Extended abstracts of a WMO/WCRP-sponsored Regional-Scale Climate Modelling Workshop : high-resolution climate modelling : assessment, added value and applications, Lund, Sweden, 29 March-2 April 2004

Bärring, Lars; René, Laprise

2005

Lund Electronic Reports in Physical Geography
No. 5, July 2005
Department of Physical Geography & Ecosystems Analysis
Lund University, Sweden
ISSN: 1402 - 9006

Reference: ***Lund eRep. Phys. Geogr., No. 5, July 2005*.**
URL: http://www.nateko.lu.se/Elibrary/LeRPG/5/LeRPG5Article.pdf

EXTENDED ABSTRACTS

of a **WMO/WCRP-sponsored**

REGIONAL-SCALE CLIMATE MODELLING WORKSHOP

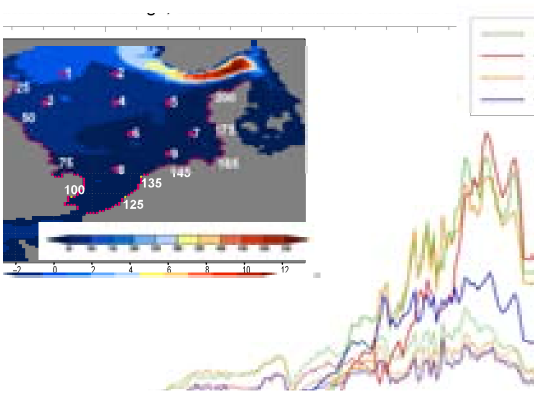
HIGH-RESOLUTION CLIMATE MODELLING: ASSESSMENT, ADDED VALUE AND APPLICATIONS

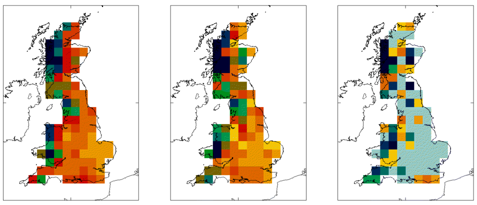
Lund, Sweden,

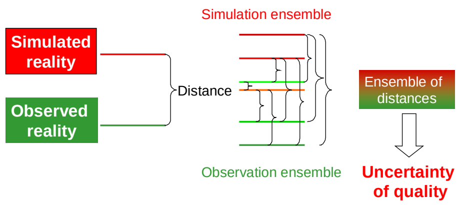
29 March – 2 April 2004

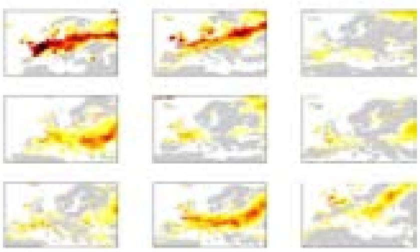
Editors:

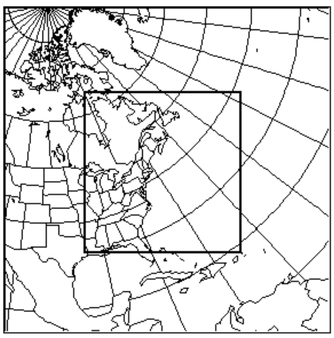
Lars Bärring & René Laprise

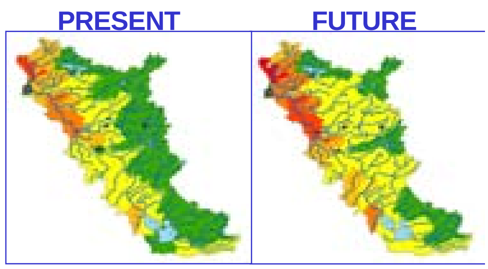






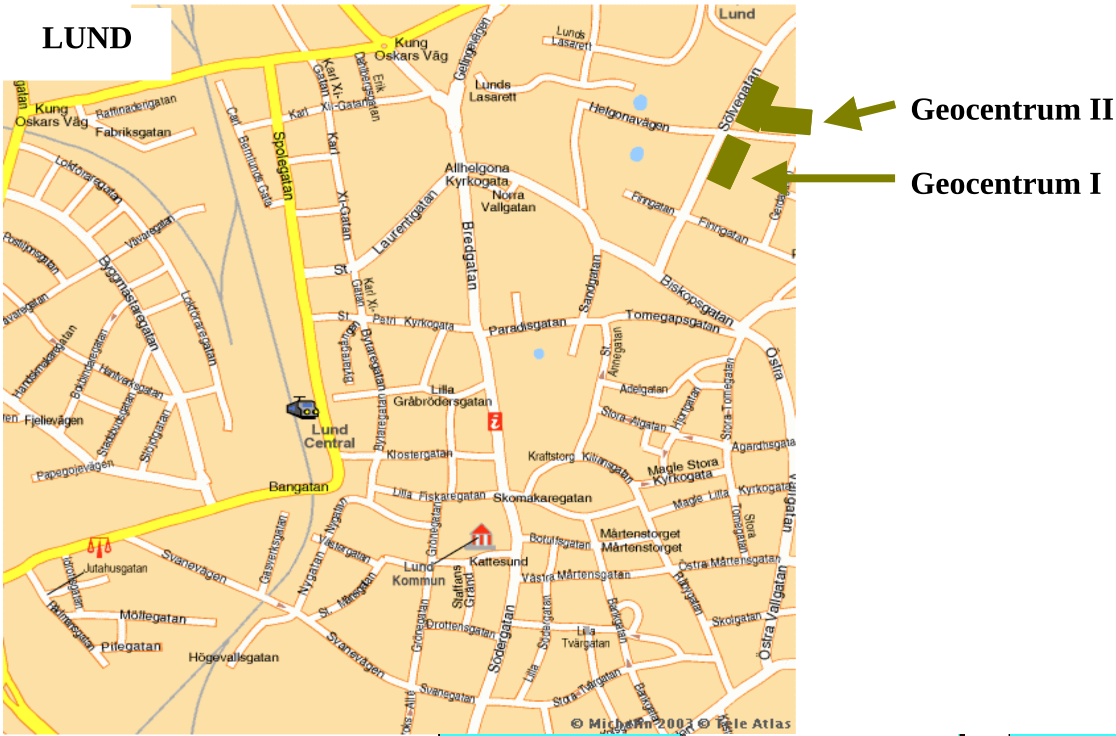






VENUE

GEOCENTRE
GeoBiosphere Science Centre
Lund University
Sölvegatan 12,
223 62 Lund,
Sweden
www.nateko.lu.se



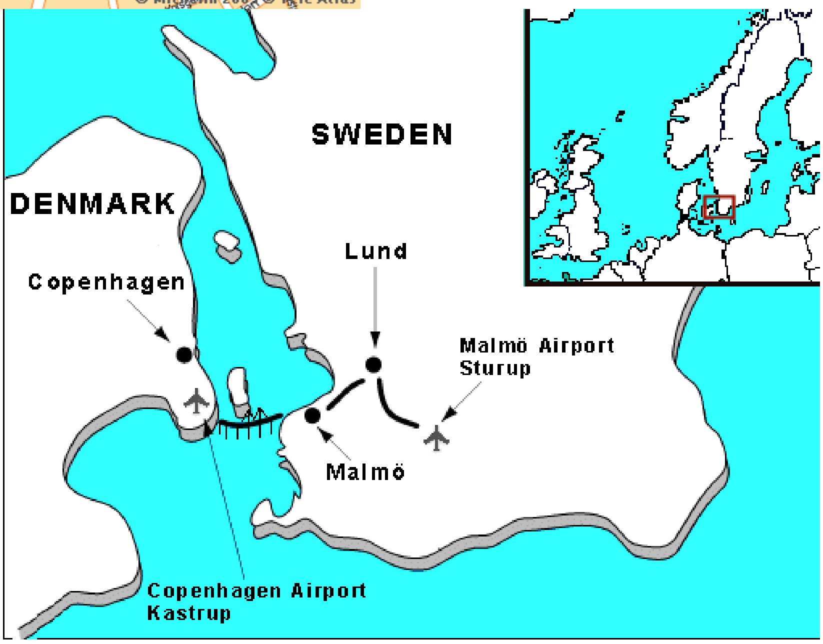


Table of contents

Introduction

Background

The Workshop is co-organized by and coordinated with the World Climate Research Programme (WCRP) of the World Meteorological Organisation (WMO), through the Working group on Numerical Experimentation (WGNE) and the working Group on Coupled Models (WGCM), and the EU/FP5-project Prediction of regional scenarios and uncertainties for defining European climate change risks and effects, PRUDENCE. Additional support is also acknowledge from FORMAS, GKSS, START and the Asia-Pacific Network (APN) for Global Change Research.

The organising committee:

René Laprise (chair), UQÀM, Principal Investigator of Canadian RCM Network
Lars Bärring, Lund University/SMHI
Filippo Giorgi, ICTP
Jens Hesselbjerg Christensen, DMI, PRUDENCE
Richard Jones, UKMO, WGCM
Ben Kirtman, COLA, WGSIP
Harry Lankreijer, Lund University, NECC
Anders Lindroth, Lund University, NECC
Markku Rummukainen, SMHI
Hans von Storch, GKSS
Werner Wergen, DWD

Programme

The Workshop consist of three sessions:

1) A general session on modeling issues, the merits and limitations.
2) A session on Application and Impacts.
3) A session on Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (PRUDENCE).

Sponsors

APN, Japan

FORMAS, Sweden

GKSS, Germany

Lund University, Sweden

NECC, Nordic countries

PRUDENCE, EU / FP5

UQÀM, Canada

SMHI, Sweden

START, China

WMO, Switzerland

Programme

Sunday, 28 March

Icebreaker **17:00-19:30**
Registration desk open

Monday, 29 March Geocentrum II, first floor, Room: PANGEA

8:00	9:00	**Registration**		
Workshop opening				**page**
9:00			**Anders Lindroth/Lars Bärring** (Organizing committee, Lund University): Welcome	
			Rene Laprise (Chair, Organizing committee): Workshop opening	
	9:30		**Venkataramaiah Satyan** (WMO, Geneva): Opening address	
Session 1.1		**General session on modeling issues (the merits and limitations)**		
9:30	10:15	Keynote 1	**Hans von Storch** (GKSS, Germany): Conceptual basis and applications of Regional Climate Modelling	**26**
10:15	11:00	Keynote 2	**Yuqing Wang** (University of Hawaii, U.S.): Regional climate modelling: Progress, challenges and prospects	**28**
11:00	11:30	**Pause**	**Registration desk open**	
11:30	12:15	Keynote 3	**Richard Jones** (Hadley Centre, Reading, UK) The value of regional climate model information at the grid-scale	**30**
12:15	13:00	Keynote 4	**René Laprise** (CRCM UQÀM, Canada): Estimating the downscaling ability of Regional Climate Models using the Big-Brother Experimental protocol	**31**
13:00	15:30	**Lunch**, **POSTERS**, **Coffee**		
15:30	16:15	Keynote 5	**Philip Duffy** (LLNL, U.S.): High resolution simulations of Global Climate	**33**
16:15	17:00	Keynote 6	**Michael Fox-Rabinovitz** (University of Maryland - College Park, U.S.): Variable – Resolution GCMs: Preliminary results of SGMIP (Stretched-Grid Model Intercomparison Project)	**35**
17:00	17:30	Speaker 1	**Raymond W. Arritt** (Iowa State University, U.S.): Project to Intercompare Regional Climate Simulations (PIRCS): Status and preliminary results of Experiment 1C	**36**
17:30	18:00	General discussion session I (1.1)		
18:00		Closing for the day		

Tuesday, 30 March Geocentrum II, first floor, Room: PANGEA

Session 1.2		**General session on modeling issues (the merits and limitations)**		
9:00	9:45	Keynote 7	**Jack Katzfey** (CSIRO, Australia): Application of limited-area models for GEWEX Cloud System Study	**36**
9:45	10:30	Keynote 8	**Colin Jones** (SMHI, Sweden): Development of physical parameterisations for high resolution climate models	**37**
10:30	11:00	Pause	**Registration desk open**	
11:00	11:45	Keynote 9	**Neil Ward** (IRI Columbia University, U.S.): The role of regional climate models in seasonal to interannual climate prediction	**37**

11:45	12:30	Keynote 10	**Bodo Ahrens** (University of Vienna, Austria): Dynamical downscaling with the limited-area model ALADIN in the European Alps	**38**
12:30	15:00	**Lunch, POSTERS, Coffee**		
15:00	15:45	Keynote 11	**Markus Meier** (SMHI, Sweden): Regional ocean modeling – climate variability and impact studies of the Baltic Sea	**40**
15:45	16:30	Keynote 12	**Klaus Dethloff** (AWI/Potsdam, Germany): High-resolution modelling of the Arctic with regional climate models	**42**
16:30	17:00	Speaker 2	**Michael Tjernström** (Stockholm University; Sweden): The Arctic boundary-layer in six different RCM compared to SHEBA observations (ARCMIP)	**44**
17:00	17:30	Speaker 3	**Frauke Feser** (GKSS, Germany): A two-dimensional discrete filter for limited area model evaluation purposes	**46**
17:30	18:00	General discussion session I (1.1 and 1.2)		
18:00		Closing for the day		

Wednesday, 31 March Geocentrum II, first floor, Room: PANGEA

Session 2.1		**Applications**		
9:00	9:45	Keynote 13	**Anders Lindroth** (NECC, Lund University, Sweden): The Nordic flux measurement network	**48**
9:45	10:15	Speaker 4	**N.O. Jensen** (Risø, Denmark): On the calculation of area-averaged or effective temperature roughness lengths	**48**
10:15	10:45	**Pause**	**Registration desk open**	
10:45	11:15	Speaker 5	**Martin Beniston** (University of Fribourg, Switzerland): The 2003 heat wave in Europe in the context of the 20th and 21st century climates	**49**
11:15	12:00	**POSTERS**		
12:00	15:30	**Lunch, POSTERS, Coffee**		
15:30	16:00	Speaker 6	**Igor Shkolnik** (Voeikov Main Geophysical Observatory, Russia): MGO Regional Climate Model: simulation of present-day climate over the Western Russia	**51**
16:00	16:30	Speaker 7	**Eugene S. Takle** (Iowa State Univ., U.S.): Simulations of current and future scenario stream flow in the upper Mississippi River basin: a regional climate model perspective	**53**
16:30	17:00	Speaker 8	**Filippo Giorgi** (ICTP, Trieste, Italy): Simulating aerosol effects in regional climate models: The case of East Asia	**55**
17:00	17:30	Speaker 9	**L. Ruby Leung** (PNNL, Richland, US): Simulating the regional climatic effect of the atmospheric brown cloud	**56**
17:30	18:00	General discussion session 2		
18:00		Closing for the day		

Thursday, 1 April Geocentrum II, first floor, Room: PANGEA

Session 2.2		**Applications**		
9:00	9:45	Keynote 15	**CongBin Fu** (START Regional Center for Temperate East Asia China): Regional climate model inter-comparaison project for Asia (RMIP)	**58**

9:45	10:15	Speaker 10	**Jozef Syktus** (National Resource Sciences Center, US): Evaluation of a dynamical seasonal climate forecast system for application in Queensland	**59**
10:15	10:45	**Pause**	**Registration desk open**	
Session 3.1		**Session on Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (PRUDENCE)**		
10:45	11:30	Keynote 16	**Jens Hesselbjerg-Christensen** (DMI/Denmark): Prediction of regional scenarios and uncertainties for defining European climate change risks and effects - PRUDENCE – the project	**60**
11:30	12:00	Speaker 11	**P.I. Vidale** (IAC-ETH, Switzerland): Variability of European climate in a heterogeneous multi-model ensemble	**61**
12:00	15:00	**Lunch, POSTERS, Coffee**		
15:00	15:30	Speaker 12	**Michel Déqué** (Météo-France): PRUDENCE: uncertainties in the GCM and RCM response	**63**
15:30	16:00	Speaker 13	**Geert Lenderink** (KNMI, Netherlands): Impact of model physics and dynamics on the summertime inter-annual variability in regional climate models	**65**
16:00	16:30	Speaker 14	**Erasmo Buonomo** (Hadley Centre, Exeter, UK): Validation and changes of extreme precipitation simulated by the regional climate model HadRM3H/HadAM3H	**67**
16:30	17:00	Speaker 15	**Klaus Keuler** (University of Brandenburg, Germany): Assessment of quality and uncertainty in regional climate simulations	**68**
17:00	18:00		General discussion session 2 (2.1 and 2.2) and 3	
18.00			Closing for the day	

Friday, 2 April Geocentrum II, first floor, Room: PANGEA

Session 3.2		**Session on Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (PRUDENCE)**		
9:00	9:30	Speaker 16	**Stefan Hageman** (MPI-Meteorologie, Hamburg): European discharge as simulated by a multi-model ensemble	**70**
9:30	10:00	Speaker 17	**Erik Kjellström** (SMHI, Sweden): Daily variability in temperature and precipitation: recent and future changes over Europe	**72**
10:00	10:30	**Pause**		
10:30	11:00	Speaker 18	**Burkhard Rockel** (GKSS, Germany): Near surface wind speed extremes over Europe in PRUDENCE control and scenarios simulations of eight RCMs	**74**
11:00	11:30	Speaker 19	**Katja Woth** (GKSS, Germany): North Sea storm surge statistics based on a series of climate change projections	**76**
11:30	12:45	General discussion session 3 (3.1 and 3.2)		
12:45	13:00	Closing of session and workshop		
13:00	15:00	**Lunch, Coffee**		

Posters

Monday-Tuesday: 3, 4, 5, 6, 14, 19, 20, 22, 26, 28, 29, 31, 33, 34, 35
Wednesday: 1, 2, 7, 8, 9, 10, 15, 16, 27, 36
Wednesday-Thursday 11, 12, 13, 17, 18, 21, 23, 24, 25, 30, 32

Participants

Bodo Ahrens
Institute for Meteorology and Geophysics
University of Vienna
Althanstrasse 14
A-1090 Vienna
AUSTRIA
ph: +43-1-472251917
Bodo.Ahrens@univie.ac.at

Georgios Amanatidis
European Commission
Brussels
BELGIUM
georgios.amanatidis@cec.eu.int

Berit Arheimer
SMHI
S-60176 Norrköping
SWEDEN
ph: +46-11-495-8260
fax: +46-11-496-8250
Berit.Arheimer@smhi.se

Raymond W. Arritt
Iowa State University
3010 Agronomy Hall
Ames, Iowa 50011-1010
USA
ph: +1-515-294-9870
fax: +1-515-294-2619
rwarritt@bruce.agron.iastate.edu

Lars Bärring
Dept. of Physical Geography and Ecosystems Analysis
Geobiosphere Science Centre
Lund University
Sölvegatan 12
SE-223 62 Lund
SWEDEN
Lars.Barring@nateko.lu.se

Martin Beniston
University of Fribourg
Department of Geosciences
Chemin du Musee 4
CH-1700 Fribourg
SWITZERLAND
ph: +41-26-300-90-10 (Secr.);
+41-26-300-90-11 (Direct)
fax: +41-26-300-97-46
Martin.Beniston@unifr.ch

Erasmo Buonomo
Hadley Centre
Met Office
Fitzroy Road
Exeter EX1 3PB
UK
ph: +44-1392-88-6079
fax: +44-1133-361072
erasmo.buonomo@metoffice.com

Daniel Caya
OURANOS
550, rue Sherbrooke O., 19e
Montréal QC H3A 1B9
CANADA
ph: +1-514-282-6464 #340
fax: +1-514-282-7131
caya.daniel@ouranos.ca

Ole B. Christensen
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK
ph: +45-39157426
fax: +45-39157460
obc@dmi.dk

Rikke M. Closter
DMI & FBL Freshwater Biological Laboratory; University of Copenhagen
Helsingørsgade 51
DK-3400Hillerød
DENMARK
ph: +45-51-80-40-13
rmc@dmi.dk

Manuel de Castro
Dept. Geofisica y Meteorologia
Facultad de Fisica
2804 Madrid
SPAIN
ph: +34-925265738
Manuel.Castro@uclm.es

Ramon de Elia
UQAM550 rue Sherbrooke O, 19e
Montreal, QC
H3A 1B9
CANADA
ph: +1-514-282-6464 ext. 245
relia@sca.uqam.ca

Michel Déqué
Météo-France
42 Av. Coriolis
F-31057 Toulouse Cedex 01
FRANCE
ph: +33-561-079382
fax: +33-561-079610
deque@meteo.fr

Klaus Dethloff
Alfred Wegener Institute for Polar and Marine Research (AWI)
Telegrafenberg A43
D-14473 Potsdam
GERMANY
dethloff@awi-potsdam.de

Philip Duffy
Lawrence Livermore National Laboratory
7000 East Ave. Livermore
USA
ph: +1-925-422-3722
fax: +1-925-422-6388
duffy2@llnl.gov

Bernard Dugas
RPN, Environment Canada
2121, Trans-Canada Highway
Dorval, Quebec
H9P 1J3
CANADA
ph: +1-514-421-4734
fax: +1-514-421-2106
Bernard.Dugas@ec.gc.ca

Anders Chr. Erichsen
DHI Water and Environment
Agern Alle 11
DK-2970 Horsholm
DENMARK
ph: +45-45-16-91-42
fax: +45-45-16-92-92
aer@dhi.dk

Ales Farda
Czech Hydrometeorological Institute
Na Sabatce 17
143 06 Praha 4
CZECH REPUBLIC
ph: +420-2-4403-2276
fax: +420-2-4403-227
afar5101@
artax.karlin.mff.cuni.cz

Frauke Feser
GKSS Research Center
Institute for Coastal Research
Max-Planck-Straße 1
D-21502 Geesthacht
GERMANY
ph: +49-4152-87-2816
fax: +49-4152-87-1888
feser@gkss.de

Krzysztof Fortuniak
University of Lodz
Dept. of Meteorology and Climatology
Narutowicza 88
PL-90-139 Lodz
POLAND
ph: +48-42-6655954
fax: +48-42-665-5951
kfortun@uni.lodz.pl

Michael Fox-Rabinovitz
University of Maryland - College Park
Room 2207, 224 CSS Bldg.
College Park, MD 20742-2465
USA
ph: +1-301-286-3604
fax: +1-301-286-2323
foxrab@essic.umd.edu

Anne Frigon
OURANOS
550, rue Sherbrooke O., 19e
Montréal QC
H3A 1B9
CANADA
ph: +1-514-282-6464 ext. 266
fax: +1-514-282-7131
frigon.anne@ouranos.ca

Congbin Fu
START Regional Center for Temperate East Asia
Institute of Atmospheric Physics
Qi Jia Huo Zi, De Sheng Men Wai Street
Beijing
100029 CHINA
ph: +86-10-62041317
fcb@tea.ac.cn

Miguel Angel Gärtner
Universidad Complutense Madrid
Fac. CC. Físicas
Ciudad Universitaria s/n.
28040 Madrid
SPAIN
Miguel.Gaertner@uclm.es

Filippo Giorgi
ICTP
Physics of Weather and Climate Section
P.O. BOX 586,
(Strada Costiera 11 for courier mail)
I-34100 Trieste
ITALY
ph: +39-040-2240-425
(or ph: +39-040-2240-449)
fax: +39-040-224-163
Giorgi@ictp.trieste.it

Stéphane Goyette
University of Fribourg
Department of Geosciences
Chemin du Musee 4
CH-1700 Fribourg
SWITZERLAND
ph: +41-26-300-97-46
fax: +41-26-300-90-22
stephane.goyette@unifr.ch

Annette Guldberg
DMI
Lyngbyvej 100
DK-2100 Copenhagen
DENMARK
ph: +45-39157433
fax: +45-39157460
ag@dmi.dk

Panos Hadjinicolaou
Centre for Atmospheric Science
University of Cambridge
Lensfield Road
Cambridge CB2 1EN
UK
ph: +44-1223-763815
panos.hadjinicolaou@atm.ch.cam.ac.uk

Tomas Halenka
Charles University in Prague
Dept. of Meteorology and Environment Protection
V Holesovickach 2
CZ-180 00 Prague 8
CZECH REPUBLIC
ph: +420-2-2191-2514
fax: +420-2-2191-2533
tomas.halenka@mff.cuni.cz

Jens Hesselbjerg Christensen
DMI
PRUDENCE
Lyngbyvej 100
DK-2100 Copenhagen
DENMARK
ph: +45-39157460
fax: +45-39157428
jhc@dmi.dk

Bruce C. Hewitson
University of Cape Town
Private Bag
7701 Rondebosch
SOUTH AFRICA
ph: +27-21-650-2878
fax: +27-21-650-5773
hewitson@egs.uct.ac.za

Niels Otto Jensen
Risoe Nat. Lab.
DK-4000 Roskilde
DENMARK
ph: +45-4677-5007
fax: +45-4677-5970
n.o.jensen@risoe.dk

Colin Jones
SMHI
SE-60176 Norrköping
SWEDEN
ph: +46-11-495-8652
fax: +46-11-495-8001
Colin.Jones@smhi.se

Richard Jones
Met. Office
Hadley Centre - Reading
Reading, RG6 6BB
UK
ph: +44-118-378-5611
fax: +44-118-378-5615
richard.jones@metoffice.com

Jona Finndis Jonsdottir
Hydrological Service
National Energy Authority
Grensasvegur 9
IS-108 Reykjavik
ICELAND
ph: +46-46-222-4367
fax: +46-46-222-4435
jfj@os.is

Jack Katzfey
CSIRO Atmospheric Research
PMB#1
Aspendale, VIC 3195
AUSTRALIA
ph: +61-3-9239-4562
fax: +61-3-9239-4444
jack.katzfey@csiro.au

Klaus Keuler
Brandenburg University of Technology Cottbus
Dept. of Environmental Meteorology
P.O.Box 101344
D-03013 Cottbus
GERMANY
ph: +49-355-691114
fax: +49-355-691128
keuler@tu-cottbus.de

Erik Kjellström
SMHI
SE-601 76 Norrköping
SWEDEN
ph: +46-11-495-8501
Erik.Kjellstrom@smhi.se

Harry Lankreijer
NECC
Dept. of Physical Geography and Ecosystems Analysis
Geobiosphere Science Centre
Lund University
Sölvegatan 12
SE-223 62 LUND
SWEDEN
ph: +46-46-222-4967
fax: +46-46-222-4011
harry.lankreijer@nateko.lu.se

René Laprise
UQAM @ OURANOS
550 rue Sherbrooke O, 19e
Montreal, QC
H3A 1B9
CANADA
ph: +1-514-2826464 ext. 265
fax: +1-514-282-7131
laprise.rene@uqam.ca

Geert Lenderink
KNMI
PO Box 201
NL-3730 AE de Bilt
NETHERLANDS
lenderin@knmi.nl

L. Ruby Leung
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352
USA
ph: +1-509-372-6182
fax: +1-509-372-6168
ruby.leung@pnl.gov

James Levine
University of Cambridge
Centre for Atmospheric Science
14 Union Road
Cambridge, CB2 1HE
UK
james@atm.ch.cam.ac.uk

Anders Lindroth
NECC
Dept. of Physical Geography and Ecosystems Analysis
Geobiosphere Science Centre
Lund University
Sölvegatan 12
SE-223 62 LUND
SWEDEN
ph: +46-46-222-0474
fax: +46-46-222-4011
Anders.Lindroth@nateko.lu.se

Philip Lorenz
Max-Planck-Institute for Meteorology
Bundesstr. 53
D-20146 Hamburg
GERMANY
ph: +49-41173-205
philip.lorenz@dkrz.de

Philippe Lucas-Picher
Université du Québec à Montréal / Ouranos
550 rue Sherbrooke West, 19e
Montréal (Québec)
H3A 1B9
CANADA
ph: +1-514-282-6464 #275
fax: +1-514-282-6464 #275
lucas-picher.philippe@ouranos.ca

Pascale Martineu
CRCM Network
UQAM @ OURANOS
550 rue Sherbrooke O, 19e
Montreal
QC H3A 1B9
CANADA
ph: +1-514-282-6464-282
fax: +1-514-282-7131
martineu.pascale@uqam.ca

Wilhelm May
DMI
Lyngbyvej 100
DK-2100 Copenhagen Ø
DENMARK
ph: +45-3915-7462
fax: +45-3915-7460
may@dmi.dk

H.E. Markus Meier
SMHI
SE-60176 Norrköping
SWEDEN
ph: +46-11-495-8612
fax: +46-11-495-8001
markus.meier@smhi.se

Cosmo Ngongondo
University of Malawi
Global Water Partnership Southern Africa
Chancellor College
P.O. Box 280
Zomba
MALAWI
ph: +265-1-339-202
fax: +265-1-524-787
cngopngondo@chanco.unima.mw

Inocencio J.J.F. Pereira
Departamento de Geografia
Universidade Eduardo Mondlane
P.O.Box 257
Maputo
MOZAMBIQUE
ph: +258-1-493114
intsemba@zebra.uem.mz

Alexandre Bernardes Pezza
Department of Atmospheric Sciences
University of São Paulo
BRAZIL
alepezza@model.iag.usp.br

Burkhardt Rockel
GKSS Research Centre
Institute for Coastal Research
Max-Planck-Str. 1
D-21502 Geesthacht
GERMANY
rockel@gkss.de

Olafur Rögnvaldsson
Vedurstofa Íslands
Bústadavegur 9
IS-150 Reykjavík
ICELAND
ph: +354-522-6000
fax: +354-522-6001
or@os.is

Markku Rummukainen
SMHI
SE-601 76 Norrköping
SWEDEN
ph: +46-11-495-8605
fax: +46-11-495-8001
Markku.Rummukainen@smhi.se

Patrick Samuelsson
SMHI
SE-601 76 Norrköping
SWEDEN
ph: +46-11-495-8614
fax: +46-11-495-8001

Venkatamariah Satyan
WMO/WCRP
7 bis Avenue de la Paix,CP 2300
CH-1211 Geneva 2
SWITZERLAND
ph: +41-22-730-8418
fax: +41-22-730-8036
vsatyan@wmo.int

Quirin Schiermeier
German Correspondent of Nature
Josephspitalstrasse 15
D-80331 Munich
GERMANY
ph: +49-89-5490-5714
fax: +49-89-5490-5720
q.schiermeier@nature.com

Igor Shkolnik
Voeikov Main Geophysical Observatory
Karbyshev str., 7
194021 St Petersburg
RUSSIA
ph: +7-812-2478668
fax: +7-812-2478668
igor@main.mgo.rssi.ru

Samuel Somot
Meteo-France / CNRM / GMGEC
42 av. G. Coriolis
F-31000 Toulouse
FRANCE
samuel.somot@meteo.fr

Jozef Syktus
Queensland Center for Climate Applications
80 Meyers Rd.
Indooroopilly 4068 Qld
AUSTRALIA
ph: +617-3896-9730
fax: +617-3896-9843
syktus@nrm.qld.gov.au

Eugene S. Takle
Iowa State University
3010 Agronomy Hall Ames
Iowa 50011-1010USA
ph: +1-515-294-9871
fax: +1-515-294-2619
gstakle@iastate.edu

Ruth Taylor
Met Office Hadley Centre
FitzRoy Road
Exeter, Devon, EX1 3PB
UK
ph: +44-1392-886885
fax: +44-1392-885681
Ruth.taylor@metoffice.com

Michael Tjernström
Stockholm University
Department of Meteorology
SE-10691 Stockholm
SWEDEN
ph: +46-70-2056631
fax: +46-8-157-185
michaelt@misu.su.se

Heikki Tuomenvirta
Finnish Meteorological Institute
P.O. Box 503
FI-00101 Helsinki
FINLAND
ph: +358-919294129
heikki.tuomenvirta@fmi.fi

Cintia Uvo
Lund University
Box118
221 00 Lund
SWEDEN
ph: +46-46-222-0435
cintia.uvo@tvrl.lth.se

P-L Vidale
IAC-ETH
Winterthurerstr. 190
Zurich
SWITZERLAND
pier-luigi.vidale@ethz.ch

Hans von Storch
GKSS Research Center
Institute for Coastal Research
Max-Planck-Straße 1
D-21502 Geesthacht
GERMANY
ph: +49-4152-87-1831
fax: +49-4152-87-1888
storch@gkss.de

Yuqing Wang
University of Hawaii
International Pacific Research Center
2525 Correa Road
Honolulu
HI 96822
USA
ph: +1-808-956-5609
fax: +1-808-956-9425
yqwang@soest.hawaii.edu

Neil Ward
IRI Columbia University
61, Rte 9W
Palisades, NY 10964
USA
ph: +1-845-680-4446
fax: +1-845-680-4864
nward@iri.columbia.edu

Joanna Wibig
University of Lodz
Dept. of Meteorology and Climatology
Narutowicza 88
PL-90-139 Lodz
POLAND
ph: +48-42-665597
fax: +48-42-6655951
zameteo@uni.lodz.pl

Martin Wild
Swiss Federal Institute of Technology
Institute for Atmospheric and Climate Science
ETH
Winterthurerstrasse 190
CH-8057 Zurich
SWITZERLAND
ph: +41-1-635-52-36
fax: +41-1-362-51-97
martin.wild@env.ethz.ch

Ulrika Willén
SMHI
SE-60176 Norrköping
SWEDEN
ph: +46-11-495-8390
fax: +46-11-495-8001
Ulrika.Willen@smhi.se

Katja Woth
GKSS Research Centre
Institute for Coastal Research
Max-Planck-Str. 1
D-21502 Geesthacht
GERMANY
ph: +49-4152-87-2819
fax: +49-4152-87-2818
woth@gkss.de

Klaus Wyser
SMHI
SE-601 76 Norrköping
SWEDEN
ph: +46-11-495-8464
klaus.wyser@smhi.se

Jiao Yanjun
University of Quebec at Montreal (UQAM)
550 Sherbrooke west, 19th floor, west tower
Montreal,Qc
H3A 1B9
CANADA
ph: +1-514-282-6464 ext. 304
fax: +1-514-282-7131
jiao.yanjun@uqam.ca

Ayrton Zadra
Meteorological Service of Canada
2121, TransCanada Highway
Dorval (Quebec)
H9P 1J3
CANADA
ph: +1-514-421-4643
fax: +1-514-421-2106
ayrton.zadra@ec.gc.ca

Johann Züger
ARC systems research
A-2444 Seibersdorf
AUSTRIA
ph: +43-50-550-3877
fax: +43-50-550-3888
johann.zueger@arcs.ac.at

Francis Zwiers
CCCma
PO Box 1700 STN CSC
Victoria, BC
V8W 2Y2
CANADA
ph: +1-250-363-8229
fax: +1-250-363-8247
francis.zwiers@ec.gc.ca

High-resolution climate modelling: Assessment, added value and applications
A Foreword

René Laprise

Dép. des Sciences de la Terre et de l'Atmosphère, Université du Québec à Montréal, and
Principal investigator, Canadian Network for Regional Climate Modelling

Preamble

In March 2000 a "Joint WGNE/WGCM *ad hoc* Panel on Regional Climate Modelling" was established, with mission of addressing several issues that had been raised by WGNE in its annual reports of the previous two years. The Panel submitted its report entitled "Atmospheric regional climate models (RCMs): A multiple purpose tool?" on the 12th of July 2001 and in modified form on the 11th of February 2002. Amongst the recommendations contained in the Panel's report was to hold a Workshop to discuss the current issues in Regional Climate Modelling: this is how the RCM Workshop "High-resolution climate modelling: Assessment, added value and applications" held in Lund, Sweden, from March 29 to April 2 2004, came to be.

This Foreword is not intended as a literature review on regional climate modelling, nor as a summary of the presentations and discussions that took place at the Lund Workshop; the Abstracts and Syntheses presented in these Proceedings fulfil this last role. The level of the discussions during the Workshop testified of the rapid evolution of paradigm that has been taking place over the last years in the field of regional climate modelling. In this essay the author expresses his personal views, as they stand now, influenced in part by the Workshop; hence the opinions that are expressed engage only its author.

The current state of regional-scale climate modelling: An essay

It is widely recognised that global General Circulation Models (GCM) of the atmosphere, coupled with land surface, ocean and sea-ice models (henceforth called CGCM), are major tools to further our understanding of the physical processes responsible for the maintenance and evolution of the climate system, including its natural variability and its response to changes in its forcing. CGCM thus constitute the most sophisticated tool for making climate projections under altered atmospheric composition or land-surface use, for example. Due to the complexity of CGCMs (whose simulation costs increase roughly as the fourth power of the linear horizontal resolution) and due to the extended simulation periods required to establish reliably their climate (from decades to several centuries), these mathematical simulators of the climate system are very demanding on computer resources, even on today's fastest super-computers. For this reason CGCMs employ rather coarse computational meshes (generally of order of a several hundred km) compared to Numerical Weather Prediction (NWP) models (a few tens of km). As a result several so-called mesoscale phenomena (such as mountain and valley circulations, heterogeneities in land surfaces, intense precipitation associated with weather fronts, squall lines and convective complexes) are not resolved in CGCMs. Studies of environmental, societal and economic impacts associated with anticipated climate changes however demand much more spatially detailed information than is currently practical with CGCMs.

Foundation of regional climate models

In view of the computational impossibility for most groups of operationally integrating high-resolution global models on climate time scales, other avenues have been investigated. In the late 80's, Giorgi and collaborators at NCAR showed that it was possible to "nest" a high-resolution, limited-area, "regional" climate model (RegCM) within a coarse-resolution GCM. The strategy consists in interpolating the atmospheric fields of coarse-resolution GCM on the regional grid in order to provide time-dependent lateral boundary conditions (LBC) required by the regional model in a buffer zone at the outer edge of its computational domain. The main task of regional climate models (RCMs) is to produce projections of climate on finer scales (e.g. severe weather events, climate extremes, precipitation distributions) consistent with the large-scale projections of CGCMs. The ansatz behind the nested-RCM technique is that, given large-scale atmospheric distributions, an RCM integrated on a suitably high-resolution grid resolving physiographic details such as topography and land use, can generate high-resolution information that is physically consistent with the driving large scales. High-resolution RCMs constitute an interesting additional tool in the climate-modelling toolbox, as RCMs' structure permits resolutions at least an order of magnitude finer than CGCMs at a comparable computational cost.

This seminal work paved the way for about a dozen research centres around the world that have since developed their own RCM. The development and validation of a complex tool such as a climate model – global or regional – is a long, arduous and painstaking process that no single individual scientist can contemplate and that relatively few institutions are capable of supporting for the long term and resources required. For this reason it is often useful to share tools to reduce the overhead of RCM development worldwide. "Community" models exist that can be obtained either for free or at a very small fraction of the development cost: RegCM, NCAR's MM5 and Hadley Centre's PRECIS, are a few examples of widely distributed models. There is however a deep concern in part of the modelling community about the potential indiscriminate use of RCMs, in the sense that RCMs software can be just picked up and applied by anyone with minimal training, to generate scenarios for climate-change impact assessment without prior validation of the quality of the results. This treat should dissipate naturally after the next IPCC assessment report (AR4), as several regional-scale climate-change scenarios will be available for impact assessment for several regions of the world, which will set standards for regional-scale scenarios as is the case now for global scenarios.

Since the very beginning the development of RCMs has been closely linked with their application for impact studies, a situation unlike that of the global modelling community that has been driven almost exclusively by "simply doing good science" without specific application attached to it. While this application-driven development of RCMs has its constraints, it has shown to have good sides too. Applications often provide alternative, non-conventional verification data and methods for validation of specific aspects of model simulations in terms of the purpose of their use. As some application models amplify shortcomings of climate model simulations, impact users provide feedback and stimulus toward improving climate models, so there is two-way interaction between the two communities. This being said, proper scientific approach must still prevail, and careful validation is a necessary step in the development of any new tool. The fact that some GCMs do a better job at reproducing observed variability than some RCMs points to the larger efforts invested in some GCMs and to the need for further development and validation of some RCMs. At the same time because RCM simulations are first-order sensitive to LBC, it is of paramount importance for the climate modelling community to continue to improve CGCMs. The European project PRUDENCE, which involves several global- and regional-climate modelling groups as well as several application groups, has clearly shown the benefits of interactions and collaborations between these communities; it stands as an example for other groups around the world.

Estimating the uncertainties of climate-change projections

State-of-the-art RCMs are beyond the stage of simply trying to further improve them. What is required for their proper application in building scenarios is to quantify the uncertainty associated with their climate-change projections. The spread between members of an ensemble provides a simple lower bound estimate of the uncertainty. The fact that systematic biases of ensemble means under current climate are less than that of individual models implies that part of the model errors varies between models, hence the partial error cancellation. Furthermore the fact that current-climate biases are generally smaller than climate-change signals lends confidence in the projections. There is however a need to investigate all possible feedback processes that participate in the climate system; we probably now cover only a small sample of all uncertainties. Finally it is important to reiterate the difference between the true uncertainty (unknown) and the perceived uncertainty. As knowledge and understanding increase in a field, naïve views that resulted in a perception of high level of confidence and small uncertainty are abandoned, and the perceived uncertainty increases; at the same time the true uncertainty may actually be decreasing as a result of error reduction.

Qualifying uncertainty provides an indication of when and where the climate-change projections are trustworthy or not. The availability of a wide range of model projections for a region provides a sense of uncertainty, preventing impact users from a naïve deterministic interpretation of single-model results. Serious groups studying climate-change impacts are now doing exploratory work rather than providing definite results, demonstrating the potential of various approaches rather than making claims, and while so doing, develop expertise, solid methodological approaches and tools. A logical approach to climate-change impact studies should concentrate more on characterising the vulnerability of various systems to a wide range of forcing, climate being just one component. Vulnerability under current climate conditions should be characterised first. The documentation of contemporary climate variations should follow, and the building of climate-change projections and scenarios would come next. Finally developing strategies for reducing vulnerability would come last. Collaboration between modelling and application communities is desirable as modellers can qualify the limitations of their simulated results, and applications can provide important feedback on the realism of simulations. (As an example, care should be exerted in coupling a water management model with an RCM to properly account for the mismatch between real catchments basins and model ones given the topography resolved on a finite grid.) Funding for regional-climate modelling work is already increasingly impact driven, not simply targeted at supporting good science for its own sake.

The added value of regional projections

The stated aim of RCMs is to add higher resolution details to, but keep the large-scale features of, GCM integrations, particularly in the context of climate change. This does not imply however that RCMs' results aggregated onto the grid of the nesting model will or should necessarily agree with the nesting data. The reliability of the nesting data varies, depending for example whether objective analyses (OA) or GCM-simulated data are used as LBC. Some scales may be incorrectly simulated by GCMs because they do not resolve part of the small-scale forcing and interactions. In this case RCM solutions may correct some intermediate scales that are present, but incorrect, in the nesting data. An example of this phenomenon is the shadow effect of the Rocky Mountains that results in dry low troposphere over most of North America, East of the Continental Divide, a large-scale effect that is captured in RCMs but is underestimated by coarse-mesh GCMs owing to their lower average mountain heights.

High-resolution RCMs, initialised with and nested at their lateral boundaries by low-resolution data, produce solutions that contain fine-scale details. These fine scales result from a combination of small-scale forcing (e.g. surface heterogeneities, localised diabatic heating), flow nonlinearities (e.g. stretching, twisting, folding, tilting) and hydrodynamic instabilities. The spin-up of fine-scale features is relatively fast for typical resolutions of RCM and nesting data. For 45-km grid RCM in mid-latitudes driven by 350-km grid data, full development in time of the atmospheric flow is achieved after some 48 h; adjustment time of land-surface variables however is much longer and depends on the details of the formulation, depth below ground, and climate regime. There is also spatial spin-up away from the lateral boundaries; for typical configurations in mid-latitudes again, full development is achieved at a distance of some 20 grid points away from the lateral boundaries. The widely agreed rule of thumb for an acceptable jump of horizontal resolution between an RCM and the nesting data is a ratio of less than 10, which is substantially more than the factor of 3 that emerges from mesoscale and weather prediction studies. New results however indicate that this ratio may not be the controlling factor; the number of coarse-mesh grid points of nesting data contained within the RCM domain appears to be more relevant, and this number should exceed a value of the order of 10 in one dimension. This new rule of thumb would imply that there is no resolution limitation for an RCM nested with a given resolution nesting data. Indeed while 45- to 60-km RCM grids are most often used, several tests are under way using 20-km and even in some cases 10-km meshes, while being nested by current CGCMs. The price to pay however is the requirement to use many grid points as RCM mesh sizes become finer.

The fact that high-resolution RCMs produce fine-scale details in their climate simulations is well established by now, and modellers hope that these are useful. There is a need to better identify the added value of RCM simulations. Scale decomposition is a first step to separate the fine scales that are permitted by the high-resolution computational grid from the large scales that are used to drive nested RCMs. The added value is unlikely to be apparent in simple statistics such as monthly means and transient eddy variances, because both measures tend to be dominated by large scales for most variables. Owing to the typical spectra of atmospheric fields, large scales are usually more energetic than small scales; this tends to hide the impact of small scales. Added value must be application related. Statistical downscaling of GCMs' simulations could provide a reference to which to compare RCM-simulated results in order to identify the added value of RCMs. An advantage of RCMs over statistical downscaling methods that require extensive historical databases for establishing transfer functions, is that they provide internally consistent downscaling of all variables; several application models however do not exploit the full benefits of this internal consistency of RCM-simulated results. Some application models require such fine-resolution input that statistical downscaling of RCMs' simulations is required; an additional advantage of RCMs is that it is easier to statistically downscale RCM results than coarse-mesh CGCM results.

Finally the added value most likely depends on the inherent limitations of the nesting data used as LBC of an RCM, and possibly on the nesting technique, as discussed below.

Lateral boundary control and predictability limits

The control exerted by LBCs on the internal solution generated by nested RCMs appears to vary with the size of the RCM computational domain and the weather regime over the geographical location of the domain, and with seasons. There is increasing evidence that, for some regions, nested models may not represent a lateral boundary value (LBV) problem. Indeed, Why should LBCs control entirely the interior? Depending on weather regime and domain size, RCMs appear to be facing the predictability limits of the initial-value problem (IVP). In such case the internal solution will diverge in time, with little control by LBC, in a fashion similar to global models; the phenomenon is referred to as "intermittent divergence in phase space" (IDPS). This behaviour appears almost systematically in RCMs' simulations carried over the Arctic, even with rather modest domain sizes. The occurrence of IDPS renders impossible the deterministic, time-by-time comparison of RCMs' simulations (nested by analyses) with observations. One would hope however that the basic climate statistics would agree, despite IDPS for individual weather events. But there is a risk that the traces of IDPS might show in some more subtle statistics, such as probability distribution functions or blocking events, and may also affect the ability of RCMs to capture the signal of interannual anomalies present in LBC. Alternatives to simple LBC nesting such as *ad hoc* nudging of large scales in the interior of the domain can be effective in preventing IDPS, as does also a reduction of domain size. One can imagine that the optimal settings for nudging (such as the strength of the nudging and the selection of scales that are forced) could be based on some relative measure of quality of the nesting data and of the nested model performance, by analogy to variational data assimilation. The nudging settings would then clearly be different for GCMs or OA nesting data, and would likely vary as a function of height, dependent variables, season, geographical location, etc. The procedure to ensure an optimal control of an RCM by nesting data is an active current research field. One danger of nudging is that its effect can hide errors or systematic biases present in models.

Current regional climate modelling activities and nesting strategies are heavily based on experience derived from applications of RCMs in mid-latitudes. These findings are not always readily transferable to other regions, as already mentioned for the Arctic; even less is known for tropical and equatorial regions. Different regions have their own natural variability and limits of predictability, resulting in different control being exerted by the lateral boundaries for a given domain size. Hence empirical operating rules of a model developed for mid-latitudes may not be appropriate for other regions; a likely example is vertical resolution (and its relation to horizontal resolution) that may have to be increased for application over the Arctic where the static stability of the atmosphere is substantially stronger than over mid-latitudes. The strong mid-latitude slant is not independent of the funding context of regional climate modelling activities. There is a need for research groups to argue with their funding agencies about the benefits to be derived from validation under different weather regimes: confidence in RCMs' projections under climate change can be gained by studying RCMs' skill in different region of parameter space. Another benefit of regularly testing RCMs over different regions of the globe is to resist the temptation of over-tuning a model for a specific region: this is the transferability issue addressed later in this Foreword.

Validation and application of regional climate models

RCMs have been used for case and process studies since their beginning. An application of RCMs that has received little attention so far however is to investigate the documented biases of current GCMs and to develop physical parameterisation packages for the next generation of higher resolution GCMs. When driven by atmospheric analyses at their lateral boundary, RCMs represent a useful intermediate step in the development of physics packages, between very controlled environments such as observations, analyses, column models, large-scale eddy simulations and cloud-resolving models on the one hand, and autonomous GCMs on the other hand. RCMs offer a controlled, realistic environment to study parameterisations behaviour in a context that is relatively free of errors transported from outside the region of investigation, compared to a GCM. A limited-area domain permits to distinguish local from global forcing, and respective contributions to parameterisation errors. Of course this will not preclude the need for further fine-tuning of parameterisations in adapting them to GCMs' resolution and for correcting potential biases that would result in slow but systematic drifts in GCMs, but that may have gone unnoticed in nested RCMs.

Proper validation of RCMs requires better high-resolution verification data than is currently available. Indeed while available gridded climatological databases constitute a prime tool to validate GCMs, they do not resolve the fine scales that are permitted by RCMs. Some high-resolution analyses do exist, but they generally do not extend back in time sufficiently to be useful to validate RCM-simulated climates. Surface observing networks with sufficient high-density and long-term records exist for only some regions of Europe. Properly calibrated remote sensing techniques offer promising perspectives, particularly because the measurements are representative of area averages, better suited for model verification than *in situ* measurements. Aircrafts measurements offer accuracy and spatial integration advantages. But in both cases the length of the available records is a limiting factor. Some tests have shown that RCMs themselves, when driven in strongly constrained mode by coarse-mesh atmospheric analyses, could be used to generate high-resolution reconstruction of recent past climate series, thus performing the task of "poor-man" data assimilation. Those reconstructions could in principle be used for validation of GCM-driven or less constrained OA-driven RCM simulations.

Other avenues

While the bulk of this Foreword focused on the climate application of one-way nested RCMs, it is appropriate to mention other applications of nested models and other approaches to regional-climate modelling. Nested limited-area models (LAM), analogous in many respects to RCMs, are used successfully by many Numerical Weather Prediction (NWP) centres around the world for short-range weather forecasting over their region of interest. Research is under way in several Seasonal to Interannual Prediction (SIP) centres to downscale the predictions of coarse-mesh GCMs with nested RCMs. Alternative approaches to regional-climate modelling such as variable-resolution and stretched-grid atmospheric GCMs allow to reach resolutions comparable to RCMs at an affordable computational cost, while retaining the advantages of global coverage and scale interactions between the region of interest and the rest of the globe. Recently one group has even successfully achieved two-way nesting of a high-resolution grid-point RCM with a coarse-resolution spectral GCM; preliminary results obtained with an RCM domain located over the Indonesian warm pool are very promising, indicating a reduction in the biases of the GCM with two-way nesting. Two-way nested and variable-resolution models may offer interesting approaches for "upscaling" studies and to develop so-called "super-parameterisations".

Finally some groups are developing medium- and high-resolution atmospheric GCMs. Due to their computational cost these models are integrated for modest periods only (a few decades). These atmospheric GCMs take their sea surface temperatures (SST) and sea ice from climate-change simulations of CGCMs. Either the CGCM-simulated SST themselves or their deviation from current-climate values are used; the latter method has the advantage of removing systematic biases that may be present in CGCM simulations, at the expense of loosing physical consistency.

Epilogue

Finally the Lund Workshop was the forum of discussions about three proposals for international collaboration in regional climate modelling, in addition to discussing the follow-up of the European project PRUDENCE, ENSEMBLES. The three proposed collaborative endeavours are briefly reviewed below.

A "North American Regional Climate Change Assessment Program" (NARCCAP) is proposed by Linda O. Mearns from the National Center for Atmospheric Research (NCAR). The fundamental scientific motivation of this project is to explore the combined uncertainty in climate-change scenarios resulting from the use of different coupled Atmosphere-Ocean General Circulation Models (CGCMs) providing boundary conditions for different Regional Climate Models (RCMs). This plan is modelled on the very successful ongoing PRUDENCE project in Europe. This collaborative programme will have several benefits. It will permit (1) the exploration of the multiple uncertainties in regional projections of CGCMs and RCMs, (2) the development of multiple high-resolution regional-climate scenarios for use in impacts models, (3) a thorough evaluation of RCMs' performance over North America, (4) the exploration of some remaining uncertainties in regional-scale climate modelling, and finally but not least, (5) the creation of greater collaboration between US and Canadian climate modelling groups, as well as with part of the European modelling community.

A "Transferability Working Group" (TWG) is proposed by Eugene S. Takle from Iowa State University (ISU). The GEWEX Hydrometeorology Panel has solicited and given strong endorsement to this proposal that will explore how well understanding of physical climate processes as modelled in RCMs transfer from one climatic region to another. TWG will collect results of RCM intercomparison projects on several continents and GEWEX continental-scale observing campaigns, to yield an overview comparison of RCMs contemporary-climate capabilities and challenges. TWG will provide a means for systematic evaluation of simulations of different climatic regions by "meta-comparison" of individual and ensemble performance among domains as well as on particular domains. A goal is to evaluate transferability of regional climate models and their components from "native" to other "non-native" regions. Such a project is an antidote against over-tuning of regional models for specific region.

