,-7.2)	-7.7(-9.6,-5.6)



Luxembourg

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.2	1.0	1.0	1.6	1.3
<s>=0.4	0.3	0.4	0.5	0.4
<med>=1.2	1.0	0.9	1.5	1.2
<p95>=1.9(1.6,2.0)	1.6(1.4,1.7)	1.6(1.4,1.8)	2.4(2.2,2.7)	1.9(1.7,2.1)
<p50>=1.2(1.1,1.4)	1.0(0.9,1.1)	1.0(0.9,1.1)	1.6(1.4,1.8)	1.3(1.2,1.4)
<p05>=0.6(0.4,0.8)	0.5(0.3,0.7)	0.4(0.2,0.6)	0.8(0.5,1.0)	0.7(0.5,0.9)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.4	7.8	-0.2	-9.9	-2
<s>=1.5	2.7	2.8	3.7	3.1
<med>=-0.3	7.9	0.8	-10.1	-2.0
<p95>=2.1(1.3,2.9)	12.2(10.7,13.6)	4.4(2.9,5.9)	-3.8(-5.7,-1.9)	3.1(1.5,4.7)
<p50>=-0.4(-1.0,0.1)	7.8(6.9,8.7)	-0.2(-1.1,0.8)	-9.9(-11.2,-8.7)	-2.0(-3.0,-0.9)
<p05>=-3.0(-3.8,-2.2)	3.3(2.0,4.7)	-4.7(-6.2,-3.2)	-16.0(-17.9,-13.9)	-7.0(-8.7,-5.4)

Moldova

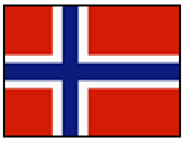
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.5	1.5	1.3	1.7	1.5
<s>=0.4	0.4	0.4	0.5	0.4
<med>=1.5	1.5	1.2	1.7	1.4
<p95>=2.1(1.9,2.3)	2.2(2.0,2.4)	1.9(1.7,2.1)	2.6(2.3,2.9)	2.1(1.9,2.2)
<p50>=1.5(1.4,1.6)	1.5(1.4,1.7)	1.3(1.2,1.4)	1.7(1.6,1.9)	1.5(1.3,1.6)
<p05>=0.9(0.7,1.1)	0.9(0.7,1.1)	0.7(0.5,0.9)	0.9(0.6,1.2)	0.9(0.7,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-1.7	3.5	0.9	-8.7	-2.3
<s>=3.2	4.4	3.8	5.3	3.2
<med>=-1.7	4.9	0.8	-10.2	-2.9
<p95>=3.5(1.9,5.3)	10.7(8.4,13.1)	7.1(5.1,9.2)	0.1(-2.7,3.0)	3.0(1.3,4.7)
<p50>=-1.7(-2.7,-0.6)	3.5(2.0,5.0)	0.9(-0.4,2.1)	-8.7(-10.5,-6.9)	-2.3(-3.4,-1.2)
<p05>=-6.9(-8.5,-5.3)	-3.6(-5.9,-1.3)	-5.4(-7.4,-3.4)	-17.5(-20.3,-14.8)	-7.7(-9.4,-5.9)

Netherlands

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.1	1.0	0.9	1.2	1.2
<s>=0.3	0.3	0.3	0.3	0.3
<med>=1.1	0.9	0.9	1.2	1.2
<p95>=1.5(1.4,1.7)	1.4(1.3,1.6)	1.4(1.2,1.5)	1.7(1.6,1.9)	1.7(1.5,1.8)
<p50>=1.1(1.0,1.2)	1.0(0.9,1.1)	0.9(0.8,1.0)	1.2(1.1,1.3)	1.2(1.1,1.3)
<p05>=0.7(0.5,0.8)	0.5(0.4,0.7)	0.5(0.4,0.6)	0.8(0.6,0.9)	0.8(0.6,0.9)

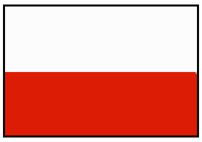
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.4	7.7	2.1	-9.8	-0.9
<s>=1.3	3.3	2.3	3.7	3.1
<med>=0.6	7.2	1.7	-10.6	-0.9
<p95>=2.6(1.9,3.2)	13.2(11.5,14.9)	5.9(4.7,7.2)	-3.7(-5.7,-1.7)	4.2(2.5,5.8)
<p50>=0.4(-0.1,0.8)	7.7(6.6,8.8)	2.1(1.3,2.9)	-9.8(-11.1,-8.6)	-0.9(-1.9,0.2)
<p05>=-1.8(-2.5,-1.1)	2.2(0.4,3.9)	-1.7(-2.9,-0.4)	-16.0(-17.8,-14.0)	-5.9(-7.6,-4.3)