Finally a coordinated project exploiting the protocol of the "Big-Brother Experiment" (BBE) is proposed by René Laprise from the Université du Québec à Montréal (UQÀM). The proposed project consists in expanding the set of experiments performed to date by the UQÀM group with the Canadian RCM (see the Abstract in the Proceedings for details on the BBE protocol). The participation of several RCMs in a BBE would allow verifying some of the subtle conclusions obtained to date, verifying that they are not model specific. The BBE permits to focus on errors specific to nested models. The BBE can serve as a useful numerical laboratory to investigate the sensitivity of RCMs' simulations to some errors in nesting data, as is the case with CGCM-simulated data, and to investigate the degree to which RCMs may actually be able to correct some of these errors. The BBE may also be used advantageously to test the impact of computational domain size, to investigate predictability issues related to domain location, to determine constraints on model resolution and domain size for a given resolution of nesting data, to diagnose the presence of artificial "domain" circulations, to quantify the magnitude of the internal variability of nested RCM and, a related topic, the degree of control exerted by lateral boundary conditions for different regions of the globe.

Synthesis of Workshop

Authors in alphabetical order:
Lars Bärring, Jens Christensen, Michel Déqué, Filippo Giorgi, Colin Jones,
Richard Jones, René Laprise, Markku Rummukainen, Hans von Storch.

Introduction

Global climate models (GCMs), coupling the atmosphere, oceans and land-surface processes, constitute the most advanced tools to study the climate system and understand its sensitivity to changes in forcing, such as the concentration of radiatively active substances or altered land use. The computational burden of GCMs' simulations over several decades forces their operational integration on meshes of some hundred kilometres. Such resolution is insufficient to describe mesoscale processes that are required for most climate-change impact studies. Regional climate models (RCMs) constitute tools allowing resolutions one order of magnitude finer than GCM, at the sacrifice of limiting the domain of investigation. On 50-km meshes, RCMs' domains typically cover surface areas of the order of (5,000 km)^2, sometimes more.

This text synthesises the oral presentations and discussions in the RCM Workshop "High-resolution climate modelling: Assessment, added value and applications" held in Lund, Sweeden, from 29 March to 2 April 2004. Sessions were grouped under the following three themes: (1) Modelling issues – Merits and limitations, (2) Applications, and (3) PRUDENCE reports.

1. Modelling issues – Merits and limitations

Topics covered under this theme include a historical review of the birth of RCMs, the identification of "added value" of RCM simulations, the conceptual basis of nesting and dynamical downscaling, the validation of the nested approach, the use of high-resolution and variable-resolution GCMs, the development of physical parameterisations, the coupling with regional ocean models, and the specific challenges of the Arctic region.

The development and application of RCMs began at the end of the 1980's with the seminal work of Filippo Giorgi and colleagues at NCAR. In the decade that followed, several groups around the world began the development of their own RCM. This proceeded mainly from two separate approaches to subgrid-scale parameterisation: either the adaptation for climate of an existing numerical weather prediction or mesoscale research model, or from the adaptation of the parameterisation of an existing GCM to the higher resolution of the RCM. In the early 1990's a project coordinated by Bennert Machenhauer at the Max-Planck Institute compared several RCMs over Europe. RCMs were also applied over several regions of the world. Already in the Second Assessment Report (SAR) of the IPCC (1996), RCMs results were presented that showed that these models could produce realistic regional details. At the end of the 1990's, several countries were beginning to develop vulnerability studies and climate-change impact and adaptation plans. The European project PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) allowed a thorough comparison of climate-change projections obtained by a variety of models, including RCMs. In an effort to reduce the overhead of RCM development and deployment, some modelling centres have made available their RCM to interested investigators. For example, versions of Giorgi's RegCM and of the Hadley Centre's HadRM models are used in several regions around the world.

RCMs can be, and have been, used for several "applications". Given the unavailability of high-resolution analyses, RCMs can be used to perform simplified regional quasi-analyses by downscaling global analyses. These analyses in turn can be used to drive applications such as studying the path ways of pollutants, modelling ocean waves, driving hydrological models, etc. RCMs are beginning to be used to downscale seasonal to interannual climate predictions of GCMs and CGCMs. RCMs can be used as a computational laboratory to develop, test and improve physical parameterisations that could be transferred into GCMs. RCMs can be used advantageously to carry process studies at higher resolution than GCMs can afford, to investigate model biases, to distinguish local from global forcing, to name just a few. RCMs are used, driven by atmospheric and ocean fields from CGCMs' climate-change projections, to do regional-scale climate-change projections. RCMs can be used to understand feedbacks and mechanisms for climate-change responses. In particular RCMs simulations can provide data for feeding "impact" models for further modelling of natural (physical and vegetal) processes and eventually societal impacts. An important issue for regional modelling is to clearly show the benefit of increased model resolution on atmospheric phenomena/energy on the scales resolved by a regional model that are not resolved by a nesting global model. In this context, the development of suitable analysis tools and filtering options to analyse particular scales of motion in isolation from other scales, is an important activity. This development allows a clean separation of the scales where added value might exist and a clearer indication of the benefits of regional downscaling might ensue.

The common view of nested limited-area RCMs is that they represent a tool to achieve dynamically consistent downscaling: from the prescription of time-varying large-scale flow and the interaction with regional-scale forcing, regional climate can be obtained as a sequence of weather states defined at high-resolution. The traditional mathematical interpretation is that nested RCM represent a "boundary-value problem". A fair number of studies have indicated the fundamentally ill-posed nature of the problem, and have suggested ways to circumvent the problem through the application of suitable nesting techniques. The downscaling technique attempts at determining small-scale weather that is dynamically consistent with large scales. In this sense it is natural to consider RCMs not as a boundary-value problem but rather as a "dynamical downscaling problem". The application of this concept leads to forcing the large scales throughout the entire RCM domain instead of prescribing dependent-variable values at (or near) the lateral boundaries: this is the large-scale nudging technique. Ideally optimal nudging coefficients should be determined taking into account model and lateral boundary errors (this could in principle be done for each dependent variables, as a function of altitude, season, region, etc.). An interesting side benefit of using large-scale nudging is that it can prevent the phenomenon known as "intermittent divergence in phase space" that results in decoupling of the internal solution of the RCM with the external solution prescribed as nesting. With large-scale nudging RCMs can be used to reconstruct historical weather from low-resolution objective analyses; high-resolution RCMs' simulations can then be used to drive several applications, such as building synthetic ocean wave climatology.

The downscaling ability of RCMs is difficult to evaluate for several reasons, including that RCMs, like all models, contain discretisation and parameterisation approximations, RCMs are affected by errors in the data used to nest them and the implementation of the nesting, and, as mentioned previously, high-resolution climatological verification databases only exist for very few regions of the world. The Big-Brother Experiment (BBE) has been designed to address the downscaling ability of nested RCM, specifically the issue related to nesting, but excluding the other sources of errors. The BBE consists in first establishing a reference climate by performing a large-domain high-resolution RCM simulation, called the Big Brother (BB). The BB simulation serves as reference for verification for a second experimental simulation called the Little Brother (LB). The LB model is identical to the BB, except for its smaller computational domain. The LB is nested with BB-simulated data that were degraded by removing fine scales; this emulates the coarse resolution of objective analyses or GCMs. When comparing the climate statistics of the LB to those of the BB, the differences can be unambiguously attributed to nesting errors. The BBE has been applied methodically with a 45-km grid version of the Canadian RCM, to two regions of North America (the East and West Coasts where the orographic forcing varies greatly), for winter and summer months when dominant dynamical and physical processes vary greatly. The climate statistics are computed in terms of stationary and transient eddies, decomposed by horizontal scales. These results serve to establish the limits of dynamical downscaling ability of RCM, as well as the optimal configuration. The BBE has been used to investigate the sensitivity to horizontal resolution jump between the nesting data and the RCM computational mesh, and the nesting time interval. This approach could (and should) be used with other RCMs to confirm the established results and expand the experiments to validate other aspects, such as other domain location (such as polar and tropical), computational domain size (both as physical size and number of degrees of freedom), and its sensitivity to nesting data (resolution and errors typical of GCMs simulations), to name just a few.

Planetary-scale climate modelling by low-resolution GCMs (e.g. T42) works somewhat fortuitously because the space-time details of small-scale weather do not matter much for the large atmospheric scales; only the overall effects of small scales matter, and these can be parameterised with some skill. High-Resolution atmospheric GCMs (HRGCMs) can be run at resolutions (T239) approaching those of typical RCMs (50 km), but at a considerably larger computational expense due to global coverage. It is found that the higher resolution, in addition to adding small-scale features, also improves the larger scales that are resolved at conventional GCMs' resolution. This is attributed to less reliance being put on parameterisations as more processes and scales are resolved. Precipitation intensity distributions are improved with increased resolution. There are remaining issues with HRGCMs as to the convergence solutions with increased resolution, to need for consequent vertical resolution, and the parameterisations sensitivity to resolution. Variable-Resolution GCMs (VRGCMs), and Stretched-Grid GCMs (SGGCMs) in general, offer an attractive alternative to HRGCMs, retaining global coverage with high-resolution in a focus area as in RCMs, which is computationally much less demanding than HRGCM. Global coverage imposes the use of the same high vertical resolution and small time step as required by the high-resolution area of the globe, which increases somewhat the overhead. The Stretched-Grid Modelling Intercomparison Project (SGMIP) in which a number of groups participated, has demonstrated the potential of the approach. There are remaining issues as to the sensitivity of parameterisations to variation and anisotropy of resolution, and creative approaches are currently investigated to increase substantially the performance of parameterisations in such models.

The role that RCMs can play towards the development and improvement of physics parameterisations suitable for high-resolution climate models has often been highlighted as an important potential benefit from regional climate modelling. However, to date only limited work has been carried in this direction, partly because usually physics schemes are designed and tested for specific modelling systems and configurations. One of the advantages of RCMs within this research context is that the use of analyses of observations to drive the RCMs allows testing physics parameterisations in realistic meteorological settings. In other words, the physics parameterisations can be tested under conditions in which the effect of errors in the large-scale fields is minimized. In particular, RCMs can be especially useful in evaluating parameterisations of turbulent boundary layer, moist convection, clouds and precipitation. As is well known, both regional and global climate models are very sensitive to the representation of cloud and precipitation processes and this constitutes an important source of uncertainty in climate-change studies. International programmes such as the GEWEX Cloud System Study (GCSS) have been established to systematically assess the performance of models at different spatial and temporal scales by comparison with a range of available observations. Such programmes should help to enhance the value of RCMs as tools for the development and assessment of physics parameterisations.

It is of increasing interest in the field of regional climate modelling to include a detailed description of regional water bodies (e.g. inland/coastal shelf seas, large lakes) as coupled components of a full regional-climate modelling system. Large water bodies (on the scale of the Baltic Sea or Great Lakes) greatly influence the local climate. Regional details of sea ice cover and sea surface temperature (SST) can influence the coastal climate in many regions and therefore need to be included in regional models. It is common practice in present RCMs to simply interpolate the SST and sea ice cover from the simulation of a Coupled Global Climate Model (CGCM). In many regions however GCMs have a very poor description, if any, of these regional seas and lakes. Prognosing the evolution of the regional water bodies comprised within the RCM domain, can greatly improve the realism of the regional climate and projected climate change. Furthermore, a number of environmental consequences of climate change, related to water quality, marine biology and chemistry, can best be assessed using coupled regional ocean-atmosphere models. Due to the detailed bathymetry in many regional seas, high resolution is required to model key regions of flow and water formation. From this perspective coupled regional ocean-atmosphere models can provide a useful tool for understanding the climate system and improving the representation of key ocean current systems in present-day GCMs. This is particularly true for the Arctic region, where the details of sea-ice cover and ocean circulation systems require high resolution for an accurate description, but may have global consequences through their impact on preferred sites of deep-water formation and the global thermohaline circulation.

RCMs are still in their infancy over the Arctic region. Nevertheless, a number of important developments have occurred in the past few years, leading to improved models and a better appreciation of the key processes needing to be modelled for accurate Regional and Global Model simulations of the Arctic. It is envisaged that RCMs will soon allow an assessment of the regional impact of climate change in the Arctic region. An assessment of the performance of present-day atmospheric RCMs over the Arctic is ongoing in the ARCMIP project (Arctic Regional Climate Model Intercomparison Project) and within the European Union funded project GLIMPSE (Global Implications of Arctic Climate Processes and Feedbacks). The Arctic region provides a number of unique challenges to climate models. Regional models offer an opportunity to study these processes in relative isolation and develop sound parameterisation schemes that can be evaluated for inclusion in GCMs, in order to improve the representation of the Arctic climate in these models. Of particular importance over the Arctic region are atmospheric conditions with frequent very stable boundary layers. Sea ice and snow processes are crucial to model accurately and are very sensitive to the representation of surface radiative fluxes, in particular terrestrial radiation. Due to the cold conditions, ice processes in clouds (radiative transfer and precipitation production) are also of key importance. A requirement for the improvement of Arctic RCMs and parameterisations for the Arctic region in general, is improved observations of key phenomena and variables. The SHEBA (Surface Heat Budget of the Arctic Ocean) observational data set is being used extensively within ARCMIP for model evaluation at a single location. SHEBA data is also being used for the development of satellite-derived observations covering a wider geographic domain over the Arctic. In evaluating model performance, surface flux quantities, such as radiative and turbulent fluxes, need to be evaluated as well as the more standard surface variables, such as temperature, winds and moisture. It is only through an analysis of the flux terms that physically based parameterisations can be developed that will improve the Arctic RCMs for the correct reasons. In particular, the performance of surface turbulent fluxes of heat and moisture appears very poor in present RCMs, when evaluated against flux measurements at the SHEBA location, although one should bear in mind the representativeness of a single-point observation against a model grid-box mean quantity. Compensating errors in the representation of terrestrial and solar radiation between clear- and cloudy-sky fluxes need further attention in the Arctic.

2. Applications

A wide range of interpretations can be given to the word “applications”. The line between model development and application activities is rather elusive. This is especially true when defining ”application” as both pursuance of increased understanding of the system under study and addressing practical problems, such as weather prediction, air quality simulations or climate-change projections. In this sense, models are always developed for one application or another. However, often “application” is used exclusively when referring to using models to investigate some specific question. In this sense, a model appears as the tool it is, shedding light on an issue that cannot be (easily) probed otherwise. Examples of this are RCMs application for climate/streamflow and climate/air quality studies. In addition to addressing a practical problem, applying a model this way provides another type of evaluation, in terms of processes and parameters that are generally not included in climate models, but that nevertheless depend on climate, and thus on the performance of a climate model.

Specific application models can provide for RCMs validation. Surface flux measurements are currently being conducted in a number of sites in the Nordic countries, valid on scales that make them useful for evaluation and/or validation of model operating at 10 – 50 km scales, the current target resolution for RCMs. There is a specific need for useful measurements of the principal surface fluxes, as such data are only available at few sites and often of a quality that makes a direct comparison between modelled and measured data quite complicated. The new data set that is assembled by the “The Nordic flux measurement network” is quite promising in this regard. Fundamental research has demonstrated the need to take into account the directional variation of heterogeneous landscape in order to adequately describe the exchange turbulent fluxes between the land surfaces and the atmosphere. The complexity does not appear to decrease as model resolution increase. The importance of this effect has been documented in a regional numerical weather prediction model; it remains, however, to be seen whether this has strong implications for climate simulations.

The analysis of RCMs simulations in the light of a specific geophysical phenomenon, the European heat wave of the summer 2003, also provides an indirect validation of RCMs simulations. The extremely warm summer of 2003 in Europe appears to bear a strong resemblance to some of the summers simulated by PRUDENCE models for the period 2071-2100 under the SRES A2 emissions scenario. The climate-change projections indicate that the summer of 2003 would be likely to repeat itself several times before the end of the 21st Century. Several historic summers, e.g. 1947, also stand out as very unusual in terms of some of the records broken. For example 1947 had more hot days than did 2003, while the number of consecutive hot days was higher in 1976 as well as in 1947. Experts still debate how to best interpret individual extreme events in the light of climate change. It is clear that more in-depth analysis of these unusual years is needed. It is generally agreed that careful wording has to be used when addressing the public about the meaning of such events in the perspective of climate change, trying to use as much as possible a terminology that underlines uncertainty, e.g. verbs such as *could* or *may*, but never *will.*

In some applications, such as feeding climate model output to hydrological modelling, the final result is affected by the accumulated effect of the whole modelling chain (LBCs / RCM / application model). To understand the reasons for any apparent bias, investigations need to be made on the successive inputs and interfaces along the modelling chain. This is relevant to improving models, but also to characterizing the application result, and whether it might be useful for decision-making. RCM data offer an internal consistency in the short time and small space scales, among the various parameters they produce. But impact models seldom exploit this consistency, often preferring to use a single parameter on which *a posteriori* corrections can be applied. The possibility of using several models without too large a spread (due to the common forcing), and the availability of 50 km-scale data instead of 300 km are the main attractive features of RCMs. Impact modellers should work closer to RCM modellers, in the same way atmosphere and ocean modellers have collaborated in the 1990's. A difficulty in using RCMs outside Europe is the problem with data for validation. Impact models can constitute very powerful tools for RCMs validation.

The alternative to running a chain of modelling to arrive at an application is incorporation of the application itself into a (regional) model. Again, the line between increased understanding and an application can be a very fine one. Particulate matter and other air pollution agents are relevant for different applications, but they also affect cloud processes and radiation and, subsequently, the simulation of meteorological state variables. This needs to be addressed also in evaluating model performance against observed data (that have felt for example the influence of particles in the atmosphere). Models containing an application module in an interactive manner also facilitate understanding feedback, such as how locally induced cooling/warming might spread the effects dynamically into surrounding regions.

It always remains to be shown whether models in their current state should be taken as “good enough” to be applied to practical problems. As models never will become perfect, in the true meaning of the word, applying them is endorsed by most modellers and stated as the very purpose by some. In general, applying models is felt helpful in the identification of model development needs, as it brings available a wider range of evaluation data, including such integrating measures such as stream flow. The regional climate modelling community feels that more regional modelling should be pursued for regions outside Europe and the U.S., such as Africa and East Asia, which would provide a useful test of the validity of RCMs and of their transferability from one weather regime to another. The application of several RCMs over Europe, Russia, the U.S., Australia and Asia, illustrates the global transferability of regional modelling in general, and of some RCMs in particular.

Several simulations of RCMs were performed over continental U.S. within the Project to Intercompare Regional Climate Simulations (PIRCS) that offers a standardised framework for the validation of RCMs driven by atmospheric analyses. Ensemble simulations of nested RCMs exhibit internal variability on several scales. The variability appears stronger, in relative terms, in the fine scales than in domain-wide scales owing to the control exerted by the lateral boundary conditions.

The Temperate East Asia Regional Center (TEA-RC) with a Regional-climate Modelling Intercomparison Project (RMIP) has launched an important modelling activity, supported by the Asia-Pacific Network (APN) and the SysTem for Analysis, Research and Training (START). The ambitious project aims at the development of a fully coupled regional climate modelling system, including the hydrosphere, biosphere and aerosols, called RIEMS (Regional Integrated Environmental Model System). In the interim the project will develop projections for their inclusion in the next IPCC Assessment Report (AR4) from several nested RCMs and a Variable-Resolution GCM.

There are several areas where regional models can be used today in a profitable manner. Seasonal prediction is a new area with high potential for RCMs, where customers already exist today. This is a potential niche area for RCMs to downscale global seasonal and extended-range forecasts. Particularly in the tropics, global seasonal forecasts show some skill in predicting planetary-scale anomalies; coupling to a regional model may allow these anomalies to be translated into more detailed, local weather related, anomalies such as precipitation. The use of RCMs for seasonal to interannual climate prediction has been explored only recently, but it offers the potential of an extremely valuable application of regional models. To date, different RCMs nested within global models have been tested in seasonal prediction frameworks over a variety of regions such as the continental U.S., South America and South Asia. The steps involved in a prediction of seasonal climate using a nested RCM-GCM system consist of: 1) Running an ensemble of coupled GCM simulations to forecast both global sea surface temperature (SST) and atmospheric fields; 2) Running ensembles of nested RCM simulations over the selected region of interest using SST and driving large-scale fields from the corresponding GCM simulations. Because the large-scale forcing fields strongly affect the RCM solution, a reliable regional-scale seasonal prediction requires good performance of both the driving GCM and nested RCM. RCMs have been shown to provide valuable fine-scale information over regions characterized by complex topographical features or by sharp gradients in the precipitation field. However, technical issues such as choice of model domain, resolution and nesting approach (e.g. standard relaxation, large-scale nudging, multiple nesting) are important when setting up a nested seasonal prediction system, particularly over tropical regions. At present, the main bottleneck in the performance of seasonal prediction systems appears to be prediction of the SST evolution at the seasonal scale. The success of model-based seasonal predictions varies widely across regions, and it is generally greater for regions characterized by higher predictability and strong SST forcing (e.g. by ENSO). RCMs are among the suite of tools that can be used in a mutually complementary way to explore issues of seasonal predictability and to produce operational regional-scale seasonal predictions.

3. PRUDENCE

PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) is a European Commission Framework Programme 5 (FP5) project looking at aspects of uncertainty in climate change over Europe, including some studies on the implications for potential impacts and European policy. PRUDENCE covers a wide range of subject areas, from global climate modelling to regional policy responses. It constitutes a major undertaking that involves 21 formal (and several more informal) partners, thus enabling integration of European-wide expertise to add value to, and provide a European perspective from, national programmes.

The current instrument of the European Commission to strengthen the European Research Area and funding projects, including on those subject areas covered by PRUDENCE, is FP6. This involves new project structures, the two main ones being Integrated Projects (IPs) and Networks of Excellence (NOEs). These provide for even larger number of partners addressing an even broader range of subject areas and working over longer timescales (e.g. 5 years, where previous FP projects were typically 3 years). Here are three examples of FP6 starting soon in areas related to PRUDENCE:

- ACCENT (Atmospheric Composition Changes: a European NeTwork) is a 5-year NOE promoting a common European strategy for research on changes in atmospheric composition, and optimising interactions with policy makers and the public. It is focusing on the role of aerosols in air quality and climate, exchanges and transport of pollutants, and atmospheric sustainability.
- ENSEMBLES is a 5-year IP on ensemble-based predictions of climate changes and their impacts. It aims to quantify natural climate variability and human impact on climate, whilst accounting for many of the uncertainties in these projections.
- SCOUT-O3 is a 5-year IP to provide reliable prediction of the evolution of stratospheric ozone and surface ultra-violet radiation. It will look at the interactions between climate change and the evolution of ozone depleting substances.

These projects were all successful submissions following the first call for proposals. Assessments of projects submitted to the second call are now underway or being completed with particular areas of interest being hot spots in the Earth system, coupled climate systems and novel paleo-reconstruction methods. The third (and final) call under FP6 is expected later this year, with climate research topics being nitrogen / carbon cycle interactions, ocean – atmosphere – chemistry interactions, adaptation and mitigation strategies, past climate and its dynamics, and climate observations.

The main purpose of PRUDENCE is to produce Europe-wide projections of climate change and to try to quantify the uncertainty of the climate-change scenario and their impact using a diversity of models, ranging from CGCMs to RCMs. The climate changes simulated in many of the PRUDENCE simulations did not only change the mean climate but also the widened the variability of, for instance, temperature in Central Europe. The PRUDENCE sessions stressed the point that RCMs might be very useful when their output is used as an input of application-oriented models. Before PRUDENCE, the European project MERCURE aimed at identifying the strengths and weaknesses of RCMs nested by atmospheric analyses. One property of high-resolution RCMs is to better represent river basin boundaries. Despite a large spread, the ensemble mean follows rather well the observations; the main drawback of current simulations is an overestimation of winter rainfall. In PRUDENCE, RCMs climate-change simulations have been used to calculate river discharge through hydrological models for the Baltic Sea and the Danube, Elbe and Rhine rivers.

A central element of PRUDENCE is the assessment of uncertainty. From previous studies such as those presented in the last IPCC report, a major contributor to uncertainty in climate-change projections of is our incomplete understanding of the physical processes of the climate system, and therefore how to represent them in climate models. Even in the globally averaged temperature response, the uncertainty associated to climate models is as large as that associated to the choice of future emissions, the other major contributor; when looking at regional patterns of change, the uncertainty is probably even larger. Too few GCMs were involved in PRUDENCE to be able to address this issue comprehensively. The three participating GCMs however were involved in a series of complementary and contrasting experiments, from which various interesting and useful conclusions can be drawn. These global models were all atmospheric GCMs and were run in ensemble mode from different initial conditions, using different emissions scenarios and different ocean conditions. Comparing these various experiments allowed contrasting the uncertainty due to, respectively, natural variability, future emissions and ocean model configuration, with the uncertainty due to atmospheric model configuration sampled by the use of three atmospheric GCMs. Looking at the overall temperature response, most uncertainty derives from the different sea-surface boundary conditions, with emissions scenario and atmospheric model configuration having similar but smaller influences. For precipitation, the influences of sea-surface forcing and atmospheric model configuration have the largest and similar influences, with emissions scenario and natural variability having similar but smaller influences. A comparable analysis was performed on the RCMs climate-change simulations over Europe, looking at the influence on uncertainty of natural variability, emissions, the driving GCM boundary conditions and RCM formulation. For temperature, the second and third factors were of largest and similar importance, with the RCM formulation slightly less, but more so than natural variability. For precipitation, the driving GCM was most important in winter, but the RCM most important in summer, with the other factors of similar and lesser importance.

PRUDENCE is also trying to establish the reliability of climate-change responses; an important element in this is the quality of the modelling systems used. In particular, it is important to understand how well processes that contribute to climate change are represented. In an analysis of simulations of many of the RCMs involved in PRUDENCE, it was found that most RCMs overestimate interannual variability of summer temperatures over much of Europe. The overestimate of the frequency of warmer summers is generally accompanied by circulation errors implying that RCMs are developing their own large-scale climates partially decoupled from that of the driving GCM. This suggests that these models may not be simply adding high-resolution details to the broad-scale projections provided by the driving GCMs for the statistics of summer temperature or associated variables. It was also noted that evaporation plays a crucial role in determining the temperature response; this is another process that needs to be accurately represented in models for their climate-change responses to be reliable.

Extreme daily precipitations increase in winter in the SMHI projections performed in PRUDENCE. In summer, extreme temperatures increase as well. The daily mean temperature distributions were compared with historical records (since 1850). Skewness changes in some areas and seasons. This can be connected to the snow albedo feedback. However, it was found to be better to study extremes with daily minimum and maximum temperatures. Daily maximum surface winds from the PRUDENCE database have been used to determine a possible increase of extreme phenomena. However the different ways of calculating this parameter make comparison difficult. Only two RCMs have been used as an input to a gust model. Without such a parameterisation, strong winds are largely underestimated. Over northern Europe, winter strong wind events increase by more than 10%. RCM outputs are also used as an input to a storm surge model. No impact on the mean is found, but an increase in the higher percentiles along western coasts of Denmark is obtained in the A2 emissions scenario.

In an investigation of changes in extreme precipitation in one of the PRUDENCE RCMs, it was shown that, in a comparison with the dense network of observations over the UK, the model performed well, with many areas showing no significant differences from the observations (at the 5% level). In fact, errors in simulating high return period annual extreme precipitation are of similar magnitude or smaller than those in annual mean precipitation. The main deviations in extreme precipitation are seen over longer averaging periods where there is a clear link with the mean biases, e.g. errors in the magnitudes of long return period 30-day average precipitation are clearly correlated with the annual mean biases. In the climate-change experiment performed with this RCM, substantial areas of Europe are predicted to undergo statistically significant changes (mostly increases) in extreme precipitation, apart from some areas in the south. In many regions, these increases take place despite reductions in annual mean precipitation, similarly to results of experiments from other PRUDENCE models. Another interesting result is that significant increases in extreme precipitation of different durations are seen in different locations, predicting different vulnerabilities in different areas, and showing the importance of considering multiple, not just single, measures of extremes.

A spread in RCMs-simulated results obtained with given emissions scenario and GCMs lateral boundary conditions, should not be considered a drawback. Indeed a great similarity in the responses, accompanying a great similarity in systematic errors, would be no more convincing. An increase in the range of responses does not necessarily imply an increase in the uncertainty: with time and progresses, GCMs and RCMs take into account more and more physical processes which introduce various feedbacks, source of divergence between models.

The topic of estimation of the uncertainty associated with climate-change projections, scenarios and impacts is very lively. The representative of the European Commission expressed the opinion that uncertainty is not yet sufficiently documented in PRUDENCE and the hope that PRUDENCE will try very hard to assess this issue critically, once the synthesis of the several projections come together towards the completion of the project. The PRUDENCE project indeed contains a complete work package promising to do so. Notwithstanding these comments, most countries look with envy at the achievements of European research community in this regard. A coordinated North American effort called NARCCAP (North American Regional Climate Change Assessment Program) is currently in its planning stage; its design is heavily modelled after the PRUDENCE project.

Conceptual basis and applications of Regional Climate Modeling

Hans von Storch

Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany
Storch@gkss.de

Introduction

A major purpose of Regional Atmospheric Models (RCMs) is to describe in detail the trajectory of weather in a limited area conditional upon a prescribed large-scale state. This "weather stream" is then used to infer details of the weather statistics (i.e., climate). In this contribution, three theses related to these climate applications of RCMs are discussed:

- Regional climate modeling is a downscaling problem.
- Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps)
- The purpose of regional climate models is to study the regional climate and its impact, not the improvement of such models.

Regional climate modelling is a downscaling problem

We conceptualize the genesis of climate by the functional "downscaling" relationship (Giorgi et al., 2001):

$$C_s = f(C_l, \Phi_s)$$

with

C_l = larger scale climate
C_s = smaller scale climate
Φ_s = physiographic detail at smaller scale.

The validity of this concept (von Storch, 2001) is supported by the observations that a simple energy-balance model, without any reference to spatial details, is adequately explaining global mean temperature; that an atmosphere at rest on an aqua planet is establishing the well known three cell-structure, with trade winds and extratropical baroclinic zones within a few weeks; that empirical downscaling method successfully specify regional and local weather and climate as a function of large scale states (Giorgi et al. 2001).

This concept of downscaling does NOT imply that smaller scales are irrelevant for the larger scales. Small scale processes, such as convection, play a key role in forming the global climate. However it is only the overall effect of these processes which matter, not the space-time details. Therefore parameterizations of small scale processes are sufficient for global (and regional) models. It is this fortuitous arrangement, which allows us simulate the global and continental climate well – even without simulating any small-scale climate adequately.

To implement the downscaling philosophy into regional atmospheric modeling, the application of the state space concept is useful (e.g., von Storch, 2001):

State space equation $\quad \Psi_{t+1} = F(\Psi_t;\eta_t) + \varepsilon_t$

Observation equation $\quad d_t = G(\Psi_t) + \delta_t$

with $\quad \varepsilon_t, \delta_t$ = model and observation errors
F = dynamical model
G = observation model

Forward integration : $\quad \Psi^*_{t+1} = F(\Psi_t;\eta_t)$

$$d^*_{t+1} = G(\Psi^*_{t+1})$$

$$\Rightarrow \Psi_{t+1} = \Psi^*_{t+1} + K(d^*_{t+1} - d_{t+1})$$

with a suitable operator K.

Here, Ψ_t, is a 3-dimensional state vector representing all relevant meteorological variables described by an RCM, **F** is the RCMs itself, ηt describes the physiographic details. G is the "observation operator", which relates the state vector to an "observable" d_t. Thus F represents theoretical knowledge about the dynamics of the regional atmosphere, whereas d_t empirical knowledge. The two terms δ_t and ε_t are unknown but non-zero error terms, reflecting the unavoidable simplifications of the dynamical model and the uncertain observations. The combined state space and observation equation is integrated forward in time by first "guessing" with the state space equation the state and the observable in future, and then by correcting this "first guess" by a term proportional to the difference of guessed observable and actually observed observable.

Obviously, this concept has little to do with conventional boundary value problems. Instead the problem is to skillfully merge different types of knowledge. In case of past weather reconstructions and of plausible future weather sequence scenarions, the empirical knowldege is about the large scale state; the dynamical knowledge is encoded in the dynamical model. The correction step, which is blending the simulated and the prescribed large-scale state is called "spectral nudging method" (SN; von Storch et al., 2001), and has been shown in a series of analyses to provide superior regional states consistent with prescribed large scale states (Meinke et al., 1994, Sotillo, 2003)

Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps)

Regional climate dynamics are also chaotic – very different trajectories may emerge from very slightly disturbed initial conditions if the large-scale states are not constrained by, for instance, spectral nudging – long after the predictive influence of the initial state has disappeared. The phenomenon is intermittent – as soon as the influence of the boundary is recovering, the "divergence in phase space" is vanishing.

The RCM tendency to exhibit IDSP depends on the degree of "flushing" the area, i.e. the time needed for disturbances travel from the boundaries through the area. For midlatitude marine climate with moderate longitudinal extension (e.g., 4000 km) lateral control is mostly sufficient (Weisse et al., 2000), while in the Arctic idps seems to be a frequent phenomenon (Rinke and Dethloff, 2000). To what extent idps is a problem in the tropics is not really known despite early numerical experiments (Yi and Vernekar, 1997). It would be rewarding theoretical exercised to infer from a given field, if the systems tends to diverge or converge in phase space.

A major conclusion to be drawn from the idps phenomenon is that deviations between observed state and RCM modeled state may be due to model errors, or insufficient lateral control. Thus, the assessment of the effect of different, for instance, parameterizations of sub-grid scale processes needs the same statistical analysis as is common since the 1970s in global climate numerical experimentation (e.g., Chervin and Schneider, 1976).

The SN (spectral nudging) method overcomes this problem to large extent, since it constrains the available part of the phase space significantly, so that major deviations can not develop (Weisse and Feser, 2003).

The purpose of regional models is <u>not</u> validation and improvement by making them more complex <u>but</u> to apply them in building of new knowledge about the real world.

Presently, RCMs are used in reconstructing detailed past weather streams of the recent past with, for instance, applications to analyzing coastal sea climate. These data sets, on wind, storms, waves, currents and surges are used in a variety of projects dealing with the assessment of oil drifts in case of accidents, the assessment of fatigue in ships and off-shore constructions, the planning of harbor constructions and of off-shore wind energy, the assessment of coastal defense measures, and the analysis of wave conditions and risks in estuaries. Other applications deal with historical and paleoclimate climates. Finally, such models are in routine use for downscaling global climate change scenarios to the impact-relevant small scales, which need responses in terms of mitigation and adaptation.

The general experience is that presently available models are suitable for these applications. Thus, requests for further improvement – as legitimate as they may be and actually are – should not be used as an argument to further postpone the use of such models. Validation and improvement are important technical aspects of regional modeling, but these important efforts should be guided by the needs of present and future applications of such models.

Conclusion

- Regional climate modeling is a downscaling problem – thus, continental scale information should be assimilated into RCMs.
- Regional climate modeling suffers from Intermittent Divergence in Phase Space (idps) – thus either SN or ensemble simulations should be done. Differences "RCM versus observations" are not necessarily reflecting model errors.
- The purpose of regional climate models is to study the regional climate and its impact, not the improvement of such models – in fact, contemporary climate model output is used for various applied studies.

References

Chervin, R.M. and S.H. Schneider, 1976: On determining the statistical significance of climate experiments with general circulation models. J. Atmos. Sci., 33, 405-412

Giorgi, F., B. Hewitson, J. Christensen, M. Hulme, H. von Storch, P. Whetton, R. Jones, L. Mearns and C. Fu, 2001: Regional climate information - evaluation and projections. In J.T. Houghton et al (eds.): *Climate Change 2001. The Scientific Basis*, Cambridge University Press, 583-638

Meinke, I., H. von Storch and F. Feser, 2004: A validation of the cloud parameterization in the regional model SN-REMO. submitted

Rinke, A., and K. Dethloff, 2000: On the sensitivity of a regional Arctic climate model to initial and boundary conditions. Clim. Res. 14, 101-113.

Sotillo, M.G., 2003: High resolution multi-decadal atmospheric reanalysis in the Mediterranean Basin. PhD dissertation. UCM, Madrid. pp 216

von Storch, H., H. Langenberg and F. Feser, 2000: A spectral nudging technique for dynamical downscaling purposes. Mon. Wea. Rev. 128: 3664-3673

von Storch, H., 2001: Models. In: H. von Storch and G. Flöser (Eds): *Models in Environmental Research*. Springer Verlag, 17-33

Weisse, R. and F. Feser, 2003: Evaluation of a method to reduce uncertainty in wind hindcasts performed with regional atmosphere models. Coastal Eng. 48, 211 - 255

Weisse, R., H. Heyen and H. von Storch, 2000: Sensitivity of a regional atmospheric model to a sea state dependent roughness and the need of ensemble calculations. Mon. Wea. Rev. 128(10), 3631-3642

Yi, Y.M. and A.D. Vernekar, 1997: Simulation of the Asian summer monsoons of 1987 and 1988 with a regional. J. Climate 10, 1965-1979.

Regional Climate Modeling: Progress, Challenges, and Prospects

Yuqing Wang

International Pacific Research Center, University of Hawaii at Manoa, Honolulu, USA

Introduction

Motivated by the need of regional climate information to understand regional climate change and its impacts, regional climate models (RCMs) were first developed mainly as a dynamical downscaling tool to address global change issues. Since the first successful demonstrations of regional climate modeling by Dickinson et al. (1989) and Giorgi and Bates (1989), much effort has been devoted to the development, evaluation, and application of RCMs. Earlier reviews on regional climate modeling can be found in Giorgi and Mearns (1991), McGregor (1997), and Giorgi and Mearns (1999), and more recent reviews was provided by Leung et al. (2003).

RCM Development

There have been a lot of work contributed to the RCM development and improvements. Both grid point models and spectral models are used in regional climate modeling studies with limited-area configuration. Most RCMs are formulated using the hydrostatic primitive equations. A few RCMs, such as MM5, CRCM, and RAMS, include nonhydrostatic terms, which allow more accurate representation of phenomena such as deep convection and mountain waves that may produce large vertical motion when fine resolution grids are used. However, in the context of regional climate modeling, improvement in the simulated climatology from the use of nonhydrostatic formulations has yet to be demonstrated.

Limited-area RCMs require information at their lateral boundaries for all meteorological variables, which can be derived from global reanalyses or GCM simulations. This information is usually incorporated via “one-way nesting”, in conjunction with a boundary relaxation zone. With “one-way nesting” the RCM circulation could differ from that of the host GCM. This is possible especially for the use of large domains, or in the tropical regions where the boundary forcing is relatively weak.

A recent development of regional climate modeling has been the application of variable-resolution global models to regional climate simulations. Variable-resolution global models essentially require no nesting data.

Dynamical downscaling

Numerous studies have demonstrated that when driven by large-scale conditions such as global analyses, RCMs can realistically simulate regional climate features such as orographic precipitation, extreme climate events, seasonal and diurnal variations of precipitation across different climate regimes, and regional scale climate anomalies such as those associated with the ENSO.

- Currently, RCMs have been used in the following dynamical downscaling studies:
- Climate change projections: driving RCMs with GCM climate-change simulations;
- Seasonal to interannual climate prediction: driving RCMs with global coupled model prediction;
- Reconstruction of regional-scale paleo-climatology: driving RCMs with GCM paleoclimate simulations;
- Reconstruction of recent past states at regional scales: driving RCMs with historic atmospheric objective analysis or reanalysis.

The use of RCMs in climate change research has grown rapidly over the last decade as indicated by the increasing volumes of literature cited between the Second and Third IPCC reports. Recent results also show that RCMs nested within the AOGCMs can improve seasonal climate predictions at the regional scale. Seasonal climate prediction may be a useful framework for testing the value of dynamical downscaling because unlike climate change projections, climate forecasts can be verified.

Climate Process Studies

RCMs have been widely used in climate process studies in the past decade. In deed, the use of high spatial resolution to resolve the complex lower boundary conditions, such as land use, orography, lake, coastline, etc., and mesoscale weather systems with the improved representation of model physics makes RCMs ideal for improving our understanding of climate processes. In this regard, RCMs are driven by the objective analysis or reanalysis to minimize the uncertainties from the lateral boundary conditions.

Regional Climate Predictability

Predictability of the first kind addresses how uncertainties in the initial state of the climate system affect the prediction of a later state; while the second kind addresses how the predictability limit of the climate system responds to changes in the boundary conditions (e.g., SST, soil moisture). Regional climate predictability is a mixed initial and boundary value problem since the initial conditions of slow evolving variables (such as SST, soil moisture) are important as well due to their long memories.

Uncertainties in driving fields:

- The skill of an RCM is largely controlled by the driving fields although some improvements are still possible in the region with strong lower boundary forcing that is lack from the coarse resolution driving GCM;

Uncertainties in the nested RCMs: These include

- Unphysical treatment of lateral boundary conditions; inconsistency in dynamics and physics between the RCM and driving GCM; unrealistic representation of physical processes; internal flow-dependent instabilities of the chaotic climate system;

- RCM predictability: Previous studies demonstrate that the predictability of regional climate is region and season dependent. In general, the summer season and tropical and subtropical regions have lower predictability than other seasons and mid-latitude regions. In addition, different variables have different predictabilities. For example, surface pressure has higher predictability than precipitation.

Challenges and Issues

Model resolution issue: What are the relative merits of increasing spatial resolution versus more accurate model physics if the resolution reaches some level? Global models can be run at resolutions equivalent to current RCM resolution very soon (in 5 to 10 years) at least for time slice experiments as what we are doing with RCMs at present. It is not clear whether we still need RCMs or RCMs will simply merge into the category of cloud-resolving models (CRMs).

Physical parameterization issue: How can we consider the dependency on both spatial resolution and time step of the model physical parameterizations? Parameterization for RCMs is more difficult than that for large-scale global models because of the quasi-equilibrium nature in a grid-cell for the latter but the non-equilibrium nature in a grid-cell for the former.

Model evaluation and diagnostic issue: What datasets do we need to evaluate climate simulations at regional scales and what sophisticated diagnostic methods can be employed to evaluate RCM performance? Special attention should be given to diagnosing internal variability and uncertainties of RCMs and the added values from RCMs in future studies. Extensive diagnostics of the sources of model biases is critical to model improvements.

Model domain size issue: Previous studies indicate that if the model domain is too large the solution for large-scale features might drift from the driving fields, while if it is too small the RCM might not allow development of internal dynamics. Question arises as to whether there is an optimal domain size with which an RCM can achieve the best simulation of regional climate. This seems resolution-dependent and needs to be studied.

Issue on modeling extreme climate events: RCMs are better than the driving GCM in simulating the probability distribution of occurrence of extreme climate events (droughts, floods, summer hot waves, winter snowstorms, etc.). This advantage needs to be further tested and demonstrated in different regions and seasons. Current RCMs have not shown promising capability in simulating tropical storms, in particular their intensity, this is an important area quite challenging due to our limited understanding of physical processes that control the tropical storm genesis and intensity.

Dynamical downscaling issue: Testing and verifying the RCM simulation for a range of climatic regimes are critical before applying the RCM to climate change projections and to impact assessment.

Model intercomparison issue: Model inter-comparison can identify model uncertainties to infer predictability of different climate regimes. Previous studies however suffer from: (1) limited regions with very limited models involved (some models were not independently developed); (2) comparisons being made mostly for final products generated by complex physical parameterizations with less attention given to diagnosing the processes leading to the differences among different models; (3) No much attention being given to the strength and weakness of different individual physics parameterization schemes; (4) Few studies that compared the energy balance, cloud radiation forcing, and diurnal cycle of clouds and precipitation.

Climate process study issue: Ensemble simulations are strongly recommended in future studies to both understanding regional climate processes and detecting signals of climate change and sensitivity due to the chaotic nature of the atmospheric motion. The use of small model domain however show small variance between simulations with different initial conditions due to strong control by large-scale driving fields.

Future Directions

- To continue the application of RCMs to dynamical downscaling;
- To contribute to the development of physical parameterizations for climate models;
- To help identify and reduce common biases in GCMs and develop super physical parameterization ensemble for GCMs;
- To conduct climate process studies to improve our understanding of different climate processes at regional scales;
- To study the contribution of high frequency weather and meso-scale signals to the larger-scale circulation (upscaling effect) with the stretched-grid global models.

References

Dickenson, R.E., R.M. Errico, F. Giorgi, and G.T. Bates, 1989: A regional climate model for western United States. *Clim. Change*, **15**, 383-422.

Giorgi, F., and G.T. Bates, 1989: The climatological skill of a regional model over complex terrain. *Mon. Wea. Rev*., **117**, 2325-2347.

Giorgi, F., and L.O. Mearns, 1999: Introduction to special section: Regional climate modeling revisited. *J. Geophys. Res*., **104**, 6335-6352.

Leung, L.R., L.O. Mearns, F. Giorgi, and R.L. Wilby, 2003d; Regional climate research—needs and opportunity, *Bull. Amer. Meteor. Soc*., **84**, 89-95.

McGregor, J. L., 1997: Regional climate modelling. *Meteor. Atmos. Phys.*, **63,** 105-117.

The value of regional climate model information at the grid-scale

Richard Jones

Met Office Hadley Centre (Reading Unit), University of Reading, Reading, RG6 6BB, UK
richard.jones@metoffice.om

Recent advances in the range of applications of regional climate models have meant that they are now being increasingly deployed to provide climate information for various applications. One major perceived attraction is that the enhanced resolution provides realistic-looking detail in simulated surface climate elements which are often those required in these applications. This encourages the exploitation of the full resolution of the data derived from the models.

The talk will explain some relevant background of the development of regional climate models and explain the growing interest in such models now the debate on climate change has moved on to issues of impacts and adaptation. The talk will look at how this wider use of regional climate models is being developed and give some examples of applications. It will then demonstrate the value of the high resolution information via direct comparison with observations and the application of grid-scale climate data. This will show that regional climate models have skill at their grid-scale and that they can be coupled to impacts models to provide accurate results. The talk will also discuss the wide potential applicability of high resolution climate data and coupled with its increasing availability stress the importance of researching the limits of this applicability.

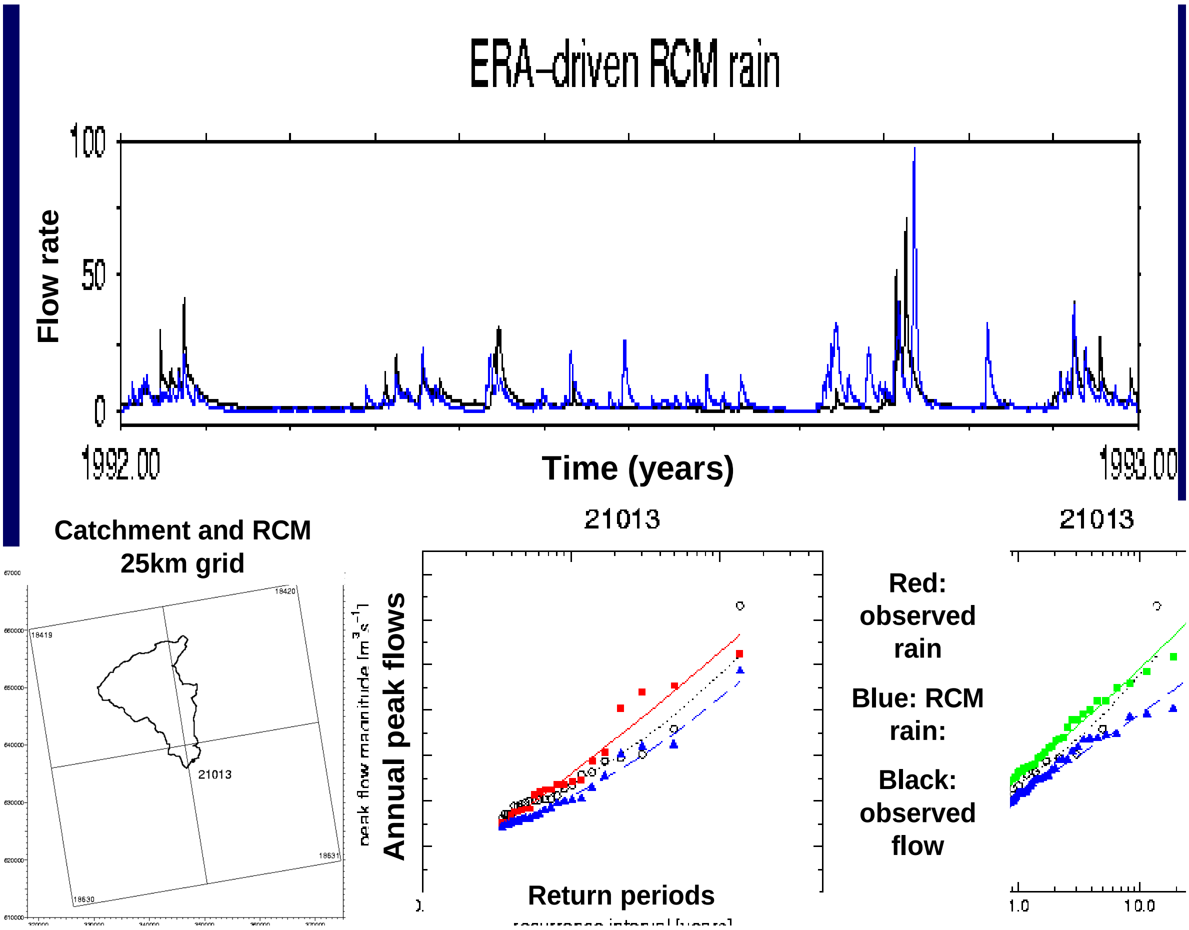


Figure 1: Graphs comparing flows simulated using hourly rainfall from a 25km RCM driven by quasi-observed boundary conditions (blue) to those using observed rainfall (red) and to observed flows (black) for catchment 21013, a 207km2 area in north east Scotland. The upper panel illustrates the RCM rainfall derived and observed flow comparison for a representative year (1992) and the lower panel peak flows (symbols) with the curve being an extreme value distribution (the generalised Pareto distribution), fitted to the point data (using L-moments) with the peak arrival times assumed to correspond to a Poisson distribution.

Estimating the downscaling ability of Regional Climate Models using the Big-Brother Experimental protocol

René Laprise

Université du Québec à Montréal (UQÀM), Montréal, Québec, Canada
laprise.rene@uqam.ca

Nested high-resolution Regional Climate Models (RCM) are increasingly used to downscale low-resolution Objective Analyses (OA) or General Circulation Models (GCM) simulations. The actual downscaling ability of RCM is difficult to evaluate for several reasons, including that, (1) RCM like all models contain discretisation and parameterisation approximations, (2) RCM are affected by errors in the data used to nest them and the implementation of the nesting, and (3) high-resolution climatological verification databases exist for very few regions of the world. The Big-Brother Experiment (BBE) has been designed to address the downscaling ability of nested RCM, specifically the issue related to nesting, but excluding the other sources of errors.

The BBE consists in first establishing a reference climate by performing a large-domain high-resolution RCM simulation, called the Big Brother (BB) (see Figure 1). The BB simulation will serve as reference for verification for a second experimental simulation called the Little Brother (LB). The LB model is identical to the BB, except for its computational domain that is smaller. The LB is nested with simulated data from the BB, whose resolution has been first degraded by removing fine scales; this emulates the coarse resolution of OA or GCM. When comparing the climate statistics of the LB to those of the BB, the differences can be unambiguously attributed to nesting, not to model or observational limitations.

The BBE has been applied methodically with a 45-km grid version of the Canadian RCM (Caya and Laprise 1999), to two regions of North America (the East and West Coasts where the orographic forcing varies greatly), for winter and summer months when dominant dymanical and / or physical processes vary greatly. The climate statistics are computed in terms of stationary and transient eddies, decomposed by horizontal scales into large and small scales, with a cut-off at about 750 km. These results serve to establish the limits of dynamical downscaling ability of RCM, as well as optimal nested model configuration.

Results to date obtained over North America indicate a good ability of a 100 by 100 grid point LB domain to recreate the fine-scale details statistics of the BB in mid-latitudes. Winter-time weather regimes appear to lend better control by lateral boundary conditions and hence BB statistics are better reproduced by LB than for the summer season. When orographic forcing is strong, as over the Rocky Mountains in winter, stationary eddies are particularly well reproduced.

For a 45-km mesh, it appears that lateral boundary conditions should not be any coarser than about a factor of 10, corresponding roughly to GCM spectral resolution of T32. Also time interval of 6 hours for providing lateral boundary conditions would appear adequate, at least as far as the verification statistics used.

While the climate statistics are in general well reproduced, it is noteworthy that a time-by-time verification of the LB with BB shows that the two simulations are not always well correlated, specially for fields such as precipitation rates. In fact in summer, precipitations are almost uncorrelated in time. This serves as a warning for case studies trying to verify in a deterministic fashion, simulations of RCMs with analyses of observations.

Further investigations are underway to study the sensitivity of a regional model to errors in the lateral boundary conditions, and whether RCMs can partly correct for these errors.

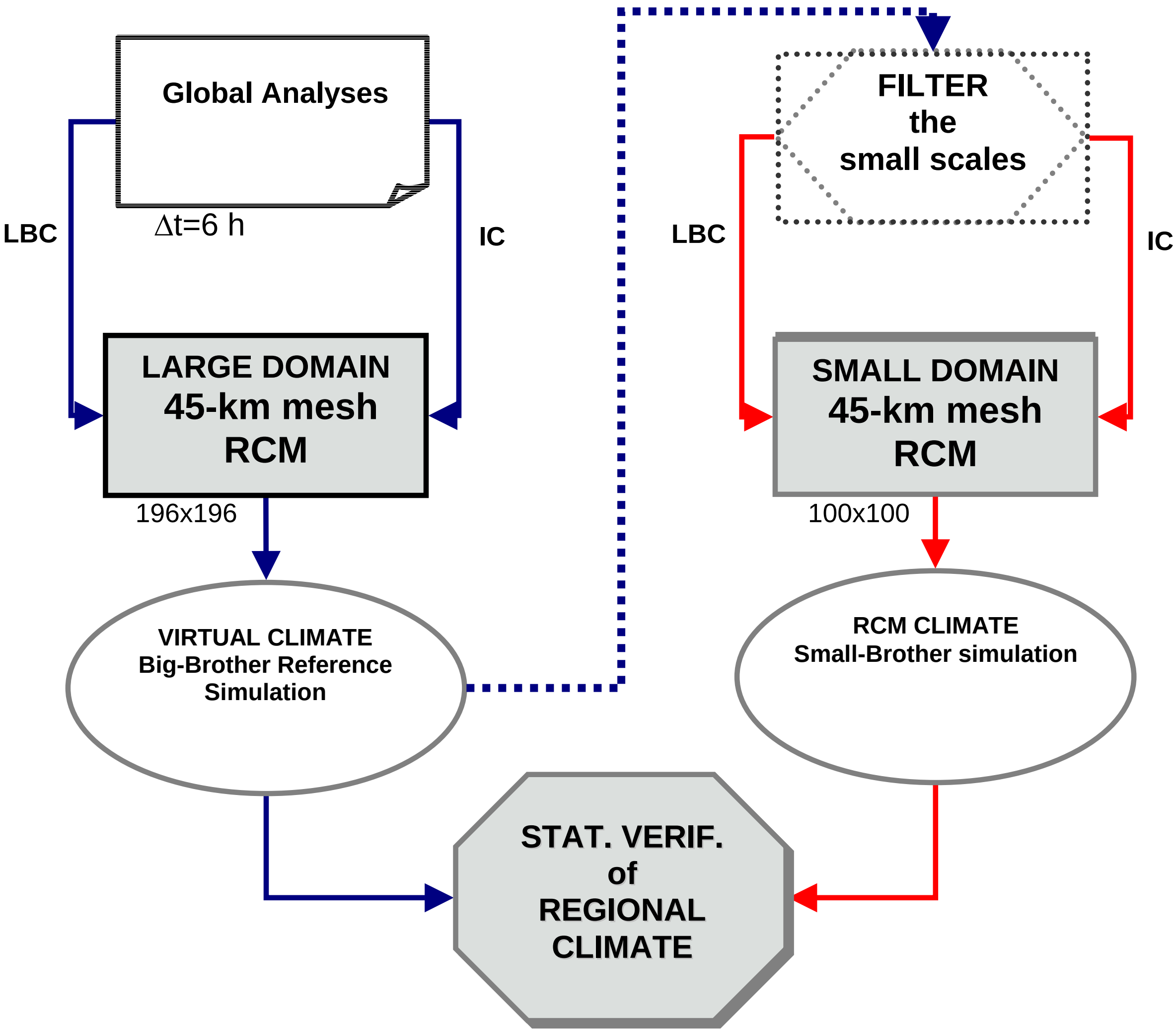


Figure 1: Schematic view of the Big-Brother protocol.

References

Antic, S., R. Laprise, B. Denis and R. de Elía, 2004: Testing the Downscaling Ability of One-Way Nested Regional Climate Model in regions of complex topography: Sensitivity to the Horizontal Resolution Jump and Updating Interval of the Lateral Boundary Conditions. Accepted in *Clim. Dyn.*

Caya, D. and R. Laprise, 1999: A semi-implicit semi-Lagrangian regional climate model: the Canadian RCM. *Mon. Wea. Rev.*, 127, 341-362.

Caya, D. and S. Biner, 2004: Internal Variability of RCM Simulations Over an Annual Cycle. *Clim. Dyn.*

de Elía, and R. Laprise, 2003: Distribution-oriented verification of Limited-Area Models forecast in a perfect-model framework. *Mon. Wea. Rev.* 131, 2492-2509.

de Elía, R., and R. Laprise, 2005: Predictability of Limited-Area Models: Twin and Big-Brother Experiments. In preparation.

de Elía, R., R. Laprise and B. Denis, 2002: Forecasting skill limits of nested, limited-area models: A perfect-model approach. *Mon. Wea. Rev.* 130, 2006-2023.

Denis, B., R. Laprise and D. Caya, 2003: Sensitivity of a Regional Climate Model to the spatial resolution and temporal updating frequency of the lateral boundary conditions. *Clim. Dyn.* 20, 107-126.

Denis, B., R. Laprise, D. Caya and J. Côté, 2002: Downscaling ability of one-way-nested regional climate models: The Big-Brother experiment. *Clim. Dyn.* 18, 627-646.

Dimitrijevic, M., and R. Laprise: Validation of the nesting technique in a Regional Climate Model and sensitivity tests to the resolution of lateral boundary conditions during summer. Submitted to *Clim. Dyn.*

Laprise, R., M. RaviVarma, B. Denis, D. Caya and I. Zawadzki, 2000: Predictability in a nested limited-area model. *Mon. Wea. Rev.* 128(12), 4149-4154.

High-Resolution Simulations of Global Climate

P.B. Duffy[1], W. Bosl[1], J. Iorio[1], J. Coquard[1], C. Doutriaux[1], K. Taylor[1], J. Milovich[1], J. Taylor[1], S. Thompson[1], M. Wehner[2], J.J. Hack[3]

[1]Lawrence Livermore National Laboratory, [2]Lawrence Berkeley National Laboratory, [3]National Center for Atmospheric Research

Motivation

Increasing horizontal spatial resolution in global climate models should in principle lead to improvements in simulated climate on regional and larger spatial scales. On the other hand, parameterizations of subgrid scale processes could produce unexpected results if resolution is increased too much; also, increasing horizontal resolution without appropriate increases in vertical resolution is in theory problematical. Thus, it is not clear *a priori* how the simulated climate will respond to large increases in horizontal spatial resolution. To investigate these issues, we performed simulations with three global climate models at a range of horizontal spatial resolutions, up to the maximum allowed by available computational resources.

Models and simulations performed

We performed simulations with three global climate models: the NCAR CCM3, CAM2 (the successor to CCM3), and the NASA/NCAR Finite Volume GCM (FVGCM). The latter uses "physics" from the CCM3 with the Lin-Rood or Finite Volume dynamical core. All simulations used prescribed climatological SSTs; for present climate, these are from observations. For increased greenhouse gas simulations we used SSTs obtained by adding to observed SSTs an SST response from a transient climate simulation performed with the PCM coupled ocean-atmosphere model. Simulations cover typically 12 simulated years, with only the final 10 years being

Table: Characteristics of global climate simulations. Where resolutions are described by truncations, Eulerian spectral dynamics were used. Where resolutions are described in degrees, the Finite Volume Dynamics were used.

Model	**Resolutions for present-climate simulations**	**Resolutions for increased GHG simulations**	**Resolution(s) model tuning performed at**
CCM3	T42, T85, T170, T239	T42, T170, T239	T42, T170
CAM2	2.0x2.5, 1.0x1.25, 0.5x0.625	None performed	T42
FVGCM	2.0x2.5, 1.0x1.25, 0.5x0.625	None performed	1.0x1.25

being analyzed. We performed a first-order retuning of some of the parameterizations in CCM3 at the T170 truncation; simulations at T170 and T239 were repeated with the retuned model. (I.e., tuning coefficients obtained at T170 were used also at T239.) We did not retune the CAM2 or FVGCM model. The table below describes some characteristics of the simulations we performed.

Results

In CCM3 we find a strong convergence of the results towards observations as the spatial resolution is increased. This is measured by decreases in RMS errors in seasonal means of nearly all meteorological quantities analyzed. These improvements are robust across seasons and across several large geographical regions. The results of the FVGCM model show a similar, but even stronger, improvement with increasing resolution. By contrast, the CAM2 results show little sensitivity to resolution when analyzed in this manner. Since both the FVGCM and CAM2 simulations use the Finite Volume dynamics, this lack of sensitivity to resolution in CAM2 is presumably attributable to some property of the model physics.

We analyzed how the realism of simulated precipitation in the U.S. depends on resolution in the CCM3 model. In seasons (DJF and SON) when simulated precipitation is primarily large-scale, the RMS error in the spatial pattern of precipitation decreases strongly as resolution is increased. In other seasons, simulated precipitation is predominately convective and RMS errors have little sensitivity to resolution. At T42 truncation the CCM3 model simulates inadequate rainfall in the form of daily events of 20mm or more. This problem is significantly reduced at higher resolution.

Simulations of effects of increased greenhouse gases with CCM3 show very similar global-scale responses at T42 and T170 truncations. Regional responses, however, can be significantly different. In most cases the cause of these regional differences is different cloud responses at T170 vs. T42. We do not assume that this aspect of the T170 results is necessarily more credible.

Future work

We have begun to perform simulations with the NCAR CAM3 model at the T170 truncation (spectral dynamics) and at 2.0x2.5, 1.0x1.25 deg and 0.5x0.625 deg (Finite Volume dynamics). Working with J.J. Hack et al. at NCAR, we intend to retune the model at

T170 and again with the Finite Volume dynamics at high resolution. We also plan to perform present-climate simulations at high resolution with a version of the CAM3 model including the Colorado State University "Superparameterization."

Peer-reviewed papers

J. Iorio, P.B. Duffy. M. Khairoutdinov, and D. Randall, Effect of model resolution and subgrid scale physics on daily precipitation in the continental United States; accepted by *Climate Dynamics.*

P.B. Duffy, B. Govindasamy, J. Milovich, K. Taylor, and S. Thompson, 2003: High Resolution Simulations of Global Climate, Part 1: Present Climate. *Climate Dynamics, 21*, 371-390, 2003.

B. Govindasamy, P.B. Duffy, and J. Coquard 2003: High Resolution Simulations of Global Climate, Part 2: Effects of Increased Greenhouse Gases. *Climate Dynamics, 21*, 391-404, 2003.

Variable –Resolution GCMs: Preliminary Results of SGMIP (Stretched-Grid Model Intercomparison Project)

Michael Fox-Rabinovitz

University of Maryland, U.S.A.,
Other SGMIP collaborators: Jean Cote and Bernard Dugas, RPN/Environment Canada, Canada, Michel Deque, Meteo-France, France, and John McGregor, CSIRO, Australia

The international Stretched-Grid Model Intercomparison Project (SGMIP) has been initiated for studying the global variable-resolution/stretched-grid approach to regional climate modeling.

The variable-resolution stretched-grid (SG) GCMs have been developed and successfully tested in the straightforward simulation mode (like that used for a typical atmospheric GCM) during the mid-late 90s. The SG-GCMs are the variable-resolution versions of the basic GCMs of the following four major meteorological centers/groups: the Meteo-France, ARPEGE model, the RPN/Canadian Meteorological Centre, GEM model, the Australian CSIRO C-CAM model, and the U.S. NASA/GSFC GEOS model. The regional climate simulation results obtained with the SG-GCMs have shown the maturity of the SG-approach. The intercomparison is focused on the following major scientific and computational issues: stretching strategies; approximations of model dynamics; treatment of model physics including its calculation on intermediate uniform resolution or directly on stretched grids; multi-model ensemble calculations; consistent regional-to-global scale interactions; optimal performance on parallel supercomputers.

The total number of global grid points for the SG-GCMs is (or close to) that of the 1º x 1º uniform grid. The area of interest is (or close to) the major part of North America: 20º – 60º N and 130º – 60º W. The regional resolution is about 0.5º. The surface boundary forcing (SST and sea ice) is used at 2º x 2.5º or 1º x 1º resolution. The 12-year simulation period, 1987-1998, includes recent ENSO cycles.

The existing reanalysis data as well as independent data like high-resolution gauge precipitation and high-resolution satellite data, are used for the SG-GCMs validation.

The 12-year SG-GCM simulations are analyzed in terms of studying: the impact of resolution on efficient/realistic downscaling to mesoscales; ENSO related and other anomalous regional climate events (floods, droughts, etc.) and major monsoonal circulations at mesoscale resolution; water and energy cycles; and global impacts.

The SG-approach allows studying not only downscaling but also up-scaling effects.

Analyzing multi-model ensemble integrations is one of the focal points of SGMIP.

The multi-model ensemble results for global and regional fields are presented at:

http://essic.umd.edu/~foxrab/sgmip.html The web site contains the related bibliography.

The experience obtained with SGMIP will allow us to make a meaningful connection to AMIP-2 as a regional project. SGMIP data can be used for consistent regional-to-global scale climate studies.

Our joint SGMIP effort, focused on a better understanding of the SG-approach, is beneficial to all the participants as well as to a broader regional and global climate modeling community.

Project to Intercompare Regional Climate Simulations (PIRCS): Status and Preliminary Results of Experiment 1C

R. W. Arritt

Iowa State University, USA

The goal of PIRCS is to improve regional climate models (RCMs) and their component parameterisations through systematic intercomparison of RCMs with each other and with observations. A wide range of modelling groups from North America, Europe, and Australia participated in PIRCS Experiments 1A and 1B, which were limited to 60-day duration owing to computational technology available in the mid-late 1990s. The present PIRCS 1C experiment is a more thorough intercomparison enabled by ongoing advances in processing power and mass storage. First, the simulations are of decadal scale, encompassing a minimal period of 1 July 1986 to 31 December 1993, with participants encouraged to continue simulation through the present. Second, modelling groups are encouraged to perform multiple simulations to test uncertainties owing to influences such as internal model variability or choice of physical parameterisation schemes.

Presently five modelling groups are engaged in PIRCS 1C using seven RCMs. Analysis of PIRCS 1C results is now at an early stage so additional participants are encouraged to join the experiment. Participation will provide documentation of individual model behaviour in relation to other widely used models (useful for model applications to impacts studies) and ensures authorship on published analyses. Preliminary examination of PIRCS 1C results has focused primarily on the North American monsoon. Results indicate that RCMs can replicate the monsoon core region in northwestern Mexico but extension of the monsoon into the southwestern United States is a greater challenge for RCMs.

Application of limited-area models for GEWEX Cloud System Study

J. Katzfey

CSIRO Atmospheric Research, Australia

The GEWEX Cloud System Study Working Group 3 is mandated to improve the representations of extratropical layer clouds in global models.

A unique feature of this group, compared to the other working groups, is we also have to improve boundary layer, cirrus, convective and polar clouds. Initially, we were not certain what was wrong with extratropical layer clouds in models. Our initial approach was to simulate real world cases using a suite of atmospheric models, ranging from SCM, CRM, LAM through to GCMs. To date, 3 cases have been simulated, and a fourth is underway. In addition, the group has also evaluated performance of GCMs in different regimes to assess which regions they are poorly simulating clouds.

Development of physical parameterizations for high resolution Climate models

C. G. Jones

SMHI, Sweden

Regional Climate Models (RCMs) are directly dependent on the quality of the imposed boundary conditions, generally derived from Global Climate Models (GCMs). It is therefore crucial to the successful application of RCMs, that GCMs are developed to provide accurate boundary conditions. The primary cause of GCM poor performance is weaknesses in the various parameterisations. RCMs can play a role in the development of improved parameterisations and offer a few key advantages over GCMs and single column models in this task.

The development of a parameterisation, within a GCM, is made difficult through error propagation from remote regions of the GCM global domain, compromising the parametric description of a particular local phenomenon. As an example, stratocumulus clouds, in the eastern subtropical oceans, are sensitive to the large-scale subsidence rate. The subsidence is part of a planetary scale circulation, in part driven by diabatic heating, associated with deep convection in regions remote to the eastern subtropical oceans. Errors in the representation of convection can cause the subsiding branch of this circulation to be also in error. Regardless of the quality of the parameterisation of stratocumulus clouds, incorrect boundary conditions, in this case large-scale subsidence, will lead to a poor simulation of these clouds. One is left trying to develop parameterisations under incorrect boundary conditions. Similar arguments apply to many other phenomena over the globe. RCMs partially circumvent this problem, by the application of boundary conditions derived from meteorological reanalyses. The large-scale atmosphere, at the scale of the model domain, is accurately described by these boundary conditions, to the extent the analyses accurately represent reality. This enables RCM parameterisations to operate under a realistic setting.

Through careful choice of domain size and location, GCM parameterisation failures can be isolated and targeted for improvement. RCM parameterisations can be evaluated at resolutions of future GCMs, with some level of interaction with the resolved scale dynamics and the RCMs located over regions of high quality observations required for evaluation of the parameterisations. This presentation will develop this theme, and suggest that close collaboration between RCM and GCM groups will benefit both parties, through improved parameterisations and the provision of more accurate GCM boundary conditions to the RCM community.

The Role of Regional Climate Models in Seasonal to Interannual Climate Prediction

N. Ward

IRI Columbia University, USA

The science of seasonal climate prediction has been challenged by the user community to provide forecast information at finer spatial and temporal scales. Regional climate models are potentially valuable tools to explore the predictability of such features. They are also among the suite of tools that could provide such forecast information. Some of the issues in these applications of regional climate models will be introduced, with examples from various tropical settings.

Dynamical Downscaling with the Limited-Area Model ALADIN in the European Alps

Bodo Ahrens, Alexander Beck

IMG, Universität Wien, Austria, Bodo.Ahrens@univie.ac.at

Abstract

Global climate simulations or analysis data have to be downscaled, e.g., with nested limited-area models (LAMs), for regional interpretation. Here, the impact of different one-way nesting strategies on precipitation simulations over the European Alps with the LAM ALADIN forced by ERA40 reanalysis is studied. Results indicate that the considered nesting strategies are comparably successful despite large resolution jumps (from 120km of ERA40 to 12km of ALADIN) involved.

Introduction

Applying a LAM in dynamical downscaling of global data issues like domain size, spatial resolution difference, nesting strategy, and systematic errors have to be considered. We investigate the applicability of the spectral LAM ALADIN (http://www.cnrm.meteo.fr/aladin/) for high-resolution dynamical downscaling of ERA40 reanalysis data (http://www.ecmwf.int/research/era) with about 120km down to 12km gridspacing over the European Alps. This involves a fairly large resolution jump *J*=(ERA40 gridspacing)/(LAM gridspacing)~10. A rule-of-thumb for ALADIN in operational weather forecasting is *J*=1.5 as a reasonable resolution jump.

Two main questions arise: (a) does the LAM ALADIN produce realistic daily mesoscale atmospheric patterns when nested into coarse-grid reanalysis data and (b) does the nesting strategies (described later) significantly influence the simulation results? The questions will be addressed through downscaling experiments for the Mesoscale Alpine Programme Special Observation Period (SOP, 9/7 to 11/15, 1999; cf. http://map.ethz.ch).

This study focuses on precipitation. Precipitation is an important meteorological quantity and the ideal quantity to measure overall simulation uncertainty and thus judges nesting uncertainties in comparison with other model errors. Evaluation is done against the Frei and Häller (FH) high-resolution rain-gauge analysis (v2.0, Frei and Häller, 2001) with daily temporal and 25km spatial resolution. The SOP mean FH analysis is shown in the Figure. Note that the effective resolution is regionally coarser due to sparse observations and that neither correction for measurement errors nor regression with height has been performed. Consequently, precipitation amount and variability is likely to be underestimated.

Experimental setup

We run ALADIN, which is operational at the Austrian NWS, with 12km gridspacing, 41 levels, domain size 2800x2500km^2 over Central Europe. Thus the evaluation area (indicated in the Fig.) is well separated from the domain boundaries. The coupling data is derived from ERA40 data with a coupling frequency of 6 hours. The Fig. shows ERA40 SOP-mean precipitation. Spatial variability is underestimated compared to the FH analysis.

As in the operational setup the global fields serve as initialization data and lateral boundary conditions (LBC) with a boundary zone following Davies (1976) of 8 grid points. This is experiment (1) named **direct** of the applied four one-way nesting strategies. The other experiments are (2) **direct32**: same as direct nesting, but with a boundary zone of 32 grid points, (3) **double**: multiple nesting, using an additional larger intermediate nest (50km grid spacing, domain size 7000x7000km^2), and (4) **blending**: combination of a spectral initialization technique to merge large scale coupling data with a small scale estimate taken from a previous LAM forecast with Davies-like LBCs (Giard 2001, Meteo-France, internal documentation). This mimics a climate mode for small scales. We always consider sequences of 30h-forecasts initialized at 00UTC discarding the leading 6h.

Results

Comparison of the ALADIN simulations with the FH analysis reveals a good agreement, in particular for the regions with heavy precipitation. In view of the smooth ERA40 pattern, the LAM clearly improves the mesoscale precipitation pattern thus indicating its applicability for dynamical downscaling (cf. the Figure).

This is confirmed by the statistics in the Table which also shows that the differences between the nesting strategies are small in the evaluation area. The statistics presented are derived from 65 consecutive days within the MAP SOP at the 100km-scale.

Table: Statistics of daily precipitation fields in respect to the FH analysis at the 100km-scale. Given are bias, the mean variance ratios of spatial (SPREX) and temporal (SPRET) fields, as well as the mean squared spatial (R_X^2) and temporal (R_T^2) field correlation (cf. Ahrens (2003) for the statistics). Optimum values are 0 for bias and 1 for the other parameters.

100km	bias [mm/d]	SPREX [1]	SPRET [1]	R_X^2 [1]	R_T^2 [1]
direct	0.22	1.50	1.16	0.51	0.67
direct32	0.06	1.54	1.10	0.49	0.67
double	0.19	1.58	1.08	0.48	0.66
blending	0.26	1.56	1.10	0.54	0.67
ERA40	-1.03	0.48	0.59	0.33	0.52

For instance, the mean spatial correlation to the FH analysis is 0.33 for the reanalysis data and improves to about 0.50 for all LAM simulations (the sample standard deviation of the mean squared spatial correlations is about 0.03). The LAM simulations overestimate spatial variability expressed by SPREX~1.5 where the ERA40 data has underestimated the variability with SPREX~0.5. The temporal variability is better represented by the LAMs (SPRET~1.1) and clearly better than by ERA40 (SPRET~0.6). Given the statistics no significant differences are found among the individual nesting strategies. In particular, the double nesting approach commonly adopted to overcome large resolution jumps does not improve the results.

Why is the LAM able to substantially improve ERA40? For a larger part it is due to the strong surface forcing through the complex orography in the European Alps. This is indicated by an experiment *orography* (not shown). This experiment is performed in the setup with direct nesting but applying an orography substantially smoothed (as in the intermediate 50km ALADIN nest). It performs in between ERA40 and ALADIN with 12km gridspacing (e.g. bias=-0.06).

At scales below 100km the performance of the simulations decreases rapidly in comparison with the FH analysis. This can partly be explained through the insufficient estimation of precipitation amounts and variability in the FH analysis at small scales.

Conclusions

Our results indicate that precipitation patterns at 100km/24h-scale are better represented in 12km ALADIN than in ERA40 data. This proves the added value by dynamical downscaling. The differences among individual nesting approaches considered are small if compared to the observations. At the 100km scale the squared temporal correlation is about 0.67 for all individual strategies. Smaller-scale performances decrease rapidly. The choice of the nesting strategy influences daily precipitation forecasts, but its impact is small compared to additional model uncertainties. Thus, we conclude that the cheapest nesting approach, direct nesting, is acceptable up to resolution jumps J=10 in dynamical downscaling of daily precipitation fields over the European Alps.

Acknowledgments

Data is provided by the MAP Data Centre and by ECMWF. This work is funded by the projects ÖAW/HÖ 22 and ARC/reclip:more.

References

Ahrens, B., Evaluation of precipitation forecasting with the limited area model ALADIN in an Alpine watershed, Meteorol. Z., 12, 245-255, 2003.

Davies, H., A lateral boundary formulation for multi-level prediction models, Quart. J. R. Met. Soc., 102, 405-418, 1976.

Frei, C. and Häller, E., Mesoscale precipitation analysis from MAP SOP rain-gauge data, MAP Newsletter, 15, 257-260, 2001

.

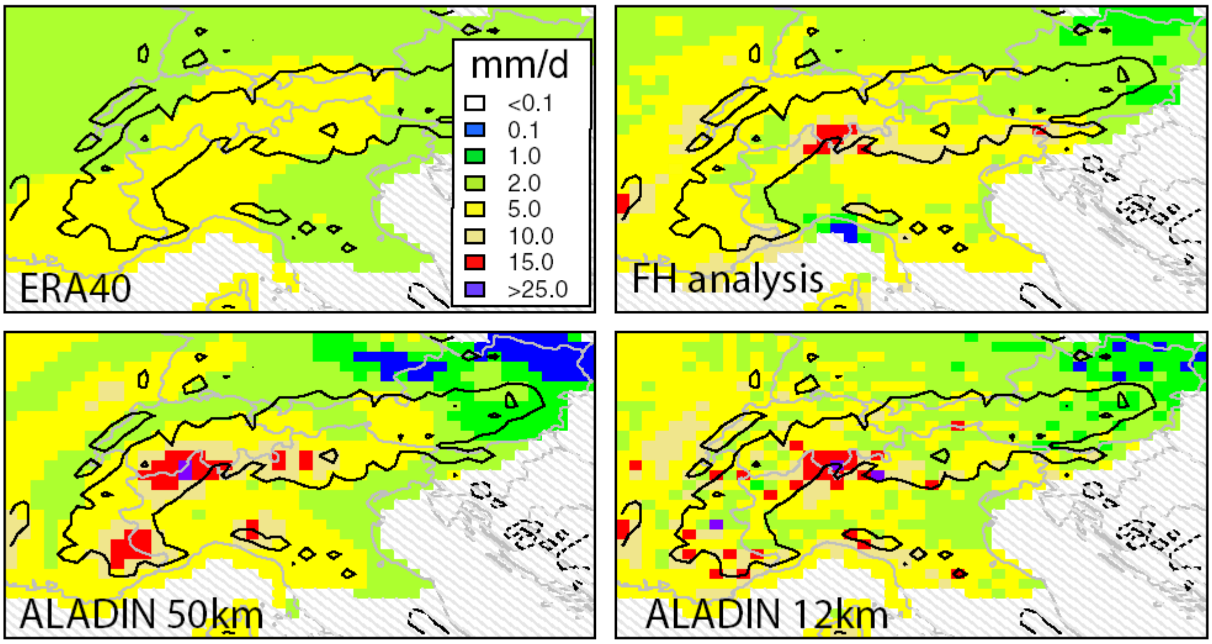


Figure: MAP SOP-mean precipitation as simulated in ERA40, ALADIN with 50 and 12km gridspacing, and derived from the FH analysis. All fields are interpolated to the 25km mesh of the FH analysis. FH analysis void areas are hatched and the black 800m height contour indicates the Alpine arc.

Regional ocean modeling – climate variability and impact studies of the Baltic Sea

H.E. Markus Meier

Rossby Centre, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, Markus.Meier@smhi.se

Introduction

Regional ocean modeling is mainly motivated by operational forecasting (e.g., navigation, national defense, marine rescue service, storm surge prediction, environmental protection and preservation), environmental assessment (using coupled biogeochemical models), and climate modeling (e.g., studies of natural climate variability, climate change impact studies). Here, the focus is on the last item discussing the merits and limitations of climate modeling at regional scale from the ocean perspective. However, it is important to note that operational applications are the main forces for regional model development. The choice of the regional model domain is very often governed by the bottom topography (e.g., semi-enclosed seas, fjords). The model domain might be a part of the world ocean, a large inland sea (e.g., the Mediterranean Sea), a shelf sea with maximum depths of 200 m, or coastal waters with maximum depths of only 20 m. Depending on the spatial scale and depending on the region the key processes in the ocean, which have to be considered, vary (e.g., tides, sea ice). Ocean models can also be classified according to the vertical coordinates used. For instance, a key activity of the DYNAMO (Dynamics of North Atlantic models) project was a systematic assessment of the ability of eddy-resolving models with different numerical formulations of the vertical coordinate to reproduce the essential features of the hydrographic structure and velocity field between 20°S and 70°N (e.g., Willebrand et al., 2001). In the following, three applications for the Baltic Sea will be discussed to illustrate the added value of regional ocean models.

Two Methods

1) Hindcast and sensitivity simulations for the period 1902-1998 have been performed using the Rossby Centre coupled ice-ocean model (RCO) for the Baltic Sea with a horizontal resolution of 2 nautical miles (Meier, 2001; Meier and Faxén, 2002; Meier et al., 2003). Daily sea level observations at the open boundary in Kattegat, monthly basin-wide discharge data, and reconstructed atmospheric surface data have been used to force RCO. The reconstruction utilizes a statistical model to calculate daily sea level pressure and monthly surface air temperature, dew-point temperature, precipitation, and cloud cover fields (Kauker and Meier, 2003). 2) For dynamical downscaling of anthropogenically induced climate change the fully coupled Rossby Centre Atmosphere Ocean model, RCAO (Döscher et al., 2002), has been used. As the model domain of RCAO is focussed on Northern Europe, data from global models have to be prescribed at the lateral boundaries. The regional scenarios differ depending on the applied global model at the lateral boundaries and depending on the utilized emission scenario (SRES A2, B2). A series of six 30-year long time slice experiments has been performed at the Rossby Centre (Räisänen et al., 2004). Two GCMs, HadAM3H from the Hadley Centre (U.K.) and ECHAM4/OPYC3 from the Max Planck Institute for Meteorology (Germany), have been used. Hereinafter, the corresponding regional simulations are denoted with RCAO-H and RCAO-E, respectively. The two control simulations represent the recent (1961-1990) climate and the four scenario simulations represent the climate of the late 21st century (2071-2100).

Results

1) Climate variability: Two main causes for the decadal variability of Baltic Sea salinity have been identified (Fig.1). About half of the decadal variability is related to the accumulated freshwater inflow. Another significant part of the decadal variability of salinity is caused by the low-frequency variability of the surface wind (Meier and Kauker, 2003a;b).

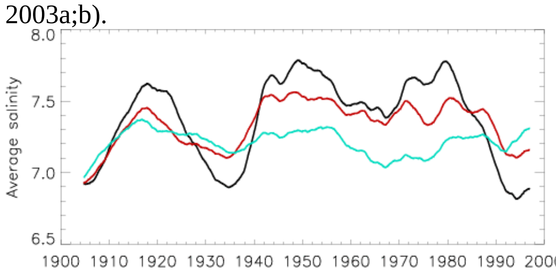


Fig 1. *4-year running mean simulated salinity in the Baltic Sea (in ‰): reference run (black), sensitivity experiment with climatological monthly mean freshwater inflow (red), and sensitivity experiment with climatological monthly mean freshwater inflow and 4-year high-pass filtered sea level pressure and associated surface winds (blue).*

2) Sea ice scenarios: Despite of uncertainties also due to biases of the global models and due to emission scenarios, some of the scenario results for sea ice are remarkably robust (Fig. 2). In the Bothnian Bay (northern Baltic) the number of ice days is in all scenarios longer than two months. However, in the Gulf of Riga (south-eastern Baltic) the probability that the number of ice days is longer than two months is in all scenarios significantly reduced (Meier et al., 2004a).

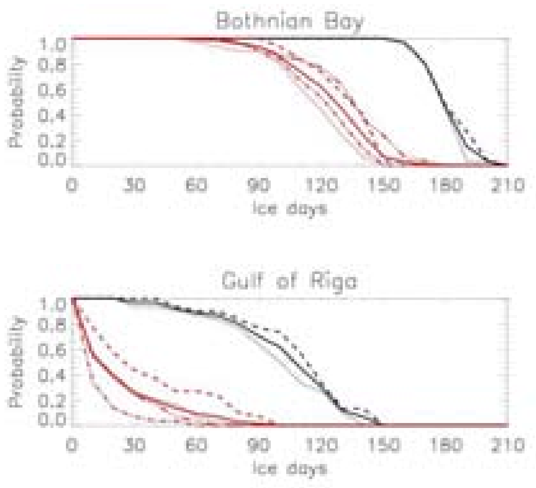


Fig 2. Cumulative probability of ice winters with more than x ice day: control mean (black solid), RCAO-H (black dotted), RCAO-E (black dashed), scenario mean (red solid), RCAO-H/A2 (red dotted),RCAO-H/B2 (red dashed), RCAO-E/A2 (red dash-dotted), RCAO-E/B2 (red dash-triple-dotted).

3) Sea level scenarios: Land uplift and the global average sea level rise are the dominant contributions to the future changes in mean sea level (Fig.3). Regional wind changes may have some impact. The risk for flooding is largest at the eastern and southern coasts of the Baltic. However, mainly due to the uncertainties of the global model results the uncertainties of the regional scenarios are large (Meier et al., 2004b).

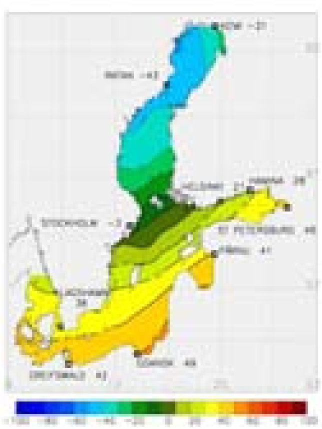


Fig 3. *Future winter (DJF) mean sea level (in cm) relative to the annual mean sea level for 1961-1990. Shown is the ensemble average with a global average sea level rise of 48cm including land uplift.*

Conclusions

Regional ocean models are useful tools for climate variability and impact studies (sensitivity experiments, regional downscaling). Due to the better representation of the topography the added value of regional ocean modeling is obvious. With increasing resolution mesoscale eddies can be investigated. However, their role for the ocean climate is still unkown. In adition to increased resolution, better parameterizations are needed (e.g., breaking internal waves, mixing in seas with tides).

Acknowledgement

This study was carried out partly within the Swedish Regional Climate Modeling program (SWECLIM, 1997-2003) and partly within the Baltic Sea Region INTERREG IIIB project `Sea level change affecting the spatial development in the Baltic Sea region' (SEAREG, 2002-2005). Financial support from the Foundation for Strategic Environmental Research (MISTRA), the Swedish Meteorological and Hydrological Institute (SMHI), and the European Regional Development Fund (ERDF) is gratefully acknowledged.

References

Döscher, R., U. Willén, C. Jones, A. Rutgersson, H.E.M. Meier, U. Hansson, L.P. Graham, The development of the regional coupled ocean-atmosphere model RCAO. Boreal Env. Res., 7, 183-192, 2002

Kauker, F., H.E.M. Meier, Modeling decadal variability of the Baltic Sea: 1. Reconstructing atmospheric surface data for the period 1902-1998, *J. Geophys. Res*., 108(C8), 3267, 2003

Meier, H.E.M., On the parameterization of mixing in 3D Baltic Sea models, *J. Geophys. Res*., 106, 30997-31016, 2001

Meier, H.E.M., T. Faxén, Performance analysis of a multiprocessor coupled ice-ocean model for the Baltic Sea. *J. Atmos. Oceanic Technol*., 19, 114-124, 2002

Meier, H.E.M., F. Kauker, Modeling decadal variability of the Baltic Sea: 2. Role of freshwater inflow and large-scale atmospheric circulation for salinity. *J. Geophys. Res*., 108(C11), 3368, 2003a

Meier, H.E.M., F. Kauker, Sensitivity of the Baltic Sea salinity to the freshwater supply. *Clim. Res*., 24, 231-242, 2003b

Meier, H.E.M., R. Döscher, T. Faxén, A multiprocessor coupled ice-ocean model for the Baltic Sea: Application to salt inflow. *J. Geophys. Res*., 108(C8), 3273, 2003

Meier, H.E.M., R. Döscher, A. Halkka, Simulated distributions of Baltic sea-ice in warming climate and consequences for the winter habitat of the Baltic ringed seal, *Ambio*, 33, 76-83, 2004a

Meier, H.E.M., B. Broman, E. Kjellström, Simulated sea level in past and future climates of the Baltic Sea, *Clim. Res*., submitted, 2004b

Räisänen, J., U. Hansson, A. Ullerstig, R. Döscher, L.P. Graham, C. Jones, H.E.M. Meier, P. Samuelsson, U. Willén, European climate in the late 21st century: regional simulations with two driving global models and two forcing scenarios. *Clim. Dyn.*, 22, 13-31, 2004

Willebrand, J., B. Barnier, C. Böning, C. Dieterich, P.D. Killworth, C. LeProvost, Y. Jia, J.-M. Molines, A.L. New, Circulation characteristics in three eddy-permitting models of the North Atlantic. Prog. Oceanog., 48, 2-3, 123-161, 2001

High resolution modeling of the Arctic with regional climate models

Klaus Dethloff, Annette Rinke, Wolfgang Dorn, Subodh Saha, Rüdiger Gerdes

Alfred Wegener Institute for Polar and Marine Research, Research Department Potsdam
dethloff@awi-potsdam.de

Introduction

The problem of global change requires to attribute observed climate changes to natural sources of variability and anthropogenic forcing factors. The Arctic is an area of the world, where climate change is likely to be largest and where natural variability has always been substantial. Recent climate modelling results have highlighted the Arctic as a region of particular importance and vulnerability to global climate change. The projections of future climate changes are complicated by complex interactions and nonlinear feedbacks of the Arctic climate system with other parts of the world as a result of global teleconnections. A main target is to identify and model the most important key processes of the climate system by an improved description of physical processes in the coupled system ocean, sea-ice, atmosphere, land, soil and snow in high-resolution regional climate models. We discuss briefly the performance of the atmospheric regional climate model HIRHAM for the Arctic, the development of the coupled atmosphere-ocean-sea-ice model HIRHAM-MOM of the Arctic and the impact of Arctic atmosphere-land-soil-snow interactions.

The atmospheric regional climate model HIRHAM

The performance of the atmospheric regional climate model HIRHAM and six other regional climate models have been described in Rinke et al. (2004). This work has been carried out in close cooperation with the US and Canadian partners as the European contribution to the Arctic Regional Climate Model Intercomparison Project (ARCMIP). The first joint experiment for the model intercomparison considered an annual simulation for the SHEBA year September 1997 to September 1998 over a domain covering the Beaufort Sea. All models apply the same SHEBA subdomain and about a 0.5 degree horizontal resolution. All models use the same lateral forcing (ECMWF analysis, updated every 6 hours) and the same lower boundary forcing (SSM/I sea ice fraction, NOAA surface temperatures, updated every 6 hours). Therefore, the differences between the different model simulations can be attributed to different model dynamics, physics, horizontal and vertical resolution.
Køltzow et al. (2003) developed a new snow and sea ice surface albedo scheme taking into account three different surface types (snow, pure sea ice, melt ponds) and being dependent on snow cover and surface temperature. With this new scheme, the shortwave absorption bias is less than 1 W/m^2 compared to the SHEBA data.

Fig. 1 shows the influence of the improved snow albedo parameterization on the mean sea-level pressure distribution in the HIRHAM simulations for 5 year long simulations 1979-1983. There is a pronounced remote influence due to the snow albedo feedback over the Arctic ocean, which is important for the performance of the regional coupled atmosphere-ocean-sea-ice model of the Arctic.

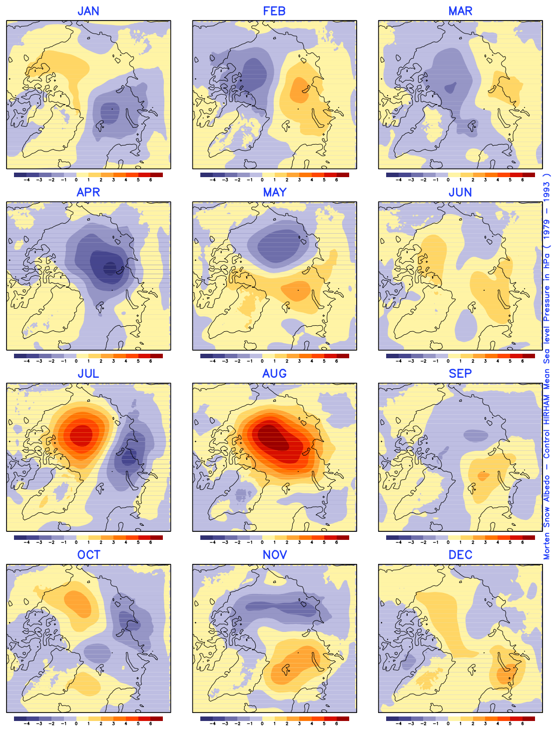


Fig. 1: Mean sea level pressure (hPa) as difference of "Køltzow et al. (2003) albedo run minus control run" for 5 years 1979-1983.

The coupled atmosphere-ocean-sea-ice model HIRHAM-MOM of the Arctic

A coupled regional climate model system of the Arctic have been developed as described in Rinke et al. (2003). The development of coupled regional atmosphere-ocean-sea-ice models shows that the strong ice retreat observed along the whole Siberian coast during summer 1990 is not reproduced by any of the simulations. Two processes may be responsible for that: ice drift and/or ice melting.

(i) The summer ice concentration in the model is strongly affected by the ratio of melting rate to ice thickness. Because the simulations has been started with too thick sea-ice as compared to observations, total melting of sea-ice is hampered in the model and ice extent as well as ice thickness are too high throughout the simulation. This problem of a unrealistic initial state can be solved simply by the use of an improved data set.

(ii) Ice melting in the East Siberian, Chukchi, and Bering Seas can also be affected by the inflow of warm ocean water through the Bering Strait. In the current model setup, the Bering Strait is closed and there is no corresponding mechanism to allow for the heat flux associated with this inflow. This missing heat source may contribute to the low ice retreat along the Siberian coast and to the fact that the Bering Strait is partly ice covered throughout the simulation.

Impact of Arctic atmosphere-land-soil-snow interactions

An improved land surface model have been implemented in HIRHAM and shown that this improves the simulation of winter and summer soil temperatures, although a cold winter bias still further exists.

Viterbo et al. (1999) detected that increased atmospheric heat flux under stable Arctic conditions could reduce the excessive cooling of the soil. Sensitivity experiments with revised stability functions for heat and momentum to increase the turbulent diffusion of heat under stable Arctic planetary boundary layer conditions have been carried out. Fig. 2 shows the mean sea level pressure as difference of the run with the revised stability functions of Viterbo et al. (1999) and the control run. Strong changes occur in the pattern of mean sea level pressure in the 5 year long simulations, mainly over the Arctic ocean. These results agree with Dethloff et al. (2001), who investigated the sensitivity of Arctic climate simulations to different boundary layer parameterizations in a regional climate model.

The presented results underline the need for the application of coupled regional climate models to understand the causes of changes in the Arctic and to develop reliable scenarios for future Arctic climate changes with respect to circulation regime shifts and greenhouse gases and aerosols as in Dorn et al. (2003).

Summary

One of the most important questions is to understand the connections between regional Arctic feedbacks and remote impacts on changes in the global circulation. This is the main topic of the EU project Global implications of Arctic climate processes and feedbacks (GLIMPSE).

There are several candidates for such kind of Arctic influences, e. g. the snow and sea-ice albedo parameterization. The improved sea-ice albedo parameterization over the Arctic ocean will be implemented into a coupled AOGCM.

The vertical resolution influences the surface inversions and the degree of the vertical decoupling between the surface and the lower troposphere as it was shown for the revised stability functions in the Arctic planetary boundary layer. The indirect effect of aerosols connected with Arctic Haze can enhance the strength of the Barents Oscillation and could exert a direct Arctic forcing on global climate anomalies.

The improved formulation of Arctic climate processes and feedbacks analysed in state-of-the-art regional climate models has the potential to change the strength of climate change scenarios in AOGCMs and to consider the current scenario results with considerable caution.

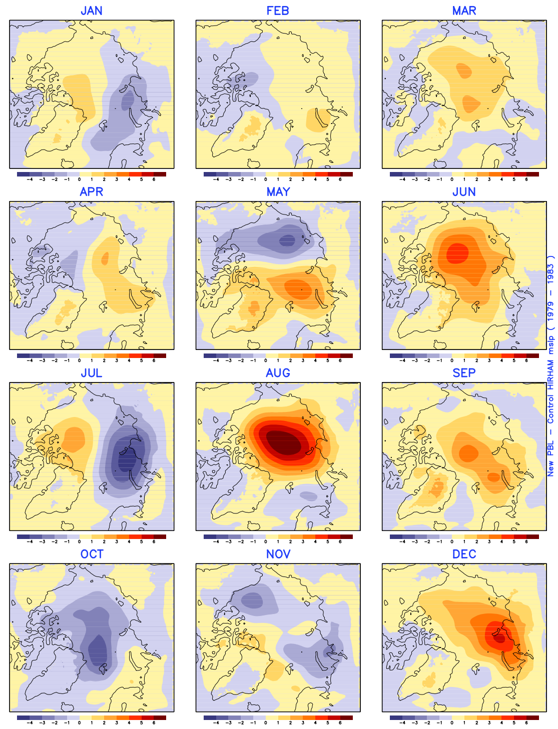


Fig. 2: Mean sea level pressure (hPa) as difference of "Viterbo et al. (1999) stability functions run minus control run" for 5 years 1979-1983.

References:

Dethloff, K., C. Abegg, A. Rinke, I. Hebestadt, V. F. Romanov, 2001, Tellus, 53A, 1.

Dorn, W., K. Dethloff, A. Rinke, E. Roeckner, 2003, Climate Dyn., 21, 447-458

Køltzow, M., S. Eastwood and J. E. Haugen, 2003, Res. Rep. 149, Norwegian Meteorological Institute, Oslo.

Rinke, A., R. Gerdes, K. Dethloff, T. Kandlbinder, M. Karcher, F. Kauker, S. Frickenhaus, C. Koeberle, W. Hiller, 2003, J. Geophys. Res., 108, 4275.

Rinke, A., K. Dethloff, J. Cassano, J. H. Christensen, J. A. Curry, J. E. Haugen, D. Jacob, C. Jones, M. Køltzow, A. H. Lynch, S. Pfeiffer, M. C. Serreze, M. J. Shaw, M. Tjernström, K. Wyser, M. Zagar, 2004, J. Climate, submitted.

Viterbo, P., A. Beljaars, J. F. Mahouf, J. Teixera, 1999, Q. J. R. Meteorol. Soc., 125, 2401.

The Arctic boundary-layer in six different RCM compared to SHEBA observations (ARCMIP)

Michael Tjernström, Mark Žagar and Gunilla Svensson, Stockholm University, Stockholm, Sweden
Klaus Dethloff and Annette Rinke, Alfred Wegener Institute for Polar Science, Postdam, Germany
John Cassano, CIRES, University of Colorado, Boulder, Colorado, USA
Susanne Pfeifer and Tido Semmler, Max Planck Institute for Meteorology, Hamburg, Germany
Colin Jones and Klaus Wyser, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

Introduction

Climate forcing, as well as drivers of climate change, are parameterized in all climate models. There is a controversy within climate modeling if the so called "model physics" has anything to do with actual physics, or if it is just a package of tunable statistic relationships of a more obscure nature. Given how climate is generated in a climate model, it is exceedingly clear to us that unless "model physics" at least attempt to model the actual physics, climate modeling is not meaningful.

The Arctic is more sensitive to climate change than most other regions. On average in 19 CMIP (Meehl et al. 2000) climate change simulations, the Arctic warms 2.5 times more the global average (Räisänen 2001). We see already today signs that global warming has started to impact the Arctic (Serreze et al. 2000, Comiso 2002). Still, the intermodel spread in the CMIP ensemble is largest in the Arctic (Räisänen 2001) and current GCM have problems reproducing today's Arctic climate (Walsh et al. 2002).

The large climate sensitivity of the Arctic is due to strong positive feedback mechanisms; the ice/snow-albedo feedback is probably the strongest. An adequate description of the fluxes of heat and momentum at the ice surface lay at the heart of a proper representation of this feedback. An evaluation of this has been difficult, due to lack of adequate data. The Surface Heat Budget of the Arctic Ocean (SHEBA, Uttal et al. 2002) experiment now makes this possible.

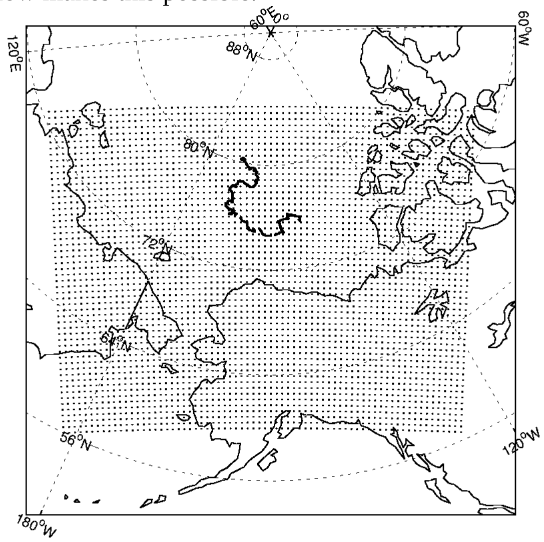


Figure 1. The ARCMIP exp. #1 model domain.

The aim of the Arctic Regional Climate Model Intercomparison (ARCMIP, Curry and Lynch 2002) project is to improve climate models for the Arctic, by comparing models to SHEBA data and to each other. In this experiment all models were set up at a common domain with the same resolution, centered on the SHEBA ice-drift track (Fig. 1). All six models (see acronyms in Fig. 2) used the same 6-hourly lateral boundary conditions from operational ECMWF analyses. Sea and ice surface temperatures and ice fractions were prescribed from satellite observations. The models were run 13 months from 1 September 1997. In this paper we focus on an evaluation of the surface fluxes and the boundary-layer vertical structure. The experiment is described in detail in Tjernström et al. (2004).

Results

In general the relatively small domain ensures that the model's larger-scale dynamics adhere to that of the driving analyses; differences do occur (Rinke etal. 2004). Fig. 2 shows weekly averaged 2-meter air temperature from all the models for some few winter months. While the temperature of the ice surface was prescribed, the models are expected to follow the observations; it is surprising to find some rather large differences between models and observations. During cold periods in December 1997, many models are ~10 ºC too warm, even as weekly averages. The coldest period, around 1 January 1998 is, however, well captured by all models. In summer (not shown), differences are smaller, but with a systematic disparity between models close to ~0 ºC (the melt-point of fresh water) and others closer to ~-1.7 ºC (the melt-point of ocean water).

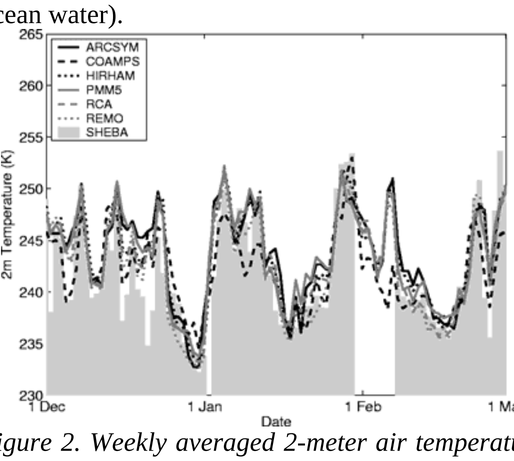


Figure 2. Weekly averaged 2-meter air temperature during winter for the different models and from SHEBA data, as indicated in the legend.

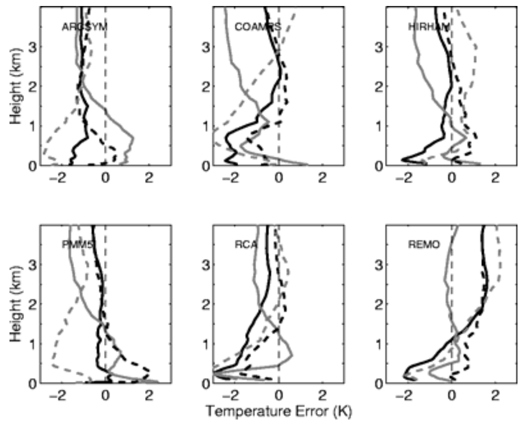


Figure 3. Seasonal averages of temperature bias profiles. Fall and winter are shown with solid, black and grey, and spring and summer by dashed, black and grey.

Seasonally averaged bias profiles of temperature are shown in Fig. 3. Two things are obvious: The biases are much larger and more variable below ~ 1 km anddifferent models behave very different also in the free troposphere. Larger biases closer to the surface indicate deficiencies in boundary-layer parameterisations, probably related to formation of low-level clouds; note the summer low-level cold-bias in all models, presumably due to an overestimated cloud-top cooling. In the free troposphere some models have a consistent bias through the year while others are very variable.

Near-surface wind speeds (not shown) follow the observed variability well in all models, but with systematic biases; annual averaged biases range from ~ -1 ms^{-1} in RCA to ~ 1.5 ms^{-1} in Polar-MM5. In some cases, this is consistent with biases in friction velocity (Fig. 4), for example the high bias in RCA u_*, consistent with the low wind-speed bias.

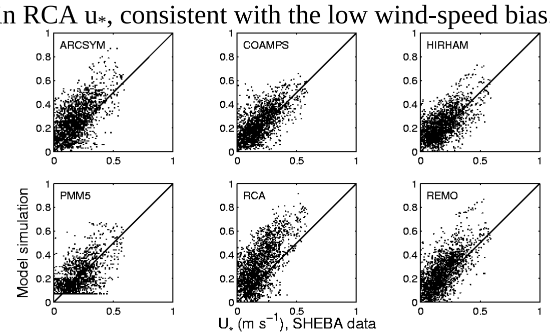


Figure 4. Scatter plot of the modeled 3 hourly friction velocity compared to SHEBA measurements

Given the difficulties to model clouds, the surface radiation fluxes are surprisingly good in most models. While some models have biases ~± 20Wm^{-2} the over-all results are promising. Considering turbulent heat fluxes, however, all models fail badly (Fig. 4). None of the model is similar to any other and neither shows significant similarity to the observations.