Norway

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=1.1	1.1	1.1	1.0	1.3
<s>=0.3	0.3	0.3	0.3	0.3
<med>=1.1	1.0	1.1	1.0	1.3
<p95>=1.6(1.4,1.7)	1.5(1.4,1.7)	1.7(1.5,1.9)	1.5(1.4,1.7)	1.8(1.6,1.9)
<p50>=1.1(1.0,1.2)	1.1(1.0,1.2)	1.1(1.0,1.3)	1.0(0.9,1.1)	1.3(1.2,1.4)
<p05>=0.7(0.6,0.8)	0.7(0.5,0.8)	0.6(0.4,0.8)	0.6(0.4,0.7)	0.8(0.7,1.0)
North				
<x>=1.3	1.3	1.3	0.9	1.4
<s>=0.3	0.3	0.4	0.3	0.4
<med>=1.2	1.2	1.3	0.9	1.4
<p95>=1.8(1.6,2.0)	1.9(1.7,2.1)	2.0(1.8,2.3)	1.4(1.2,1.6)	2.1(1.9,2.3)
<p50>=1.3(1.1,1.4)	1.3(1.2,1.4)	1.3(1.2,1.5)	0.9(0.8,1.0)	1.4(1.3,1.6)
<p05>=0.7(0.6,0.9)	0.8(0.6,1.0)	0.7(0.4,0.9)	0.4(0.3,0.6)	0.8(0.6,1.1)

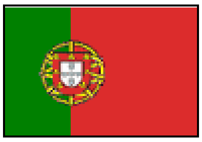
Precipitation[%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=3.5	7.0	6.3	-2.4	3.8
<s>=2.1	3.5	3.4	3.3	2.8
<med>=3.1	6.6	6.0	-2.6	3.8
<p95>=7.0(5.8,8.1)	12.7(10.8,14.5)	11.8(10.0,13.7)	3.2(1.4,4.9)	8.3(6.9,9.8)
<p50>=3.5(2.8,4.3)	7.0(5.8,8.1)	6.3(5.1,7.5)	-2.4(-3.5,-1.2)	3.8(2.9,4.8)
<p05>=0.1(-1.0,1.2	1.2(-0.7,3.0)	0.8(-1.1,2.5)	-7.9(-9.6,-6.1)	-0.7(-2.2,0.7)
North				
<x>=4.2	-0.1	7.0	5.6	6.2
<s>=5.1	7.1	7.5	2.0	5.3
<med>=2.3	-1.9	4.6	5.2	3.8
<p95>=12.5(9.5,15.5)	11.5(7.4,15.5)	19.3(15.1,23.7)	8.9(7.7,10.0)	14.9(11.8,17.9)
<p50>=4.2(2.3,6.2)	-0.1(-2.7,2.5)	7.0(4.2,9.9)	5.6(4.8,6.3)	6.2(4.3,8.2)
<p05>=-4.1(-7.0,-1.1)	-11.7(-15.8,-7.6)	-5.3(-9.6,-0.9)	2.3(1.1,3.5)	-2.4(-5.4,0.7)



Poland

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.3	1.3	1.1	1.3	1.4
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.2	1.3	1.1	1.2	1.4
<p95>=1.8(1.7,2.0)	1.8(1.7,2.0)	1.6(1.5,1.8)	2.0(1.8,2.2)	2.0(1.8,2.1)
<p50>=1.3(1.2,1.4)	1.3(1.2,1.4)	1.1(1.0,1.3)	1.3(1.2,1.4)	1.4(1.3,1.5)
<p05>=0.8(0.6,0.9)	0.8(0.7,1.0)	0.6(0.5,0.8)	0.6(0.4,0.8)	0.8(0.7,1.0)