Discussion

It is our belief that friction in these models was tuned against surface pressure to ensure reasonable synoptic systems development, worrying less about the actual friction. The modeled turbulence thus "picks up the slack" from other unknown deficiencies in the models. Non-linear feedbacks between wind speed and turbulence adjust to an unrealistic balance, disrupting the turbulent fluxes. The results are superficially nice representations of Arctic climate, sometimes for the wrong reason. If coupled to an ocean model with sea-ice, we suggest that the result may be a poor representation of current conditions. We leave the consequences for the reliability of Arctic climate change simulations to the reader to ponder upon.

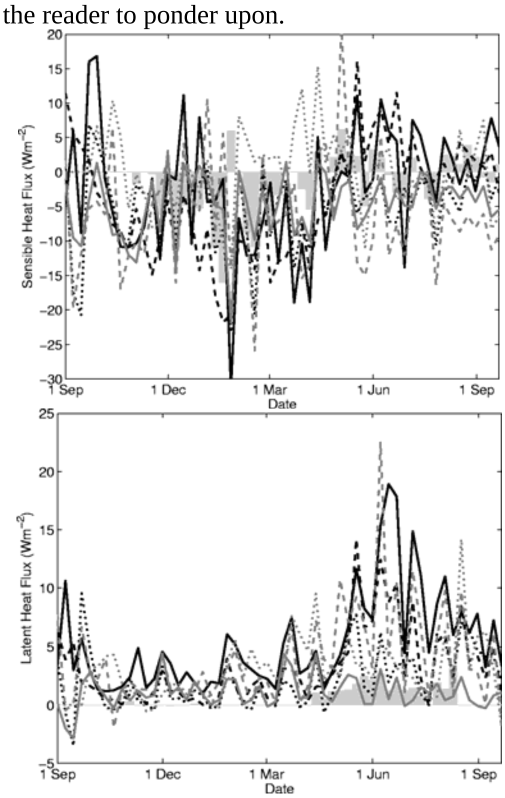


Figure 4. Weekly averaged turbulent sensible (upper) and latent (lower) heat flux. Legend is the same as in Figure 2.

References

Comiso, J. C., 2002: A rapidly declining perennial sea ice cover in the Arctic. *Geophys. Res. Let.*, **29** (20), 1956,doi:10.1029/2002GL015650.

Curry J.A. and A.H. Lynch 2002: Comparing Arctic Regional Climate Models. *EOS Trans. Amer. Geophys. Union.* , **83**, 87.

Meehl, G. A., and coauthors, 2000. The Coupled Model Intercomparison Project (CMIP). *Bull. Am. Meteorol. Soc.*, **81**, 313-318.

Rinke A., and coauthors, 2004: Evaluation of an Ensemble of Arctic Regional Climate Models: Spatial Patterns and Height Profiles, *J. Clim*., Submitted.

Räisänen, J., 2001: CO2-induced climate change in the Arctic area in the CMIP2 experiments. SWECLIM News letter, **11**, 23 – 28.

Serreze, M., and coauthors, 2000, Observational evidence of recent change in the northern high-latitude environment. *Climate Change*, **46**, 159-207,

Uttal, T., J. and coauthors, 2002: Surface Heat Budget of the Arctic Ocean. *Bull. Am. Meteorol. Soc.*, **83**, 255-276

Walsh, J. E., W. M. Kattsov, W. L. Chapman, V. Govorkova and T. Pavlova, 2002: Comparison of Arctic climate by uncoupled and coupled global models. *J. Clim.*, **15**, 1429 – 1446.

A two-dimensional isotropic discrete filter for limited area model evaluation purposes

Frauke Feser and Hans von Storch

Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany
feser@gkss.de

Introduction

Limited area models have gained more and more importance during the last years and the regional model simulations increased in their spatial resolution as well as in their temporal extent. But, the question of added value compared to models of lower resolution in time and space is still only answered fragmentarily. To obtain a tool to advance with this question, a two-dimensional isotropic discrete filter was developed. It serves as a means to classify meteorological fields according to their spatial dimensions by filtering certain wave number ranges and thereby performs a spatial scale separation of the atmospheric fields.

A Fourier filter can be used to separate the spatial scales of a limited area modeled field. But, this filter may cause problems if there is a spatial trend in the field. When filtered by a partial reconstruction of Fourier components, the filtered field would have marked long wave contributions, even if the original field would be a smooth spatial trend without any wave contributions. Similarly, the high-pass filter would return spurious short waves.

Because of this incapability of Fourier filters to deal with fields with trends the fields have to be detrended first when using a standard Fourier filter. An approach which avoids the detrending of the data was suggested by Denis et al. (2002) who used a two-dimensional discrete cosine transform. Thereby, in contrast to the discrete Fourier transform (Errico (1985)), the spectra are not modified throughout the wave number range and an effective, scale selective filtering is achieved. Another method to circumvent the trend problem is to use a digital filter (e.g., Shuman (1957), Shapiro (1970, 1975)).

a ***b*** ***c***

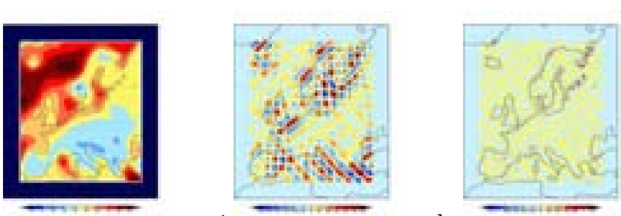


Fig 1. One-dimensional digital filtered wind speed fields: (a) low-pass filtered, (b) medium-pass filtered, and (c) high-pass filtered.

Digital filter

At first we used a digital filter in only one dimension, it was applied in zonal and in meridional direction separately (Figure 1). Thereby it got obvious that, especially for the middle- and high-pass filtered fields, diagonal structures were not filtered in a correct way (Figure 1b and c). Therefore a true two-dimensional discrete filter had to be developed.

We were able to construct an efficient algorithm to determine such isotropic filters with response functions close to requested terms. A wave number range has to be selected and the according response function (Figure 2), which depends only on the two-dimensional wave number, is calculated in wave number space. The filter is determined by formulating an appropriate approximation, which leads to a linear equation system for the filter weights (Figure 3). A multiplication of the atmospheric field with the filter weights gives the filtered spatial field.

a ***b*** ***c***

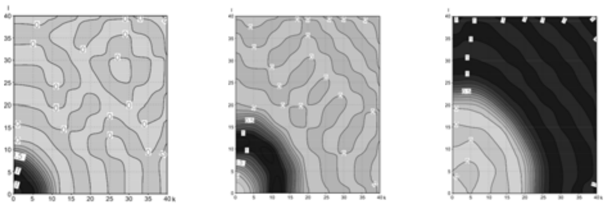


Fig 2. Filter response functions for: (a) low-pass filter, (b) medium-pass filter, and (c) high-pass filter.

Response function

The response function is calculated by first assuming a 2-d periodical function which can be expanded into Fourier components:

$$f(x,y) = \sum_{k,l=-K}^{K} \alpha_{kl} e^{i(kx+ly)}$$

with $\alpha_{k,l} = \alpha^*_{-k,l} = \alpha^*_{k,-l} = \alpha_{-k,-l}$ because *f(x,y)* is a real function. The arguments *x* and *y* vary between *0* and *2π*.The filtered function is given by a tilde

$$\tilde{f}(x,y) = a_{00} f(x,y) + A + B + C$$

with

$$A = \sum_{n=1}^{N} a_{n0}[f(x,y+\hat{n}) + f(x,y-\hat{n}) + f(x+\hat{n},y) + f(x-\hat{n},y)]$$

$$B = \sum_{n=1}^{N} a_{nn}[f(x+\hat{n},y+\hat{n}) + f(x+\hat{n},y-\hat{n}) + f(x-\hat{n},y+\hat{n}) + f(x-\hat{n},y-\hat{n})]$$

$$C = \sum_{n=2}^{N}\sum_{m=1}^{n-1} a_{nm}[\, f(x+\hat{n}, y+\hat{m}) + f(x+\hat{n}, y-\hat{m})$$
$$+ f(x-\hat{n}, y+\hat{m}) + f(x-\hat{n}, y-\hat{m})$$
$$+ f(x+\hat{m}, y+\hat{n}) + f(x+\hat{m}, y-\hat{n})$$
$$+ f(x-\hat{m}, y+\hat{n}) + f(x-\hat{m}, y-\hat{n})]$$

with the convention $\hat{n} = 2\pi n / L$ and $\hat{m} = 2\pi m / L$. L is the size of the area in number of grid points, which are counted by the integers *n* and *m*. The transformation from *n* to $\hat{n}$ is required as we have assumed *f* to vary on the interval *[0,2π]*.

The filter weights are denoted by a_{nm}. The resulting response function κ after further transformations (not shown) for wave numbers *k,l* is given by:

$$\kappa(k,l) = a_{0,0} + \sum_{n=1}^{N}[2a_{n0}(\cos(k\hat{n}) + \cos(l\hat{n}) + 4a_{nn}\cos(k\hat{n})\cos(n\hat{n})$$
$$+ \sum_{n=2}^{N}\sum_{m=1}^{n-1} a_{nm}[\cos(k\hat{n})\cos(l\hat{m}) + \cos(l\hat{n})\cos(k\hat{m})]$$

The constants *2* and *4* account for the multiple use of the same filter weights in one filter application.

The response functions are shown in Figure 2 for a low-pass (a), medium-pass (b), and high-pass (c) filter. The response functions show a well-defined wave number range where the response is close to 1 and a smooth transition to response values of about 0. The transition area can be selected pretty narrow as can be seen for the band-pass filter (b) which results in a rather sharp defined filter.

The resulting filter weights are shown in Figure 3. The low-pass filter weights (Figure 3a) show a homogenous structure with highest values in the middle of the weighting area and decreasing values further away from the filter base point. This will result in a large mean value. The medium-pass filter weights (Figure 3b) include several transitions between positive and negative values and thereby the mean value will be filtered and only the smaller structures will remain. The high-pass filter weights (Figure 3c) comprise a yet higher number of changes in sign. Thus, only the smallest structures will pass this filter.

a ***b*** ***c***

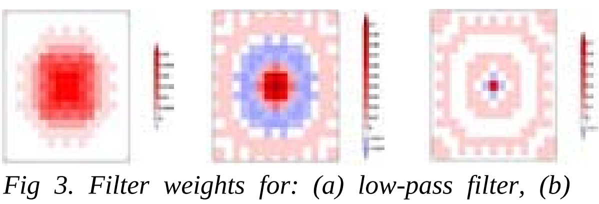


Fig 3. Filter weights for: (a) low-pass filter, (b) medium-pass filter, and (c) high-pass filter. The center weight a00 is the mid point.

Results

The results of a regional model run were filtered with the presented filter for 3 wave number ranges. The result of a first snapshot can be seen in Figure 4. It shows the unfiltered data (a), a low-pass (b), medium-pass (c), and high-pass filtered (d) zonal wind speed field for a winter day. The low-pass filtered field (b) shows the smoothed field and displays only the very large scales. The medium-pass filtered data (c) lacks the large scale information and shows mainly land-sea interactions on the regional scale. The high-pass filtered part displays the highest scales which are located almost exclusively in the coastal zones for this wind speed example. The 2-d-filtering lead to filtered data that shows none of the stripes due to none-effectively filtered diagonal structures that were apparent in the 1-d-filter methods mentioned before (e.g. as can be seen in Figure 1). An effective scale separation was achieved.

a *b* *c* *d*

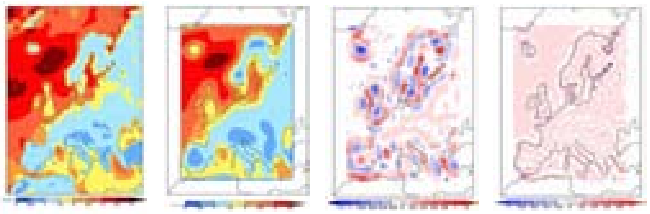


Fig 4. Two-dimensional digital filtered zonal wind speed fields at a height of 10 m: (a) unfiltered data, (b) low-pass filtered, (c) medium-pass filtered, and (d) high-pass filtered.

Acknowledgement

We thank R. Laprise for valuable discussions regarding this work. He proposed the idea of an isotropic two-dimensional filter. We are also grateful to B. Gardeike who prepared some of the Figures for us.

References

Denis, B., J. Côté, and R. Laprise, Spectral Decomposition of Two-Dimensional Atmospheric Fields on Limited-Area Domains Using the Discrete Cosine Transform (DCT), *Mon. Wea. Rev.*, Vol. 130, pp. 1812-1829, 2002

Errico, R., Spectra computed from a Limited Area Grid. *Mon. Wea. Rev.*, Vol. 113, pp. 1554-1562, 1985.

Shapiro, R., Smoothing, Filtering, and Boundary Effects. *Reviews of Geophysics and Space Physics*, Vol. 8, pp. 359-387, 1970

\- 1975: Linear Filtering. *Mathematics of Computation*, Vol. 29, pp. 1094-1097.

Shuman, F. G., Numerical methods in weather prediction: II. Smoothing and filtering. *Mon. Wea. Rev.*, 85, pp. 357-361, 1957

The Nordic flux measurement network

A. Lindroth

Lund University, NECC, Sweden

In 2002 the Nordic Council of Ministers launched a programme for setting up a number of so called Centres of Excellence in climate change research. One of these centres is NECC, the Nordic Centre for Studies of Ecosystem Carbon Exchange and Its Interactions With the Climate System, coordinated by Lund University. The NECC is a virtual Centre consisting of 14 research groups from institutes in Denmark, Iceland, Sweden and Finland and it started its activities 1 January 2003. With the creation of this centre the existing Nordic measurements of carbon dioxide and methane exchange from different ecosystems are linked in one Nordic flux-network. Currently 47 sites are within the Centre, including 26 eddy-flux sites with measurements in forests, wetlands, lakes, agricultural sites and one urban site. The main aim of the Centre is to obtain a better understanding of the factors regulating the carbon balance of typical sub-arctic and boreal ecosystems and to improve the co-operation in both research and education in the field of carbon exchange. In addition to carbon dioxide and methane fluxes, the eddy covariance sites are also measuring the surface heat fluxes, which are of key importance in climate modelling. Besides flux towers, the NECC also has a flux aircraft at its disposal. With the aircraft, fluxes can be measured at larger scales, which are more adopted to the scales at which the climate models are operating at. Some example results both on carbon and energy fluxes from typical Nordic ecosystems are shown.

On the calculation of area-averaged or effective temperature roughness lengths

N. O. Jensen and C. B. Hasager

Risoe Nat. Lab. Denmark

A two-dimensional atmospheric flow model in the horizontal domain is used to calculate the area-averaged temperature roughness length and sensible heat flux in a typical Danish landscape. The model is a further development of the work described in Hasager and Jensen, 1999: Surface flux aggregation in heterogeneous terrain (*Q. J.R. Meteorol. Soc.*, **125**, 2075-2102). The model is run with input of high-resolution satellite-based maps of leaf area index (LAI), surface temperature, land cover type and local roughness (z_0). The output are spatial averages of the effective roughness for momentum $<z_0>$ and for scalars $<z_{0t}>$.

The values obtained are relevant grid parameters in regional weather forecast and climate models. The model gives an explicit calculation of $<z_{0t}>$ that is no longer proportional to $<z_0>$. The study includes a comparison of model results and field observations at the Foulum site in Jutland, Denmark. Furthermore a model parameter sensitivity study is undertaken for variations in magnitude and distribution of LAI and the effect on $<z_{0t}>$ and the sensible heat flux in the landscape. The paper describes some details of the model and discusses typical calculation results.

The 2003 heat wave in Europe in the context of 20th and 21st century climates

Martin Beniston

Department of Geosciences, University of Fribourg, CH-1700 Fribourg, Switzerland
Martin.Beniston@unifr.ch

Introduction

The record heat wave that affected many parts of Europe during the course of summer 2003 has been seen by many as a “shape of things to come”, reflecting the extremes of temperature that summers are projected to have in the later decades of the 21st century (Beniston, 2004; Schär et al., 2004). The heat wave resulted in absolute maximum temperature records exceeding for the first time in many locations in France, Germany, the United Kingdom, and Swizerland records that had stood since the 1940s and early 1950s, according to the information supplied by national weather agencies and highlighted in the annual report of the World Meteorological Organization (WMO, 2003). Regional climate simulations undertaken for European region highlight the fact that summers may become regularly as hot as the 2003 event by the end of the 21st century.

Results from observations and model simulations

Figure 1 illustrates the annual values of summer Tmax (JJA Tmax, i.e., the average of daily maximum temperatures recorded in June, July, and August) from 1901-2003 at Basel, Switzerland. The 2003 event stands out as a “climatic surprise”, in the sense that it is the first time that average JJA Tmax in Basel has exceeded the 27°C threshold since 1952, the 28°C threshold since 1947, and the 29°C for the first time in this century-long record. The 2003 heat wave comes at the end of a 40-year period during which summers were markedly cooler than the warm summers of the mid-20th century. Positive Tmax anomalies in Basel exceeded 6°C.

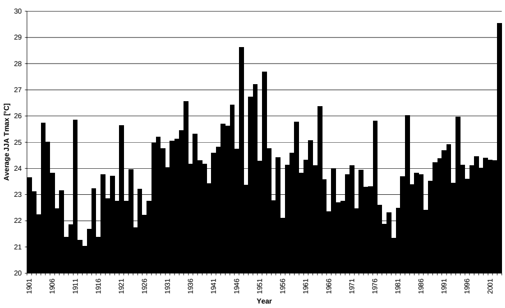


Fig 1. Summer (JJA) maximum temperatures recorded at Basel, Switzerland, from 1901-2003.

Within the European Union project PRUDENCE (Christensen et al., 2002), a suite of regional climate models have been applied to the investigation of climatic change over Europe for the last 30 years of the 21st century, enabling *inter alia* an insight into possible changes in the extremes of temperature by 2100. The HIRHAM4 regional climate model (RCM) of the Danish Meteorological Institute (Christensen et al., 1998) is one such model whose results correspond well with those of the other RCMs used in PRUDENCE. Furthermore, simulations of the reference climatic period 1961-1990 has shown that HIRHAM4 exhibits skill in reproducing contemporary climate, thereby providing some confidence as to its capability for simulating the characteristics of temperatures in the future.

The RCM results mapped over Europe for maximum temperatures and threshold excess have implications for the future course of extreme events such as the increase of heat waves and the reduction in cold spells and frost days. According to the baseline used, the very definition of a heat wave could change in a future, systematically-warmer climate, compared today. The climate of southern Spain, for example, that is currently characterized by temperatures exceeding 30°C for about 60 days per year on average may in the future experience over 150 days or more, i.e., close to half the year. Under such circumstances, the notion of heat wave loses some of its value when a rare or exceptional feature of today’s climate becomes commonplace in tomorrow’s climate. Figure 2 shows the shift in JJA Tmax between the 1961-1990 reference period and 2071-2100 for the RCM grid-point closest to Basel.

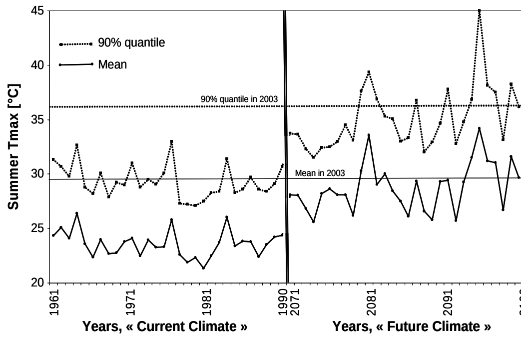


Fig 2. Changes in mean and 90% quantile of summer (JJA) maximum temperatures in Basel, Switzerland between contemporary (1961-1990) and future (2071-2100) climates. The level of 2003 temperatures is illustrated for comparison purposes.

A closer analysis of the persistence of the event based on an exceedance of the 30°C threshold at Basel reveals, however (see, for example, Beniston, 2004), that 2003 exhibited fewer days (41) than 1947 (49). Furthermore, there were only 12 consecutive days in 2003 during which Tmax exceeded 30°C as opposed to 1976 (16) or 1947

(14). The 1940s stand out as a decade in which a clustering of summers with a threshold excess of 20 days or more is not uncommon, whereas such events tend to diminish in the 1970s and 1980s. According to the statistics considered, therefore, 2003 is not seen to have broken all records in terms of extremes; the sudden jump to high exceedance values following over a quarter century where summers never exceeded the 30°C threshold for 20 days or more does, however, constitute a totally different behavior from the rest of the century.

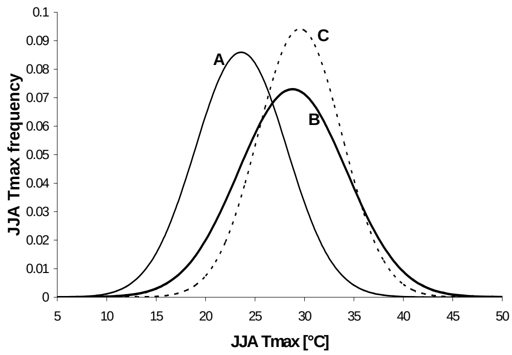


Fig. 3. Gaussian distributions fitted to the mean summer maximum temperature data at Basel, Switzerland, for A) the 1961-1990 reference period; B) the 2071-2100 A-2 scenario simulation; and C) the 2003 heat wave.

Figure 3 illustrates the Gaussian fits to the JJA Tmax data the contemporary (curve A) and future climates (curve B); the 2071-2100 period is accompanied by a change in the variance of the distribution, which is a feature that has been observed in other studies (Katz and Brown, 1992). The Gaussian distribution of the 2003 maximum summer temperatures (curve C) is the only instance in the 20th century record of a range of summer maximum temperatures that is located entirely within that of the 2071-2100 period and with an almost identical median value.

Conclusions

Society will face considerable challenges, when faced with the heat waves of similar or greater intensity to the 2003 event, that are projected to become more common in the latter decades of the 21st century. In view of the severity of the impacts that affected much of Europe throughout the summer of 2003, such as excess deaths recorded in France, Italy, and Spain (WHO, 2003), crop failures in many of the producing countries, and strongly-reduced discharge in numerous rivers, the recent heat wave as a “shape of things to come” is a signal that should be given appropriate consideration by decision-makers.

References

Beniston, M., 2004: The 2003 heat wave in Europe: A shape of things to come? Geophys. Res. Letters, 31, L02202

Christensen, O. B., Christensen, J. H., Machenhauer, B., and Botzet, M., 1998: Very high-resolution regional climate simulations over Scandinavia – Present climate. J. Climate, 11, 3204-3229

Christensen, J.H., T. Carter, F. Giorgi, PRUDENCE Employs New Methods to Assess European Climate Change, *EOS*, Vol. 82, p. 147, 2002

Katz, R. W., and Brown, B. G., 1992: Extreme events in a changing climate: Variability is more important than averages. Climatic Change, 21, 289-302

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

WHO, 2003: The health impacts of 2003 summer heat-waves. Briefing note for the Delegations of the fifty-third session of the WHO (World Health Organization) Regional Committee for Europe, 12 pp.

WMO, 2003: World Meteorological Organization statement on the status of global climate in 2003. WMO publications, Geneva, 12 pp.

MGO Regional Climate Model: simulation of present-day climate over the Western Russia

I. M. Shkolnik, V.P. Meleshko, and V.M. Gavrilina

Dynamic Meteorology Department, Voeikov Main Geophysical Observatory, St. Petersburg, Russia
email: igor@main.mgo.rssi.ru

Introduction

The study is aimed at evaluation of the MGO RCM systematic errors using different sets of the lateral boundary conditions (LBC) derived from the NCEP/NCAR reanalysis (Kalnay et al., 1996) and simulated by the MGO AGCM. The MGO RCM (Shkolnik et al., 2000) is a primitive equation model with σ-coordinate in the vertical (14 layers). The prognostic variables are the components of horizontal wind, air temperature, specific humidity, and surface pressure. For solving the modeling equations in the horizontal a cartesian grid domain with 105×121 grid points is used (~50 km resolution). The model incorporates physical package of the MGO GCM. The global data at the lateral boundaries are assimilated using newtonian relaxation over 10 grid points; the inflow/outflow formulation for humidity is modeled.

Data and experiments

The reanalysis data was available every 6 hours for wind, temperature, water vapor, and surface pressure from 1982 to 1987. Same characteristics from the MGO GCM AMIP II simulation have been stored at 6-hour intervals for the same time slice. Two 6-year climate simulations with the RCM have been carried out driven first reanalyzed (experiment is further referred to as RCM+REA) and then GCM produced fields (RCM+GCM). Both runs included observed SST/SI.

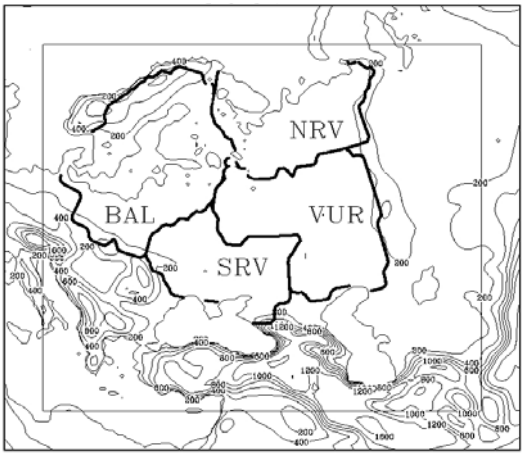


Fig.1 The MGO RCM domain, topography, and watersheds' boundaries. The area between two rectangulars corresponds to relaxation subdomain.

We have compared the RCM simulated surface air temperature and precipitation against high resolution CRU analyses (New et al., 1999) and NCEP/NCAR reanalysis over the full domain and four terrestrial watersheds: the Baltic (BAL), the northern rivers of the Western Russia (NRV), the southern rivers of the Western Russia (SRV), and the Volga/Ural rivers (VUR). In Fig.1 shown are the modeling domain, topography, and watersheds' boundaries.

Results

Due to soil adjustment the results of the first year of each simulation have been rejected from the analysis. Table 1 contains seasonal and annual root mean square (RMS) and mean differences between computed and observed spatial distributions of the surface air temperature and precipitation for RCM+REA and RCM+GCM. As compared against GCM driven model the RCM+REA reproduced the temperature closer to that observed, notably in winter, while summer distributions appeared to be similar in both experiments. However, the precipitation biases revealed weak sensitivity to different types of the LBC. These biases can be attributed to larger modeling errors over complex topography as compared to those over central plains and to larger uncertainties in observational estimates over extent areas in southern and eastern parts of the domain. The precipitation biases are also subject to considerable uncertainty due to small sample size. It is noticeable in full domain the RCM tends to undersimulate the temperature and likely oversimulate the precipitation in both reanalysis and GCM driven simulations.

Tab. 1 RMS and mean differences between simulated and observed surface air temperature and precipitation over full domain (relaxation subdomain is not included)

	RCM+REA		RCM+GCM	
	RMS	mean	RMS	mean
surface air temperature, °C				
DJF	2.2	-0.2	2.8	-1.3
JJA	**2.5**	**-0.7**	**3.2**	**-0.4**
year	**1.9**	**-0.7**	**2.5**	**-1.0**
precipitation, mm/day				
DJF	0.6	0.0	0.5	0.1
JJA	**1.2**	**0.7**	**0.9**	**0.5**
year	**0.8**	**0.4**	**0.6**	**0.3**

Let us consider the annual differences between the RCM simulated precipitation and that observed over the watersheds (shown in table 2 and 3). As can be seen in the tables 2 and 3 the use of reanalysis at the lateral boundaries leaded to considerable reducing the precipitation biases over all the watersheds that comprise the central plains with satisfactory observational network. The use of reanalysis at the lateral boundaries resulted in reducing the temperature biases over these areas by 1-2 °C.

Tab. 2 RMS and mean annual differences (mm/day) between simulated with different LBC and observed precipitation over BAL and NRV.

	BAL		NRV	
	RCM+ REA	RCM+ GCM	RCM+ REA	RCM+ GCM
RMS	0.26	0.41	0.45	0.49
mean	0.02	0.04	0.03	0.11

Tab. 3 RMS and mean annual differences (mm/day) between simulated using different LBC and observed precipitation over SRV and VUR.

	SRV		VUR	
	RCM+ REA	RCM+ GCM	RCM+ REA	RCM+ GCM
RMS	0.37	0.59	0.47	0.49
mean	0.25	0.32	0.26	0.28

It is expected the temporal variability of the atmospheric characteristics described by the RCM is dependent upon a combination of external and internal factors, i.e. LBC evolution and nonlinearities in the model physics and dynamics associated with higher resolution. We have compared the RCM simulated monthly mean anomalies of temperature and precipitation over the watersheds against those derived from higher resolution observations and lower resolution driving reanalysis. The anomalies have been calculated as differences between the values of the temperature and precipitation for each month from 1983 to 1987 and the whole period mean value for the respective month in the RCM+REA, observation and reanalysis. In table 4 shown are the temporal correlation coefficients computed between sequences of simulated and observed (reanalyzed) temperature and precipitation anomalies over the watersheds.

Tab.4 Temporal correlation between simulated (RCM+REA) and observed (reanalyzed) monthly mean anomalies of temperature and precipitation from 1983 to 1987 over the watersheds.

	BAL	NRV	SRV	VUR
temperature				
RCM vs OBS	0.90	0.80	0.66	0.66
RCM vs REAN	**0.89**	**0.79**	**0.64**	**0.63**
precipitation				
RCM vs OBS	0.89	0.65	0.34	0.32
RCM vs REAN	**0.79**	**0.50**	**0.24**	**0.21**

It can be seen in the table that model produced temperature anomalies are in reasonable agreement with both the observation and driving reanalysis, while the precipitation anomalies are reproduced by the RCM closer to observational estimates rather than to low resolution reanalysis. The remoteness from the lateral boundaries of the inland VUR and SRV watersheds can explain somewhat larger discrepancies between simulated and observed anomalies over these.

Summary

Two 6-year regional climate simulations with the MGO RCM have been carried out. The simulations included the NCEP/NCAR reanalysis and GCM produced lateral boundary conditions. The biases associated with the errors in boundary fields contributed to the total modeling biases with 1-2 °C for surface air temperature and 10-50% for simulated precipitation over the areas with satisfactory observational network. However, full domain precipitation biases have weakly been affected. When driven by the reanalysis the RCM

- tends to slightly undersimulate surface air temperature and oversimulate precipitation throughout the year as compared against observation. However, the uncertainties in observational estimates can be found over extent areas complicating the model's evaluation.
- simulates monthly mean anomalies of surface air temperature and precipitation closer to high resolution observations than to the lower resolution reanalysis estimates. This suggests reasonable response of the RCM to mesoscale forcings.

References

Kalnay E. et al. The NCEP/NCAR 40 year reanalysis project. *Bull. Am. Meteor. Soc.*,Vol. 77, 1996.

New, M. M. Hulme and P.D. Jones. Representing twentieth century space-time climate variability. Part I: development of a 1961-1990 mean monthly terrestrial climatology. *J. Climate*, 12, pp. 829-856. 1999.

Shkolnik, I.M., V.P.Meleshko, T.V.Pavlova. Regional hydrodynamical model for climate studies over Russia. *Meteorol. Hydrol.*, 4 , pp.32-49, 2000.

Impacts of Climate Change on Stream Flow in the Upper Mississippi River Basin: A Regional Climate Model Perspective

Eugene S. Takle[1,2], Manoj Jha[3], Zaitao Pan[4], and Roy Gu[3]

[1]Department of Agronomy, [2]Department of Geological and Atmospheric Sciences, [3]Department of Civil, Construction, and Environmental Engineering, Iowa State University, Ames USA
[4]Department of Earth and Atmospheric Sciences, St. Louis University, St. Louis. MO USA.

Introduction

Impact of climate change on stream flow in the Upper Mississippi River Basin (UMRB) is evaluated by use of a regional climate model (RCM) coupled with a hydrologic model - Soil and Water Assessment Tool (SWAT). The SWAT model was calibrated and validated against measured stream flow data using obse rved weather data. The potential impacts of climate change on water yield and other hydrologic budget components were then quantified by driving SWAT with current and future scenario climates.

Models and data

The UMRB (Fig. 1) is in the region unique to the U.S. where summertime mesoscale convective precipitation is dependent on nocturnal water vapor flux convergence [*Anderson et al.*, 2003]. Neither the NCAR/NCEP reanalysis (NNR) nor global climate models capture this essential mechanism. Finer grid spacing is needed to resolve the fine-scale dynamical processes that lead to timing, location, and amounts of precipitation [*Anderson, et al.*, 2003].

Fig. 1. The UMRB and delineated 8-digit HUCs.

The SWAT model [*Arnold et al.*, 1998] is a physically based, long-term, continuous watershed simulation model. It operates on a daily time step and assesses the impact of management on water, sediment, and agricultural chemical yields. SWAT requires daily precipitation, max and min air temperature, solar radiation, wind speed and relative humidity as meteorological input. We used four sets of climate data to drive SWAT (Fig. 2): one observed data set from stations and three sets of RCM simulated climate data generated using RegCM2 with a horizontal grid spacing of 52 km [*Pan et al.*, 2001], thereby providing approximately 160 grid points within the UMRB. The results of the GCM of the Hadley Centre (HadCM2) were used to provide the basic climate information for assessing the impact of climate change and uncertainty. The GCM contemporary climate corresponds roughly to the decade of the 1990's, selected from the HadCM2 simulations without enhanced greenhouse gas (GHG). The future scenario (2040s) climate is from a transient simulation that assumed a 1% per year increase in effective GHGs after 1990.

This study is designed to evaluate both the projected change in stream flow due to climate change and the uncertainty in the results. Figure 2 shows SWAT runs with historical and RCM generated climates. Results of the simulation (SWAT 1) with station data from 1979-88 are compared with measured stream flows to evaluate the capability of SWAT in representing observed discharges. A good proxy for error introduced by the RCM is the difference between SWAT results produced when an RCM is driven by observed climate interpolated to the RCM grid (NNR, 1979-88) and results produced by the observed climate (SWAT 1). Global model error is evaluated by the difference between SWAT 3 and SWAT 2.

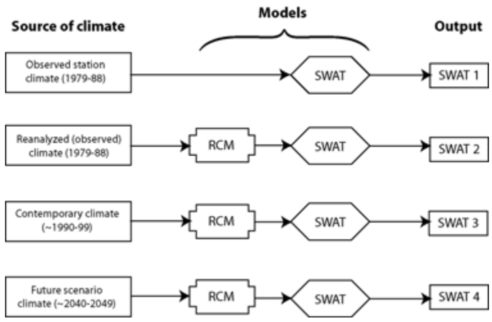


Fig. 2. RCM/SWAT simulations.

Results

Measured stream flows during 1989-1997 at USGS gauge station 05587450, Mississippi River near Grafton, IL were used to calibrate SWAT. Flow validation was conducted using stream flow data for the period from 1980 to 1988. Measured and simulated annual (Fig. 3) and monthly stream flow show good agreement. The calibrated SWAT model was run with RCM weather for the period 1979-1988. The output is labeled as "SWAT 2" in Fig. 2. The annual simulation matched well with measured data, with the largest error in 1988, a year of extreme drought in the central U.S. The RCM gives a very good estimate of mean annual precipitation and interannual variability of annual stream flow over the basin. However on sub-annual time scales, errors in the RCM, in addition to errors in routing and timing of snowmelt, can introduce errors in stream flow that limit the usefulness of this method on such time scales.

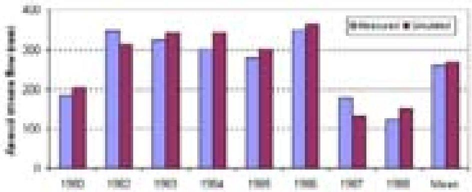


Fig. 3 Measured and simulated annual stream flows near Grafton, IL for validation.

Climate Change Impact Assessment

The impact of climate change on hydrology was quantified by driving the calibrated SWAT model with RCM-generated weather corresponding to the contemporary and future scenario climates nested in the global model as denoted by SWAT 3 and SWAT 4 in Fig. 2. Annual average stream flow increased by 50% due to climate change, with the largest increase occurring in spring and summer.

With the 21% increase in precipitation and accompanying changes in temperatures for the future scenario climate as simulated by the RCM, SWAT produced an 18% increase in snowfall, a 19% increase in snowmelt, a 51% increase in surface runoff, and a 43% increase in recharge, leading to a 50% net increase in total water yield in the UMRB. The highest percentage bias (18%) was attributable to GCM downscaling error. However, the highest individual model RMSE was found in RCM performance. RCM model simulation error was low on the annual basis, but high for seasonal values.

Annual stream flow tends to have a quasi-linear relationship with annual precipitation (Fig. 4). The regression line plotted represents measured annual stream flow vs. observed annual precipitation for 1980 through 1997. We found that the slopes for SWAT1 and SWAT3 are not different from the observed but that SWAT2 and SWAT4 are different from the observed data and different from each other. This means that SWAT produces the same relationship between precipitation and stream flow as is observed and that SWAT driven by a regional model used to downscale global climate model results does also. However, more stream flow per unit of precipitation is produced the future scenario climate.

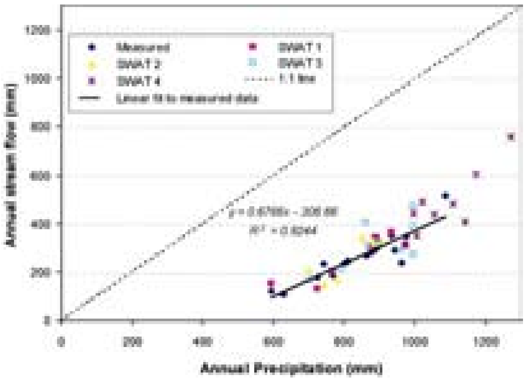


Fig. 4 Relationship between annual stream flow and annual precipitation for various climates.

Summary

The SWAT model produced stream flow with a reasonable accuracy on annual and monthly basis. The GCM downscaling error (18%), was only one third of the simulated change (50%) in annual stream flow due to climate change. This gives confidence that such a downscaling procedure has value for impacts assessment provided the quality of the global model driving the RCM is high. Our results also suggest that the relationship of stream flow to precipitation may change in a future climate, a unit increase in precipitation causing a larger increase in stream flow. See Jha et al. (2004) for details.

Acknowledgements

This research was sponsored by the ISU Agronomy Department Endowment Funds, University of Iowa Center for Global and Regional Environmental Research, and the Biological and Environmental Research Program (BER), U.S. DOE through the Great Plains Regional Center of NIGEC (CA # 26-6223-7230-007). Computer resources used for this study were partly provided by NCAR CSL facility.

References

Anderson, C.J., and Co-authors, Hydrological processes in regional climate model simulations of the central United States flood of June-July 1993, *J. Hydrometeor., 4,* 584-598, 2003.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams, Large area hydrologic modeling and assessment Part I: Model development, *J. Amer. Wat. Res. Assoc., 34*, 73-89, 1998.

Jha, M., Z. Pan, E.S. Takle, and R. Gu, Impact of climate change on stream flow in the Upper Mississippi River Basin: A regional climate model perspective. *J. Geophys. Res*., 2004 (in press).

Pan, Z., J.H. Christensen, R.W. Arritt, W.J. Gutowski, Jr., E.S. Takle, and F. Otieno, Evaluation of uncertainties in regional climate change simulations, *J. Geophys. Res., 106.* D16):17,737-17,751, 2001.

Simulating aerosol effects in regional climate models: The case of East Asia

Giorgi, F., Bi, X. and Y. Qian

Abdus Salam International Centre for Theoretical Physics (ICTP), Strada Costiera 11, 34100, Trieste, Italy

Regional climate models (RCMs) can be very useful tools to study the regional climatic effects of antropogenic aerosols. In this regard, due to its rapid economic development, East Asia is one of the regions where aerosol effects can be expected to be especially important. In this paper we intercompare a series of multi-year simulations with a coupled regional chemistry-climate model for east Asia to assess the relative importance of direct and indirect (Type I) effects of anthropogenic sulfate on the climate of the region. Both direct and indirect aerosol effects induce a negative radiative forcing that results in a cooling of the surface and in a decrease of precipitation. Under present day sulfur emissions, the direct aerosol effects prevail during the cold season, while the indirect effects dominate in the warm season (when cloudiness is maximum over the region). When both the direct and indirect effects are included, the surface cooling varies in the range of -0.1 K to over -1 K throughout the region and extended areas of statisti cally significant cooling are found in all seasons except winter. The indirect effects largely dominate in inhibiting precipitation, especially during the summer. When we double the sulfur emission to crudely account for the effects of additional aerosol types, the direct effects are substantially strengthened, while the indirect effects are only marginally affected. This indicates that the indirect effects over the region might be asymptotically approaching their maximum efficiency. Overall, the indirect effects appear necessary to explain the observed temperature record over some regions of China, at least in the warm season. We are currently implementing additional aerosols within our regional modeling framework, including black carbon (BC) organic carbon (OC) and mineral dust. Some preliminary results from antropogenic sulfate, BC and OC simulations over the European-African region will be presented.

Simulating the Regional Climatic Effects of the Atmospheric Brown Cloud

L. Ruby Leung[1], Yun Qian[1], Chul Eddy Chung[2], and V. Ramanathan[2]
[1]Pacific Northwest National Laboratory, Richland, WA; [2]Scripps Institution of Oceanography, La Jolla, CA

INTRODUCTION

In a recent international study, the Indian Ocean Experiment (INDOEX) (Ramanathan et al. 2001), widespread pollution was frequently found to occur over large sections of the Indian Ocean, South Asia, Southeast Asia, and China, which is home to about 60% of the world's population. The dense brownish pollution haze layer, now known as the Atmospheric Brown Cloud or ABC (Ramanathan and Crutzen, 2003), is about 3 km thick and the size of the continental U.S. The aerosol particles in the haze come from large-scale biomass burning and industrial emissions in the region. Analyses of the INDOEX field observations revealed significant impacts of the haze layer on regional climate. For example, Ramanathan et al. (2001) documented a reduction of about 10 to 15% in solar radiation reaching the surface, and increase in solar heating of the lower atmosphere. These changes stabilize the atmosphere to result in reduced evaporation and precipitation. They further affect the monsoon circulation and rainfall patterns through increasing the frequency and strength of the thermal inversion, which then traps more pollution.

APPROACH

A regional climate model (RCM) based on the Penn State/NCAR Mesoscale Model (MM5) (Grell et al. 1993) is used to study the effects of the aerosols on the regional climate and hydrological cycle. The model has been applied to the western United States (Leung et al. 2003) and East Asia (Leung et al. 1999) at 40 km and 60 km horizontal resolution respectively where the model realistically simulated the distinct regional climate features associated with the strong topographic variations in the western U.S. and the East Asian summer monsoon.

To examine the effects of aerosol on regional climate, we performed two 10-years simulations with the RCM driven by large-scale circulation from the European Center for Medium Range Weather Forecast (ECMWF) TOGA analysis for October 1, 1990 through September 30, 2000. The two 10-years simulations are called the control and INDOEX simulations respectively. In the latter, aerosol forcing (i.e., solar heating rate change in the atmosphere due to anthropogenic aerosols) derived from INDOEX was prescribed in the simulation. Similar to the standard experiment described by Chung et al. (2002), the downward direct solar radiation reaching the surface is reduced by 1.5 times the imposed lower atmospheric heating derived from INDOEX, which yields an effective ratio between the aerosol forcing at the surface and the atmosphere about –0.9 over land, which is near the mean value observed during INDOEX. The prescribed aerosol forcing follows a uniform profile vertically from the surface to 700 hPa, above which the forcing is zero.

Figure 1 shows the RCM domain and spatial distribution of the column-integrated aerosol forcing in April. The forcing is above 20 W/m^2 over India and the surrounding area. Consistent with the aerosol concentrations that are higher during the dry or winter monsoon season, the prescribed aerosol forcing increases gradually from zero in October to reach a maximum in April and declines rapidly to zero by the end of May. The same space-time varying aerosol forcing is applied each year in the INDOEX simulation. The difference between the control and INDOEX simulations represent the effects of the aerosol forcing on the regional climate of the region.

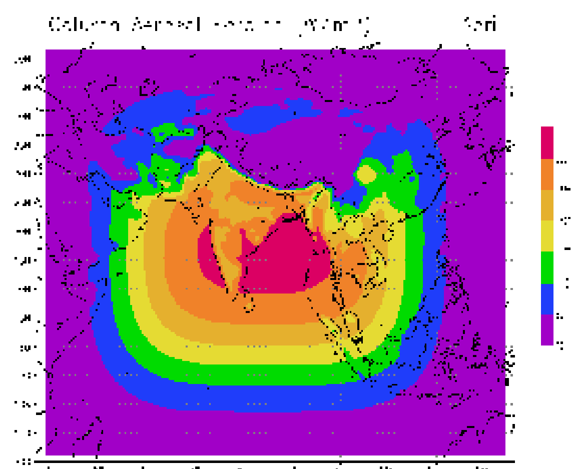


Figure 1. Column-integrated aerosol forcing prescribed in the INDOEX simulation averaged over April.

RESULTS

The RCM simulated realistically the contrast between the winter and summer monsoon rainfall in Asia. During DJF, there was little precipitation over India except near the southern tip. Precipitation over

China was also well simulated at less than 3 mm/day. During summer, the model correctly simulated the spatial distribution of precipitation over India, with heavy precipitation in the western Ghats. The monsoon rainfall in China, however, is too strong compared to the observations. During spring, the model also produced too much precipitation, especially over China, when compared with observations. The model also reproduced the seasonal and spatial variations of surface temperature very well. Larger temperature biases of less than 3^{o}C are found over the Tibetan Plateau, northwest and northeast India, and China, during different seasons.

As a result of the aerosol forcing, large changes occurred in the seasonal mean net solar radiation at the surface. During December-January-February (DJF), there is a net change of about –20 to –30 W/m^2 over India and Southeast Asia. In response to the larger imposed aerosol radiative forcing, reduction in the net solar radiation at the surface reaches –25 to –35 W/m^2 during March-April-May (MAM).

Figure 3 shows the difference in surface temperature between the INDOEX and control simulations for the winter (DJF) and spring (MAM) seasons when the prescribed aerosol forcing is stronger. Because aerosol reduces the solar radiation reaching the surface, there is a cooling up to 1^{o}C over most of India and Southeast Asia during the winter and spring seasons. However, surface warming is apparent over the Tibetan Plateau of up to 1^{o}C. This warming is associated with an increase in the net surface solar radiation of about 5 – 10 W/m^2. Since the aerosol forcing over the Tibetan Plateau is near zero (see Figure 1), this change in solar radiation is related to a reduction in cloud cover in the INDOEX simulation, which may result from changes in large-scale circulation induced by the aerosol forcing, rather than a direct response to the aerosol forcing. Analyses are being performed to further examine the physical and dynamical processes that are responsible for the changes over the plateau and changes in the hydrological cycle that may result from the warming.

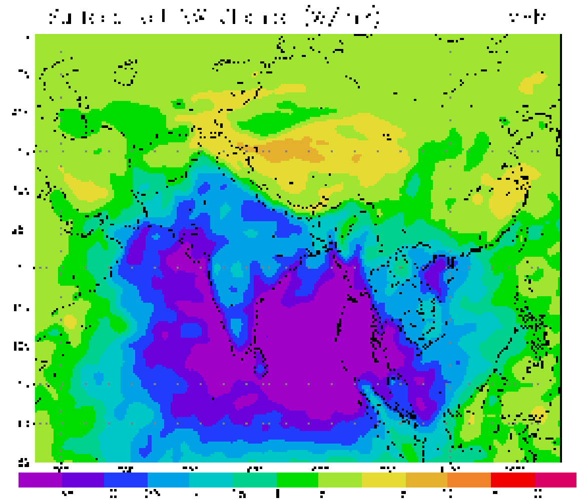


Figure 2. Mean seasonal change in net surface solar radiation (W/m^2) for spring(MAM).

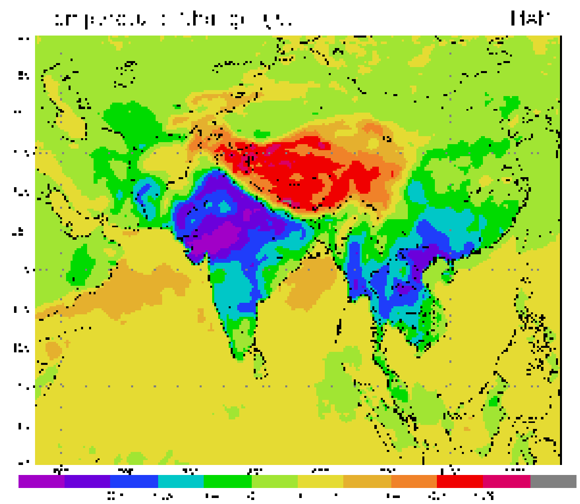


Figure 3. Mean seasonal surface temperature change (^{o}C) for DJF and MAM.

REFERENCES

Chung, C.E., V. Ramanathan, and J.T. Kiehl, 2002: Effects of the South-Asian absorbing haze on the Northeast Monsoon and surface-air heat exchange. *J. Clim*., **15(17)**, 2462–2476.

Grell, G., J. Dudhia, and D.R. Stauffer, 1993: A description of the fifth generation Penn State/NCAR mesoscale model (MM5). *NCAR Tech. Note., NCAR/TN-398+IA*, Nat. Cent. for Atmos. Res., Boulder, CO.

Leung, L.R., Y. Qian, and X. Bian, 2003: Hydroclimate of the western United States based on observations and regional climate simulation of 1981-2000. Part I. Seasonal Climate. *J. Clim*., **16(12)**, 1892-1911.

Leung, L.R., S.J. Ghan, Z.-C. Zhao, Y. Luo, W.-C. Wang, and H. Wei, 1999: Intercomparison of regional climate simulations of the 1991 summer monsoon in East Asia. *J. Geophys. Res*., **104(D6)**, 6425-6454.

Ramanathan, V., et al., 2001: Indian Ocean Experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze. *J. Geophys. Res*., **106**, 28371-28398.

Ramanathan, V. and P. J. Crutzen, 2003: Atmospheric Brown Clouds. *Atmospheric Environment*, **37**, 4033-4035.

Regional Climate Model Inter-comparison Project for Asia (RMIP)

C. B. Fu[1], S. Y. Wang[1], Z. Xiong[1], W. J. Gutowski[2], D. K. Lee[3], J. L. McGregor[4], Y. Sato[5], H. Kato[6], J.-W. Kim[7], M.-S. Suh[8] , J.M. Fong[1]

1) START Regional Center for Temperate East Asia, IAP/ Chinese Academy of Sciences, China: 2) Department of Geological and Atmospheric Sciences, Iowa State University, U.S.A.; 3) School of Earth and Environment, Seoul National University (SNU), South Korea; 4) Division of Atmospheric Research, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia; 5) Meteorological Research Institute/JMA, Atmospheric Environment and Applied Meteorology Research Department, Japan; 6) Central Research Institute of Electric Power Industry (CRIEPI), Japan; 7) Department of Atmospheric Sciences, Yonsei University, South Korea; 8) Department of Atmospheric Sciences, Kongju National University, South Korea

The Regional Climate Model Intercomparison Project (RMIP) for Asia has been developed to evaluate and improve regional climate model (RCM) simulations of monsoonal climate under joint support of the Asia-Pacific Network for Global Change Research (APN), Global Change System for Analysis, Research and Training (START), the Chinese Academy of Sciences and several projects of participating nations. The project currently involves 10 research groups from Australia, China, Japan, South Korea and the United States, as well as scientists from India, Italy, Mongolia, North Korea and Russia.

RMIP has three simulation phases, phase I: an 18 months run for the period of April 1997 – September 1998 to cover a full annual cycle and two extremes cases in monsoon behavior; phase II: a ten years run of January 1989 – December 1998 to examine simulated monsoon Climatology, and phase III: simulation of climate change scenario in 21st century nested with global model outputs. This paper presents RMIP goals, implementation design, and initial results for the first and second phases.

The objectives of RMIP for Asia are:

- To examine systematically the performance of a group of RCMs in Asia as the knowledge base for further improvement of the RCMs;
- To develop an ensemble of the results from a group of RCMs to be used for comparison with GCMs in order to assess the value of RCM in regional climate study;
- To develop scenarios of regional climate change in Asia by an ensemble of a group of RCMs nested with one or more GCMs.

The experiment is designed in a domain covered most of Asia continent, part of western Pacific, Arabian sea, Bay of Bengal and South China Sea, with the center at 35N/105E, 151°x111° in longitude and latitude, at 60km resolution; The 1°x1° Land cover data of ISLSCP and 0.5°x0.5° Topography data of NCAR are used in all models experiments which are driven by NCEP data with the lateral boundary conditions updated every 6 hours.

A key part of RMIP is validation of models with observations. To this end, we have assembled a rich database of 710 observing sites for which 514 have daily records. These sites provide observations of temperature and precipitation. We complement this database with gridded analyses of monthly precipitation from Xie and Arkin (1997), several fields from the NCEP-NCAR reanalysis (Kalnay et al.1996), and sea-level pressure from the Japan Meteorological Agency.

Preliminary results from Phases I and II can be summarized as follows:

(1) All the models can reproduce the spatial patterns of averaged annual, winter and summer temperature reasonable well, but with cold bias over the most areas of continent;

(2) The seasonal cycle and inter-annual variation of temperature are well simulated by all models, but the magnitudes are different from observation by about ±3 .

(3) The spatial pattern of seasonal total precipitation are well captured by nearly all the models, with the winter better than other seasons, but most models tend to overestimate the precipitation in arid and semi-arid regions of central Asia, especially in winter;

(4) The seasonal cycles of precipitation are well simulated, but not for the inter-annual variations.

(5) Most models can basically simulate the evolution of main rain belts, but there are significant differences among different models in against the observations.

(6) The ensemble mean fields of both temperature and precipitation, even in a simple scheme, are in better agreement with the observation than any single model in most cases, but it is not the case for the variability of precipitation.

A more detail analysis of 18 months run is made for the regions of China, Japan and Korea where more dense observation station data are available for validation. The ensemble average biases of temperature of 9 participating models simulation over China, Korea and Japan are –2.05, -0.3 and 0.0061 °C respectively for the summer of 1998 and –0.96, -2.99 and –2.81 °C respectively for winter of 1997. The ensembled precipitation bias of 9 participating models ranges from –5~6% in winter 1997. In summer 1998, the ensemble precipitation bias is up to -30% over Korea Peninsula, which is much more distinct than over China and Japan (-6% and 10% respectively).

Evaluation of a Dynamical Seasonal Climate Forecast System for Application in Queensland

Syktus[1], J.I., McKeon[1], G.M., Flood[1], N., Smith[2] I. and L. Goddard[3]

[1]Natural Resource Sciences Centre, Department of Natural Resources and Mines, 80 Meiers Road, Indooroopilly Qld 4068
[2]CSIRO Atmospheric Research, Aspendale, Vic 3095
[3]International Research Institute for Climate Prediction, New York, USA

This paper describes the results of research on the application of a dynamically downscaled seasonal climate prediction system at Queensland Department of Natural Resources and Mines (NR&M). The NR&M seasonal climate prediction system consists of a Global Climate Model (GCM) and double nested Regional Climate Model (RCM) that produces regional predictions at high resolution for Queensland. A study has been completed using this system forced with observed sea surface temperatures for period 1965-2000. The skill of the modelling system was evaluated in terms of spatial and temporal variability and the capacity to simulate extremes (defined as the 15th and 85th rainfall percentiles).

Major findings were that: (a) use of RCMs increased the accuracy of simulated rainfall; and (b) simulated ensemble average rainfall was more highly correlated with SOI than observed rainfall; and (c) when the output was linked to the Aussie Grass modelling system a comparison with the current SOI operational systems revealed similar or better performance than the benchmark statistical forecasting system when evaluated in terms of production and resource condition.

The NR&M seasonal climate prediction system has been run operationally using predicted sea surface temperatures since September 1998 at monthly intervals. Ensemble predictions with lead-times of 7 months allow a probabilistic approach to risk management. The model output forms part of the IRI Net Assessment Forecast utilised world-wide and successfully provided an early warning of increased chance of drought in eastern Australia in 2002.

Prediction of Regional Scenarios and Uncertainties for Defining EuropeaN Climate Change Risks and Effects -- PRUDENCE -- The Project

Jens H. Christensen and the PRUDENCE team

Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark
jhc@dmi.dk

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. 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, although increasing efforts are being made to produce higher resolution climate simulations, particularly at the regional scale. Simple models include, at best, a limited physical representation of the climate system. 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. Perhaps even more important, regional signals of climate change often reflect the coarse resolution and the patterns of change can be significantly altered when resolution is increased.

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

1. to address and reduce the above-mentioned deficiencies in projections;
2. 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;
3. 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:

i. appropriate computational resolution - obscures or precludes analysis of the events;
ii. long-term climate model integrations - drastically reduces their statistical significance;
iii. 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. 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 first synthesizing results obtained over more than two years of coordinated research efforts by a total of 21 European full partners from 9 countries and associated participants representing more than 4 additional countries are highlighted.

Variability of European climate in a heterogeneous multi-model ensemble

P.L. Vidale, R. Wegmann, C. Schwierz, D. Lüthi, C. Frei, C. Schär

IAC-ETH Zürich, Switzerland
pier-luigi.vidale@ethz.ch

Introduction

Recent work on climate change for Europe (Schär et al. 2004) has stressed once more the need to consider both changes in climate and changes in its variability. It is important to establish whether our understanding of variability in current climate is sufficiently advanced to support the investigation of the mechanisms and feedbacks involved in projected climate change. It is also of interest to understand to what degree the changes in variability are associated with changes in the atmospheric general circulation or are the result of local processes and feedbacks.

Based on current CRU and ERA analyses, we present a multi-model comparison of the simulation of interannual variability from the PRUDENCE (Christensen et al. 2003) model consortium, comprising both global and regional climate models.

Models and data

Results from the CHRM regional climate model (Vidale et al. 2003), forced with Hadley Center HadAM3 lateral boundary data, show a summer climate change signal very much in line with that produced by the other models in the PRUDENCE consortium (see Christensen et al. 2004, this issue) and particularly evident in southern Europe. Schär et al. (2004) showed however, for the same climate change experiment, that a large central European region, to the north of the main region of temperature/precipitation change, displays a sizeable increase in summer temperature (T_{2m}) variability.

Table1: list of PRUDENCE models and simulations used in this study

Institute	Driving Data HadAM3H A2				Model
	Control	ArrangeCode	Scenario	ArrangeCode	
DMI	HC1	a	HS1	b	HIRHAM
	HC2	c	HS2	d	
HC	achgi	e	ackda	f	HadRM 3H
	acdhd	g	acftc	h	HadAM3H A2
	acdhe	i	acfld	j	
ETH	HC_CTL	k	HC_A2	l	CHRM
GKSS	CTL	m	SA2	n	CLM
MPI	3003	o	3006	p	REMO
SMHI	HCCTL	q	HCA2	r	RCAO
UCM	control	s	a2	t	PROMES
ICTP	ref	u	A2	v	RegCM
KNMI	HC1	w	HA2	x	RACMO
CNRM	DA9 (1)	y	DE5 (2)	z	Arpège
	DE3 (1)	za	DE7 (2)	zb	
	DE4 (1)	zc	DE6 (2)	zd	

(1) Driving Data Observed SST
(2) Driving Data HadCM3 A2

We focus on summer (JJA) interannual variability of precipitation and temperature. The current climate (1961-1990) variability, as represented by all models and averaged over the region of maximum change in variability (central Europe) is summarized in Fig. 1 and also contrasted with that of two observational data sets: CRU and ERA40.

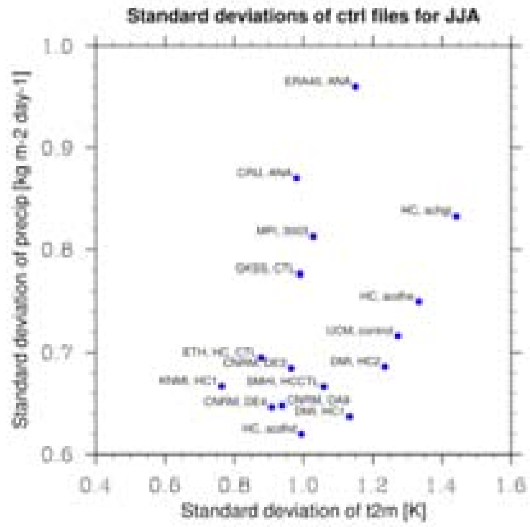


Fig 1. Summer temperature and precipitation interannual variability for current climate simulations (1961-1990)

It is clear from Fig. 1 that a fairly wide range of estimates are produced by the different simulations, but temperature variability is in the range of 0.7-1.5 K and precipitation variability within 0.6-1.0 mm per day. In general, the heterogeneous model ensemble seems to represent temperature variability fairly well, while underestimating precipitation variability.

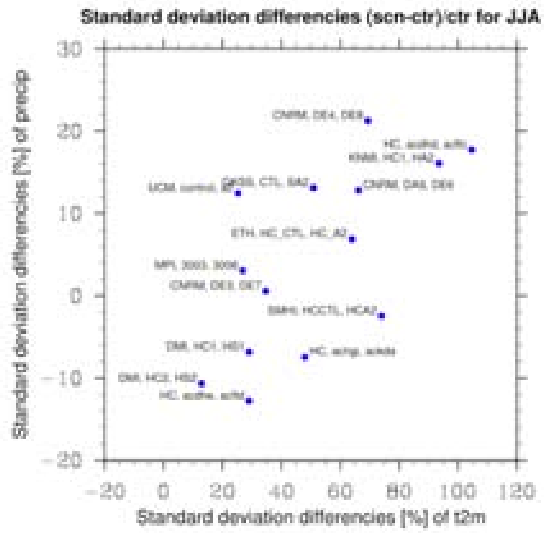


Fig 2. Summer (JJA) temperature and precipitation variability change for PRUDENCE models (2071-2100 versus 1961-1990).

For future climate, the Δ variability shows a central European signature recognizable in most model maps, while the area averaged values are shown in Fig. 2. It is of interest to notice that all model simulations show an increase in temperature variability (10-100%), while only five of the simulations show a decrease of precipitation variability. The Δ variability in the ensemble appears to be aligned along a diagonal line, so that a link between changes in temperature and precipitation variability seems to emerge.

Plots of the deviations (from each model's current JJA mean) of temperature, precipitation and soil moisture for the same region and period indicate, for the summer period, a tendency towards warm and dry conditions, also to be associated with negative soil moisture anomalies. Figure 3, in which current climate is shown in blue and scenario climate in red, shows four examples for the case of a very moderate change in variability (DMI experiments HC2/HS2) and a more prominent change in variability (HC experiments ACDHD/ACFTC). Both of these examples of deviations from the mean show that the shift in the scenario climate favors warmer and dryer summers, with shifts of opposite sign from the point of view of temperature and of soil moisture content.

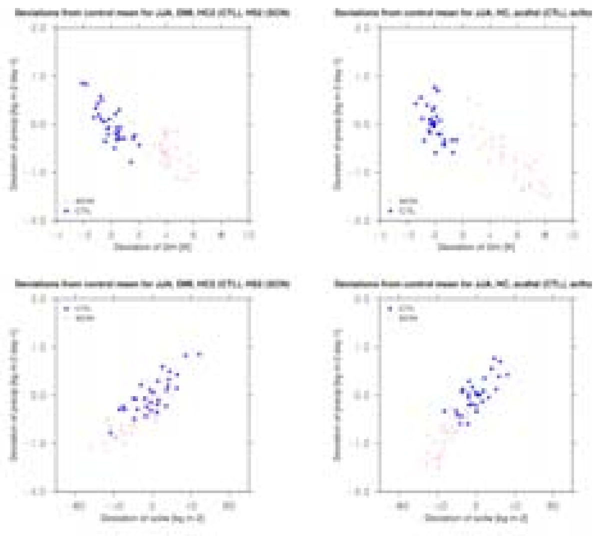


Fig 3. Summer (JJA) deviations of temperature/precipitation (top) and soil moisture/precipitation (bottom), in relation to 1961-1990 simulated climate.

This soil moisture-precipitation-temperature signature, present throughout the entire ensemble suggests a possible common mechanism, which is very likely activated in some portion of each summer: while with more winter precipitation (see Christensen et al., 2004, this issue) a full soil moisture recharge is more likely, a quicker snow melt and an earlier activation of vegetation in Spring will cause a steeper slope of the soil moisture loss curve, which could cause the soils to reach the wilting point at an earlier date in summer. This type of idealized seasonal evolution is illustrated in Fig. 4.

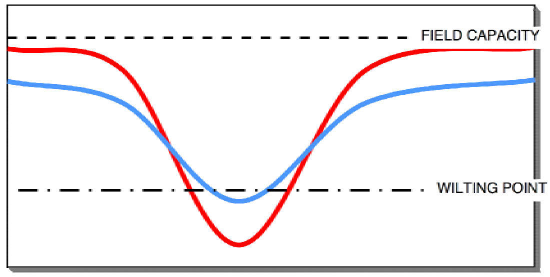


Fig 4. Idealized yearly evolution of root zone soil moisture for control (blue) and scenario (red) experiments. Axis runs from January to December, for a typical mean European climate.

Summary and future work

The analysis of an ensemble of climate change experiments reveals a common feature in the simulated scenarios, with a shift towards a larger number of warmer and drier summers. While a soil moisture-precipitation feedback mechanism is likely active in all models, it is necessary to also investigate the role of changes in the pressure distribution, which could affect the growth of the boundary layer and control convection, together with changes in the storm tracks. Further work on the possible existence of thresholds in the simulated climate needs to take into consideration the soil parameters used in each modeling system, with particular attention given to wilting point, which, if reached early in the summer season, could trigger the extended drought periods that are apparent in at least some of the simulations we have analyzed so far.

Acknowledgements

Numerical simulations described in this work were carried out at the ETH Computer Center in Zürich and at the Swiss Supercomputing Centre (CSCS) in Manno (TI).

References

Christensen, J.H., T. Carter, F. Giorgi, PRUDENCE Employs New Methods to Assess European Climate Change, *EOS*, Vol. 82, p. 147, 2002

Christensen, J.H., 2004: PRUDENCE - Model reproducibility and climate change, Lund Electronic Reports in Physical Geography, available at: http://www.natgeo.lu.se/Elibrary/LERPG/LERPG.html, Extended Abstract, 2pp.

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

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

PRUDENCE: uncertainty in the GCM and RCM response

M. Déqué

CNRM/Météo-France, Toulouse, France

In the framework of the PRUDENCE project, a large number of scenarios using different radiative forcings, different boundary conditions, and different models have been produced. Even if we restrict to seasonal mean systematic error and seasonal mean impact of a few fields, a comprehensive analysis requires a great wall to post all the figures from the various experiments. The human brain is very efficient to analyze the difference between two maps, provided they are located close to each other and use the same color palette and the same scale. But as the number of maps to cross-analyze increases, the task becomes difficult: one needs to mentally cluster the maps with similar features, which requires time, care, and memory.

Multidimensional Scaling (MDS, also named Proximity Factor Analysis) is a statistical technique which makes the cross comparison easier, at the cost of approximations. If we have 3 maps to analyze, we can plot the 3 maps, but we can also consider that this 3 maps belong to a plan in the phase space. This plan is characterized by one origin point, and two vectors: this gives 3 n-dimensional datasets (i.e. 3 new maps) if the maps have n grid points. But we have and additional information: the 3 original maps can be plotted as 3 points in this plan. In a single plot, one can see if the maps are aligned (scaling) or if two maps are close to each other (clustering). If we want to know which map is the closest to a 4th map, we just need to project this 4th map onto the plan and consider the position of the 4 points in the plot. This method is no more valid when we want to cross-analyze more than 3 maps, as there is little reason why the points belong to a common plan. Here we need MDS. This method uses the distance matrix to calculate the plan on which, after projection, the 2-d distances are are close as possible (in least square sense) to the original distances. The new distances are, by construction, smaller than the original ones, but we are often interested only by the relative positions of the points in the phase space, so this is not a problem. MDS applies to any kind of distances (correlation-based, mean absolute value, ...). However, in the case of quadratic (or euclidean) distances, MDS is simply an EOF analysis, in which the first two principal components are scaled by the square root of the corresponding eigenvalues.

MDS is applied to the systematic errors of 2m temperature and precipitation in DJF and JJA of 3 GCMs: CNRM, Hadley Centre, and MPI. It shows that the 3 models form a triangle inside which the observed climatology can be projected. When we consider the climate impacts of various scenarios through their 2-d projections, a different behavior is observed. All simulations are close to each other (temperature) or in the same quadrant (precipitation) with respect to present climate. This indicates that models respond with some agreement to an external forcing, although their systematic errors are completely different. Another interesting result is that B2 simulations are on a line connecting present climate and A2 simulation (scalability of the response).

A second method to analyze the ensemble of climate impact is to consider, at each grid point, the variance of the various simulations. The variance is not calculated with the full ensemble, but separately on sub-ensembles of simulations:

- using the same model, same boundary condition and same scenario
- using the same model and same boundary condition
- using the same model and same scenario
- using the same boundary condition and same scenario

We can thus identify the uncertainty due to sampling, scenario, boundary condition, and model. The global averages are given in Table 1.

A third method consists of setting error bars about the mean impact, based on the standard deviations calculated above. It has been applied only to model uncertainty. At each grid point, the standard deviation due to model is divided by the square root of the number of models (here 3), which yields the standard deviation of the mean of 3 models. A simple confidence interval is the mean impact plus or minus two standard deviation. The minimum impact is defined at each grid point as the interval boundary which has the lesser absolute value. For temperature, this is always mean minus two standard deviations. Thus a map of minimum impact can be plotted against the map of mean impact. In areas where the 3 models agree on the response, the minimum impact is close to the mean impact; otherwise it is weak. The patterns of the mean and minimum impact are similar for temperature. The global average is 3.3K (DJF) and 3.1K (JJA) for the mean impact, 2.8K (DJF) and 2.5K (JJA) for the minimum impact. As far as precipitation is concerned, only a few features remain significant in the minimum impact: increase over the tropical Pacific and winter midlatitudes, decrease over Southern Pacific Convergence Zone, North East Brazil, and Carribean Sea.

This triple approach has also been applied on the European domain to the 3 GCMs. It has also been applied on the European domain to the 10

RCM involved in PRUDENCE (models from CNRM, DMI, ETHZ, GKSS, Hadley Centre, ICTP, KNMI, MPI, SMHI and UCM). All the results and maps are available in a technical report of the PRUDENCE project.

Table 1: Mean standard deviation due the 4 sources of uncertainty for temperature (K) and precipitation (mm/day) in DJF and JJA for the GCMs over the globe.

	T DJF	T JJA	P DJF	P JJA
sampling	0.3	0.3	0.3	0.3
scenario (A2/B2)	1.1	0.8	0.3	0.3
boundary condition	1.9	2.0	0.5	0.5
model	0.8	1.0	0.5	0.6

Impacts of model physics and dynamics on summertime inter-annual variability in regional climate models.

Geert Lenderink, Bart van den Hurk, Aad van Ulden and Erik van Meijgaard

Atmospheric Research Devision, KNMI, De Bilt, The Netherlands
lenderin@knmi.nl

Introduction

The inter-annual variability of the monthly mean temperature in summer is studied in 9 different RCM simulations of the present-day climate as performed in the PRUDENCE project (http://prudence.dmi.dk and Christensen et al. 2002). All RCMs are driven by the same HadAM3H boundaries, and their behavior is compared to the CRU TS2.0 monthly mean time series from 1960-1990 (Mitchell et al. 2004) and to the fields in the driving HadAM3H simulation.

Variability

Figure 1 shows that the inter-quantile range between the 90% and 10% quantile of the monthly mean temperature in JJA is overestimated in most parts of Europe in the global HadAM3H simulation, in particular by 1-2 ^{o}C in France, Spain and southeastern Europe. The downscaling with the regional model HadRM3H (same physics) causes a significant increase in temperature variability, which is now clearly much larger than observed. On the other hand, the temperature variability in KNMI model RACMO2 (Lenderink et al. 2003) is (much) close(r) to the observations.

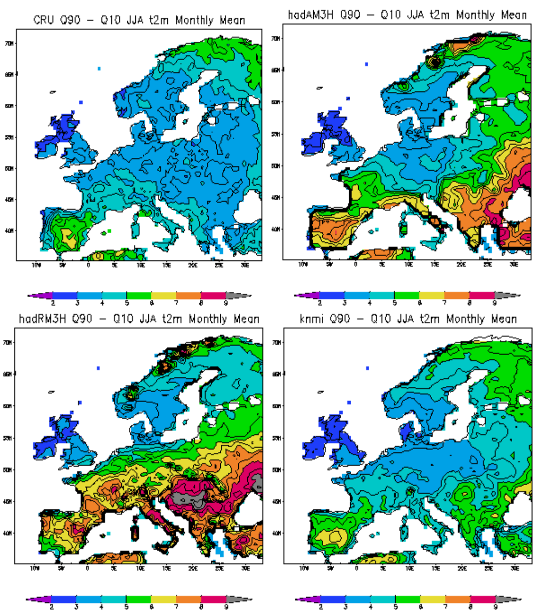


Fig 1 Inter-quantile range between the 90% and the 10% quantile of monthly mean temperature (for JJA) in the CRU TS2.0 observational data set, in HadAM3H, and in two RCMs, HadRM3H and RACMO2.

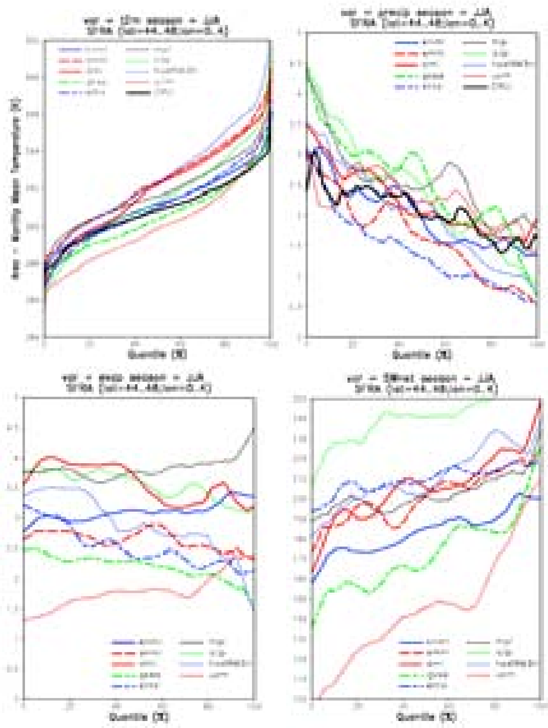


Fig 2. Quantile plot of the area-averaged monthly mean temperature for southern France, with the corresponding (as a function of temperature quantile, slightly filtered) precipitation, evaporation (both mm/day) and net shortwave radiation at the surface (W/m2) (1mm/day corresponds to 30 W/m2)

Figure 2 shows a quantile plot of the area-averaged temperature over France. Most RCMs tend to overestimate the temperature of the highest quantiles in France by two degrees or more. The slope of the temperature curve is also steeper than observed. The corresponding precipitation shows a steeper temperature dependency in most RCMs, with most models over (under) estimating precipitation for the coldest (warmest) summer months. Temperature and shortwave radiation are positively correlated in all RCMs, but the relation between temperature and evaporation is not unique: some RCMs display decreasing values of evaporation for the warmest months (e.g. HadRM3H), signifying the evaporation control of the dry soil, while others sustain high evaporation rates. Also note that for shortwave radiation, despite the large spread between the extremes, five RCMs are rather close to each other. For evaporation, all RCMs are different, and no clustering is seen.

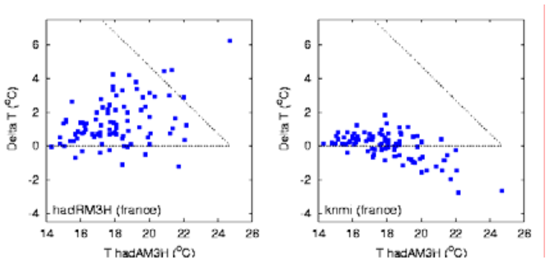


Fig. 3. Temperature difference between RCM (l.h.s.: HadRM3H; r.h.s.: RACMO2) and HadAM3H simulation, as a function of temperature in HadAM3H, for an area average in France.

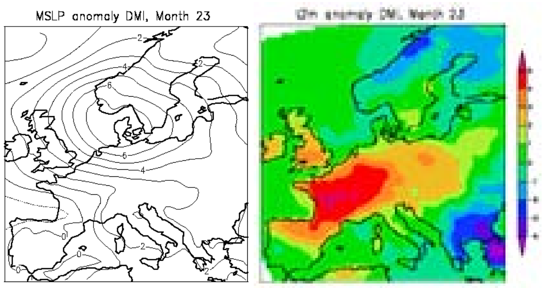


Fig 4. Temperature and mean sea level pressure anomaly (RCM-HadAM3H) (corrected for the mean bias between RCM and HadAM3H) for one typical month

Several RCMs simulate temperatures for France that deviate strongly from the temperature in the driving HadAM3H model, as shown e.g. for HadRM3H in Fig. 3, whereas in other RCMs [e.g. RACMO2 and RCAO (SMHI)] the temperature remains much closer to the HadAM3H temperatures. Further inspection revealed that, in general, the same models that deviate strongly from the HadAM3H temperatures are also characterized by a larger inter-annual variability in monthly mean summer temperatures (with the exception of RCAO).

To illustrate the potential cause for this behavior in one RCM, we show in Fig. 4 the temperature anomaly for one month with high temperatures in the RCM but only average temperatures in HadAM3H. A clear temperature anomaly over southwestern Europe is seen. At the same time, the RCM has developed a significant pressure anomaly with a high-pressure anomaly of 7 hPa over Denmark – note that these are monthly means. Related to this pressure anomaly are southeasterly winds over France, which is consistent with the temperature anomaly over that area.

After this rather anecdotic example, we computed pressure anomalies between the ten warmest and ten coldest months in France. Taking the temperature of the RCM, five out of 9 RCMs had pressure anomalies that deviated significantly from the HadAM3H pressure fields. Figure 5 shows the case for HIRHAM, where a much stronger "blocking" situation is shown in the RCM pressure fields than in the driving fields (note that these are the same months). A similar analysis, but now using the months with extreme temperatures in the HadAM3H simulation, showed that in that case the pressure deviations were much smaller.

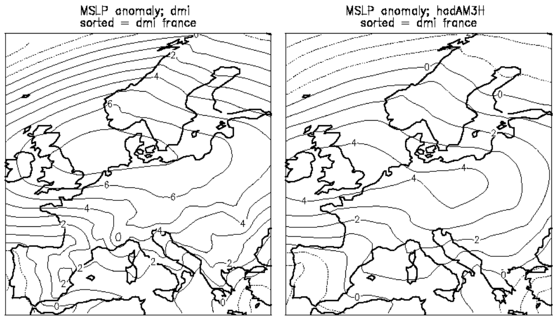


Fig 5. Mean pressure anomaly in HIRHAM between the 10 warmest and 10 coldest months in HIRHAM (dmi) (l.h.s.), and the pressure anomaly in the HadAM3H simulation for the same months (r.h.s.)

Discussion

There is a considerable spread in the ability of the RCMs to develop their own internal dynamics. In general, those models that are lively with respect to the dynamics also reveal the largest temperature variability. Two natural questions are: i) what is cause and effect, and ii) are these deviating dynamics physically realistic, or are they (for example) caused by numerical artefacts due to inconsistencies at the lateral boundaries. Influences of the domain (size and location), boundary relaxation schemes, and physics should be explored more thoroughly. As such, experience with the KNMI model RACMO2 showed that the influence of the boundary relaxation scheme and the formulation of soil (moisture) scheme can be significant (Lenderink et al. 2003).

Acknowledgement

We would like to thank the PRUDENCE community, and in particular Ole Christensen, for providing the data.

References

Christensen, J.H., T. Carter, F. Giorgi, PRUDENCE Employs New Methods to Assess European Climate Change, *EOS*, Vol. 82, p. 147, 2002

Mitchell, T.D. Carter T.R., Jones P.D., Hulme H., and New M., 2004: A comprehensive set of high resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Submitted to J. of Climate.

Lenderink, G. et al., 2003: Simulation of present-day climate in RACMO2: first results and model developments. KNMI technical report TR-252.

Validation and changes of extreme precipitation simulated by the regional climate model HadRM3H/HadAM3H.

Erasmo Buonomo and Richard G. Jones

Hadley Centre, Met Office, Exeter, UK
Erasmo.Buonomo@metoffice.com

Introduction

An analysis of the precipitation obtained from the regional climate model HadRM3H/HadAM3H has been carried out, in order to assess the skill in reproducing the present climate and investigate the changes in the future under a climate change scenario.

Simulated and observed data

Two ensembles of three simulations have been performed as part of the EU project PRUDENCE, one for the present climate (1960-1990) and the other for the SRES A2 emission scenario (2070-2100). The domain includes Europe and part of North Africa. The quality of the extreme precipitation has been assessed by comparing the return levels obtained from the Generalized Extreme Value (GEV) distributions fitted to the annual maxima, with confidence intervals estimated with the profile likelihood method.

Two duration periods have been considered, 1 day and 30 days; the latter has been included to study the effect of periods of persistent high rainfall.

The results of the analysis have been validated by comparing with the daily precipitation dataset for Great Britain, generated at the Centre of Ecology and Hydrology (CEH) by aggregating rain-gauge data over the RCM grid.

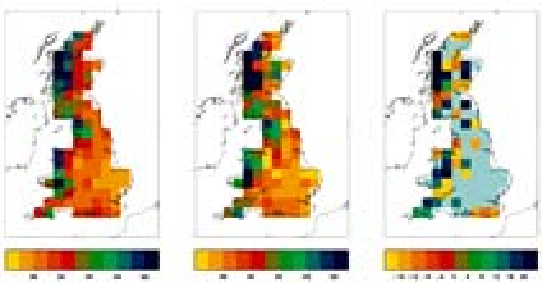


Fig 1. Return levels for the 2-years return period, from annual maxima of 1-day duration.. Left, CEH observation (1960-90), mm/day; centre, HadRM3H ensemble, mm/day; right, percentage of difference between simulated and observed results

Results

The results from the validation show the ability of the RCM to capture the patterns of the spatial distribution of extremes, with the tendency to overestimate rainfall on the mountains and negative bias on the Western side of Great Britain, as shown in fig. 1.

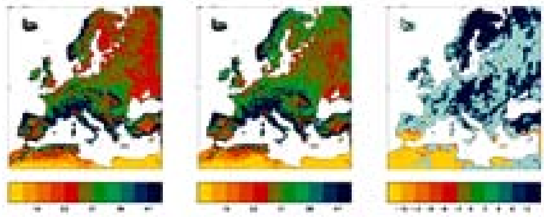


Fig 2.Return levels for the 2-years return period, annual maxima for 1-day duration.. Left, present climate HadRM3H ensemble (1960-1990), mm/day; centre, SRES A2 scenario ensemble (2070-2100), mm/day; right, percentage of change between future and present climate

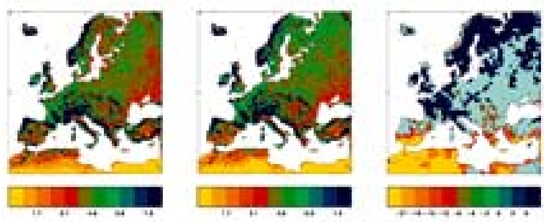


Fig 3 .Same as Fig. 2 for 30-days duration.

Changes due to the climate change scenario have been estimated for the whole domain of the simulation. The simulated change of average annual precipitation (not reported here) shows a reduction of rainfall over Central and Southern Europe. With the exception of North Africa, the results for extremes show significant increase of return levels over large areas in Europe for the 1-day events (Figure 2); the analysis for the 30-days period (Figure 3) gives a limited increase of the areas with reduction of extreme rainfall and shift in pattern of the areas of significant changes over Central Europe, suggesting the need to consider different duration periods when assessing the impact of increased precipitation extremes.

Assessment of quality and uncertainty in regional climate simulations

Klaus Keuler, Alexander Block, Eberhard Schaller

Dept. of Environmental Meteorology, Brandenburg University of Technology, Cottbus, Germany
keuler@tu-cottbus.de

Introduction

The interpretation of climate simulations requires a detailed knowledge of the accuracy or in fact of the uncertainty by which the applied models are able to represent the climate conditions of a selected period. A simple visual comparison of a model result with an appropriate observational data set is insufficient to assess the quality of the simulation. Objective quantitative methods are additionally required to determine the distance between the simulated and observed climate conditions. As well as different models or model configurations yield different realizations of the same climate period, the observational reference data – gridded data sets for a set of climate parameters – also provide only an image or approximation of the true conditions. We must therefore act on the assumption that both parts of the evaluation, the simulated and the observed 'reality', should always be represented by an ensemble of realizations (see Fig 1). The quality of the simulated 'reality' is then quantified by a set of distances calculated between each member of the simulation ensemble with each member of the observation ensemble. The resulting ensemble of distances characterizes the range of uncertainty for the quality of the climate simulations.

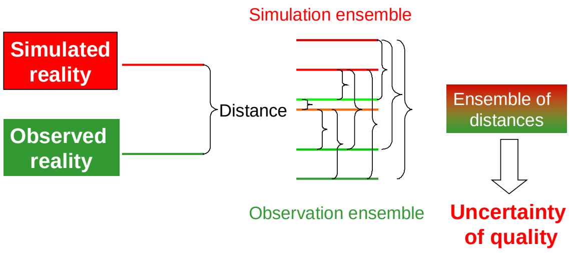


Fig 1. Scheme for a multi-model and multi-observation ensemble approach to quantify the uncertainty of climate model quality.

Model simulations and data sets

Three different high-resolution regional climate models – two versions of the hydrostatic model REMO (BTU, MPI) and a climate version of the non-hydrostatic mesoscale model MM5 (IMK) – were used to simulate the period from 1979 to 1993 for Central Europe. The time-dependent boundary values required for the dynamical nesting procedure were interpolated from ECMWF reanalysis data ERA15 to the regional model grids with a horizontal resolution of about 18 km.

Different data sets of the Climate Research Unit (CRU), from ECMWF reanalyses and a specially compiled high-resolution data set of the German Weather Service (DWD) are used as reference data, to compare the model results with observed or analyzed climate conditions of the simulated period. A set of well defined key figures is introduced to measure the distances between the simulated and the reference data for

- the horizontal distribution of long-term means,
- the annual cycle of long-term area means.

The distances are quantified for classical climate parameters like the mean sea-level pressure (MSLP), the 2-meter temperature (T_{2m}), the amount of precipitation (pp), the diurnal temperature range (DTR), and the horizontal near surface wind velocity (v_{10m}) as well as for the short- and long-wave radiant flux densities at the top of the atmosphere and at the ground, the sensible and latent heat fluxes at the surface and finally for the frequencies of specific events like the number of days with significant (pp>1mm) or intense (pp>10mm) precipitation, the number of frost-, ice- and summer-days, and the number of days with snow cover.

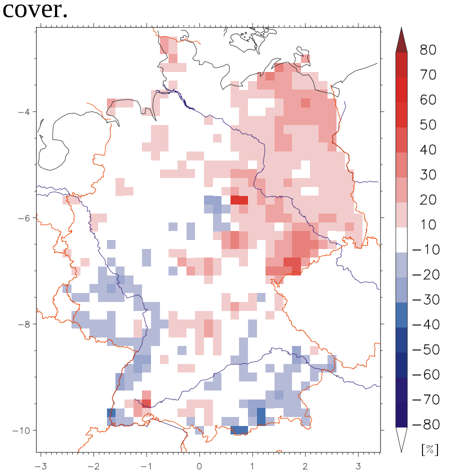


Fig 2. Relative difference between the 15-year mean annual precipitation simulated with MM5 and the corresponding reference data of DWD in percent.

Results

The evaluation procedure to determine the quality of the regional climate models and its range of uncertainty shall be demonstrated in the following on the basis of the simulated precipitation for the area of Germany. Fig 1 gives an example for the horizontal distribution of the precipitation deviations between one of the simulations and one of the reference data sets. For a more detailed quantification of the deviations the cumulated frequency distribution of the grid-box differences (as shown in Fig 1) is calculated. The resulting percentiles for the differences between several data sets and the DWD reference data are given in Fig 3. The median of the relative deviations varies between 8 and 12 percent. For 95 % of the area of Germany the deviations are not larger than between 26 and 42 %, depending on the pair of data sets being compared. The deviations of the reference data CRU and ERA are of the same order of magnitude as the deviations between model and reference data.

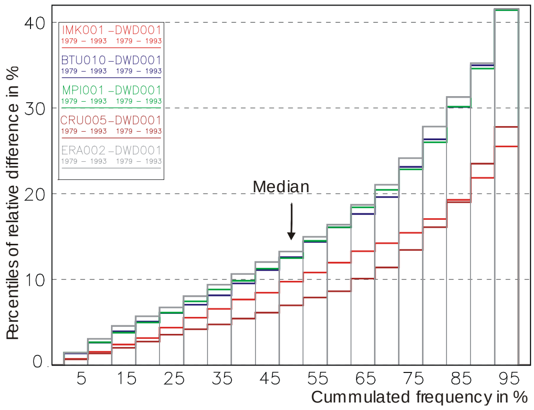


Fig 3. Frequency distribution of relative grid-box differences for mean annual precipitation of sub-region Germany calculated between the three model simulations IMK, BTU, MPI and the reference data of DWD and between the other two reference data CRU, ERA and the DWD data.

The annual cycles of mean monthly precipitation for all six data sets are given in Fig 3. The course of all curves is very similar. The deviations of the simulations from the reference data are again comparable to the differences between the reference data itself.

For an objective quantification of the distances between the horizontal distributions of the annual means (see Fig 1) of two data sets and between the temporal developments of their area means for a specific sub-region (see Fig 3) the following key figures were selected and calculated.

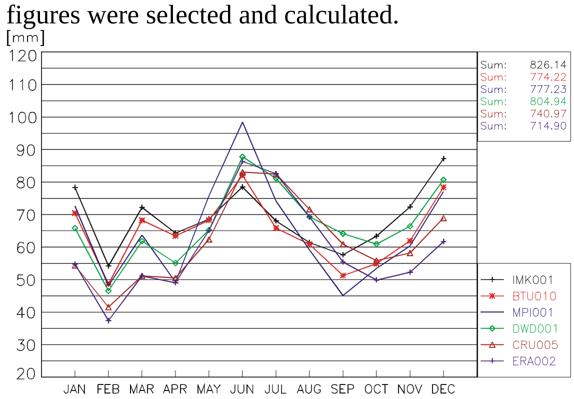


Fig 3. Mean annual cycle of precipitation for Germany from model simulations (IMK, BTU, MPI) and reference data (DWD, CRU, ERA). Annual amounts are given in the upper right panel.

Distance measures for horizontal patterns:

- difference of the area means (BIAS),
- root mean square error/difference of grid-box values (S-RMSE),
- ratio of spatial variances (RSV),
- pattern correlation between the horizontal distributions of the anomalies (PACO).
- Distance measure for annual cycles:
- root mean square error/difference (T-RMSE),
- ratio of temporal variances (RTV), and
- temporal correlation of the time series of monthly means (TCO),
- ratio of the yearly amplitudes (ROYA) and
- mean absolute monthly difference of the climatological annual cycles (MAMD).

The following table summarizes the ranges of the distance measures as calculated for the area of Germany from the intercomparisons of the different model simulations with all available reference data for 5 different climate parameters.

	MSLP (hpa) (unit=1)	**T_{2m} (K) (unit=1)**	**pp (mm/year) (unit=1)**	**DTR (K) (unit=1)**	**V (m/s) (unit=1)**
BIAS	**-0.5 – 0.8**	**-1.1 – 1.0**	**-31 – 105**	**-1.2 – 0.9**	**0.8 – 1.0**
S-RMSE	**0.6 – 1.1**	**0.3 – 1.2**	**108 – 194**	**0.5 – 1.3**	**0.9 – 1.9**
RSV	**1.3 – 1.5**	**0.35–0.94**	**0.65– 2.51**	**0.60– 1.79**	**0.60 – 0.96**
PACO	**0.98–0.99**	**0.79–0.96**	**0.45– 0.90**	**0.67– 0.79**	**0.73 – 0.76**
95 Percent.	**0.9 – 1.5**	**0.5 – 1.7**	**26 – 42 %**	**0.9 – 2.2**	**1.5 – 1.7**
T-RMSE	**0.9 – 2.1**	**1.1 – 1.7**	**11.7 -18.9**	**0.7 – 1.8**	**0.8 – 1.0**
RTV	**1.10–1.33**	**0.92–1.40**	**0.84– 1.26**	**0.50– 1.95**	**1.02 – 1.86**
TCO	**0.91 – 1.0**	**0.99 – 1.0**	**0.75– 0.90**	**0.82– 0.96**	**0.86 – 0.96**
ROYA	**1.02–1.16**	**0.96-1.19**	**0.68– 1.29**	**0.80– 1.36**	**0.95 – 1.55**
MAMD	**0.7 – 1.1**	**0.7 – 1.1**	**6.6 – 14.1**	**0.3 – 1.2**	**0.8 – 1.0**

These numbers quantify the accuracy of the applied regional models to reproduce the climate conditions of Germany as they are known from different observational or analyzed data sets. For example, the simulated annual MSLP has an area mean uncertainty range (BIAS) for Germany of -0.5 to 0.8 hPa. Its spatial (PACO) and temporal correlation (TCO) to the reference data is very high, but the temporal variance (RTV) and therefore also the amplitude of the climatological annual cycle (ROYA) are overestimated by the simulations between 10–33 % and 2–16 %, respectively.

Perspective

As a next step the same distance measures will be calculated between the ensembles of a scenario and a control experiment. The comparison of these values with the quantified uncertainty ranges of the evaluation experiments should give more evidences whether the simulated changes are reliable or not.

European discharge as simulated by a multi-model ensemble

Stefan Hagemann and Daniela Jacob

Max Planck Institute for Meteorology, Bundesstr.55, 20146 Hamburg, Germany
Hagemann@dkrz.de

Introduction

Several regional climate models (RCMs) participate in the European project PRUDENCE, which aims to predict uncertainties in RCM simulations over Europe. The RCMs comprise the ARPEGE model (Déqué et al. 1998) of Météo-France (CNRM), a modified version of the German Weather Service's 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) 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.

One of the tasks of MPI is to perform hydrological studies that include both their own RCM simulations and those from other RCMs. A special focus is put on the discharge from large European rivers. The discharge will be 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 is necessary to perform additional analyses to partition total runoff into components that represent fast and slow responses. This is 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 is used which additionally uses RCM evapotranspiration as input. As a first step, the discharge is simulated for the RCM control simulations.

Results

In order to evaluate the simulated discharge, a validation of the simulated hydrological cycle is also performed. Here, several large European catchments are 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.

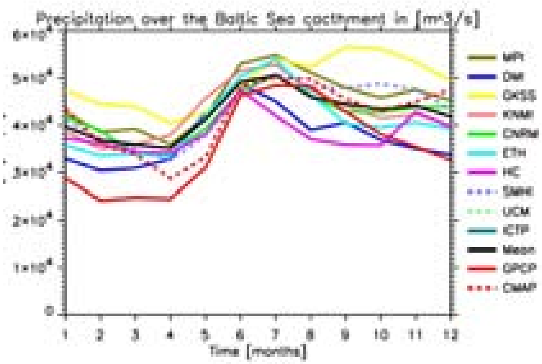


Fig 1. Precipitation over the Baltic Sea catchment. Unit: m^3/s

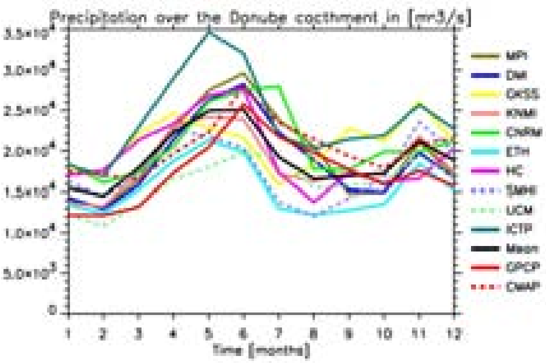


Fig 2. Precipitation over the Danube catchment. Unit: m^3/s

Fig. 1 and 2 show that both problems still exists for most of the RCMs, and they also become visible in the multi-model ensemble mean. Observations comprise CMAP (Xie and Arkin 1997) and GPCP (Huffman et al. 1997) precipitation data. CMAP precipitation data are not corrected for the systematic undercatch of precipitation gauges which is especially significant for snowfall. For GPCP data, a correction has been applied which is known to be too large by a factor of about 2 (Rudolf, personal communication, 2001) so that the actual precipitation amounts are expected to be in between GPCP and CMAP.

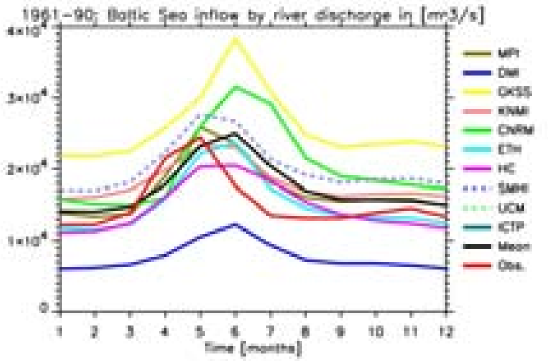


Fig 3. Inflow into the Baltic Sea. Unit: m^3/s

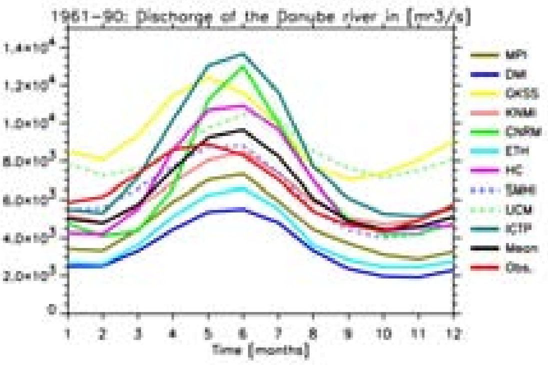


Fig 4. Discharge of the Danube river. Unit: m^3/s

Fig. 3 and 4 show the simulated discharges into the Baltic Sea and for the Danube river. The intercomparison of the simulations shows that a large spread exists between the models. The multi-model ensemble mean is usually closer to the observations than each of the models, especially if several catchments and variables are considered.

Acknowledgement

I would like to thank all PRUDENCE members who provided data to the DMI data server, especially Ole Bossing Christensen (DMI), Pier Luigi Vidale (ETH), Enrique Sanchez (UCM), and Xunqiang Bi who helped me to solve problems with the data, as well as Ahmed Qureshi (MPI) for his technical support.

References

Christensen JH, Christensen OB, Lopez P, van Meijgaard E, Botzet M, The HIRHAM 4 regional atmospheric climate model. *Danish Meteorological Institute, Scientific Report*, 96-4, 1996

Déqué M, Marquet P, Jones RG, Simulation of climate change over Europe using a global variable resolution general climate model. *Clim Dyn*, 14,:pp. 173-189, 1998

Doms G, Steppeler J, Adrian G, Das Lokal-Modell LM. *Promet*, 27, No. 3/4, pp. 123-129, 2002

Gaertner, MA, Christensen OB, Prego JA, Polcher J, Gallardo C, Castro M, The impact of deforestation on the hydrologic cycle in the western Mediterranean: An ensemble study with two regional models. *Clim Dyn*., 17, pp. 857 873, 2001

Giorgi, F, Mearns LO, Marinucci MR, Bates GT, Development of a second-generation regional climate model (Regcm2). Part I: Boundary-layer and radiative transfer processes. *Mon. Wea. Rev.*, 121, pp. 2794 2813, 1993a

Giorgi, F, Mearns LO, DeCanio G, Bates GT, Development of a second-generation regional climate model (Regcm2). Part II: Convective processes and assimilation of lateral boundary conditions. *Mon. Wea. Rev.*, 121, pp. 2814 2832, 1993b

Hagemann S, Dümenil Gates L, Validation of the hydrological cycle of ECMWF and NCEP reanalyses using the MPI hydrological discharge model. *J Geophys Res* 106: pp. 1503-1510, 2001

Hagemann S, Dümenil Gates L, Improving a subgrid runoff parameterization scheme for climate models by the use of high resolution data derived from satellite observations, *Clim. Dyn.* 21, pp. 349-359, 2003

Hagemann, S., B. Machenhauer, R. Jones, O.B. Christensen, M. Deque, D. Jacob, and P.L. Vidale, Evaluation of Water and Energy Budgets in Regional Climate Models Applied Over Europe, *Clim. Dyn*, accepted, 2004

Huffman, G.J., R.F. Adler, A. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, R.J. Joyce, A. McNab, B. Rudolf, U. Schneider und P. Xie, The Global Precipitation Climatology Project (GPCP) combined precipitation data set, *Bull. Amer. Meteor. Soc.*, 78, 5-20, 1997

Jacob D, A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin. *Meteorol Atmos Phys* 77: pp. 61-73, 2001

Jones RG, Murphy JM, Noguer M, Simulation of climate change over Europe using a nested regional climate model. I: Assessment of control climate, including sensitivity to location of lateral boundaries. QJR Meteorol Soc 121, pp. 1413-1449, 1995

Lenderink G, van den Hurk BJJM, van Meijgaard E, van Ulden AP, Cuijpers H, Simulation of present-day climate in RACMO2: First results and model developments. *KNMI Technical Report* 252, 24 pp., 2003:

Lüthi D, Cress A, Davies HC, Frei C, Schär C, Interannual variability and regional climate simulations. *Theor Appl Climatol* 53, pp. 185-209, 1996

Räisänen J, Hansson U, Ullerstig A, First GCM-driven RCAO runs of recent and future climate. In SWECLIM Newsletter No. 12, pp. 16-21, 2002

Xie, P., und P. Arkin, Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates and numerical model outputs, *Bull. Amer. Meteor. Soc* , 78, 2539-2558, 1997.

Daily variability in temperature and precipitation: Recent and future changes over Europe

Erik Kjellström

Rossby Centre, SMHI, SE 60176 Norrköping, Sweden, Erik.Kjellstrom@smhi.se

Introduction

Changing variability in daily temperature and precipitation in the European region is studied under recent, present, and simulated future climatic conditions. Changes in the probability distributions for these variables are studied. It is shown how the asymmetry of these distributions changes differently depending on location and season.

Models and data

Results from the Rossby Centre Regional Climate Model System (RCAO) are used in this work. The RCAO and the simulations are described in more detail in Räisänen et al., (2003; 2004). Daily variability in the RCAO results is studied in Kjellström (2004). Here, the RCAO results are compared to results from other European centers running RCMs with different configurations within the PRUDENCE project (Christensen et al., 2002). The RCMs have been run for the future time period 2071-2100 using SRES emission scenarios A2 and B2 (Nakićenović et al., 2000) and for a control time period (1961-1990). All models have been run with forcing boundaries from the Hadley Centre AGCM HadAM3H (Gordon et al., 2000). In addition RCAO and the model from the Danish Meteorological Institute (DMI) have been run with forcing boundaries from ECHAM4/OPYC3 from the Max-Planck Institute for Meteorology (Roeckner et al., 1999). The horizontal resolution of the RCMs has been in the order of 50 km for most of the models.

Results and discussion

Figure 1 shows simulated changes in the probability distribution for summertime temperature at the 2m-level in one gridbox close to Paris in France. It is clearly seen that the distribution broadens and gets less skewed in the future climate compared to the control period. The largest changes are on the warm side of the distribution. For instance, the 99th percentile increases with about 12 oC while the median increases with “only” 9 oC. This kind of larger temperature increase in warm days compared to the mean is simulated in a zone stretching across Europe in east-westerly direction (Figure 2). This zone is connected to large changes in the water cycle (not shown). Cloud cover, precipitation and soil moisture show large decreases in this area in the future scenarios compared to the control climate.

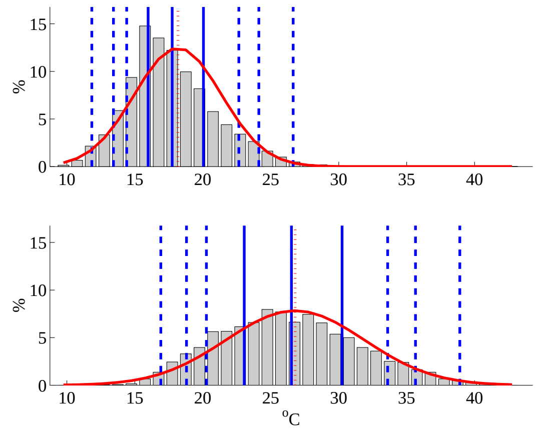


Fig 1. Summer (JJA) 2m-temperature in a gridbox in France. The upper (lower) panel shows the control climate (A2 scenario). RCAO has been run with lateral boundaries taken from ECHAM4/OPYC3. The bars show daily data (N=2700), the blue lines are percentiles (1^{st}, 5^{th}, 10^{th}, 25^{th}, median, 75^{th}, 90^{th}, and 99^{th}) and the red full line is a Gaussian fit to the data.

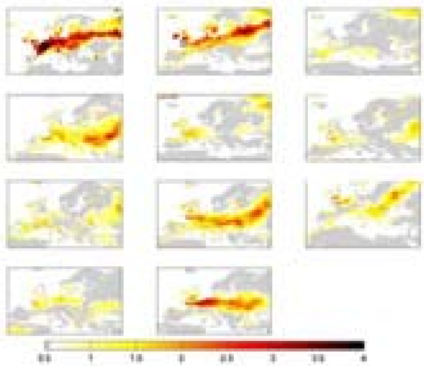


Fig 2. Summer (JJA) change in daily 2m-temperature (°C) between A2 and control. Shown is the change in the 95^{th} percentile minus the change in the median. Each panel represents one experiment from the PRUDENCE groups (models). Top row from left: Hadley Centre (HadAM3H – global driving model), Hadley Centre (HadRM3H) and MPI-met (REMO). 2^{nd} row: KNMI (RACMO), GKSS (CLM) and ETH (CHRM). 3^{rd} row: DMI (HIRHAM), SMHI (RCAO) and ICTP (RegCM3). The last row shows the simulations from DMI and SMHI with driving boundaries taken from ECHAM4/OPYC3.