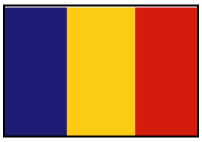
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.7	6	3.2	-4	-1.1
<s>=2.1	3.5	2.5	4.9	2.5
<med>=0.8	6.3	2.9	-4.7	-0.9
<p95>=4.1(3.0,5.2)	11.8(10.0,13.7)	7.3(5.9,8.6)	4.1(1.5,6.7)	3.0(1.6,4.3)
<p50>=0.7(0.0,1.4)	6.0(4.7,7.2)	3.2(2.3,4.0)	-4.0(-5.6,-2.3)	-1.1(-2.0,-0.3)
<p05>=-2.6(-3.8,-1.5)	0.2(-1.7,2.0)	-1.0(-2.3,0.4)	-12.0(-14.6,-9.4)	-5.3(-6.7,-3.9)



Portugal

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.3	1.0	1.2	1.7	1.3
<s>=0.4	0.3	0.4	0.5	0.4
<med>=1.2	0.9	1.1	1.6	1.2
<p95>=1.9(1.7,2.1)	1.4(1.3,1.6)	1.9(1.7,2.1)	2.4(2.2,2.7)	2.0(1.7,2.2)
<p50>=1.3(1.1,1.4)	1.0(0.8,1.1)	1.2(1.0,1.3)	1.7(1.5,1.8)	1.3(1.2,1.4)
<p05>=0.6(0.4,0.8)	0.5(0.3,0.6)	0.4(0.2,0.7)	0.9(0.6,1.1)	0.6(0.4,0.9)

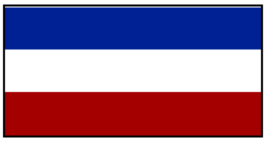
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-6.1	1.5	-11.6	-19	-9.2
<s>=2.7	3.6	5.6	6.8	3.5
<med>=-6.0	0.5	-10.9	-18.9	-9.3
<p95>=-1.6(-3.0,-0.1)	7.5(5.6,9.4)	-2.4(-5.3,0.5)	-7.9(-11.5,-4.1)	-3.6(-5.4,-1.7)
<p50>=-6.1(-7.0,-5.2)	1.5(0.2,2.8)	-11.6(-13.5,-9.7)	-19.0(-21.3,-16.6)	-9.2(-10.4,-8.1)
<p05>=-10.6(-12.1,-9.2)	-4.4(-6.3,-2.5)	-20.8(-23.9,-8.0)	-30.1(-33.7,-26.8)	-14.9(-16.7,-13.2)



Romania

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.5	1.4	1.2	1.7	1.4
<s>=0.3	0.4	0.3	0.5	0.3
<med>=1.4	1.4	1.2	1.8	1.4
<p95>=2.0(1.8,2.1)	2.1(1.9,2.3)	1.7(1.5,1.8)	2.5(2.3,2.7)	1.9(1.7,2.0)
<p50>=1.5(1.3,1.6)	1.4(1.3,1.6)	1.2(1.1,1.3)	1.7(1.6,1.9)	1.4(1.3,1.5)
<p05>=0.9(0.8,1.1)	0.8(0.6,1.0)	0.8(0.6,0.9)	1.0(0.7,1.2)	1.0(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-2.2	3.4	-0.2	-9.6	-2.9
<s>=2.2	3.5	2.9	5.5	2.4
<med>=-2.0	3.2	-0.7	-8.3	-3.8
<p95>=1.4(0.2,2.5)	9.2(7.3,11.1)	4.6(3.0,6.2)	-0.5(-3.4,2.4)	1.0(-0.2,2.3)
<p50>=-2.2(-2.9,-1.4)	3.4(2.2,4.6)	-0.2(-1.2,0.8)	-9.6(-11.4,-7.7)	-2.9(-3.7,-2.1)
<p05>=-5.8(-7.0,-4.6)	-2.4(-4.4,-0.6)	-4.9(-6.5,-3.5)	-18.7(-21.6,-15.8)	-6.9(-8.2,-5.6)