Likewise, temperature on cold days in winter increase much more than the average temperature increase. This is exemplified in Figure 3 that illustrates the simulated temperature change in Stockholm (panels to the right).

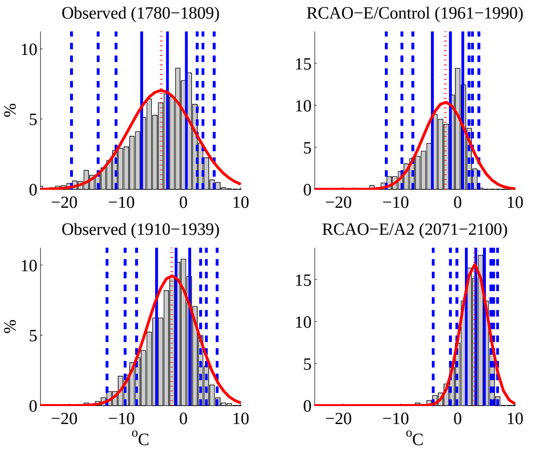


Fig 3. Winter (DJF) 2m-temperature in Stockholm, Sweden. To the left are observations from two time periods (Moberg et al., 2002). The top (bottom) panel shows the period with the coldest (warmest) 30-yr DJF mean in the time series dating back to 1756. To the right are the simulations from RCAO driven with lateral boundaries taken from ECHAM4/OPYC3.

Larger changes in temperatures on cold days as compared to average temperatures is a general feature in large parts of the model domain during winter (Figure 4). The area in eastern Europe with the largest differences is to a large degree coinciding with the simulated changes in snow cover (not shown).

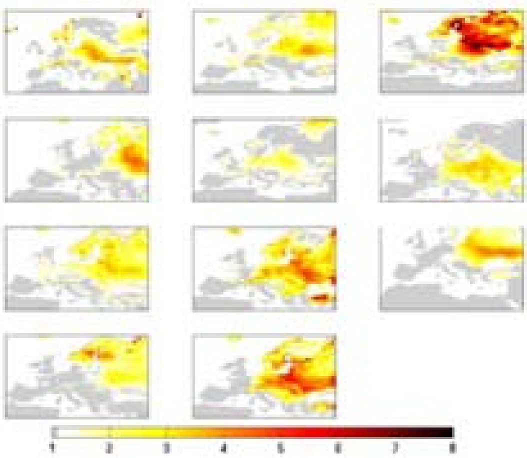


Fig 4. Winter (DJF) change in daily 2m-temperature between A2 and control. Shown is the change in the 5th percentile minus the change in the median. See Figure 2 for explanations of what is shown in each panel. Unit: °C.

A comparison with historical data on wintertime temperature in Stockholm shows that the model simulated and observed changes in daily variability is similar (Figure 3, compare panels to the left with panels to the right). In particular, the much stronger increase in temperatures on cold days compared to the average temperature increase as observed in warm compared to cold historical periods is simulated also by the model for this specific location.

The contribution from heavy precipitation events is simulated to increase over most parts of Europe in all seasons (not shown). This is the case not just in northern Europe where total precipitation is simulated to increase but also in many areas in southern Europe where total precipitation is simulated to decrease.

Acknowledgements

This work is a part of the European PRUDENCE project (project EVK2-CT2001-00132 in the EU 5th Framework program for Energy, environment and sustainable environment.

References

Christensen, J.H., T. Carter, F. Giorgi, PRUDENCE Employs New Methods to Assess European Climate Change, *EOS*, Vol. 82, p. 147, 2002

Gordon, C., et al., The simulation of SST, sea ice extent and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics*, 16, 147-166, 2000.

Kjellström, E., Recent and futures signatures of climate change in Europe. Accepted for publication in Ambio, 2004.

Moberg, A., et al., Daily air temperature and pressure series for Stockholm (1756-1998). *Climatic Change 53*, 171-212, 2002.

Nakićenović, N., et al., Emission scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, 599 pp, 2000.

Räisänen, J., et al., *GCM driven simulations of recent and future climate with the Rossby Centre coupled atmosphere – Baltic Sea regional climate model RCAO*, SMHI Reports Meteorology and Climatology 101, SMHI, SE 60176 Norrköping, Sweden, 61pp, 2003.

Räisänen, J., et al., European climate in the late 21st century: regional simulations with two driving global models and two forcing scenarios. *Climate Dynamics*, 22, 13-31, 2004

Roeckner, E., et al., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate*, 12, 3004-3032, 1999.

Near surface wind speed extremes over Europe in PRUDENCE control and scenario simulations of eight RCMs

Burkhardt Rockel

GKSS Research Centre, Geesthacht, Germany

ntroduction

Storms are one of the forces of nature which future changes are assessed within the European Union funded project PRUDENCE. In the following some of the main results from a study on future changes of near surface wind speeds from an ensemble of regional climate models (RCM) are presented.

Data base

Results from eight different RCMs were taken into account. Each model provides data on an approx. 50 km horizontal grid from two 30 year simulations: A control run under present climate conditions and a SA2 scenario run. Data were taken from the PRUDENCE data archive at DMI. For this study I used the daily mean and maximum surface near wind speed.

Daily maximum wind speed

It turned out that the definition of the maximum wind speed was not uniformly defined in the different models. The definitions can be divided into three groups:

1. Maximum of 3hourly instantaneous output (UCM model)

$$u_{\max} = \max(u_{00}^{10m}, u_{03}^{10m}, u_{06}^{10m}, \ldots, u_{21}^{10m})$$

2. Maximum of time step values (DMI, KNMI, MPI-HH, SMHI models)

$$u_{\max} = \max(u_{t_1}^{10m}, u_{t_2}^{10m}, \ldots, u_{t_n}^{10m})$$

3. Maximum of time step values and an additional gust parameterisation (ETHZ and GKSS models)

$$u_{\max} = \max(f(c_{t_1})u_{t_1}^{k}, f(c_{t_2})u_{t_2}^{k}, \ldots, f(c_{t_n})u_{t_n}^{k})$$

where c is the transfer coefficient for momentum, $f(c)$ is a specific function of c, and k is the lowest model layer.

Whether a gust parameterisation is applied to the near surface wind or not makes a substantial difference in the strength and thus in the frequency of occurrence of strong wind events. Counting the number of days with strong winds (8Bft and above) gives not a single event when calculating the maximum daily wind speed by equations 1 or 2 (see figure 1 left). This is unrealistic since there are storms with 8Bft and above in reality. Applying gust parameterisations on the other hand seem to give too many storm events. From figure 1 (right) it can be seen that the number of events over Mid-Europe are between 800 and 1000 in 30 years. This means about 30 events per year.

Daily mean wind speed

Daily maximum wind speed is not the appropriate parameter to assess the future changes in surface near wind speed extremes in this framework since the calculation of $u_{\max}$ is not the same in all eight RCMs. I used the 99% percentile of the daily mean wind speed instead.

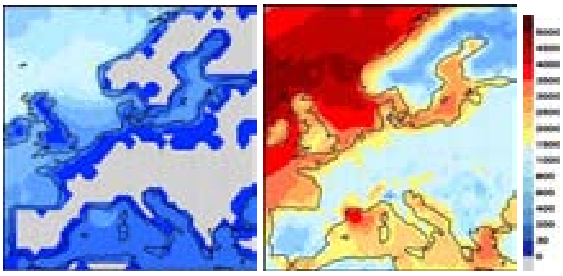


*Fig 1. Number of events in 30 years with daily maximum wind speed of 8Bft and above. Left without, right with gust parameterisation*I

For this study I divided Europe into eight sub domains as shown in figure 2.

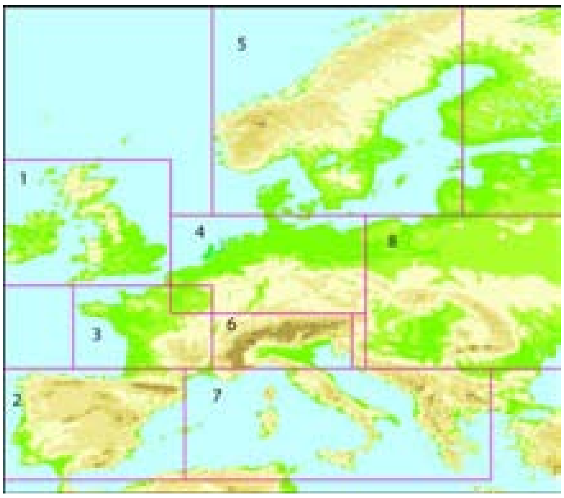


Fig 2. European sub areas

As an example results from the area 2 (Iberian Peninsula) and area 4 (Mid-Europe) are shown here in figures 3 and 4. The figures show the 99% percentile of the daily mean wind speeds within a month averaged over 30 years. The box plots divide the results from the different RCMs into quartiles. It shows the spread in the RCM results as well as the mean over all RCMs. Different colours stand for different seasons: blue for winter, green for spring, red for summer, and brown for autumn. On the left hand side of the figures the results from the present climate run are shown. The changes to the future scenario are given on the right hand side.

The results for the Iberian Peninsula (figure 3) show a large spread between the models. The difference between the model with the lowest values and that one with the highest values exceeds in most of the months 5 m/s. The range where within 50% of the models lay has a fairly constant value of 2 m/s throughout the year.

Results for future changes in wind speed (right hand side of figure 3) show an increase for spring and mid summer and a decrease for the other months.

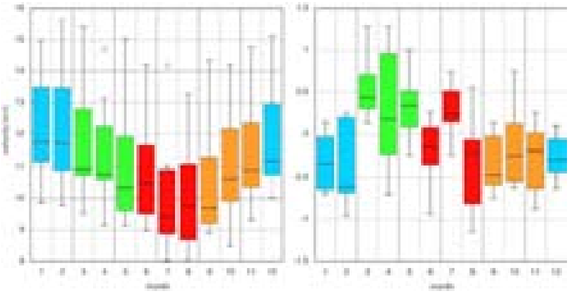


Fig 3. 99% percentile of the daily mean wind speeds within a month averaged over 30 years over the Iberian Peninsula. Quartiles show the distribution of the results from the different RCMs

The results for Mid-Europe shown in figure 4 differ from those for the Iberian Peninsula in different aspects. The differences between the model with the lowest and that one with the highest values are 4 m/s and less for each month. The 50% range is not as homogeneous as in the results for area 2. The width varies between about 1.5 and 2.5 m/s.

In contrary to the Iberian Peninsula the models show an increase in near surface wind speed during winter over Mid-Europe and a decrease in spring.

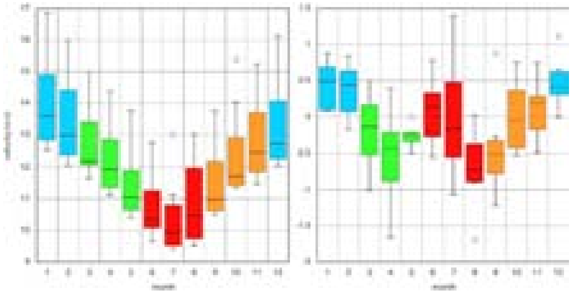


Fig 4. 99% percentile of the daily mean wind speeds within a month averaged over 30 years over the Iberian Peninsula. Quartiles show the distribution of the results from the different RCMs

Conclusions

Results of this study about the future changes in near surface wind speeds show an increase over Mid- and Northern-Europe (areas 1,3,4,5,8) in winter. Only area 4 was discussed here as an example. Over the Iberian Peninsula the increase occurs in spring.

In this study I investigated the daily mean winds instead of the maximum daily values. It showed up that the contributing RCMs followed different ways in defining the maximum daily wind speed. This fact has been overlooked at the start of PRUDENCE. In future studies the maximum wind speed should be defined more properly before starting the model simulations. Models with implemented gust parameterisations may provide the maximum wind speeds including gusts as a separate output field.

North Sea storm surge statistics based on a series of climate change projections

Katja Woth

Institute for Coastal Research, GKSS, Geesthacht, Germany

katja.woth@gkss.de

Introduction

Obviously, the threat of storm surges is a serious environmental problem for low-lying coastal regions. Kauker and Langenberg (2000) and Langenberg et al. (1999), among others, have shown that storm surges and their statistics can satisfactorily be modeled with hydrodynamical models, especially if the focus is on long-term statistics rather than on single events.

Possible changes in North Sea storm surge climate are studied in a systematic manner. Following up on previous studies, we use the tide-surge model TRIM (Tidal Residual and Intertidal Mudflat) to derive storm surge climate and extremes from atmospheric conditions. This exercise is carried out as an ensemble study based on a series of 30-year atmospheric regional simulations under present-day and enhanced greenhouse gas conditions.

The atmospheric regional simulations were prepared within the EU project PRUDENCE. The research strategy of PRUDENCE is to compare simulations of different regional models (RCMs) 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 Center based on the IPCC A2 SRES scenario. Results for modeled storm surges obtained by using regional model output from four RCMs, namely CLM (GKSS), RCAO (SMHI), REMO5 (MPI) and HIRHAM (DMI) are presented.

Modeled storm surge statistics

Since most impact damage is expected in the coastal zone storm surge residuals were analyzed for 209 extracted grid cells along the North Sea coast. The inset of Figure 1 shows the TRIM integration area, the bathymetry as well as the 209 coastal grid points located along the North Sea coast, extending from Aberdeen in Scotland to Smogen in Vestgötland.

Figure 1 shows a comparison between the modeled surge forced with **CLM, RCAO, REMO5 and HIRHAM** data as difference in surge-extremes between present-day simulation and the A2 SRES scenario. The maximum of the modeled surge for each year was selected and these annual maxima were averaged across each of the two 30-year periods. The dotted lines indicate the upper limit of the 95% confidence interval. If the difference in surge between control run and scenario exceed the threshold of statistical confidence, the difference can be interpreted as significant on the 95 % level of uncertainty.

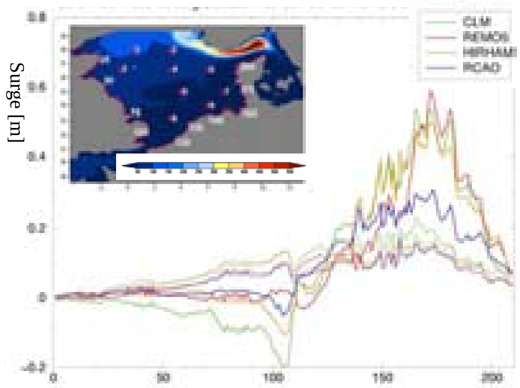


Fig 1. Difference in 30-year mean of winter maximum surge levels (unit: meter) from 30 years control run and A2 SRES scenario for near-coastal locations along the North Sea coast (as indicated as red point along the coasts in the inset). Dotted line: limits of stat. significance (95%) of differences in surge for present natural variability

Along the UK coast, all curves remain below the dotted lines, indicating that no significant change in surge statistics is happening there. Nevertheless, at about 50% of all locations, namely those along the Dutch, German and Danish coast, all curves are above the corresponding dotted line, showing a noticeable increase of the mean maximum winter surge for the A2 SRES scenario.

The increase in surge extremes of up to almost 60 cm is similar for the HIRHAM, CLM and REMO5 forcings whereas the RCAO forcing leads to an increase of up to 20 cm, which is noticeably smaller but it shows nevertheless the increasing trend. The effect of the general increase of sea level is not included in this analysis.

Possible reasons for these changes in storm surge statistics and their range, found in the different downscaling exercises, are expected among others in the slightly different atmospheric RCM performances, used to force the tide-surge model.

Changes in North Sea storminess

Therefore we analyzed the different meteorological forcing conditions over the North Sea with a focus on changes between the control run and the SRES A2 scenario in the 99%-ile of 6-hourly 10 m wind speeds coming only from westerly direction (Fig. 2).

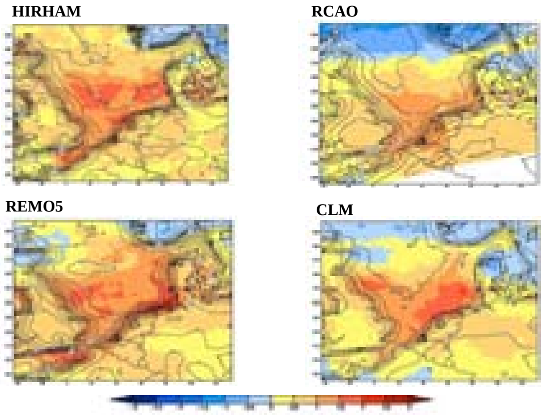


Fig 2. Change between CTL and A2 projections in 99-percentile based on 6-hourly 10m westerly wind speed (DJF) for four RCMs. Contour lines show mean of 30 intra-yearly percentiles of CTL, Color: Changes in the scenario relative to the control run.

The RCAO wind is increased by up to 1 and 1.5 m/s over large areas of the North Sea, whereas in the HIRHAM, REMO5 and the CLM models this signal is enhanced by up to 2.5 m/s. The CLM model shows higher values in the control run (isolines: up to 2 m/s) than the other models.

On the other hand, to consider changes in frequency of storms we have “counted” storms, by determining how often a wind threshold of 20.8 m/s (Beaufort 9) and 24.5 m/s (Beaufort 10; “storm”) is exceeded (Weisse et al., 2004) in winter (DJF). This exercise was carried out for 9 selected grid boxes over the North Sea area for conditions of the control run as well as the A2-scenario run. Fig. 3 shows the number of events for all 30 years, for 9 selected grid cells over the North Sea area.

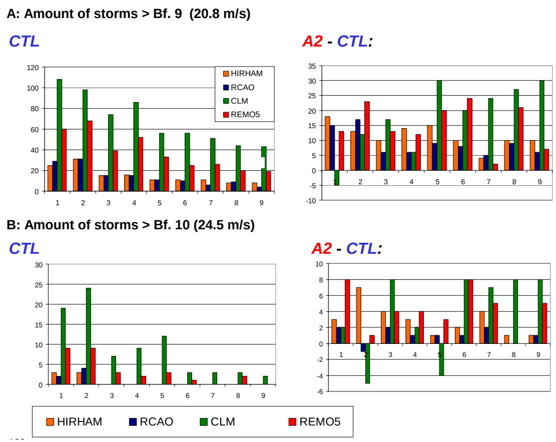


Fig 3. “Storm count” at 9 selected 50 × 50 km² grid boxes (locations shown in Fig.1) in the control run and A2 scenario run with HIRHAM, RCAO, CLM and REMO5 data.

In the southern and eastern part of the North Sea (cells 5 to 9), which is of special interest for continental coastal storm surges, the CLM has about 40 events larger then Bf. 9, REMO5 only about 20, whereas in HIRHAM and RCAO the count goes down to 10 events for the 30-year control period. Wind speeds larger than 24.5 m/s (Bf 10) again are clearly more often simulated in CLM and REMO5 than in the RCAO and HIRHAM model runs. In the A2 SRES simulations we find an increase compared to the control runs in all RCM simulations. The REMO5 and CLM shows the highest increase of up to 100% in the number of moderate storms, whereas the increase in the HIRHAM and RCAO simulations for moderate storms turns out to be smaller. This contrast between HIRHAM and RCAO on the one hand and REMO5 and CLM on the other increases with larger wind speeds: In the HIRHAM and the RCAO runs, one very severe event evolves in the A2 scenario run but none in the control run.

Conclusion

The difference in modeled surge using the four different RCM meteorological forcings is fully consistent with the analyzed change in high wind speeds – which is much larger in CLM, HIRHAM and REMO5 than in RCAO. But all four RCMs show an increase in the higher 10 m westerly wind percentiles, which is consistent with the positive trend in surge extremes around the North Sea coast. Statistical significance can be obtained in all parts of the continental North Sea coast whereas the East coast of the UK is not affected by this expected increase of surge extremes based on the SRES A2 scenario at the end of this century.

Acknowledgement

This work has been supported by funding from the European Union under the *Prediction of Regional Scenarios and uncertainty for defining European Climate change risks and Effects* (PRUDENCE) project.

References

Kauker, F and H Langenberg, 2000: Two models for the climate change related development of sea levels in the North Sea. A comparison. Clim. Res. 15, 61-67

Langenberg, H., A. Pfizenmayer, H. von Storch and J. Sündermann, 1999: Storm related sea level variations along the North Sea coast: natural variability and anthropogenic change.- Cont. Shelf Res. 19: 821-842

Weisse, R., H. von Storch and F. Feser, 2004: Northeast Atlantic and North Sea storminess as simulated by a regional climate model 1958-2001 and comparison with observations. submitted.

Climate Change Impact on Water Quality – model results from southern Sweden

Berit Arheimer[1], Johan Andréasson[1], Sofia Fogelberg[1], Holger Johnsson[2], Kristina Mårtensson[2], Charlotta Pers[1], Kristian Persson[2] and Jörgen Rosberg[1]

[1] Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden.
[2] Swedish University of Agricultural Sciences (SLU), Dept. Soil Sciences, Uppsala, Sweden
Berit.Arheimer@smhi.se

Introduction

Nitrogen transport from land (mainly by rivers) is contributing to the eutrophication problems in lakes and the Baltic Sea. The amount of nitrogen (N) transported is a result of point-source emissions, atmospheric deposition, soil leaching, and biochemical removal processes (retention) in fresh-water. Except from point-source emissions, all these factors are strongly influenced by the weather (e.g. temperature and precipitation) and would thus be affected by a climate change. This study focus on the most important processes regulating the amount of nitrogen transported from land to sea. In addition, the problem with high algal concentrations is implicitly explored for one lake. The aim was to quantify the expected changes of N flow and algal growth by applying Regional Climate Model (RCM) scenarios on hydrochemical and biogeochemical modelling tools. The study was located to River Rönne å (1900 km^2) and Lake Ringsjön (40 km^2).

Models and data

The modelling of water quality was made for a control scenario of present conditions and six regional climate change scenarios, representing the years 2071-2100. Climate data was received from the Rossby Centre regional Atmospheric model, RCA (Räisänen et al., 2003). The different scenarios refers to various assumptions of boundary conditions, e.g., global circulation models (GCM), and future CO_2 emissions, but also to spatial resolution, and oceanographic and hydrologic modelling, which all gives different warming (Table 1). The method for transferring the signal of climate change from RCA to hydrological/biogeochemical modelling was based on the delta change approach (Andréasson et al., 2004).

Nitrogen leaching from arable land was simulated by using the SOILNDB model (Johnsson et al., 2002) for combinations of 15 crops and 4 soils in each of the 3 different agricultural regions of the catchment. Semi-randomised crop sequences of a total of 10,000 years were produced. Daily simulations were made repeatedly for a 20-year climatic period of each RCA scenario to produce average leaching rates for each crop.

Water discharge and N concentrations at the catchment scale was modelled by using the HBV-N model (Arheimer and Brandt, 1998). The Rönne å River was divided into 64 subbasins. In each of these N load from arable root zone losses is added to emissions from rural households, leaching from other land cover, point sources and atmospheric deposition. Residence time in groundwater, rivers and lakes are calculated by the model, as well as N removal in groundwater, streams and lakes. The discharge from upper subbasins is routed into lower, so that all subbasins are coupled along the river network. The model was applied for a 20-year period with daily calculations for each scenario, using RCA and SOILNDB results as input data.

Algal growth and biogeochemical processes in Lake Ringsjön was modelled by the combined hydrodynamic PROBE - biogeochemical BIOLA model (Pers, 2002). This model simulates the continuous change of lake stratification and water quality due to weather, inflow, and processes in the lake and in the sediments of eutrophic lakes. The model is one-dimensional and has several layers, which are horizontally homogeneous. However, when applied to Lake Ringsjön, it simulates 3 coupled lakes to account for spatial variations. The model calculates daily concentrations of e.g. 5 nutrients and 6 biological state variables in the water-body in each layer (1 m.).

Table 1. Some characteristics of the six RCA scenarios, which were used in the modelling.

RCA version	GCM	Emission scenario	Global ΔCO_2 equiv. (%)	GCM resolution (degrees)	RCA resolution (~km)	Global ΔT (GCM) (ºC)	Sweden ΔT (RCA) (ºC)
RCA1	HadCM2	+1% per yr	150	2.5ºx3.75º	44	2.6	3.7
RCA1	ECHAM4/OPYC3	+1% per yr	100	2.8º	44	2.6	3.8
RCAO	HadCM3/AM3	sres - A2	220	1.25ºx1.875º	49	3.2	3.6
RCAO	ECHAM4/OPYC3	sres - A2	220	2.8º	49	3.4	4.5
RCAO	HadCM3/AM3	sres - B2	130	1.25ºx1.875º	49	2.3	2.5
RCAO	ECHAM4/OPYC3	sres - B2	130	2.8º	49	2.6	3.5

Results and Discussion

All crops showed higher root-zone leaching rates as an effect of climate change (Fig. 1). The increase was 14-38%, depending on scenario. The increased leaching could be referred to increased water runoff and mineralisation during winter, when there is no N uptake by crops. Even though the crop season was prolonged and the dates for various management practices were adapted to the new climate, this did not compensate for the elevated losses.

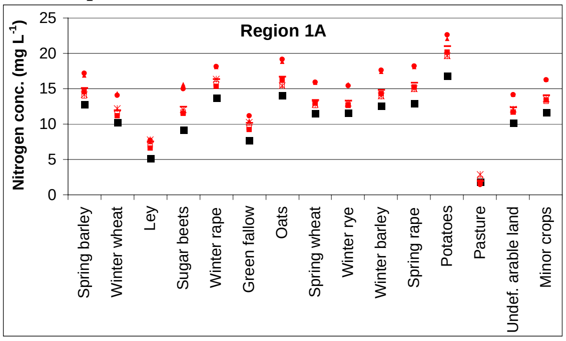


Figure 1. Annual average of root zone concentration based on simulations with SOILNDB. The figure shows the average leaching for crops on several soil types for each climate scenario (red dots).

Accordingly, all scenarios resulted in elevated riverine N concentrations. As an annual average this increase differed between 7-19%, according to scenario. Annual N transport from land to sea increased in all scenarios. Half of the scenarios gave less water discharge and the other half more discharge. The general trend in all scenarios was that the present seasonal hydrological dynamics was pronounced, i.e. resulting in more dry summers and more wet winters.

All scenarios resulted in higher contribution of nitrogen from the agricultural sector. This increase varied between 1000-2000 tonnes N/yr. (20-50%), depending on scenario. The natural nitrogen removal (retention) also increased for all scenarios compared with the present climate and, thus, the increase in net load to the sea was less pronounced (< 1000 tonnes N/yr.). Considering the spatial variation (Fig. 2), the areas already contributing a lot to the load were most disposed to increased leaching. However, some remote areas not contributing to the load on the sea today, will probably contribute in a future climate, which should be considered in management plans.

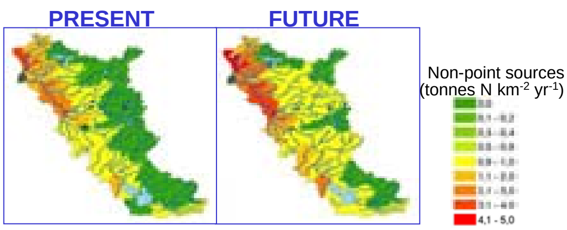


Figure 2. Spatial contribution of N load to the sea for the Rönne å catchment at present and in one of the scenarios (RCAO-ECHAM4/OPYC3-A2).

The biogeochemical lake scenarios resulted in higher concentrations of all state variables, except for phytoplankton, which was reduced by 20-50%. The phytoplankton reduction was caused by more favourable conditions for cyanobacteria (Fig. 3), which increased by 150-350% on an annual basis in the different scenarios and different basins of the lake. This effect may have serious impact on future water use as cyanobacteria blooms are unpleasant for recreation and may be toxic.

Total phosphorus concentration increased by some 50% and detritus up to 120% on an annual average in different scenarios. This was probably caused by increased efficiency of the nutrient cycle and higher mineralisation and release rates from sediments. This may also have negative impact on the water use, and contribute to further problems downstream in the watercourses, in the coastal bay and in the sea. Overall, the present seasonal dynamics seem to be strengthened by a climate change.

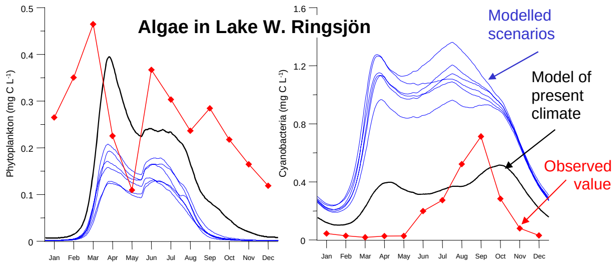


Figure 3. Development of lake algae; phytoplankton (left) and cyanobacteria (right). Note the different scales!

Acknowledgement

The study was performed in a co-operation between the research programmes VASTRA and SWECLIM, both financed by Mistra.

References

Andréasson, J., Bergström, B., Carlsson, B., Graham, P. and Lindström, G. 2004. Hydrological change – climate change impact simulations for Sweden. Ambio (in press).

Arheimer, B and Brandt, M., 1998. Modelling nitrogen transport and retention in the catchments of southern Sweden. *Ambio 27(6):471-480.*

Johnsson, H., Larsson, M.H., Mårtensson, K. and Hoffmann, M. 2002. SOILNDB: A decision support tool for assessing nitrogen leaching losses from arable land. *Environmental Modelling and Software, 17:505-517.*

Pers, B.C. 2002. Model description of BIOLA – a biogeochemical lake model. *Swedish Meteorological and Hydrological Institute, Report RH No. 16, Norrköping, 69 pp.*

Räisänen, J., Hansson, U., Ullerstig, A., Döscher, R., Graham, L.P., Jones, C., Meier, H.E.M., Samuelsson, P. and Willén, U., 2003. European climate in the late 21st century: regional simulations with two driving global models and two forcing scenarios. *Climate Dynamics*, published on-line 14 Nov 2003, DOI: 10.1007 / s00382-003-0365-x.

Scale decomposition of the water budget in a regional climate model

Soline Bielli and René Laprise
Université du Québec à Montréal (UQÀM), Montréal, Québec, Canada
bielli.soline@uqam.ca

The added value (AV) provided by regional climate models (RCM) with respect to global climate models (GCM) or global analyses used to drive the regional simulation may be decomposed into three main contributions: the lateral boundary, the discretisation and the non-linear interactions between different scales. The objective of this study is to assess the contribution of this later factor to the AV.

Water plays a key role in the energetics of the climate and precipitation produced by GCM generally exhibits large differences compared to precipitation produced by RCM. Indeed, precipitation is greatly influenced by topographic and small-scale regional features as well as mesoscale circulation. Thus the water budget was chosen for the scale decomposition.

The water budget is defined as:

$$d_t\overline{Q} = -\nabla.\overline{F} + E - P \quad \text{where}$$

$$\overline{F} = \overline{UQ} = \frac{1}{g}\int_{sfc}^{top} U(x,y,p)\cdot Q(x,y,p)\,dp$$

is the horizontal moisture flux, Q is the humidity, U the horizontal wind, E the evapotranspiration and P the precipitation. $(\overline{\ })$ is for vertical integral. To isolate the contribution of different scales, the Discrete Cosine Transform (DCT) is used as it allows efficient decomposition of non-periodic fields (see Denis *et al.* 2002 for details).

The divergence of the moisture flux, which is a quadratic term, is handled as follow: Q is defined as $Q=Q_0+Q_L+Q_S$ where Q_0 represents the very large scales (the domain-mean value is used as a first approximation), that are larger than the RCM domain, Q_L represents large scales that are both resolved by the RCM and the global reanalyses, and Q_S represents the small scales (wavelength smaller than 300 km) that are only resolved by the RCM, which constitutes the AV of the RCM. The same decomposition for both components of the horizontal wind is performed. The vertically integrated moisture flux is then written as:

$$\overline{F} = \overline{F}_0 + \overline{F}_G + \overline{F}_S \quad \text{and}$$

$$\overline{F} = \sum_{k\in(0,L,S)}\sum_{l\in(0,L,S)} \overline{U_kQ_l} = \overline{U_0Q_0} + \overline{U_0Q_L} + \overline{U_0Q_S}$$
$$+\overline{U_LQ_0} + \overline{U_LQ_L} + \overline{U_LQ_S}$$
$$+\overline{U_SQ_0} + \overline{U_SQ_L} + \overline{U_SQ_S}$$

Finally the divergence of each term is calculated.

The Canadian Regional Climate Model (CRCM) (Caya and Laprise 1999) is used for a simulation with 45-km mesh siz and 29 Gal-Chen levels, driven by NCEP reanalyses. A winter-month simulation (February 1990) is used over a domain of about 8000 km by 6000 km centred over Canada. The simulation outputs are interpolated over the 17 pressure levels of the NCEP reanalyses. The NCEP reanalyses have a T32 resolution and are interpolated over the CRCM 45-km grid. A mask (Boer 1982) is used to removed the values that are below the ground level using the CRCM surface pressure.

The 4 terms of the water budget for an instantaneous moment at 00Z 15 Feb. 1990 are displayed on fig. 1 where two main structures can be seen: a dipole of convergence-divergence over the east coast of America associated with a north-south band of precipitation typical of winter time, and a second dipole over the Atlantic ocean with a west-east orientation.

Fig. 2 displays the 9 decomposed terms of the moisture divergence flux. It shows that large-scale dominant terms are those involving the large-scale humidity (U_0Q_L and U_LQ_L). The dominant small-scale terms are those related to the small-scale humidity with large and very large-scale winds (U_0Q_S and U_LQ_S). These last two terms tend to modulate the large-scale structures that are represented in the large-scale terms such as to increase the central amplitude of the features and to decrease their spatial extension. The term involving only small scales U_SQ_S is weaker but shows also an interesting signal.

The same decomposition is applied to the NCEP driving data and results show that the cross-term that involved small-scale terms have no contribution as expected. Indeed the added value of the RCM is dominantly represented by non-linear interactions between small- and large-scale features in this case. The large-scale structure of the divergence is very similar to the pattern seen on the CRCM decomposition.

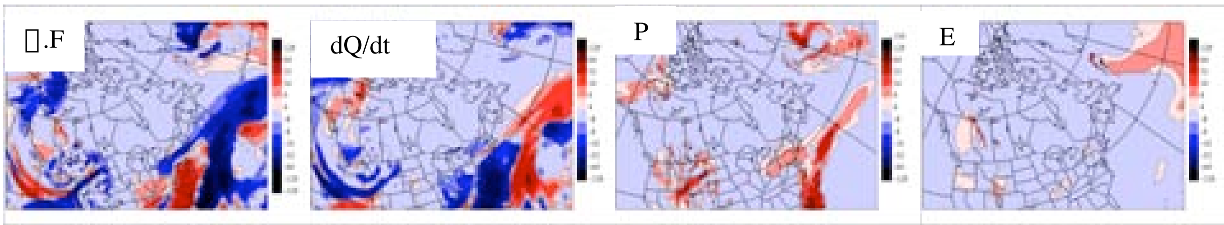


Figure 1:Water budget terms for 00Z 15 Feb. 1990 in CRCM simulation, mm/day.

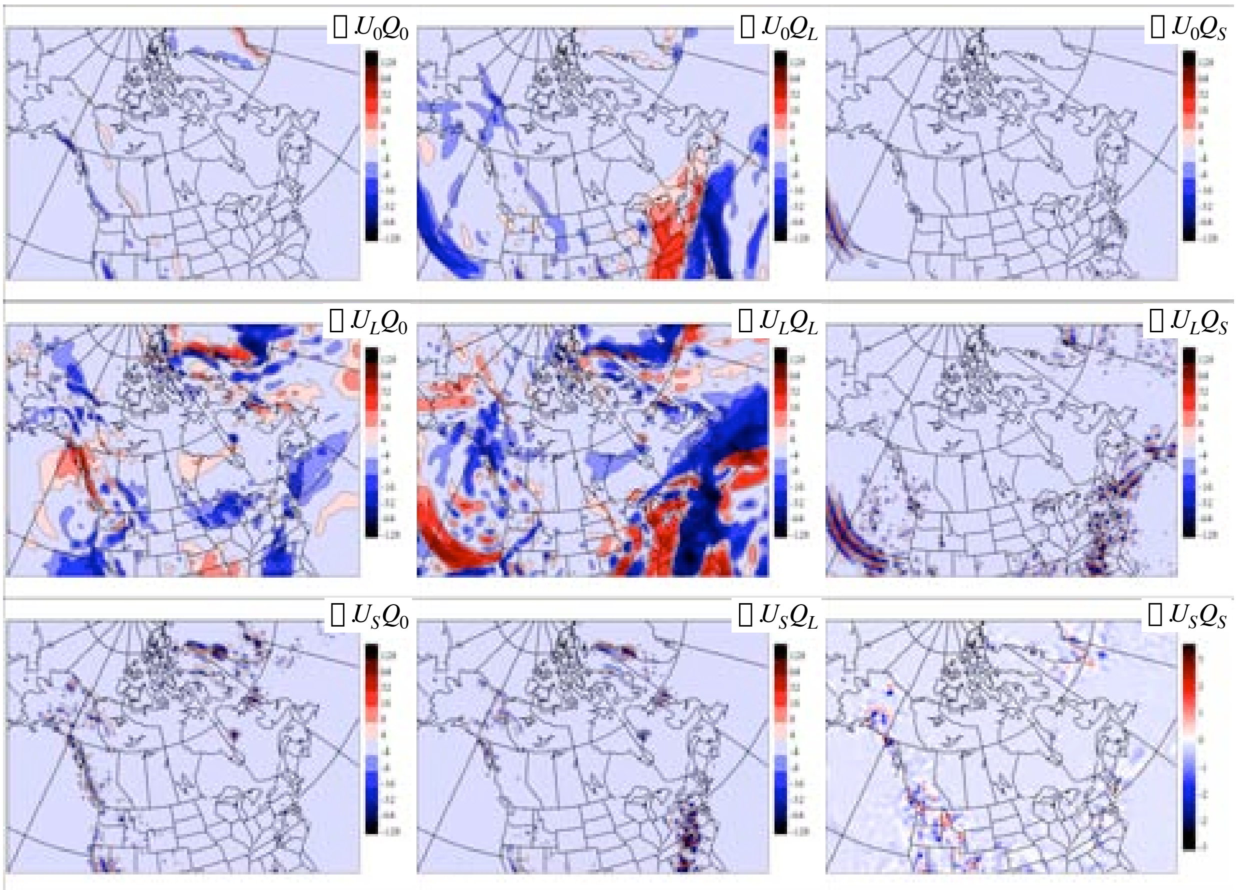


Figure 2:The 9 terms of the scale decomposition of the divergence of the moisture flux, in mm/day, for 00Z 15 Feb. 1990 for the CRCM simulation driven by NCEP reanalyses. Note that the U_SQ_S term is displayed with a different color scale.

References:

Boer, G. J. 1982: Diagnostic equations in isobaric coordinates. *Mon. Wea. Rev.*, 110, 1801-1820.

Caya, D. and R. Laprise, 1999: A semi-implicit semi-Lagrangian regional climate model: The Canadian RCM. *Mon. Wea. Rev*. 127, 641-362

Denis, B., J. Côté and R. Laprise, 2002: Spectral decomposition of two-dimensional atmospheric fields on limited area domains using the discrete cosine transform (DCT). *Mon. Wea. Rev.*, 130, 1812-1829.

Internal Variability of RCM Simulations over an Annual Cycle

by Daniel Caya and Sébastien Biner

Ouranos Consortium; 550, Sherbrooke O., 19è étage, tour Ouest, Montréal (QC) Canada, H3A 1B9
(514) 282-6464 ext. 340; Fax: (514) 282-7131, caya.daniel@ouranos.ca

Model and results

Three one-year simulations generated with the Canadian RCM (CRCM; Caya and Laprise 1999) are compared to each other in order to study internal variability in nested regional climate models and to evaluate the influence exerted by the lateral boundary information supplied by the nesting procedure. All simulations are generated over an annual cycle. The simulations use different combinations of surface and atmospheric initial conditions but all of them share the same set of time-dependent lateral boundary conditions taken from a simulation by the Canadian GCM. A first simulation is used as control, the second simulation is launched with different atmospheric and surface Initial Conditions (IC) and the third simulation is launched taking its surface IC from the control simulation. Therefore, comparing the control simulation with the second one results in a pair of simulations having difference in both the atmospheric and surface IC (DAS). Comparing the control with the third simulation results in differences in the atmospheric IC (DA) and comparing the two last simulations gives a pair with differences only in the surface IC (DS). Fig. 1 compares the root-mean-square differences (*RMSD*) between the sea-level pressure (*slp*) from each pair of simulations.

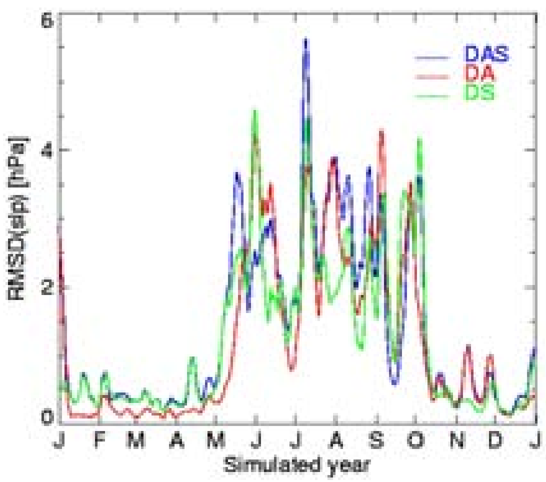


Figure 1. The RMSD time series for the slp fields.

Two distinct regimes are present in the time series of the *RMSD*: in winter, simulations are almost identical to each other resulting in very low *RMSD* values while in summer large discrepancies develop between pairs of simulations. Figure 2 illustrates this with the *slp* fields from two CRCM simulations differing only in their initial conditions. These two *slp* fields are as different as two independent meteorological situations. For water vapour related fields such as precipitation or specific humidity, these discrepancies are sometimes as large as the monthly-averaged variability.

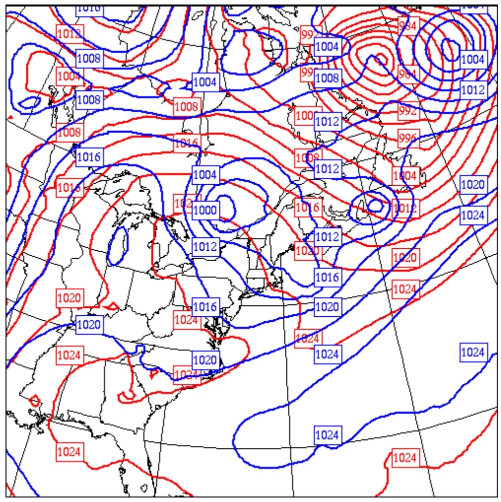


Figure 2. The slp fields for July 9th 00Z from two simulations having differences only in their IC.

In order to evaluate the importance of these differences on the simulated climate, the time-averaged value of the mean square difference ($MSD = [RMSD]^2$) between a pair of simulations α and β for the field ψ over a period of time p is computed as

$$\overline{MSD_{\psi_{\alpha\beta}}}^{p} = \overline{RMSD^2_{\psi_{\alpha\beta}}}^{p} = \overline{\overline{\left(\psi_\alpha(i,j,t) - \psi_\beta(i,j,t)\right)^2}^{p}}^{d}$$

where $\overline{}^{p}$ is an averaging operator in time over the period p and $\overline{}^{d}$ denotes the spatial average over the domain. Each field ψ can be separated in its time average ($\overline{\psi}$) over the period p and the perturbation (ψ') from this average to obtain

$$\overline{MSD_{\psi_{\alpha\beta}}}^{p} = \overline{\left(\overline{\psi_\alpha}^{p} - \overline{\psi_\beta}^{p}\right)^2}^{d} + \overline{\left(\sigma_{\psi_\alpha} - \sigma_{\psi_\beta}\right)^2}^{d} + \overline{2\sigma_{\psi_\alpha}\sigma_{\psi_\beta}\left(1 - R^{\psi}_{\alpha\beta}\right)}^{d}$$

where σ_ψ and R^ψ are respectively the temporal standard deviation and the temporal correlation over the period *per.* As it can be seen, three terms contribute to the total $\overline{MSD_{\psi_{\alpha\beta}}}^p$. The first term (TAVG) is associated with the square of the difference of the mean values (standing eddies) of each simulation. The two other terms, are related to the transient eddies. The second term (TSIG) results from differences between the temporal standard deviation and vanishes if the simulated fields share identical spatial distribution of temporal standard deviations; the third term (TCOR) is related to the temporal correlation between the fields and vanishes when the evolutions of the weather systems in the two simulations are totally correlated. The relative contribution to the total *MSD* from each of these three sources has important repercussions on the interpretation of model simulations. While any contribution from the first two terms will modify the simulated climate, the contribution from the third term has no effect on it.

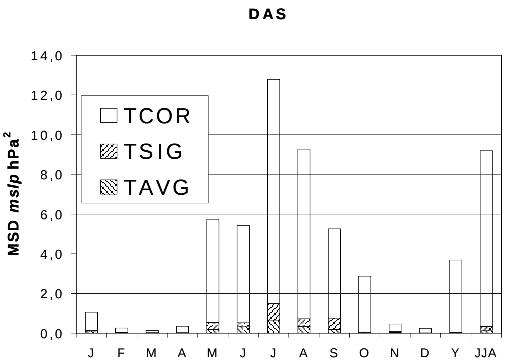


Figure 3. The contribution from the three components of MSD for mslp (where TCOR, TSIG and TAVG are the correlation, variance and mean components respectively).

Figures 3 and 4 present the distribution of the three components of the *MSD* for mslp and precipitation computed for each month of the year, for the entire year (y), and for the summer season (JJA) where the *MSD* is the largest. It can be seen that most of the *MSD* is associated with the correlation term (TCOR). However, for some fields (as July precipitation in Fig. 4) the variance term (TSIG) can have a significant contribution. In order to assess if the short samples (one month) can affect the interpretation, the statistics were computed over a period *p* set to cover the summer season (three months). It can be seen in Figure 4 that while the JJA total *MSD* is the simple average of the individual months, the contribution from the variance and the mean terms is reduced. The relative contribution of the correlation term to the total *MSD* increases with the period on which the statistics are computed. The same exercise was repeated for a period *p* set to cover the entire year (Y in Fig. 4) and this time, most of the MSD results from the correlation term.

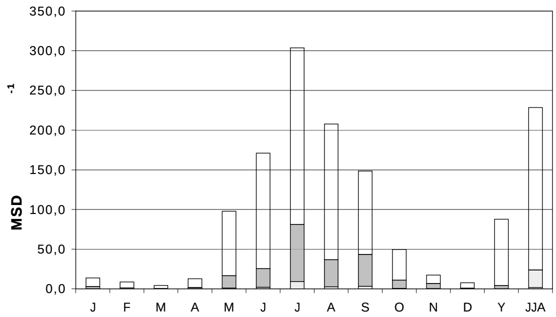


Figure 4. Same as Fig. 3 for precipitation.

Conclusion

The present analysis of the climate statistics shows that, although the evolution of atmospheric circulation can be quite different in summer, the climate statistics become similar when computed over a sufficiently long period of time. However, the large differences observed in summer have to be taken into account in sensitivity studies. As an example, differences in the evolution of a given weather event could be interpreted as a response to changes in the forcing when in fact it is only a manifestation of the internal variability of the modelling system. As shown in this study very large differences can be observed in simulations sharing identical forcings. Therefore, a sensitivity study performed over a short simulation (for example the evolution of a given weather system) would probably require an ensemble of simulations to separate the signal from the noise induced by the internal variability. An extensive analysis of the internal variability with this small ensemble of three simulations can be found in Caya and Biner (2004).

References

Caya, D. et S. Biner, 2004 : Internal Variability of RCM Simulations Over an Annual Cycle. *Clim. Dyn. Clim.* **22,** 33-46.

Caya, D., et R. Laprise, 1999 : A semi-implicit semi-Lagrangian regional climate model: The Canadian RCM. *Mon. Wea. Rev.* **127,** 341-362.

Effects of resolution in an RCM: From 50 to 12 km

O. B. Christensen[1], J. H. Christensen[1], and C. Frei[2]

[1]Danish Meteorological Institute, Copenhagen, Denmark. [2]ETH, Zürich, Switzerland
obc@dmi.dk

Introduction

Within the PRUDENCE project a sequence of regional climate model (RCM) experiments have been performed with the HIRHAM model at varying resolution, but with identical boundary conditions from the HadAM3H global atmospheric climate model. Both control and future scenario experiments have been performed.

Models and data

A comparison of the experimental results for 50, 25, and 12 km resolution with the observational data set of Frei and Schär shows that 50km resolution is insufficient to capture the fact that precipitation maxima should be located on slopes and not on the top of mountains in the Alps.
Climate change of precipitation properties measured in relative terms seems to be rather large scale, i.e. not very dependent on the resolution. This still means, however, that it is necessary to have high-resolution climate change calculations in order to have future-climate fields that are realistic on the length scale necessary for a description of the Alpine region.

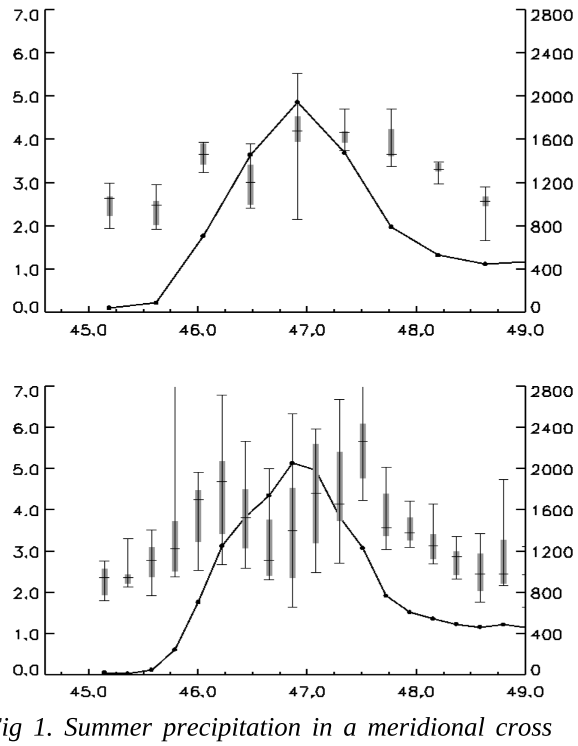


Fig 1. Summer precipitation in a meridional cross section across the Alps between 11 and 13.5 eastern longitude as a function of latitude. Upper panel: 50km resolution. Lower panel: 25km resolution. Only in the higher resolution a realistic maximum of precipitation on the slopes is seen.

Acknowledgement

This research is supported by the European Commission under Framework Programme V Key Action "Global Change, climate and biodiversity", 2002-2005, contract No. EVK2-CT2001-00132.

References

Frei, C, and C. Schär: A Precipitation Climatology of the Alps from High-resolution Rain-gauge Observations. Int. J. Climatol., **18**, 873-900, 1998

Forecasting Skill Limits in Limited-Area Models

Ramon de Elia and René Laprise: e-mail: relia@sca.uqam.ca
Université du Québec à Montréal, Montréal, Québec, Canada

Introduction

Limited-area models (LAMs) are powerful tools for predicting and studying weather patterns that have been used by the scientific community for a long time. The hypothesis implicit in their development concerns their ability to generate meaningful small-scale features that were absent in the initial and in the boundary conditions, being these provided either by a lower resolution model output or analysis. A number of studies in the last 20 years evaluated the validity of the mentioned hypothesis with a variety of results (e.g. Anthes et al., 1985).

The present work intends to build upon previous results and it concentrates on the predictability and downscaling ability of LAMs. The method followed here consists of a series of experiments using a perfect-model approach that is an extension of the work done by Laprise et al. (2000) and by Denis et al. (2001), nick-named the Big-Brother Experiment. An extended version of this work can be found in de Elia et al. (2002), and de Elia and Laprise (2003).

Experimental framework

The Canadian Regional Climate Model (CRCM) described in Caya and Laprise (1999) is used for a series of simulations with 45 km horizontal grid spacing, 18 levels in the vertical, and a 3 h nesting frequency. A first integration is made for a month in a domain of 196x196 grid points in the horizontal, nested with NCEP analyses of February 1993. This high-resolution simulation (``reference run" hereafter) becomes our ``truth" to which other runs will be compared.

The output fields produced by this reference run are then filtered to remove smaller scales in order to simulate a low-resolution dataset. These low-resolution fields are then used to drive simulations over a smaller domain (100x100 in the horizontal, keeping the vertical and horizontal resolution untouched) performed in the centre of the larger domain (see Fig. 1). This setup permits the comparison of the output of both simulations in the same region and therefore assesses the ability of the one-way nesting to reproduce the results of the larger domain. Since both simulations use the same formulation (dynamics, physics, resolution, etc), differences in results can be attributed to the nesting technique (one way, 10 pt nesting zone).

This comparison, however, must take into account the model internal variability due to its sensitivity to initial conditions. For this reason, a study of the predictability of this LAM is presented first.

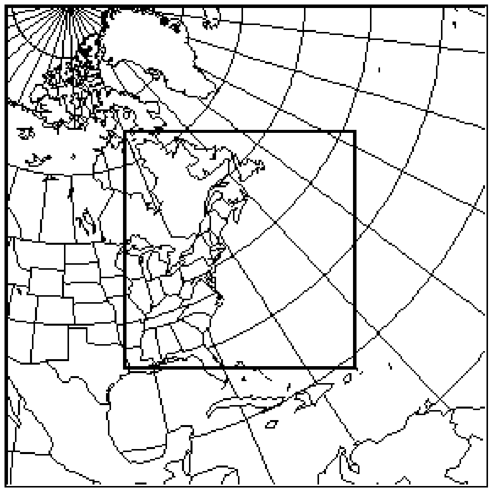


Figure 1. Integration domains

In order to make values statistically stable, results from both predictability and downscaling studies were obtained using 24 runs of the small-domain model integrated during 4 days, each one starting in successive days of February 1993. In this way, for example, the 48-hour integration ensemble average implies the average over 24 different 48-hour integrations, one day apart.

Predictability

The predictability was tested by performing model integrations over the small domain without filtering the driving data (from the large domain), but introducing a small perturbation in the initial conditions. Figure 2 shows the time evolution of the RMS difference between the 850-hPa vorticity fields generated by the reference run and the perturbed simulation as a function of wavenumber (normalized by the standard deviation of the reference simulation as a function of wavenumber). It can be seen that the growth (loss of predictability) is highly dependent on wavenumbers; being very limited for small wavenumbers and almost reaching the critical value $\sqrt{2}$ for large wavenumbers.

The temporal evolution of each wavenumber shows that they tend to reach different asymptotic values, and that each one possesses a particular time scale in which these values are reached. It has been found that these timescales differ little from those encountered in global models, being mostly proportional to wavelength.

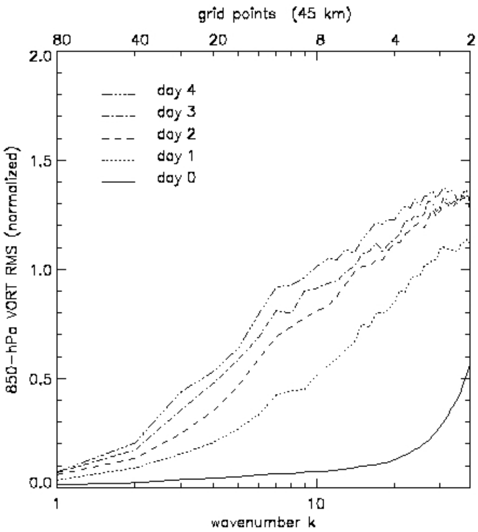


Figure 2. Root-mean-square difference as a function of wavenumber between the "reference" and the "downscaling" run.

Downscaling ability

When small-scale information is removed from the boundary and initial conditions, the challenge to the nested model is to regenerate those small scales. Figure 3 displays the time evolution every three hours of the standard deviation of the 850-hPa vorticity field as a function of wavenumber (normalized by the standard deviation of the “reference” run). The solid line depicts the time t=0. This shows that after 18 hours the downscaling run is able to regenerate the right amount of variability.

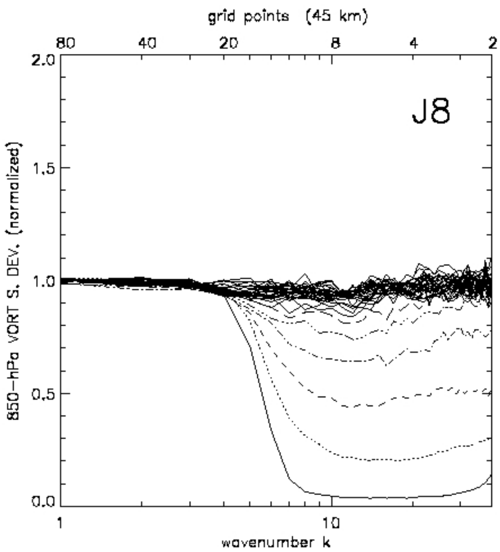


Figure 3.Time evolution of variability in downscaling run.

On the other hand the ability of the LAMs to regenerate *accurately* small-scale features may be questioned. Figure 4 is similar to Fig. 2, but for the filtered case. It shows the inability of the model to diminish the normalized RMS difference except for the first day and in a narrow wavenumber band, between *k=6* and *k=12*. In addition, this gain does not seem important in any of the other model variables. It is also worth noting that the limiting curve for day 4 is close to the one displayed in Fig. 2. Subsequent studies suggest that high-resolution information increases predictability when present in the initial conditions, but is almost irrelevant in the boundary conditions.

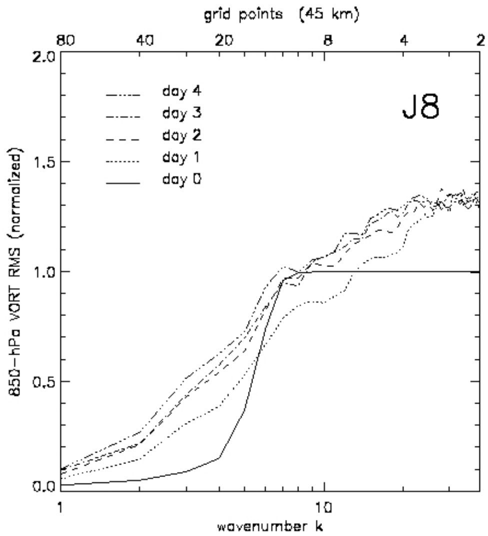


Figure 4. As in Fig. 2 but for the difference between the "reference" and the filtered “downscaling” run.

Concluding remarks

This work increases the already growing evidence regarding the existence of internal variability in one-way nested LAMs. It is shown that they possesses limited predictability, and –probably related to the previous result-- that the regeneration of small scales is of good quality with respect to the amount of variability, but inaccurate in the location and intensity of the small-scale weather patterns.

Caution must be exerted to generalize these tentative conclusions, because too little is known about their sensitivity to factors not considered here (e.g. grid size, nesting scheme, geographic location).

References:

Anthes et al., 1985; *Advances in Geophysics*, Vol. 28, 159-202.

Caya, D. and R. Laprise, 1999; *Mon. Wea. Rev*., **127**, 341-362.

de Elia et al., 2002; *Mon. Wea. Rev*., **130**, 2006-2023.

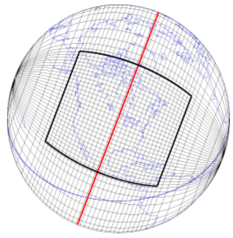
de Elia and Laprise, 2003; *Mon. Wea. Rev*., **131**, 2492-2509.

Denis et al., 2001; *Clim. dyn*., **18**, 627-646.

Laprise et al., 2000; *Mon. Wea. Rev*., **128**, 4149-4154.

Paegle at al., 1997; *Meteor. Atmos. Phys*., **63**, 53-69.

Current state of GEM climate simulation at RPN



Bernard Dugas[1] and Katja Winger[2]

[1]Recherche en Prévision Numérique, Meteorological Service of Canada
[2]Université du Québec à Montréal
Bernard.Dugas@ec.gc.ca

1. Introduction

The Canadian Meteorological Centre/Recherche en Prévision Numérique (CMC/RPN) operational Global Environmental Multi-scale (GEM) model is generally used to perform the short and medium range forecasts required by the Meteorological Service of Canada (MSC) clients. The model is also being used for seasonal forecasts, followings its Historical Forecast (HFP) validation, and for even longer term type integrations. These last simulations and their comparison with climate means are essentially seen as a mean to evaluate the meteorological performance of the operational model. Accordingly, the recently developed Limited Area Model (LAM) GEM mode is a particularly important addition given the increasing resolutions at which even global operational forecast models are now routinely run.

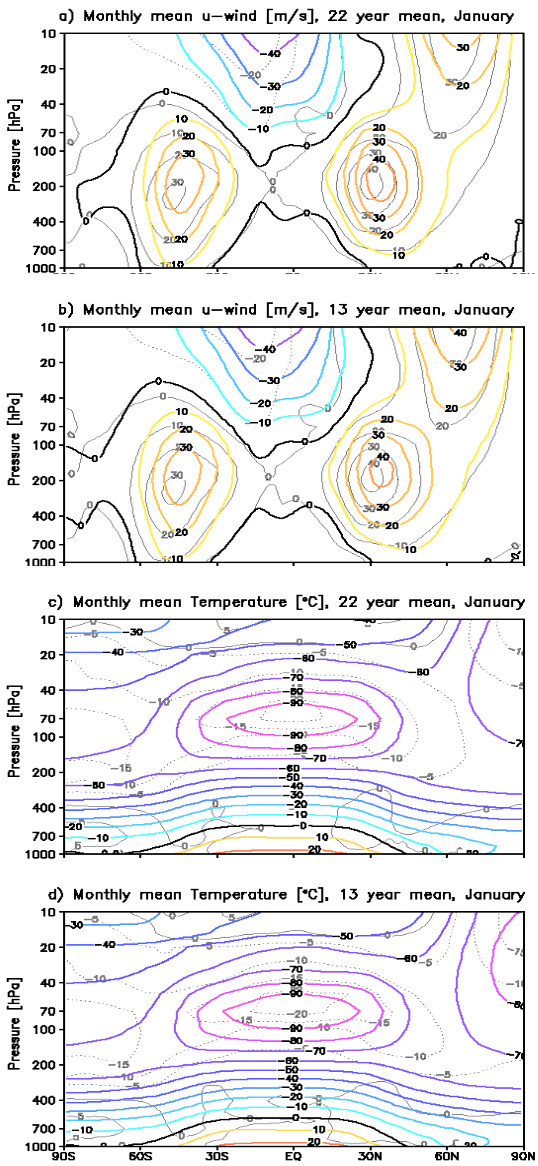
2. Model and data

We compare results from a uniform 22-year AMIP2 (Atmospheric Model Inter-comparison Project v2) simulation, from a 13-year SGMIP (Stretched Grid Model Inter-comparison Project) variable resolution simulation and from a preliminary 2-year LAM (Limited Area Model) climate simulation, all using the GEM forecast model. These will be referred to by their acronyms in the following text. The AMIP2 also provides boundary conditions to the LAM. The same physics parameterizations are used for all three runs. The only differences relate to the horizontal grid used in each and the length of the time step. This is set at 22.5 minutes for SGMIP and LAM and 45 minutes for AMIP2. The LAM and SGMIP also share their maximum resolution area, which covers all of North America (NA) with a 50 km mesh. The number of horizontal mesh points on the SGMIP grid is approximately that of a global 1° uniform grid. The minimum SGMIP horizontal resolution is 1.8°, slightly less than the AMIP2 1.5° resolution. The vertical discretization is chosen such to be appropriate for the higher resolution SGMIP and LAM versions and consists of 60 hybrid vertical layers, with a top level at 2 hPa. The maximum vertical resolution occurs in the near the surface and in the PBL, with a 500 m secondary maximum around the equatorial tropopause. Results are compared with the freely available ERA40 re-analysis means for the corresponding periods.

3. Results

The AMIP2 and SGMIP global means and variances are very similar and the only significant differences between them can be explained by the increased resolution over NA. The simulations display the same strength and weaknesses, *i.e.* a too deep troposphere which can be seen by the vertical displacement of both the mid-latitude zonal wind jets and of the Tropical tropopause.

Fig. 1 January mean AMIP2 (a, c) and SGMIP (b, d)



U and T. Background fields are ERA40 total U fields and T difference fields. Units are m/s and °C.

AMIP2 and SGMIP suffer from excess precipitation over the mid-latitudes and do not produce enough over the ITCZ. This has been traced to the Kuo-type convection scheme and a correction is forthcoming.

The deep troposphere is thought to be related to faulty radiation and cloud interactions in the tropics: As a consequence a more recent radiation code is also being implemented. SGMIP does manage to be in better balance than AMIP2 in terms of global energy and moisture budgets. With respect to the transient evolution of these budget terms, SGMIP is generally closer to ERA40 than is AMIP2.

Finally turning to the high resolution domain results, Fig. 2 shows the January mean surface air temperatures over most of NA for AMIP2, SGMIP and LAM, respectively. All three images are very similar, except that, as expected, the LAM and SGMIP show much more detail, particularly over the Western part of the continent where the orography is important. At this point, we believe that most of the differences between the LAM and SGMIP results can be explained by the different averaging periods. Further tests where the LAM is driven by a SGMIP-configured model are currently under way to verify this.

4. Conclusions

The results from the AMIP2 and SGMIP simulations are very similar with respect to the large scales. The two generally share the same strengths and weaknesses. As expected, significant differences between the two can be seen over the SGMIP North-American high resolution domain.

The SGMIP and LAM results over North America are also rather similar. Some of the differences can probably be attributed to the small number of samples in this preliminary LAM simulation.

Acknowledgements

The authors gratefully acknowledge the help of Michel Desgagné and Lubos Spacek, both of RPN, with the GEM/LAM version. This research was partly supported by the Office of Science (BER), U.S. Department of Energy, Grant No. DE-FG02-01ER63199.

References

Côté, J., S. Gravel, A. Méthot, A. Patoine, M. Roch and A. Staniforth (1998). The operational CMC-MRB Global Environmental Multiscale (GEM) model. Part I: Design considerations and formulation. *Monthly Weather Rev.*, **126**, pp. 1373-1395.

Côté, J., J.-G. Desmarais, S. Gravel, A. Méthot, A. Patoine, M. Roch and A. Staniforth (1998). The operational CMC-MRB Global Environmental Multiscale (GEM) model. Part II: Results. *Monthly Weather Rev.*, **126**, pp. 1397-1418.

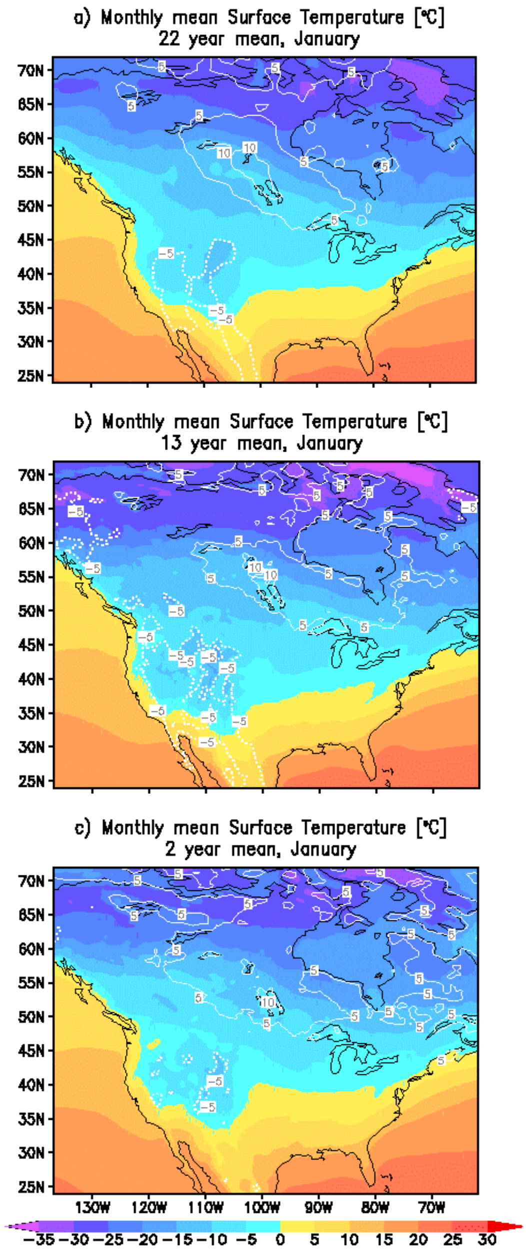


Fig. 2 January mean AMIP2 (a), SGMIP (b) and LAM (c) surface air temperatures. Background fields are ERA40 difference fields. Units in °C.

Consequences of Weather and Climate Changes for Marine Ecosystems

Erichsen, A. C., Rasch, P. S., Uhrenholt, T. & K. Edelvang

DHI Water & Environment, Denmark

In coastal areas and regional seas the marine environment is largely influenced by the local meteorology, not only regarding the long-term conditions such as monthly rainfalls etc, but also the frequency and intensity of meteorological events such as storms. Different aspects of climatic changes must be considered when studying regional marine systems compared to the global ocean.

To evaluate the impacts of climatic change scenarios on the marine environment, a 3D hydrodynamic (HD) and ecological model (ECO Lab) has been developed and setup. The model area includes almost the entire North Sea, the Baltic Sea and the interconnecting seas, whereas the areas in focus are the interconnecting seas. The model has two open boundaries – one in the English Channel, and one between Norway and Scotland – but the primary forcing, determining the physical hydrodynamic conditions, are the meteorological forcings. Meteorological forcings utilised in the model are air pressure, wind speed and –direction, air temperature, precipitation, evaporation and cloud cover as well as photosynthetic active light (PAR).

As the meteorological fields are the primary model forcing, this 3D model is a strong tool when assessing the overall impact on the state of the marine environment due to climatic changes. After application of climate model forcing the 3D model complex will be used to evaluate the effects of:

Increased temperatures: Increased temperatures will favour bacteria compared to phytoplankton. This is the result of an experiment carried out in Bergen, Norway. It is most likely that carbon and nutrients will be kept in the water phase, which might be beneficial to bottom oxygen conditions. However, increased temperatures will strengthen the halocline altering the oxygen transport from the surface to the bottom.

Increased precipitation: Increased precipitation is most likely to increase erosion of nutrients and suspended matter. Together with increased sediment fluxes and re-suspension this will increase the nutrient stress and increase primary production.

Regional weather systems: The environmental state of the Baltic Sea is closely linked to the occurrence of Major Baltic Inflows (MBI). MBIs are strongly linked to air pressure and wind directions.

Changes in local wind speed: Stratification of the water column dictates many properties of both hydrodynamics and ecology. Even minor climatic changes in frequency and/or intensity of storms can have a significant impact on the ocean.

The hypotheses described above will be assessed and investigated within the research project CONWOY – Consequences of weather and climate changes for marine and freshwater ecosystems - Conceptual and operational forecasting of the aquatic environment.

Application of a slab surface energy balance model to determine surface parameters for urban areas

Krzysztof Fortuniak, University of Lodz, Poland, Brian Offerle and Sue Grimmond , Indiana University, USA

Motivation

The parameterisation of surface processes is key to the improvement of meso- and large- scale numerical weather/climate prediction. This remains a problem in areas that are extensively urbanized as their adequate representation is necessary to improve the numerical models of climate change and, to be able to downscale potential changes to the city scale to predict human comfort in cities under changing climate. Here a simple slab surface energy balance model for urban areas is evaluated.

The model

The slab model has a surface canopy layer treated as a single entity with specified physical parameters. The 'ground' of the urbanized areas is an 'urban slab' with physical parameters that differ from rural ones. The heat storage term (ΔQ) is modelled as a ground heat flux (Q_G) determined by numerical solution of a 1-d heat diffusion equation with ten levels. The bottom boundary conditions are set by constant temperature at 1m depth typical for the analysed season. Surface temperature evolution is determined by analysis of the full energy balance equation. In the radiation budget (Q^*) the incoming short-wave radiation on the horizontal surface is approximated with the Davis et al. (1975) scheme. The 24 h measured average of incoming long-wave is used. Turbulent sensible heat fluxes (Q_H) are based on Monin-Obukhov similarity theory with Businger's functions for the flux-profile relations. Louis's (1979) method as modified by Mascar et al. (1995) is used. The method uses different roughness lengths for heat and momentum. This is fundamental to simulations of urbanised areas as z_{0m}/z_{0h} ratio can be of the order of 10^5-10^{10} (Voogt & Grimmond, 2000). To determine a latent heat flux (Q_E), an aerodynamic resistance concept is applied. Surface resistance is calculated using a modified Best (1998) procedure. The upper boundary conditions of the surface scheme are linked to a simple 1-d, first-order boundary layer model with K-closure technique for 28 levels (Fortuniak 2003). The horizontal homogeneity at the rural area is assumed but advection of rural air into the town is taken into account by simultaneous calculation for rural and urban points.

Data

The modelled components of the urban energy balance are compared to observations (Fig. 1). Data used in simulation comes from measurements of the urban energy balance components made in Lodz since November 2000 (Offerle at al. 2004). The measurement system is located at the top of a 20 m tower mounted on 17 m high building which is at least as high as any of the surrounding buildings. Thus the measurement height is close to the roughness sub-layer height in the neighborhood. The length dimension of the source area for turbulent fluxes change from ~300 m to ~600 m (unstable - stable conditions). Thus the data represent local-scale conditions of the surrounding area rather than a specific urban structure. As surface-atmosphere exchanges are most distinct for a particular surface type under fine weather conditions these types of days were chosen for analysis. Parameters used in simulation are: ground heat capacity: $C_g = 2.0\ 10^6\ \mathrm{J\,m^{-3}\ K^{-1}}$; ground thermal conductivity: $k_g = 1.5\ \mathrm{W\,m^{-1}\,K^{-1}}$; roughness length for momentum: z_{0m}= 0.6 m; roughness length for heat: z_{0h} = 0.00001 m; incoming longwave radiation: constant (averaged from measurements for each day); albedo and emissivity: $\alpha = 0.08$, $\varepsilon = 0.9$ (except March 28th when $\alpha = 0.13$, $\varepsilon = 0.85$ and Dec. 8th when $\alpha = 0.23$, $\varepsilon = 0.85$ - snow); soil moisture content: SMC = 3-8% (summer), SMC = 15-35% (winter). Though the values of C_g and k_g are somewhat greater than those of typical urban surface materials (e.g. concrete and asphalt) (ASHRAE 1981), this reflects the increased diurnal magnitude of heat storage in a 3 – dimensional surface relative to a slab with the same thermal properties. Other values are characteristic for the 'urban slab' in a typical Central-European town.

Results

Despite the simplicity of the model it is capable of reproducing many features of the urban climate using realistic parameters (Fig. 1). Both the diurnal course and range of energy balance components are well represented by the model for each of the clear sky days modelled in all of the seasons. Still, small model-measurement inconsistencies can be seen (Fig 1). The largest differences are a result of the variability in the measured turbulent fluxes. Simple boundary layer schemes do not represent convective structures of the mixed layer and can not capture such irregularities. There is a tendency to underestimate the turbulent fluxes in the morning hours probably because the boundary layer scheme produces weak morning growth of the mixed layer. The modeled outgoing radiation tends to be smaller than measurement as a result of using a fixed incoming longwave radiation and ignoring urban geometry.

References

ASHRAE 1981. *ASHRAE Handbook: 1981 Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers: Atlanta.

Best M.J., 1998, A model to predict surface temperatures, *Bound.-Layer Meteorol*., 88, 279-306.

Davies, J.A., Schertzer, W., Nunez, M., 1975: Estimating global solar radiation, *Bound.-Layer Meteor*., 9, 33-52.

Louis, J.-F., 1979: A parametric model of vertical eddy fluxes in the atmosphere, *Bound.-Layer Meteorol*., 17, 187-202.

Mascart, P, Noilhan, J, Giordani, H, 1995, A modified parameterization of flux-profile relationship in the surface layer using different roughness length values for heat and momentum, *Bound.-Layer Meteorol*., 72, 331-344.

Offerle, B, CSB Grimmond, K Fortuniak, 2004, Heat storage and anthropogenic heat flux in relation to the energy balance of a central European city center. *Int. J. Climatol*.. (Submitted).

Fortuniak, K, 2003, A slab surface energy balance model (SUEB) and its application to the study on the role of roughness length in forming an urban heat island, *Acta Univ. Wrat*., 2542, 368-377.

Voogt, JA, Grimmond, CSB., 2000, Modeling surface sensible heat fluxes using surface radiative temperatures in a simple urban Area, *J. Appl. Meteor*., 39, 1679-1699.

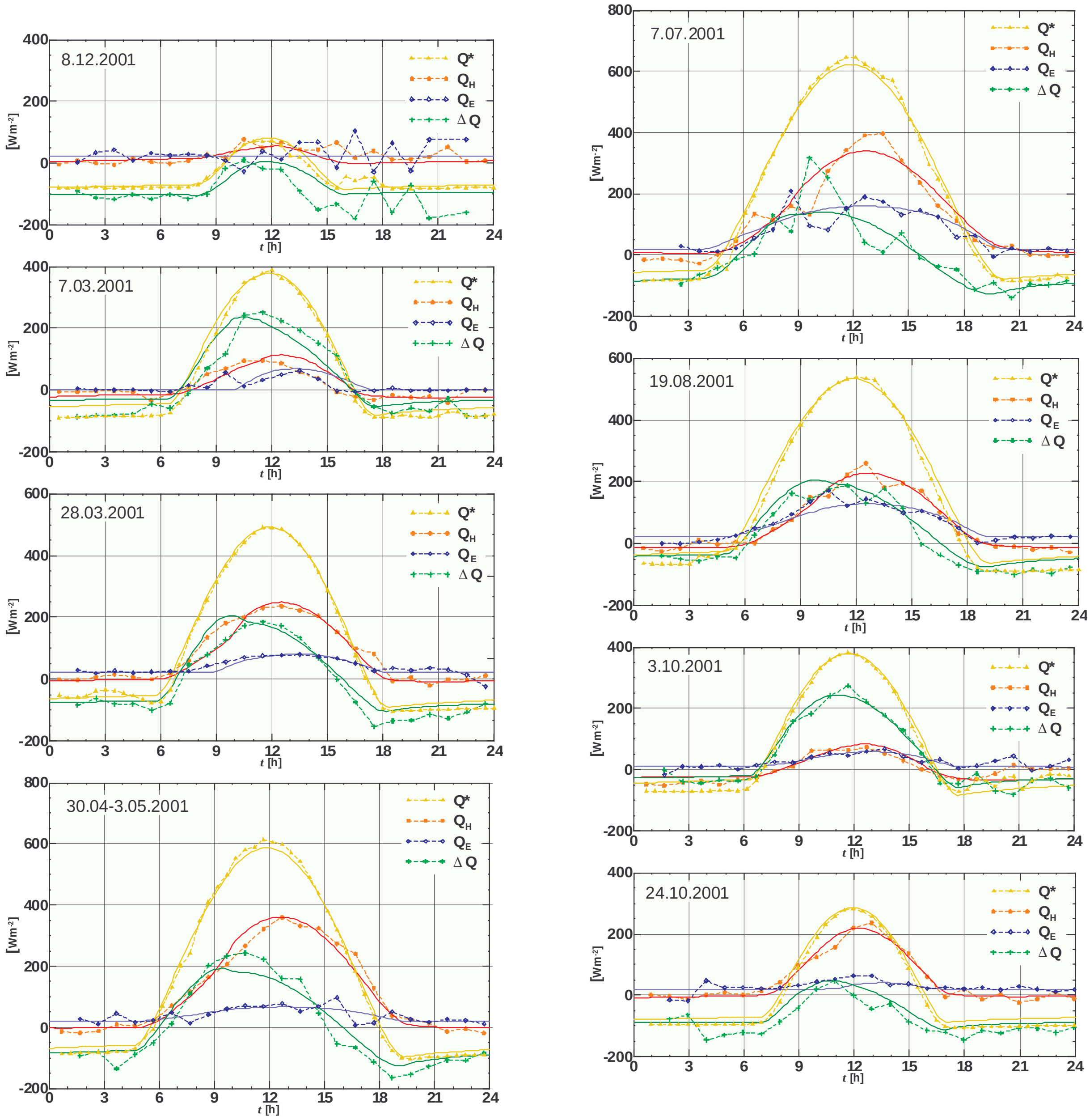


Fig. 1 Measured (dashed lines) and modelled (full lines) components of the urban energy balance components

The Canadian Regional Climate Model: Validation of its hydrology for rivers in northern Quebec and Labrador

Anne Frigon, Michel Slivitzky and Daniel Caya. Ouranos, Montreal, Canada. Email: frigon.anne@ouranos.ca

The CRCM's regional surface hydrology, is evaluated by comparing model output from a 25-year simulation with streamflow observations over 12 basins of interest (ranging in size from 13 000 km^2 to 73 000 km^2), covering a total area of 435 000 km^2. Runoff is an appealing component to validate climate models as it represents spatial and temporal integration of watershed processes.

The CRCM was run over North America for a 25-year period with the following configuration: - January 1975 to December 1999 (after a 2-year spin-up) - 45 km horizontal resolution - 193 x 145 grid points - 29 vertical levels (model top at 29 km) - 15 minute time steps - lateral boundary conditions from 6-hr NCEP atmospheric reanalyses-1 (NRA-1) - sea surface conditions from monthly AMIP-II observations (SST & sea-ice) - spectral nudging of large scales (horizontal winds; >1400 km) (Riette and Caya, 2002).

This version of the CRCM (V3.6.1) basically contains the 2nd generation Canadian GCMii physics (McFarlane *et al.*, 1992) which comprises a single-layer surface scheme. Soil water holding capacity varies over every grid point depending on vegetation and soil characteristics. Some subgrid-scale parameterizations, such as convection and cloud onset, have been adapted to the CRCM's finer resolution (Laprise *et al.*, 2003). Surface runoff is generated instantly when total soil moisture exceeds water holding capacity, returning water surplus to the ocean without river routing or groundwater storage.

Global Analysis

Table 1 presents a summary of the 25-year annual climatology over the 12 basins for CRCM and NRA-1, and comparisons with observations (OBS). Even though CRCM overestimates annual precipitation (PCP) by 18%, it underestimates runoff (RNFF) by 22% because its evapotranspiration (EVAP) is much too important (+119%). The model's evapotranspiration is driven mostly by its soil water holding capacity which is quite important, ranging from 546 mm to 766 mm. Such soil water availability generates important evapotranspiration fluxes. This behavior is noted mainly in summer and to a lesser extent in the fall.

Annual precipitation from NRA-1 is comparable to CRCM's but the reanalyses underestimate runoff (-42%) more than the CRCM (-22%) because their evapotranspiration is even more overestimated (+181%) than CRCM's (+119%). The CRCM's overestimation of precipitation and underestimated runoff is notable in Table 1. Again, it is the overestimated evapotranspiration that causes the model's runoff to become so low. Interannual variability in precipitation and runoff show poor synchronism with observations. This behavior prevents us from looking into a particular year but still allows us to explore the model's climatology.

Table 1: Mean annual values over the 12 basins for CRCM and NRA-1. Differences with OBS are in parentheses (absolute in mm/day and %). Shaded values are residuals.

	PCP	RNFF	EVAP
	mm/day		
CRCM	2.81 (0.43 / 18%)	1.32 (-0.38 / -22%)	1.49 (0.81 / 119%)
NRA-1	2.90 (0.52 / 22%)	0.90 (-0.71 / -42%)	1.91 (1.23 / 181%)
OBS	2.38	1.70	0.68

Regional analysis

Figure 1 presents the observed long-term mean annual runoff for the 12 basins. In Figure 2, we note that the CRCM bias for runoff is smaller in the SW region while the model's precipitation bias (figure 3) is weaker in the NE area. Such behavior is related to the model's evapotranspiration which is quite important and does not show as much spatial variability as its precipitation.

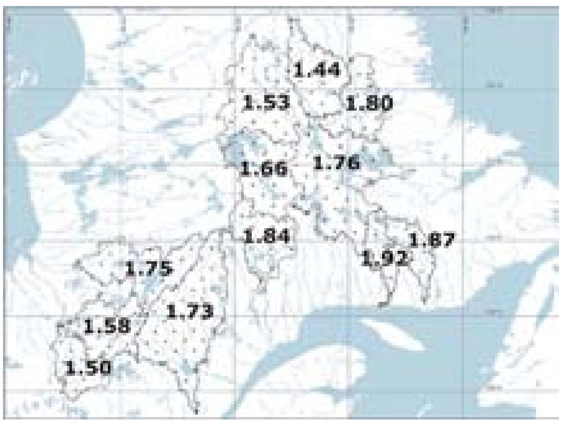


Figure 1: Long-term (1975-1999) observed mean annual runoff (mm/day).

With estimated annual mean observed values around 0.68 mm/day, the CRCM's EVAP shows a bias of +0.81 mm/day (Table 1). In the SW area, we find that the model's EVAP and PCP overestimations nearly compensate themselves so that runoff underestimation is in the order of 0.2 mm/day. However, in the NE area, the CRCM's EVAP overestimation takes precedence over its PCP overestimation to give a more important runoff underestimation (around 0.5 mm/day).

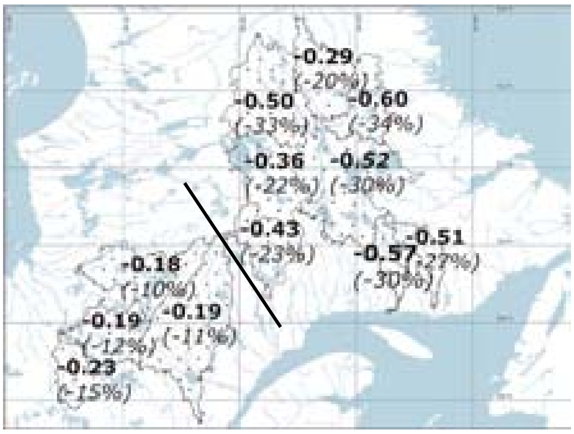


Figure 2: Annual runoff bias for the CRCM (bold in mm/day; italic in %).

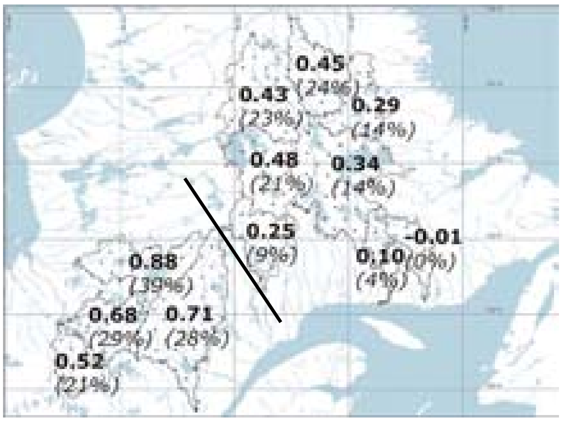


Figure 3: Annual precipitation bias for the CRCM (bold in mm/day; italic in %).

We can therefore identify 2 distinct areas that differ in their runoff bias, mainly because of the CRCM's precipitation behavior:

(1) SW area: with a weaker runoff underestimation because of CRCM's more important PCP overestimation. For this region, the annual PCP bias is distributed evenly through the year with seasonal biases varying from ~20% to ~37%.

(2) NE area: with a more important runoff underestimation because of CRCM's weaker PCP overestimation. In this region, the weaker annual PCP bias is mainly related to the model's less important bias in fall, winter and spring (5% to 7%) while for the summer, the precipitation bias is similar (~35%) to the one observed in the SW region.

Conlusion and Future Plans

With its current single-layer surface scheme, the CRCM underestimates annual runoff mainly because of its important evapotranspiration, which is mainly related to the model's very high soil water holding capacity. The model's fall transition also suffers from being too warm and thus delays the onset of snow cover (not shown).

While the implementation of the multi-layer surface scheme CLASS (Canadian LAnd Surface Scheme; Verseghy, 1996) into the CRCM is being done (and will take a few months!), we plan to start 30-year simulations with an intermediate version of the CRCM which contains: (1) new radiation (more spectral bands and new water vapor continuum), (2) new clouds (triggered by humidity and stability), (3) new surface fluxes diffusion, (4) constant soil water holding capacity of 100 mm, to decrease summer evapotranspiration and improve the model's behavior in transition periods.

Acknowledgments

We would like to acknowledge that streamflow data was provided by: Centre d’expertise hydrique du Québec from the Québec Department of Environment, Hydro-Québec, Société d’électrolyse et de chimie Alcan ltée, and the Churchill Falls and Labrador Corporation. Monthly precipitation and temperature data was obtained from the Climatic Research Unit (Mitchell *et al*., 2003).

References

Laprise, R., D. Caya, A. Frigon, and D. Paquin (2003) Current and perturbed climate as simulated by the second-generation Canadian Regional Climate Model (CRCM-II) over northwestern North America, *Climate Dynamics*, 21(5-6), 405-421.

McFarlane, N.A., G.J. Boer, J.-P. Blanchet and M. Lazare (1992) The Canadian climate centre second-generation general circulation model and its equilibrium climate, *Journal of Climate*, 5(10), 1013-1044.

Mitchell, T.D., T.R. Carter, P.D. Jones, M. Hulme and M. New (2003) A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). *Journal of Climate*: submitted

Riette, S., and D. Caya (2002) Sensitivity of short simulations to the various parameters in the new CRCM spectral nudging. Research activities in Atmospheric and Oceanic Modelling, edited by H. Ritchie, *WMO/TD* - No 1105, Report No. 32: 7.39-7.40.

Verseghy, D. L. (1996) Local climates simulated by two generations of Canadian GCM land surface schemes, *Atmos.-Ocean*, 34(3), 435-456.

Towards the development of a high resolution extreme wind climatology for Switzerland

Stéphane Goyette, Department of Geosciences, University of Fribourg, Switzerland

Project overview

This study aims at establishing a high-resolution climatology of extreme winds over Switzerland using a numerical modelling approach. The basic model is the Canadian Regional Climate Model (CRCM; Caya and Laprise, 1999) to which is applied a new windgust parameterisation (Brasseur, 2001; Goyette *et al.*, 2003). This model has previously shown genuine skill in downscaling a number of observed windstorms over Western Europe using the NCEP-NCAR reanalysis as driving data (*e.g.* Goyette *et al.*, 2001). As input data, this study uses the simulated outputs of the UK HADLEY Center's HADCM3 coupled ocean-atmosphere global model - available in the EU 5th Framework Program "PRUDENCE" project (Christensen *et al.*, 2002)- for the 1961-1990 period. Using the multiple self-nesting procedure of the CRCM, a number of storms are downscaled at 2 km over Switzerland. The preliminary analysis of ten windstorms is very encouraging: the potential areas which experienced severe winds agree well with observations. Most of the severe winds episodes are embedded in westerly flows; however observations show that strong winds may also be generated by southerly and northerly type of flows. These results thus prompt the need for further storm investigation to encompass the largest portion of potential extreme wind cases since the ultimate goal is to assess the change in the behaviour of extreme winds under climate changes based on the IPCC A2 greenhouse-gas emission scenario.

Methodological approach

This paper describes briefly the modelling approach and the suitability of the method. Work is currently underway to simulate and compile a number of extreme windstorms over Switzerland using the CRCM nesting methodology. The end product of this compilation is expected to form a basis for the development of a realistic high resolution extreme wind climatology for Switzerland. This study uses the simulated outputs of the UK HADLEY Center's HADCM3 coupled ocean-atmosphere global model for the 1961-1990 control period. These, along with the corresponding SSTs and sea-ice conditions, serve to adequately prescribe the model's evolving lateral and lower boundary conditions. The HADCM3 outputs have been sorted out to identify the probable situations leading to extreme windstorms over Switzerland; these are then simulated independently as specific episodes. These situations are first downscaled to 160 km with the CRCM for a nine-day period, following which the 160 km atmospheric outputs serve as driving nesting conditions for the subsequent 60 km run with same model, whose outputs drive the 20 km integration, whose results serve as driving conditions for the 5 km integration and, finally, these drive the final 2 km integration for a one-day simulation over Switzerland to which the new windgust parameterisation has been applied as shown in Fig 1. Thirty of such wind storms would eventually form the necessary basis to develop the "climatology" of extreme winds.

Preliminary results

The preliminary analysis of ten windstorms is very encouraging; the potential areas which experienced very strong winds agree well with observations. Most of the simulated windstorms (10/12) are generated by winter westerlies induced by deep cyclones travelling in the North Atlantic towards the Baltic. The mean sea-level pressure pattern averaged during the simulated storms with the 160-km CRCM is in agreement with the NCEP-NCAR mean sea-level pressure average over the 10 most violent wind storms recorded in Switzerland since 1978 compiled from the ANETZ automated station data (Bantle, 1989). The mean low pressure centre is located over Southern Scandinavia-Baltic Sea and the high is located over the Azores; this configuration produces a strong pressure gradient with isobars tilted in the northwest-southeast direction thereby generating westerly flow in Switzerland. The spatial pattern and mean daily maximum wind speed are simulated realistically at 2 km and include a number of details (Fig 2). The maximum windspeed is of main interest since it is the gusty nature of the wind that has significant small-scale impacts in mountains and in lowlands of Switzerland. These impacts range from human victims, damage to forests, agricultures, and infrastructures (Beniston, 2003). Using station and simulated data, no obvious relationship is found between the gust speed and elevation, which precludes a simple scaling of the gust speed with station height. The behaviour of the gusts at all stations for the first ten storms show that the simulated speed mean distribution exceeds the observed mean maximum winds by about 4 m s^{-1}; comparisons with station elevation show that the excess in wind gust velocities tends to correlate with positive elevation difference between station height on the grid and the observed one.

Future work

Severe storms events are the basis of severe weather, and a dominant characteristic is their associated high winds. Maximum gust speed averaged over a number of storms is one of the main interests for the development of this extreme wind climatology. This study mainly focused on winter storms generated by westerly flows. Observations show that some wind storms may also be generated by purely southerly flow (South Foehn) or by northerly to north easterly flow (Bise). These preliminary results thus prompt the need for further storm investigation and simulation. This preliminary step is a prerequisite to study the behaviour of extreme winds with a fine resolution in order to assess the change following a climatic change as projected for the 21st century by a number of GCMs.

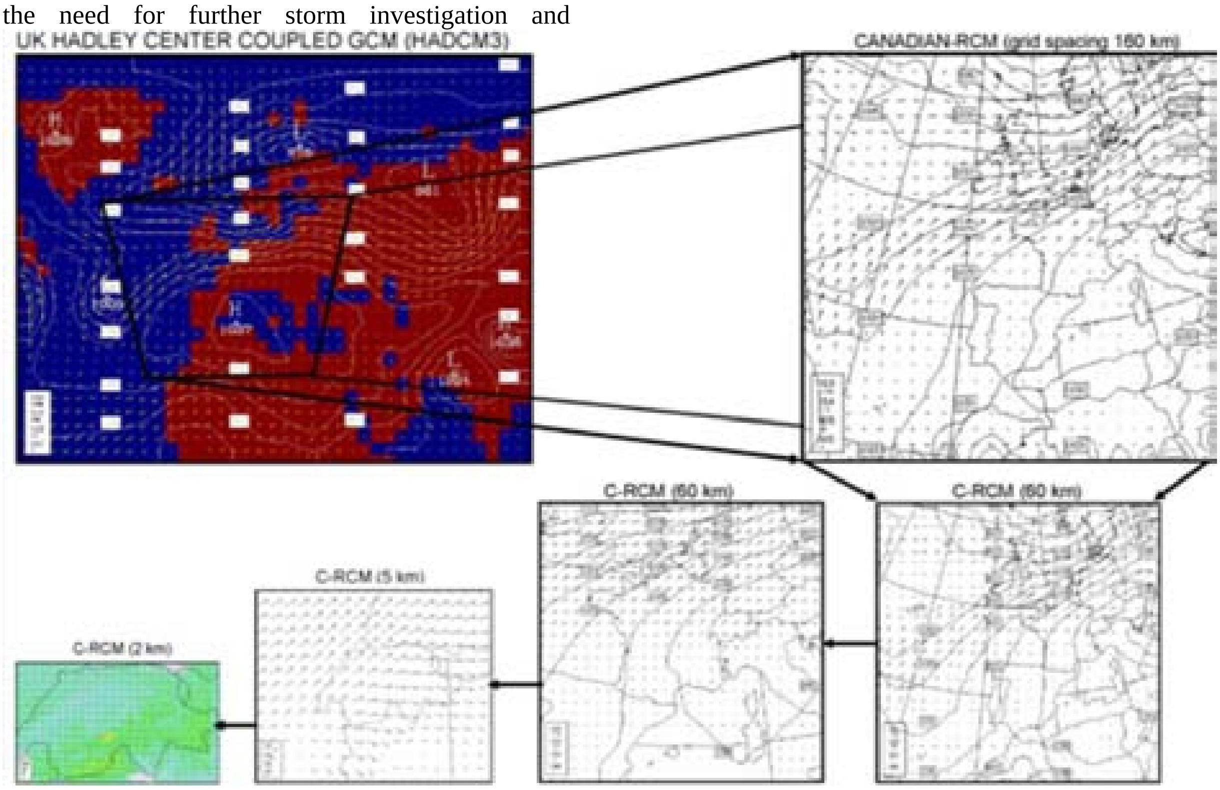


Fig. 1. *Cascade self nesting technique used to refine windstorms simulated with a coarse resolution GCM (here the Hadley Centre's coupled General Circulation Model HADCM3) with the CRCM down to 2-km grid spacing.*

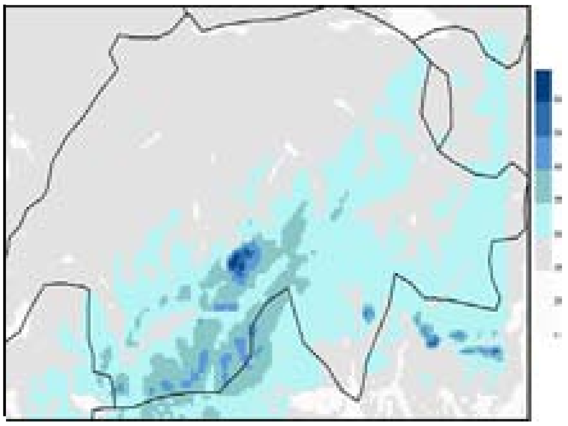


Fig. 2. *Mean daily maximum wind speed spatial distribution simulated with the 2-km CRCM over Switzerland. Wind speed is in m s^{-1}, shades over 25 m s^{-1} are indicated on the right scale.*

References

Bantle, H., Program documentation for the Swiss climate data base at the computing center of ETH-Zürich, MeteoSuisse publication, Zürich, Switzerland (in German).

Beniston, M., 2003: Climatic change in mountainous regions: a review of possible impacts. Climatic Change, 59, 5-31.

Brasseur, O., 2001: Development and Application of a Physical Approach to Estimating Wind Gusts, Mon. Wea. Rev., 129, 5-25.

Caya, D., and R. Laprise, 1999: A semi-implicit semi Lagrangian regional climate model: the canadian RCM. Mon. Wea. Rev., 127, 341-362.

Christensen, J. H., T. R. Carter, F. Giorgi, 2002 : PRUDENCE employs new methods to assess Euripean climate change, EOS (American Geophysical Union Newsletter), 83/13.

Goyette, S., O. Brasseur, and M. Beniston, 2003 : Application of a new wind gust parameterisation. Multi-scale case studies performed with the Canadian RCM. J. of Geophys. Res., 108 (D13), 4374.

Goyette, S., M. Beniston, D. Caya, J. P. R. Laprise, and P. Jungo, 2001 : Numerical investigation of an extreme storm with the Canadian Regional Climate Model : The case study of windstorm VIVIAN, Switzerland, February 27, 1990. Clim. Dyn, 18: 145-178.

NCEP-NCAR data: available from CDC web site at : `http://www.cdc.noaa.gov`

How can RCM reproduce the extremes

T. Halenka[1,3], J. Kalvová[1], Z. Chládová[1], A. Demeterová[1], K. Zemánková[1], A. Farda[1,2],

1) Dept. of Meteorology and Environment Protection, Charles University
2) Czech Hydrometeorological Institute
3) Regular associate of Abdus Salam ICTP
tomas.halenka@mff.cuni.cz

Introduction

About four years ago, in framework of local projects funded by Grant Agency of Czech Republic and Ministry of Environment an effort was started to develop the regional climate model based on NWP model ALADIN used for weather prediction purposes in Czech Hydrometeorology Institute. The main target has been to have a tool for more detailed evaluation of potential climate change for the territory of Central Europe and complex terrain of Czech Republic mainly (Huth et al., 2003). As the technical implementation of such a high resolution RCM (20km) was quite difficult task in conditions of Czech Republic, we used in parallel the model RegCM3 in coarser resolution as a source of know-how and for planning the experiments with ALADIN. As it was not possible to complete some longer run (more than some years) in framework of above mentioned projects, we have finally made experiment with RegCM3 for period 1961-2000 aiming to test the capability of RCM to reproduce extremes (with emphasis to precipitation), which was well fitted into special call for projects announced after 2002 flood in Czech Republic and dealing with extreme events.

Model configuration

We have used the regional climate model RegCM3 available from ICTP, Physics of Weather and Climate Group. It is model originally developed in NCAR (Dickinson et al., 1989; Giorgi, 1990) and based on NCAR-PSU (National Center for Atmospheric Research – Pennsylvania State University) MM4 compressible hydrostatic grid point model but with modified physics for use in climate studies, further upgraded by Giorgi et al. (1993a,b) and later on modified in ICTP with some new parametrization schemes. Dynamical core of the RegCM3 is now similar to that of the hydrostatic version of MM5, physical packages are more or less based on CCM3 with some additional changes, mainly in description of cloud and precipitation processes (SUBEX scheme by Pal et al., 2000), and optional settings, like inclusion of lakes, choice of horizontal and vertical resolution, top of the model, map projection etc. We run the model on bigger Central European domain with 45km resolution in grid 100x80, centered for 50N, 15E (Prague), with 23 vertical σ-levels up to 70hPa and basic timestep 150s. We used 10'x10' orography, which can be seen in Fig.1 for domain of comparison with observational data. Clear underestimation of northern border chain of rather narrow mountains should be pointed out here.

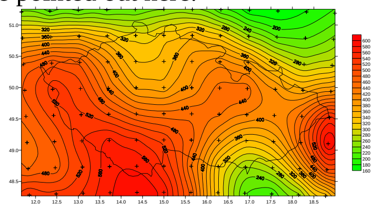


Fig 1. Model orography in domain of comparison

In this experiment the RegCM3 was driven by boundary condition prepared from NCEP/NCAR reanalysis for period 1961-2000. For SST GISST from Met Office were used. Basic results of 1961-2000 simulation are presented in Fig.2 for temperature and in Fig.3 for precipitation.

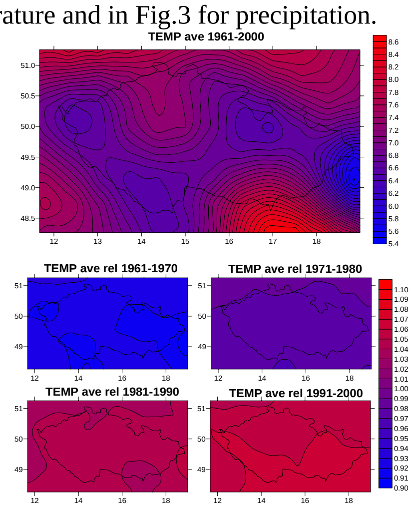


Fig 2.Basic results for average temperature. Whole period (upper panel),individual decades against whole period average (four lower panels).

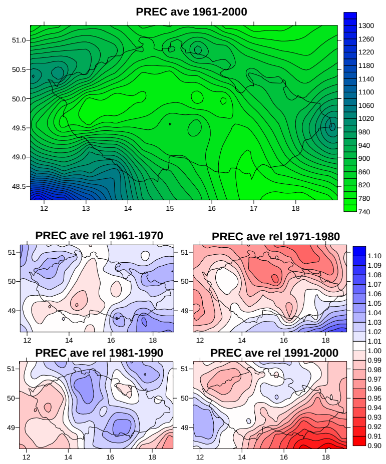


Fig 3. As Fig.2,but for annual precipitation.

Comparison of model results vs. observations

For comparison time series of daily precipitation, average temperature as well as daily maximum and minimum temperature were prepared in model points on domain of interest shown in Fig.4. There are locations of stations with reliable data covering the whole period of simulation marked as well there.

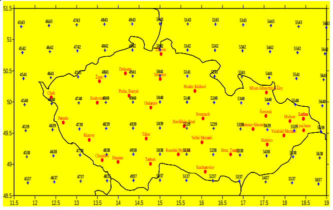


Fig.4. Model points and stations location (red).

The results of comparison for selected couples of observational site and nearest model point are presented. Frequencies of exceedance of given daily threshold are displayed in Fig. 5. It can be pointed out overestimation of model precipitation for low thresholds, quite reasonable agreement for precipitation about 5 – 30 mm and underestimation in extremes. The biggest departure of model results can be seen for mountain station Lysa Hora, especially in summer, which could be due to orographically enhanced precipitation and convection in subgrid scale. In Fig.6 the comparison for extremes is presented in terms of daily precipitation for given return period. Model fails again for mountainous station while the highland station values are reproduced quite well.

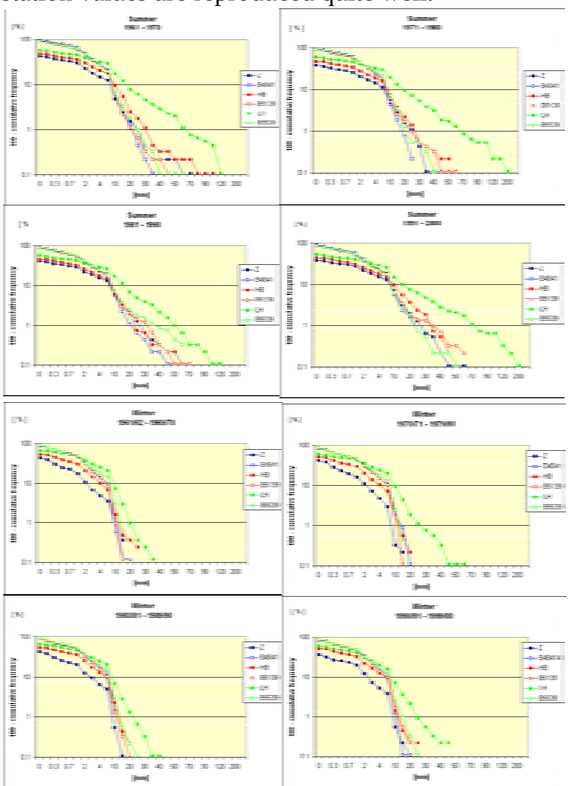


Fig.5. Frequency of exceedance of daily threshold, model(filled symbol) vs. observations (empty), Zatec (blue), Havlickuv Brod (red) and Lysa Hora (green).