Serbia and Montenegro

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.4	1.2	1.8	1.4
<s>=0.4	0.4	0.3	0.6	0.3
<med>=1.4	1.3	1.1	1.8	1.4
<p95>=2.1(1.9,2.3)	2.0(1.8,2.3)	1.7(1.5,1.9)	2.8(2.5,3.0)	1.9(1.8,2.1)
<p50>=1.4(1.3,1.6)	1.4(1.2,1.5)	1.2(1.1,1.3)	1.8(1.7,2.0)	1.4(1.3,1.5)
<p05>=0.8(0.6,1.0)	0.7(0.5,0.9)	0.6(0.4,0.8)	0.9(0.6,1.2)	0.9(0.7,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-3.3	2.4	-2.6	-11.2	-3.3
<s>=2.4	3.2	3.5	6.3	2.1
<med>=-3.0	2.7	-2.5	-9.8	-3.8
<p95>=0.6(-0.6,1.8)	7.6(5.9,9.3)	3.2(1.3,5.1)	-0.9(-4.3,2.3)	0.1(-1.0,1.2)
<p50>=-3.3(-4.1,-2.5)	2.4(1.3,3.5)	-2.6(-3.8,-1.4)	-11.2(-13.4,-9.1)	-3.3(-4.0,-2.6)
<p05>=-7.2(-8.4,-6.0)	-2.9(-4.5,-1.2)	-8.4(-10.4,-6.6)	-21.5(-25.0,-18.1)	-6.7(-7.7,-5.6)

Slovakia

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.3	1.2	1.6	1.4
<s>=0.4	0.4	0.3	0.6	0.4
<med>=1.3	1.3	1.1	1.5	1.4
<p95>=2.0(1.8,2.2)	1.9(1.7,2.1)	1.7(1.6,1.9)	2.5(2.2,2.8)	2.0(1.8,2.2)
<p50>=1.4(1.2,1.5)	1.3(1.2,1.4)	1.2(1.1,1.3)	1.6(1.4,1.8)	1.4(1.3,1.6)
<p05>=0.7(0.5,0.9)	0.7(0.5,0.9)	0.6(0.4,0.8)	0.6(0.3,0.9)	0.8(0.6,1.0)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.6	7.5	1.3	-7.3	-2.5
<s>=2.4	4.4	3.0	5.8	2.2
<med>=-0.3	8.0	1.3	-7.2	-2.4
<p95>=3.3(2.0,4.5)	14.8(12.5,17.2)	6.2(4.6,7.8)	2.2(-1.0,5.2)	1.1(-0.1,2.3)
<p50>=-0.6(-1.4,0.2)	7.5(6.0,9.0)	1.3(0.3,2.3)	-7.3(-9.2,-5.3)	-2.5(-3.3,-1.8)
<p05>=-4.5(-5.6,-3.2)	0.3(-2.1,2.5)	-3.6(-5.1,-1.9)	-16.8(-19.9,-13.6)	-6.2(-7.4,-5.0)

Slovenia

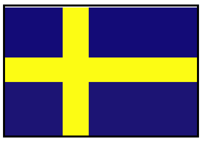
Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.2	1.1	1.7	1.4
<s>=0.3	0.3	0.3	0.4	0.3
<med>=1.3	1.3	1.1	1.8	1.4
<p95>=1.8(1.7,2.0)	1.7(1.6,1.9)	1.6(1.4,1.7)	2.4(2.2,2.7)	1.8(1.7,2.0)
<p50>=1.4(1.3,1.5)	1.2(1.1,1.3)	1.1(1.0,1.2)	1.7(1.6,1.9)	1.4(1.3,1.5)
<p05>=0.9(0.7,1.0)	0.8(0.6,0.9)	0.7(0.5,0.8)	1.0(0.8,1.2)	0.9(0.8,1.1)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-0.6	10.3	0.0	-9.7	-0.9
<s>=1.9	5.3	3.7	5.1	2.5
<med>=-0.5	9.9	0.1	-9.3	-1.2
<p95>=2.6(1.6,3.7)	19.0(16.1,22.0)	6.1(4.2,8.1)	-1.3(-4.1,1.3)	3.3(1.9,4.6)
<p50>=-0.6(-1.3,0.0)	10.3(8.4,12.2)	0.0(-1.2,1.4)	-9.7(-11.5,-8.1)	-0.9(-1.7,0.1)
<p05>=-3.8(-4.8,-2.8)	1.7(-1.1,4.5)	-6.1(-8.1,-4.1)	-18.1(-20.9,-15.5)	-5.0(-6.4,-3.7)

Spain

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
North				
<x>=1.3	1.0	1.1	1.9	1.4
<s>=0.4	0.3	0.4	0.5	0.4
<med>=1.3	1.0	1.0	1.8	1.3
<p95>=2.0(1.8,2.2)	1.6(1.4,1.8)	1.8(1.6,2.0)	2.7(2.4,3.0)	2.0(1.8,2.2)
<p50>=1.3(1.2,1.5)	1.0(0.9,1.1)	1.1(1.0,1.3)	1.9(1.7,2.1)	1.4(1.2,1.5)
<p05>=0.7(0.5,0.9)	0.4(0.3,0.6)	0.5(0.2,0.7)	1.1(0.8,1.3)	0.7(0.5,0.9)
South				
<x>=1.4	1.1	1.3	1.8	1.4
<s>=0.4	0.3	0.4	0.5	0.4
<med>=1.4	1.1	1.3	1.8	1.4
<p95>=2.1(1.8,2.3)	1.6(1.4,1.8)	2.0(1.8,2.3)	2.6(2.3,2.8)	2.0(1.8,2.2)
<p50>=1.4(1.3,1.5)	1.1(1.0,1.2)	1.3(1.2,1.5)	1.8(1.6,2.0)	1.4(1.3,1.5)
<p05>=0.7(0.5,0.9)	0.5(0.4,0.7)	0.6(0.4,0.8)	1.0(0.8,1.3)	0.8(0.6,1.0)

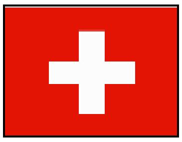
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
North				
<x>=-5.7	1.9	-8.6	-14.4	-5.2
<s>=1.6	2.0	2.7	4.2	2.7
<med>=-5.7	1.9	-8.5	-13.9	-5.1
<p95>=-3.1(-4.0,-2.3)	5.2(4.2,6.3)	-4.1(-5.6,-2.7)	-7.4(-9.8,-5.1)	-0.7(-2.2,0.7)
<p50>=-5.7(-6.3,-5.2)	1.9(1.2,2.6)	-8.6(-9.6,-7.7)	-14.4(-15.9,-12.9)	-5.2(-6.1,-4.2)
<p05>=-8.4(-9.2,-7.5)	-1.4(-2.6,-0.3)	-13.1(-14.6,-11.7)	-21.4(-23.6,-19.0)	-9.7(-11.1,-8.2)
South				
<x>=-8.6	-2.4	-13.1	-15.1	-8.4
<s>=3.1	4.2	4.4	7.9	3.2
<med>=-9.1	-3.7	-13.0	-14.9	-8
<p95>=-3.4(-5.1,-1.8)	4.4(2.2,6.7)	-5.8(-8.1,-3.5)	-2.1(-6.2,2.2)	-3.1(-4.8,-1.4)
<p50>=-8.6(-9.7,-7.5)	-2.4(-3.8,-0.9)	-13.1(-14.6,-11.6)	-15.1(-17.7,-12.3)	-8.4(-9.5,-7.3)
<p05>=-13.7(-15.5,-12.0)	-9.2(-11.4,-6.9)	-20.3(-22.7,-17.9)	-28.0(-32.2,-23.9)	-13.6(-15.3,-11.9)



Sweden

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=1.2	1.3	1.2	1.1	1.3
<s>=0.3	0.3	0.3	0.3	0.3
<med>=1.2	1.2	1.2	1.1	1.3
<p95>=1.6(1.5,1.8)	1.7(1.6,1.9)	1.7(1.5,1.8)	1.5(1.4,1.7)	1.8(1.7,2.0)
<p50>=1.2(1.1,1.3)	1.3(1.2,1.4)	1.2(1.1,1.3)	1.1(1.0,1.2)	1.3(1.2,1.4)
<p05>=0.8(0.7,0.9)	0.8(0.6,0.9)	0.8(0.6,0.9)	0.6(0.5,0.8)	0.9(0.7,1.0)
North				
<x>=1.3	1.5	1.4	1.0	1.5
<s>=0.3	0.3	0.4	0.2	0.3
<med>=1.2	1.4	1.4	1.0	1.5
<p95>=1.8(1.6,1.9)	2.1(1.9,2.3)	2.0(1.7,2.2)	1.3(1.2,1.5)	2.0(1.9,2.2)
<p50>=1.3(1.2,1.4)	1.5(1.4,1.7)	1.4(1.2,1.5)	1.0(0.9,1.1)	1.5(1.4,1.6)
<p05>=0.9(0.7,1.1)	1.0(0.8,1.2)	0.7(0.5,0.9)	0.6(0.5,0.8)	1.0(0.8,1.2)

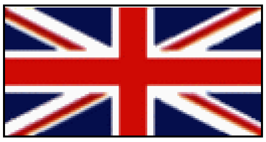
Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
South				
<x>=3.5	11.4	4.4	-2.1	2.4
<s>=1.5	3.7	1.9	3.3	3.3
<med>=3.5	11.2	4.5	-2.9	2.2
<p95>=5.9(5.1,6.7)	17.4(15.5,19.4)	7.5(6.5,8.5)	3.3(1.6,5.2)	7.9(6.1,9.6)
<p50>=3.5(3.0,4.0)	11.4(10.2,12.6)	4.4(3.7,5.0)	-2.1(-3.3,-1.0)	2.4(1.3,3.6)
<p05>=1.1(0.3,1.9)	5.4(3.3,7.2)	1.3(0.3,2.3)	-7.6(-9.3,-5.8)	-3.0(-4.7,-1.3)
North				
<x>=5.3	9.0	7.5	2.7	5.8
<s>=2.9	4.3	4.8	2.2	3.0
<med>=4.9	8.0	7.0	2.3	5.1
<p95>=10.1(8.4,11.8)	16.1(13.8,18.6)	15.4(12.6,18.3)	6.4(5.1,7.8)	10.7(8.9,12.5)
<p50>=5.3(4.3,6.4)	9.0(7.4,10.7)	7.5(5.8,9.3)	2.7(1.9,3.6)	5.8(4.6,6.9)
<p05>=0.6(-1.1,2.2)	1.9(-0.6,4.5)	-0.4(-3.3,2.4)	-0.9(-2.3,0.5)	0.8(-0.9,2.6)



Switzerland

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=1.4	1.2	1.2	1.7	1.4
<s>=0.4	0.4	0.4	0.4	0.3
<med>=1.3	1.2	1.1	1.7	1.4
<p95>=2.0(1.8,2.2)	1.8(1.6,2.0)	1.8(1.6,2.0)	2.5(2.2,2.7)	1.9(1.7,2.1)
<p50>=1.4(1.3,1.5)	1.2(1.1,1.3)	1.2(1.1,1.3)	1.7(1.6,1.9)	1.4(1.3,1.5)
<p05>=0.8(0.6,1.0)	0.6(0.4,0.8)	0.6(0.4,0.8)	1.0(0.8,1.3)	0.9(0.7,1.0)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=-1.7	4.4	0.1	-8.1	-3.1
<s>=1.6	3.0	3.3	4.1	2.1
<med>=-1.3	4.2	1.0	-7.1	-3.5
<p95>=0.9(0.1,1.8)	9.3(7.7,10.9)	5.5(3.7,7.2)	-1.4(-3.5,0.7)	0.4(-0.8,1.5)
<p50>=-1.7(-2.2,-1.1)	4.4(3.4,5.4)	0.1(-1.1,1.2)	-8.1(-9.5,-6.7)	-3.1(-3.8,-2.3)
<p05>=-4.2(-5.1,-3.4)	-0.5(-2.1,1.0)	-5.4(-7.1,-3.6)	-14.8(-17.0,-12.6)	-6.6(-7.7,-5.4)



UK

Temperature[ºC] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.9	0.7	0.8	1.0	1.0
<s>=0.2	0.2	0.3	0.3	0.2
<med>=0.8	0.6	0.7	1.0	1.0
<p95>=1.3(1.2,1.4)	1.1(1.0,1.2)	1.2(1.1,1.3)	1.5(1.3,1.6)	1.4(1.3,1.6)
<p50>=0.9(0.8,1.0)	0.7(0.6,0.8)	0.8(0.7,0.9)	1.0(1.0,1.1)	1.0(1.0,1.1)
<p05>=0.5(0.4,0.6)	0.3(0.2,0.4)	0.3(0.2,0.5)	0.6(0.5,0.8)	0.7(0.5,0.8)

Precipitation [%] (ann)	(DJF)	(MAM)	(JJA)	(SON)
<x>=0.6	6.5	1.3	-8.9	1.2
<s>=1.6	3.0	1.6	3.4	2.6
<med>=0.0	6.8	1.3	-8.9	0.7
<p95>=3.2(2.4,4.1)	11.5(9.9,13.0)	4.0(3.1,4.9)	-3.3(-5.1,-1.4)	5.5(4.2,6.9)
<p50>=0.6(0.0,1.1)	6.5(5.5,7.6)	1.3(0.8,1.9)	-8.9(-10.1,-7.8)	1.2(0.4,2.1)
<p05>=-2.1(-3.0,-1.2)	1.6(0.1,3.3)	-1.3(-2.2,-0.4)	-14.6(-16.4,-12.8)	-3.1(-4.5,-1.7)