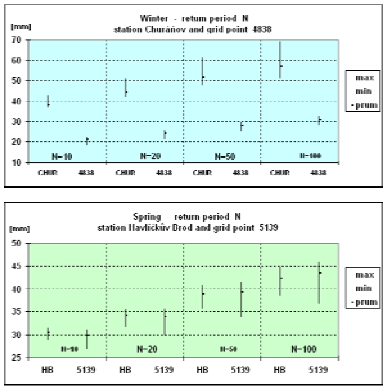


Fig.6. Comparison of daily precipitation with return period 10, 20, 50 and 100 years for mountain station Churanov (above) and station H. Brod (bottom).

Conclusions

Generally, it can be seen from this experiment that RCM is capable to reproduce precipitation extremes, but still with some drawbacks. There are significant failures for mountainous subgrid regions, especially in summer. Further analysis showed us that comparison may differ in time, probably with interdecadal changes in circulation. More detailed evaluation will be necessary using other data.

Acknowledgement

Our thanks go to ICTP for making RegCM available as well as to NCEP/NCAR for reanalyses, Met Office for SST data and CHMI for observational data. The study was carried as project 205/03/Z024 supported by GACR.

References

Dickinson R.E., Errico R.M., Giorgi F. and Bates G.T., 1989: A regional climate model for the western United States. Clim. Change, 15, 383-422.

Giorgi F., 1990: Simulation of regional climate using a limited area model nested in a general circulation model. J. Climate, 3, 941-963.

Giorgi, F., M.R. Marinucci, and G.T. Bates, 1993a: Development of a second generation regional climate model (RegCM2) I: Boundary layer and radiative transfer processes. Mon. Wea. Rev., 121, 2794-2813.

Giorgi, F., M.R. Marinucci, G.T. Bates, and G. DeCanio, 1993b: Development of a second generation regional climate model (RegCM2) II: Convective processes and assimilation of lateral boundary conditions. Mon. Wea. Rev., 121, 2814-2832.

Huth, R., R. Mládek, L. Metelka, P. Sedlák, Z. Huthová, S. Kliegrová, J. Kyselý, L. Pokorná, M. Janoušek, T. Halenka: On the integrability of limited-area numerical weather prediction model ALADIN over extended time periods. *Studia geoph. geod.*, 47, 863-873, 2003.

Pal, J. S., E. E. Small, and E. A. Eltahir: Simulation of regional-scale water and energy budgets: Representation of subgrid cloud and precipitation processes within RegCM. *J. Geophys. Res.*, 105, 29579-29594, 2000.

Prediction of Regional Scenarios and Uncertainties for Defining EuropeaN Climate Change Risks and Effects -- PRUDENCE -- The Project

Hesselbjerg Christensen, J.
Danish Meteorological Institute, Denmark

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. 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, although increasing efforts are being made to produce higher resolution climate simulations, particularly at the regional scale. Simple models include, at best, a limited physical representation of the climate system. 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. Perhaps even more important, regional signals of climate change often reflect the coarse resolution and the patterns of change can be significantly altered when resolution is increased. PRUDENCE is a European-scale investigation funded by the European Commission with the following objectives: 1. to address and reduce the above-mentioned deficiencies in projections; 2. 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; 3. 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: i) appropriate computational resolution - obscures or precludes analysis of the events; ii) long-term climate model integrations - drastically reduces their statistical significance; iii) 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. 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 first synthesizing results obtained over two years of coordinated research efforts by a total of 21 European full partners from 9 countries and associated participants representing more than 4 additional countries will be highlighted.

URL: http://prudence.dmi.dk

START-supported RCM modeling in Africa

Hewitson, B. C.

University of Cape town, South Africa

The poster reviews the RCM activities in Africa supported by START over the last decade. Developments in researcher and infrastructure capacity are discussed, along with current modeling work. Current RCM applications include extensive modeling of nested RCMs in GCM simulations for future climate simulations, under the auspices of the AIACC program, and which seek to address the need for regional climate change scenarios for the impacts community. In addition, RCM expermients exploring the land surface interactions with the atmoshere over southern Africa are reviewed, and initial results presented detailing the regional climate sensitivity to surface perturbations.

Simulation of extreme inflow events in the Baltic Sea using the coupled regional climate modeling system BALTIMOS

Daniela Jacob[1], Philip Lorenz[1] and Andreas Lehmann[2]

[1] Max Planck Institute for Meteorology, Hamburg, Germany
[2] Institute for Marine Research, University of Kiel, Kiel, Germany

jacob@dkrz.de

The observed Baltic Sea inflow event

During January 2003 an inflow of highly saline, cold and extremely oxygen-rich water from the North Sea into the Baltic Sea was recorded at Darss Sill. Calculations using the sea level difference of about 50 cm at the Landsort gauge yield an estimate of 180 km3 (for comparison the annual river runoff is about 450 km3). Such exceptional inflows are the only possibility to renew the deep water of the central Baltic Sea and to improve the oxygen situation there. They are initiated by a specific sequence of meteorological conditions.

The coupled model system BALTIMOS

A fully coupled regional climate model system for the Baltic Sea region, called BALTIMOS, was developed in the framework of BALTEX / DEKLIM (German Climate Research Programme 2001–2006; http://www.deklim.de) by linking existing model components for the atmosphere (model REMO; Jacob, 2001), for the ocean including sea ice (model BSIOM; Lehmann and Hinrichsen, 2002), for the hydrology (model LARSIM) as well as for lakes.

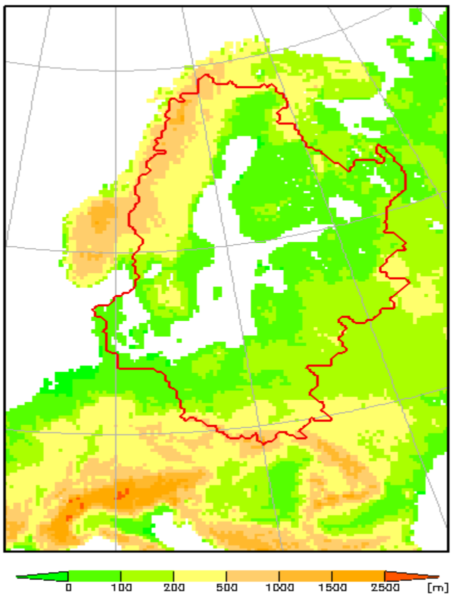


Fig 1: BALTIMOS domain with Baltic Sea catchment (red line).

The model system consists of high resolution model components: atmosphere 1/6° (~ 18 km) with 20 vertical levels; ocean-ice 5 km with 60 vertical levels; hydrology 1/6° (~ 18 km).
The model domain covers the whole drainage basin of the Baltic Sea as well as major parts of Europe (figure 1). All interfaces between the model components have been specified in co-operation with their respective partners. After that the partners prepared module versions according to these interfaces and delivered them to the Max Planck Institute for Meteorology, where the coupled model system was implemented. The coupling time step between all components is 1 hour. All components except the Ocean/Seaice module BSIOM are formulated in an identical horizontal coordinate system.

Simulation of the inflow event

The exceptional inflow event has been simulated successfully with the atmospheric and oceanographic components of the BALTIMOS model system. The simulation was initialized at 1st of February 2002 and integrated until October 2003.

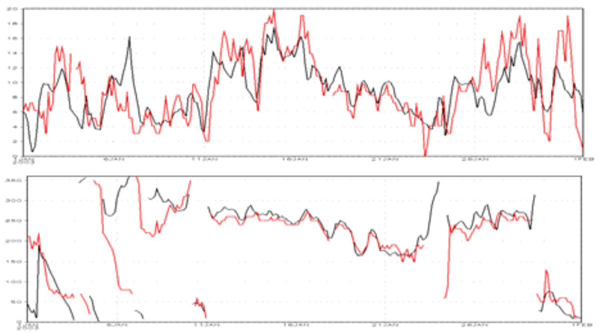


Fig 2: Wind speed [m/s] (upper panel) and wind direction [deg] (lower panel) for January 2003: Measurements at the SYNOP-station "Arkona" at the island of Rügen (red line) and BALTIMOS simulation for the appropriate grid box (black line).

Figure 2 shows the good agreement between observed wind speed and direction at "Arkona" (island of Rügen) against the simulated BALTIMOS results for the appropriate grid box. In particular the shift from easterly winds in the beginning of January to strong westerly winds in the middle of January is represented well.

In accordance to observations, the highly saline, cold water entered the Bornholm basin in the end of January (figure 3). Unusual warm water flowing into the Bornholm basin in September 2002 led to relatively high temperatures in depths between 60 and 70 meters. This persistent warm water anomaly was finally displaced by the inflow in January.

Acknowledgements

This research was funded by the German Climate Research Programme (DEKLIM) of the Federal Ministry of Education and Research (BMBF).

References

Jacob, D., A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin, Meteorology and Atmospheric Physics, Vol. 77, 61-73, 2001

Lehmann, A. and H.-H. Hinrichsen, Water, heat and salt exchange between the deep basins of the Baltic Sea. Boreal Env. Res., 7, 405-415, 2002

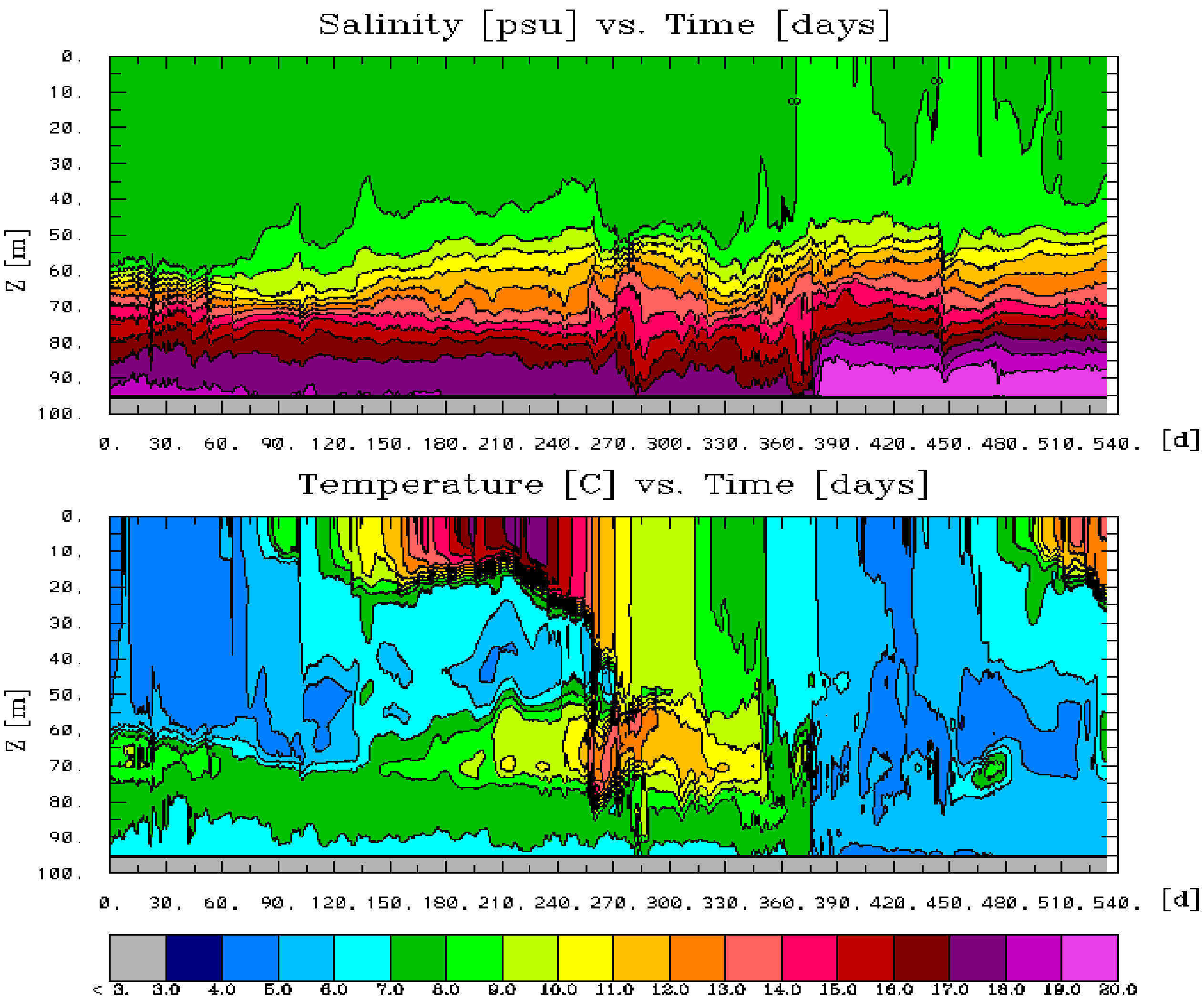


Fig. 3: BALTIMOS: Temporal evolution of vertical profiles of salinity [psu] (upper panel) and temperature [°C] (lower panel) at Bornholm Deep for the period February 2002 to June 2003.

Representation of the variability of atmospheric circulation in the North Atlantic and its relation to long term variability of Icelandic Hydrological Series

Jonsdottir, J. F.[1] and C. Uvo [2]

(1) Hydrological Service, National Energy Authority, Iceland
(2) Department of Water Resources Engineering, Lund University, Sweden

The variability of the atmospheric circulation has great effects on the precipitation and runoff in Iceland. The island is situated in the middle of the North Atlantic Ocean in the path of the low-pressure frontal systems that transport moisture and thermal energy from the South to the North.

A multivariate statistical analysis is performed on discharge data for several rivers in Iceland. The variability in the characteristics of the rivers is large since their watersheds are in various parts of the country, where glaciers and groundwater play a large role in the hydrology of some of the watersheds. The modes of variability are identified by a principal component analysis and the physical explanation of the modes is searched for by canonical correlation with data on precipitation, temperature, sea level pressure and sea surface temperature.

This study has the goal of identifying processes that relate the variability of the atmospheric circulation to the variability of the Icelandic rivers. It will thereby reveal the most suitable predictors for the hydrological conditions in Iceland based on indices and information on general prevalent circulation patterns.

Bark beetle damage in a changing climate

Anna Maria Jönsson[1)], Carin Nilsson[2)], Lars Bärring[2)], Ingrid Stjernquist[1)] and Peter Schlyter[3)]
1) Dept. of Ecology, Plant Ecology and Systematics, Lund University, 223 62 Lund, Sweden
2) Geobiosphere Science Centre, Dept of Physical Geography & Ecosystems Analysis, Lund University, 223 62 Lund, Sweden
3) Department of Physical Geography and Quarternary Geology, Stockholm University, 106 91 Stockholm, Sweden
Anna_Maria.Jonsson@ekol.lu.se

Introduction

Ecosystem responses to climate variations/changes typically involve interactions between several processes that are sensitive to various climatic variables. In many cases the responses are non-linear because of thresholds in the process interactions. Here we explore one particular system, involving managed forest ecosystems, where the possibility of a substantial economic impact of a future climate change has been intensely debated within the forestry community.

Windthrown spruce trees (*Picea abies*) are the key-factor for an in-crease in population size of the spruce bark beetle (*Ips typographus*). A high frequency and magnitude of storm damage events thus increases the risk for a build up of a large population. In turn, this increases the risk for severe attacks on healthy standing trees.

Living spruce trees defend themselves with resin and alteration of nutritional quality. A large *Ips* population and an aggregation of attacks are the keys for the bark beetles to overcome the defence, eventually killing the trees.

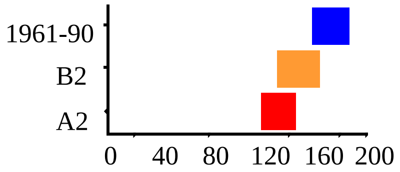
Models and data

We have explored the performance of the beetle population models (*ref. 1*) when fed with various meteorological data. Daily temperature data and recorded storm damage were used as input data to the population model of bark beetle development and compared to observed attacks by bark beetles. **1)** The model was able to capture the typical timing of different development stages of bark beetle populations. **2)** In a second step, the simulated population dynamics were validated with long-term observed bark beetle attacks (1986-2000). To achieve this we used output from the **snREMO** regional model with spectral nudging and forced with NCEP reanalysis boundaries (*ref. 2*). This kind of data is directly linked to the observed weather and has the main characteristic of climate model output as grid-box averages. This validation captured the importance of storm frequency and sanitary cutting for the interannual population development. We thus conclude that the bark beetle population model capture the essential interactions between weather variables and population dynamics. **3)** Thirdly, the bark beetle model was run with input from both meteorological station data for the period 1961-90 and daily data from the **HadRM3H** regional climate model and the frequency distributions of timing of the different *Ips* development stages were compared. Compared with point observations (station data), the 30-year frequency distribution ('climatology') of timing of key developmental stages as simulated with data from the HadRM3H model only differed by one or two days. **4)** We use the HadRM3H SRES A2 and B2 scenario runs to explore the possible impact of future climate change scenarios on bark beetle population development.

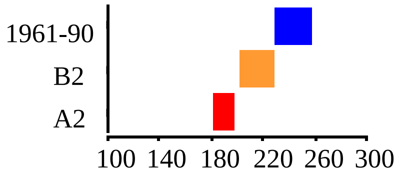
Present day and future situation at Växjö, southern Sweden.

Temperature data from the Hadley Centre regional climate model HadRM3H for the control period 1961-1990 compared with the future scenarios SRES A2 and SRES B2 for 2070-2099.

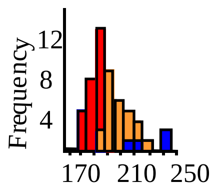
1. Date of spring swarming



2. Date of completed development



3. Date of summer swarming



Today, most parts of Sweden have only one *Ips* swarming period per year, a second generation is rarely produced, and the winter mortality of immature bark beetles is very high.

Higher temperatures in the future will increase the risk for a swarming period during late summer (*Fig.3*), as the spring swarming (*Fig.1*) and the development from egg to bark beetle (*Fig.2*) will be completed earlier than today.

Conclusion

These results (*Fig. 1-3*) show how a general temperature increase (degree-day sum) may interact with 'climatic extremes' (frost days and wind-throw events, i.e. windstorms) to change the risk of bark beetle attacks, which already today can be a large threat to Norway spruce forest.

Acknowledgement

This work is carried out within the EU/FP5 *MICE* project, contract no. EVK2-CT-2001-00118. We thank Frauke Feser and Hans von Storch (GKSS) for providing data from the snREMO reanalysis runs, and Tom Holt and Matt Livermore (CRU/UEA) for providing the HadRM3H data for the *MICE* project.

References

1. Jönsson, A.M., Harding, S. and Ravn, H.P. 200x: A model for *Ips typographus* predicting the population dynamics based on available brood trees and developmental temperatures. *In.Prep*
2. . Feser, F., R. Weisse and H. von Storch, 2001: Multidecadal atmospheric modelling for Europe yields multi-purpose data. *EOS* **82**, 305+310

Wind, waves and work at the 2003 America's Cup in New Zealand: Wind forecasting using C-CAM

Katzfey, J. and J. McGregor

CSIRO Atmospheric Research, Aspendale, Australia

The poster will present the wind forecasts made for the Swiss Alinghi sailing team that won the prestigious America's Cup in Auckland, New Zealand in March 2003.

The America's Cup race is a showcase of new technology, and this was true for the wind forecasting as well as for sailboat design and tuning. Using a state-of-the-art atmospheric regional climate model, C-CAM, developed at the Commonwealth Scientific Industrial Research Organisation (CSIRO) in Melbourne, Australia and adapted to the special needs of the team, it was possible to provide wind direction and speed predictions down to 1 km over the 5 km race course for the 2-3 hour race. This information was displayed real time on laptops so that the weather and sailing teams could have up-to-the minute advice until just before the start of the race.

The poster describes how the forecasts were made and their impact on the races. Jack will gladly discuss his experiences and describe what it was like to be part of the winning team during this exciting event.

High-resolution climate change simulation for Central Europe

Klaus Keuler, Alexander Block

Dept. of Environmental Meteorology, Brandenburg University of Technology, Cottbus, Germany
keuler@tu-cottbus.de

Introduction

The analysis of possible regional impacts of global climate changes requires the application of a complex downscaling technique which is able to provide the regional structures of the expected global and continental changes for a specific scenario. Here, the method of dynamical downscaling is applied to perform continuous high-resolution long-term regional climate simulations driven by time-dependent lateral boundary values.

Model simulations

Two 15-year-long time-slices with transient greenhouse gas forcing representing present-day climate conditions and a future climate scenario according to the SRES-B2 storyline have been simulated for Central Europe with the atmospheric regional climate model REMO (Jacob and Podzun 1997). The time-dependent lateral boundary values and the sea surface temperatures required by the regional simulation were interpolated in two steps from the results of a transient global climate simulation with the coupled AOGCM ECHAM4-T42+OPYC3 (Roeckner et al., 1999) via a high-resolution global atmospheric climate simulation with ECHAM4-T106. The two regional simulations have a horizontal resolution of about 18 km and correspond to the periods 1971-1985 and 2071-2085, respectively. The simulated climate change signals are analyzed by the differences between the two 15-year climatological means for the annual and monthly averages of the 2-meter air temperature (T_{2m}), the precipitation (pp), and the diurnal temperature range (DTR).

Results

The simulated temperature rise over the land surface of Central Europe varies between 3.5 K and 5 K (Fig 1a) with maximum values in the south-western part of the Alps. The average increase over the reference domain shown in Fig 1, which is only a part of the whole model domain, amounts to 3.6 K (Fig. 2a). The corresponding increase for the sub-region of Germany is about 3.8 K. The warming is significant for all months with a maximum value of 4.8 K for Germany in July and reduced values during the winter months (Fig 2a).

The annual precipitation amount (Fig 1b) only increases in the northern part of the reference domain (up to 20%) and decreases over the Alps, south-west France, and Spain (up to 30%). Over large parts of the domain, in particular over Germany, the changes are smaller than ±5 %. This very weak and nonuniform modification of the

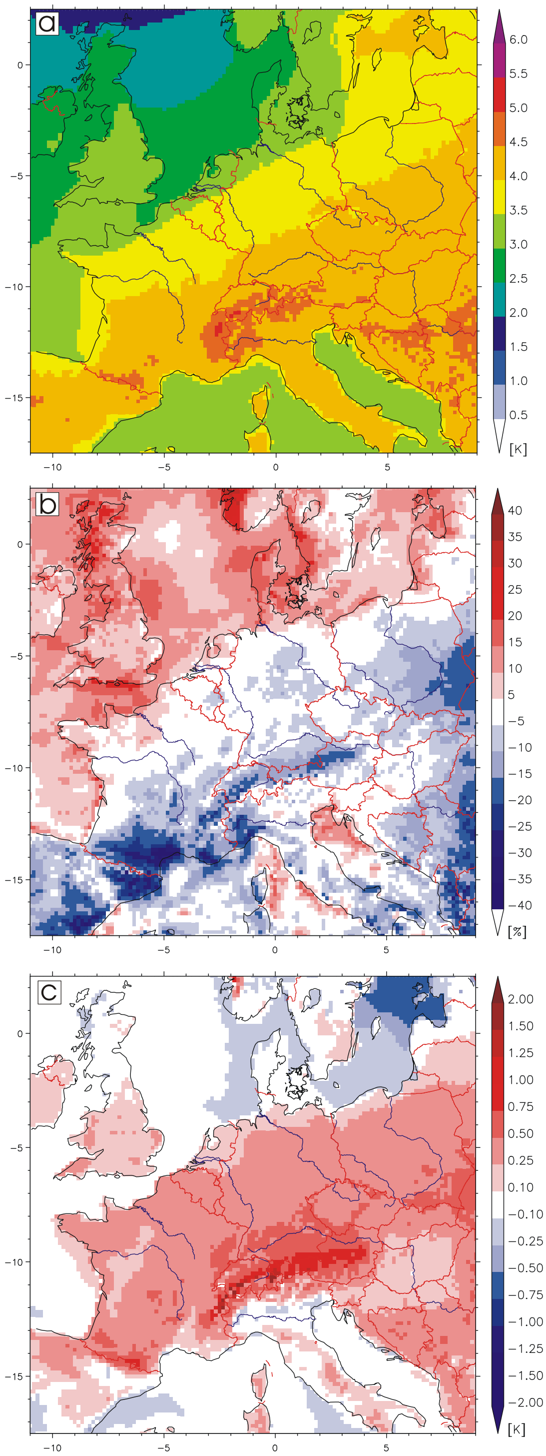


Fig 1. Climate change (Scenario – Control run) of annual mean temperature T_{2m} (a) in K, precipitation (b) in %, and DTR (c) in K.

annual precipitation amount for Germany is consistent with the results of a previous high-resolution climate change experiment by Keuler et al. (2003) for the IS92a scenario. The change of the annual precipitation averaged over the entire domain is also very weak (+18 mm). The modifications for single months are in general stronger than the changes of the annual values. For the area of Germany, for example, precipitation increases during the winter months between 10 mm (Feb.) and 30 mm (Dec.) and decreases around 10 to 15 mm/month during the summer (Fig 2b). But only the modifications for April, July, and December turn out to be statistically significant.

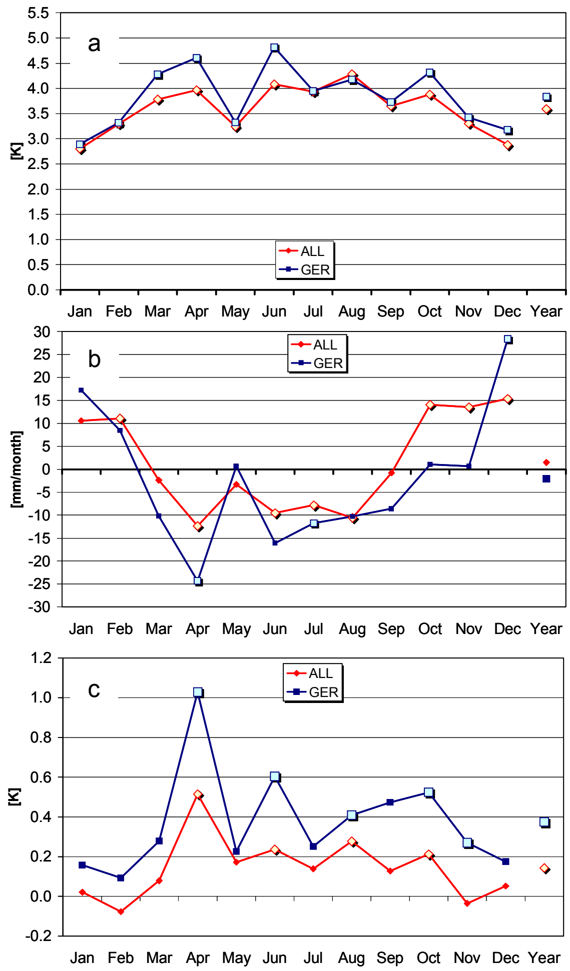


Fig 2. Climate changes of the monthly means of T_{2m} (a) in K, precipitation (b) in mm/month, and DTR (c) in K. The two curves represent the area means of the changes for the whole reference domain (red, ALL) and for Germany. Accentuated marks indicate statistically significant changes on a 95 % level.

The annual mean of the diurnal temperature range (DTR) increase over nearly all land surfaces of the reference domain with maximum values in the Alpine area of up to 1 K (Fig 1c). Over sea the amplitude of the daily temperature variation is much smaller and remains nearly unchanged with the exception of a slight reduction over the Baltic. For Germany the annual average of the DTR rises about + 0.4 K, mainly due to a stronger increase of the daily maximum temperature than the corresponding minimum value. The strongest significant increase occurs for April (Fig 2c), the month with the strongest reduction of precipitation and a simultaneous considerable warming.

According to the general warming, the number of summer days (T_{max} > 25 °C) increases and the number of frost days (T_{min} < 0 °C) decreases (not shown here). For the area of Germany 80 % more summer days occur in the scenario run than in the control run, whereas the number of frost days is reduced by 40 %.

Conclusion

The presented climate change signals are the result of the first of four simulations of the same scenario with different regional climate models or model configurations. Considerable modifications were found for a number of climate parameters – much more than shown in this short overview – but not all of them could be proved to be significant. The analysis of the additional experiments still must be waited for to confirm the detected changes and to estimate their possible ranges of uncertainty.

Acknowledgement

The presented study is part of the joint research project QUIRCS funded by the German Ministry for Education and Research within the German climate research program DEKLIM. Global control and scenario runs were performed and provided by colleagues of the Max-Planck Institute for Meteorology in Hamburg .

References

Jacob, D., R. Podzun, Sensitivity studies with the regional climate model REMO, *Meteorol. Atmos. Phys.*, 77, 119-129, 1997

Keuler, K., A. Block, E. Schaller, High resolution climate change simulation for Central Europe, In: *High Performance Computing in Science and Engeneering '03*, edt. by E. Krause et al., Springer, Berlin, 11-22, 2003

Roeckner, E., et al., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate*, 12, 3004-3032, 1999.

Influence of regional scale information on the global circulation: A two-way nesting climate simulation

Philip Lorenz and Daniela Jacob

Max-Planck-Institute for Meteorology, Hamburg, Germany

philip.lorenz@dkrz.de

Introduction

A two way nested climate model system has been setup using a global and a regional atmospheric climate model. Within the domain of the regional model the global model is updated every timestep by the aggregated corresponding results of the regional model for this timestep. There is a feedback from the regional model to the global model.
A 10-year simulation has been carried out with this two way nested climate model system using a two way nested domain covering the equatorial Western Pacific region (”warm pool”).

The two way coupled model system

To address a two-way-nesting (TWN) approach for coupling a regional atmospheric climate model with a global climate model, the Max Planck Institute for Meteorology (MPI-M) models REMO (Jacob, 2001) and ECHAM4 (Roeckner et al., 1996) were used. The ECHAM4 model is a global atmospheric general circulation model with a spectral representation of the prognostic variables except the water components. It is used in this work with a T42 horizontal resolution and a corresponding time step of 24 minutes.

Global Atmospheric Climate model ECHAM4

- Resolution: Horizontal: T42 Vertical: 19 Levels
- Time step: 24 minutes
- Prognostic variables:

Temperature	spectral
Divergence	spectral
Vorticity	spectral
spec. Humidity	grid
liquid water	grid
surface pressure	spectral

Regional Atmospheric Climate Model REMO

- Resolution: Horizontal: 1/2° Vertical: 19 Levels
- Time step: 4 minutes
- Prognostic variables:

Temperature	grid
horizontal wind components (U,V)	grid
spec. Humidity	grid
liquid water	grid
surface pressure	grid

Table 1: Characteristics of the used models

REMO is a regional hydrostatic atmospheric climate model, the set of physical parameterizations of this model is absorbed from the global ECHAM4 model. It is used in this work with a 0.5° horizontal resolution with a corresponding time step of 4 minutes. The characteristics of the used models are shown in table 1.
In an (up to now used) one-way-nesting mode REMO is initialized and driven at the lateral boundaries using data from (Re)-Analysis products resp. global model output; there is no feedback from the regional model to the global model. Within the presented two-way-nesting approach, every time-step all the prognostic variables of the ECHAM4 model are updated within the regional model domain by the corresponding results of the REMO model for this time step. A schematic flow diagram of the two way nested system is shown in figure 1.

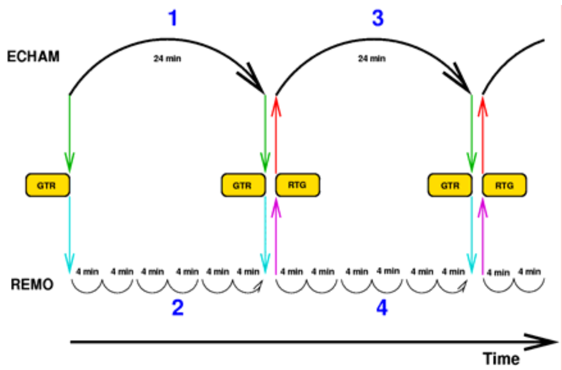


Fig. 1: Schematic flow diagram of the two way nested system. GTR: global to regional interpolation RTG: regional to global aggregation

Results of a 10 year Integration

A two-way-nested and an ECHAM4-only run initialized at the 1st of January 1980 were integrated for 10 years using observed SST data (AMIP); the two-way-nested regional domain covers the Western Pacific / Indonesian Warm Pool (110° E – 155° E; 12° S – 12° N; 91 x 49 grid points). Figure 2 shows the orography and land-sea-mask of the two-way-nested domain in the REMO 0.5°-horizontal resolution against the ECHAM4-T42 horizontal resolution.

The "warm pool" region has been chosen because it is an area with a very large energy input into the atmosphere. The poorly represented land-sea distribution and orography in the global model with the T42 horizontal resolution is much more realistic in the REMO 0.5° resolution.

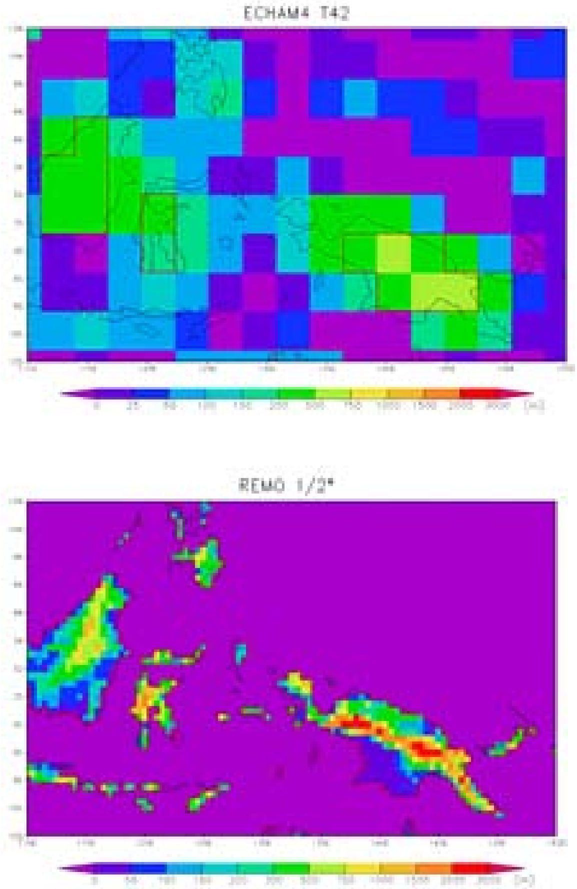


Fig. 2: Orography [m] and land-sea-mask (red line) of the two-way-nested region covering the Western Pacific ”warm pool” region in the ECHAM4-T42 horizontal resolution (upper panel) and in the REMO 0.5° horizontal resolution (lower panel)

A comparison between the results of these runs for the 10-year seasonal zonal mean temperature (figure 3) shows especially for the boreal summer season a warming of the polar upper troposphere and a cooling of the upper tropical troposphere. In the MPI-M-Report No. 218 (Roeckner et al., 1996) a comparison between ECHAM4-T42 and ECMWF analysis indicates a significant systematic cold bias in the polar upper troposphere and a warm bias of the upper tropical troposphere of the ECHAM4 model in T42 resolution. Hence these systematic temperature biases are all in all reduced within the presented two-way nested ECHAM4-REMO simulation.

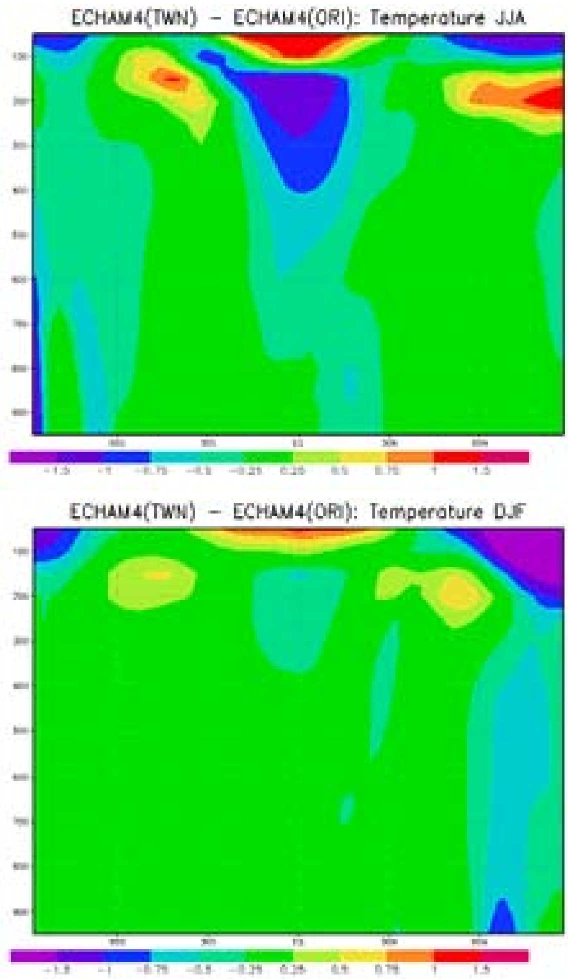


Fig. 3: 10 year seasonal zonal mean temperature difference [K] two-way-nested ECHAM4 – ECAHM4-only for boreal summer (upper panel) and boreal winter (lower panel).

Conclusions

The two way nested ECHAM4 – REMO atmospheric climate model system has been setup and can be integrated numerically stable for a 10-year period. Preliminary results show an influence on the simulated global climate, even in regions not covered by the two-way-nest domain. There are indications that the systematic error can be reduced by the finer resolution of specific regions that are important for the global circulation.

The results of the conducted 10-year integration will be analyzed in more detail.

References

Jacob, D., A note to the simulation of the annual and inter-annual variability of the water budget over the Baltic Sea drainage basin, Meteorology and Atmospheric Physics, Vol. 77, 61-73, 2001

Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, U. Schulzweida: The Atmospheric General Circulation Model ECHAM-4: Model description and simulation of present-day-climate. Max Planck Institute for Meteorology, Hamburg, , Report No. 218, 1996

RCM's internal variability as function of domain size and large scale nudging

Philippe Lucas-Picher[1], Daniel Caya[2] and Sébastien Biner[2]

[1]UQÀM, Montréal, Québec, Canada (e-mail: picher@sca.uqam.ca)
[2]Ouranos Consortium, Montréal, Québec, Canada

Internal variability is an intrinsic property of the climate system, which generates variability even in the absence of any forcing. This variability comes from the dynamic and thermodynamic non-linear relations which govern the fluid flow of the atmosphere and oceans. These relations occur at all time and spatial scales, making everything interconnected. Internal variability is thus present everywhere and at any times.

Global Climate Models (GCM) are useful tools to simulate past and future evolution of the climate system in response to different forcing. Two GCM simulations started with different initial conditions will diverge to a level reproducing Earth system internal variability. Each of these simulations will give a different realization with time and thus explain the need of ensemble of simulations to get robust and reliable climate simulations, as used for climate change scenarios.

Regional Climate Models (RCM) have been use for more than a decade to capture regional climate features which can't be obtained by GCM. To provide high-resolution climate information on their limited area domain, RCMs need information at their lateral boundary. This information usually comes from low resolution GCM or reanalyses. Consequently, RCM's internal variability is usually lower then GCM's one because the RCM domain is limited and a continual flow of information feeds the domain at the boundaries. Thus, two RCM simulations started with different initial conditions but using identical lateral boundary conditions will still diverge, but the lateral boundary information may limit them from becoming too different from one another.

Thereby, the present investigation aims at analyzing the influence of domain size and large scale nudging parameterization on the internal variability of a given RCM. Pairs of simulations with the Canadian RCM started with different initial conditions for various domain size and large scale nudging setup were realized. Statistical analysis of these simulations shows that internal variability increases with domain size and that the large scale nudging is a useful tool to reduce the internal variability of a RCM.

Applying PRECIS regional climate modelling system over eastern North America

Pascale Martineu

Université du Québec à Montréal (UQÀM), Montréal, Québec, Canada
martineu.pascale@uqam.ca

Introduction

PRECIS, Providing REgional Climates for Impacts Studies, is an atmospheric and land-surface regional climate modelling system developed by the Hadley Centre. The PRECIS system is based on the latest RCM version developed by the Centre, and it has been designed to be user-friendly and easily implemented on any fast PC with Linux system. Given its versatility regarding the computer setting and its capability to be applied over any area of the globe to provide high-resolution climate, it could become a useful tool for projections of future climate change and for impact and vulnerability assessments.

The author describes her experience of using PRECIS, and shows preliminary results of a PRECIS experiment over eastern North America.

PRECIS parameters

This system is based on the atmospheric component of HadCM3, PRECIS_1.0, with a horizontal resolution of 0.44° (~50km) or 0.22° (~25km) on its own rotated lat-lon grid (Fig. 1), 19 levels in the vertical, and 5-min time step.

Figure 1. Defining the experimental domain on an interactive control panel; to ensure that PRECIS grid boxes are quasi-regular in area, the coordinate pole of the lat-lon RCM grid is rotated and placed over the centre of the domain.

The nesting frequency is 24h for the surface boundary conditions over water (surface temperature and ice extents from AMIP II) and 6h for the lateral boundary conditions (dynamical atmospheric information from ECMWF ReAnalysis data, provided from 12/1978 to 05/1982). The driving atmospheric fields are relaxed across a 8-point buffer zone at each vertical level.

PRECIS set up

While PRECIS runs on any fast PC with any Intel-compatible processor under Linux operating system, it is not able to run on other Unix systems. In the present case, the PRECIS environment is an Intel® Xeon™ processor 2.8 GHz, 1GB memory, 120GB disk space, OS Linux RedHat 9. Designed for dual-processor server and workstation platforms, the Intel® Xeon™ Processor delivers outstanding performance for compute-intensive applications like enhanced 3D visualization, intensive scientific calculations, and multithreaded applications in multitasking environments. Although this performance status seems perfect for PRECIS, the Hadley Centre has not previously tested the Xeon processor.

The semi-automatic installation process of PRECIS_1.0 is launched from two DVD-ROMs, and supplied input data (e.g. three years worth of global reanalysis data required to initialize and drive PRECIS) and CDAT (interactive plotting interface).

Figure 2. A Graphical User Interface (GUI) controls all PRECIS operation

No recompilation is required before running PRECIS. The graphical user interface (Fig. 2) allows the user to select the attributes of PRECIS experiment: (1) Region (e.g. over eastern North America, with the new origin of the coordinate system defined over the centre of Québec (Canada) (see Fig. 1); grid 79x75, 0.44°), (2) Scenario (ERA-15), (3) Period (1978/12/1 – 1980/2/3), (4) Diagnostics output, and (5) Run or Stop PRECIS.

The monitoring of our PRECIS experiments identified two problems of PRECIS. The first one is the relative speed of PRECIS, unexpectedly slow and variable (Fig. 3): the Xeon 2.8GHz running PRECIS on 79x75 grid took 13.4 days to run 1 year experiment (relative speed of 60min/Day). As reference, MetOffice tests have indicated a relative speed of 18min10s/Day for a 2.8GHz Intel P4 processor on a 106x111 grid.

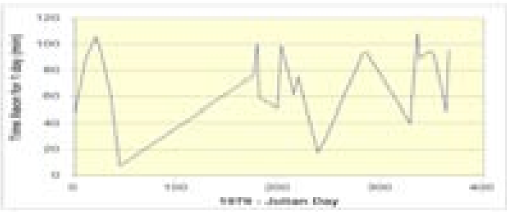


Figure 3. Relative speed of Xeon 2.8GHz running PRECIS on 75x79 grid, 19 levels

The second problem is related with the visual interface: while PRECIS is running, no plot of the model output over previous days of integration is available. Normally, the user can monitor PRECIS on real time.

Post-processing PRECIS data

CDAT (Climate Data Analysis Tools) is supplied with PRECIS to process the output data and visualize the results. Global datasets from the driving GCM (ERA) and climatology (CRU) are also supplied with PRECIS, i.e. global data as 3-month seasonal mean data for the period from 12/1978 to 05/1982 (ERA dataset) or to 11/1982 (CRU dataset). In order to evaluate our PRECIS experiment, these global data were regridded onto the grid used by PRECIS. Figures 4 to 6 show the comparison of PRECIS simulations at high resolution with ERA and CRU regridded datasets. The winter (DJF) and summer (JJA) mean temperatures at 1.5 m (Fig. 4, 5) and precipitation (Fig. 6) for the period of 1979 to 1881 are presented.

Conclusion

While the behaviour of PRECIS in our PC environment is still misunderstood (e.g. relative speed of PRECIS), results to date obtained over eastern North America indicate a good ability of PRECIS at 0.44° to simulate climate.

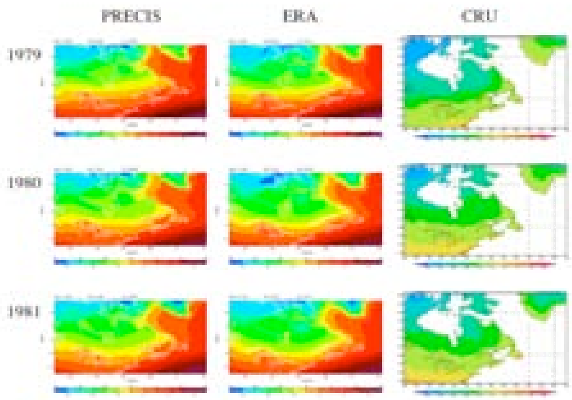


Figure 4. Winter (DJF) mean surface temperature (C) as simulated by PRECIS, as nested data by ECMWF Reanalysis data (ERA), and analysed by CRU (Mitchell et al. 2004)

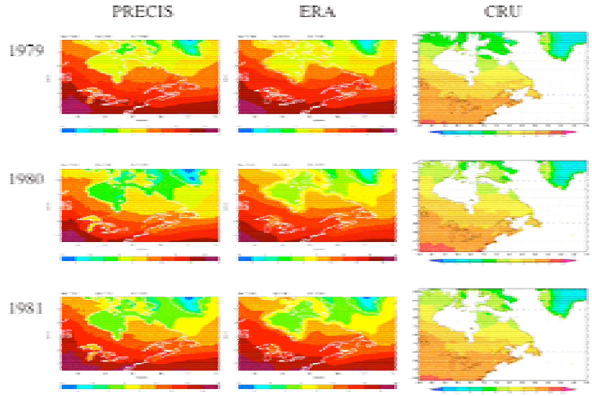


Figure 5. Summer (JJA) mean surface temperature (C) as simulated by PRECIS, as nested data by ECMWF Reanalysis data (ERA), and analysed by CRU (Mitchell et al. 2004)

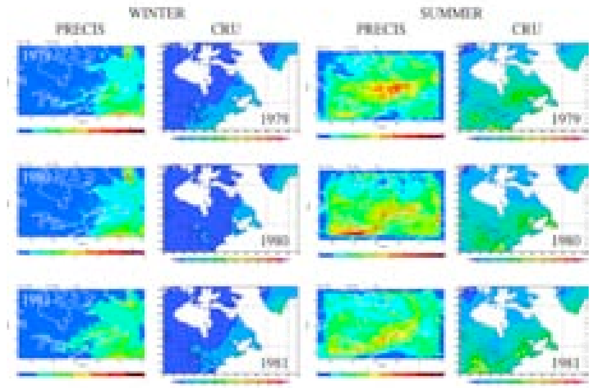


Figure 6. Winter (DJF) and Summer (JJA) mean precipitation rates (mm/Day) simulated by PRECIS and analysed by CRU (Mitchell et al. 2004)

Acknowledgements

The author addresses her acknowledgments to the Canadian Regional Climate Modelling Network at UQÀM and Ouranos Consortium that supported this initiative. She also thanks Mr Mourad Labassi for his assistance with the PRECIS installation, Dr Yanjun Jiao for his help to regrid global CRU climate data onto the PRECIS experiment domain and Dr Ramon de Elia for reviewing generously this abstract.

References

Jones, R., D. Hassel, D. Hudson, S. Wilson, G. Jenkins and J. Mitchell, 2003. Workbook on generating high resolution climate change scenarios using PRECIS, ed. Met Office, UK, 32p.

Mitchell, T.D., T.R. Carter, P.D. Jones, M. Hulme, and M. New, 2004. A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001- 2100). *Journal of Climate* (Subm.)

Wilson S., D. Hassel, D. Hein, R. Jones and R. Taylor, 2003. Installing and using the Hadley Centre regional modelling system - PRECIS version 1.0, ed. Met Office, UK, 108p.

PRECIS web site : http://www.precis.org.uk.

High resolution global modeling at DMI - Recent achievements and future plans

May, W.

Danish Meteorological Institute, Denmark

About 5 years ago we performed several simulations with the ECHAM4 atmospheric GCM at a horizontal resolution of T106 with 19 vertical levels, with the uppermost level at 10 hPa: one simulation with observed monthly mean SSTs and sea-ice conditions prescribed as lower boundary forcing (December 1978 – February 1994) and two so-called time slices for the present-day (January 1970 – December 1999) and the future climate (January 2060 – December 2089) with the lower boundary forcing as obtained from a transient climate change simulation with a low-resolution coupled climate model (ECHAM4/OPYC at a horizontal resolution of T42). These simulations have been considered in several international research projects focussing on various aspects, such as storms and surges in the North Atlantic region, the hydrological cycle, or the Indian summer monsoon.

At DMI a new atmospheric GCM has been set up, combing the dynamical core of the IFS numerical weather prediction model (cycle 22, but we envisage an upgrade to cycle 23) from ECMWF with the physical parameterisations of the ECHAM5 atmospheric GCM. This new atmospheric GCM can be run at a horizontal resolution of T159 with 31 (standard resolution) or 60 vertical levels, with the uppermost level at 0.1 hPa. That is, the model's prognostic variables, i.e., the geopotential height, divergence and vorticity, and specific humidity at the 31 levels and the surface pressure are given in spectral coordinates, while the other variables are given on the corresponding linearized reduced Gaussian grid, with 320 grid points along a parallel of latitude at low latitudes and a decreasing number of grid points at higher latitudes. In combination with the advanced numerical scheme, which allows for a relatively long time step, this particular geometry considerably reduces the computing time, so that with this model also extended simulations can be performed at a high horizontal resolution of T159. We have just performed a 30-year simulation (with 31 vertical levels) with climatological monthly mean SSTs and sea-ice conditions prescribed as lower boundary forcing, demonstrating the feasibility of running a global atmospheric GCM at such a high horizontal resolution for several decades.

Regional climate modelling activities at CSIRO

McGregor, J., Nguyen, K. and J. Katzfey

CSIRO Atmospheric Research, Aspendale, Australia

CSIRO has been undertaking regional climate modelling for over a decade, using the Division of Atmospheric Research Limited Area Model (DARLAM). Simulations have been performed for a variety of domains and purposes. The longest nested climate simulations with DARLAM were of 140-year duration, and were performed over Australia down to 60 km resolution. Long finer-resolution simulations were also performed.

In recent years, a variable-resolution global GCM has been developed at CSIRO, providing an alternative approach for high resolution atmospheric modelling from the usual one-way nested procedure. The model is known as the Conformal-Cubic Atmospheric Model (C-CAM). C-CAM is now used for most of the regional climate modelling activities at CSIRO. The advantages of C-CAM include:

1) Its numerics have better accuracy and less artificial diffusion.
2) C-CAM has no lateral boundaries.
3) For regional climate runs, C-CAM requires from the AOGCM only SSTs/sea-ice and, for cases of fairly strong stretching, the far-field winds.

This talk will show a number of regional climate simulations using C-CAM, mostly at 60 km resolution:

a) Simulations of Australian climate from 1960-1990, driven by NCEP reanalyses.
b) 10-year simulations of Australian climate with and without flooded inland lakes.
c) 30-year simulations of present and future Australian climate, driven by the CSIRO Mk3 AOGCM.
d) 10-year simulations of present-day climate over Southeast Asia, at resolutions of both 60 km and 14 km.

Simulations of the Canadian RCM over two distinct regions.

BY DOMINIQUE PAQUIN AND DANIEL CAYA

Ouranos Consortium; 550, Sherbrooke O., 19è étage, tour Ouest, Montréal (QC) Canada, H3A 1B9
(514) 282-6464 ext. 261; Fax: (514) 282-7131; paquin.dominique@ouranos.ca

Introduction

Using a Regional Climate Model (RCM) over many parts of the world is becoming a standard step in a thorough validation of a RCM. The Canadian RCM (CRCM; Caya and Laprise, 1999) has been frequently tested and validated for climate simulations (many years) over various parts of North America (Laprise et al., 1998, 2003; Frigon *et al.* 2002). It has also been used over Europe and portion of Africa for shorter simulations (months). The opportunity offered by the PRUDENCE project to compare the CRCM with many RCMs over Europe was a motivation to configure our model over the European domain and to carry long simulations of current and perturbed climate. As a first step toward these simulations, a single year simulation driven by NCEP reanalyses is made over Europe. To compare the performance of the model over this new domain, a simulation with the exact same version of the CRCM is made over the usual North American domain. The present work looks at the performance of the model over the two domains by comparing simulated precipitation fields with observations.

Model and results

Two short 20-month simulations were carried with the CRCM over North American and European domains. The simulations cover the period May 1995 to December 1996 and are driven by he first NCEP reanalyses with SSTs taken from AMIP-II. The North American domain has 193 x 145 grid points while the European domain uses a 121 x 121 grid. Both domains are integrated at 45-km resolution with a 15-minute time step and 29 levels in the vertical. Both simulations have large-scale winds (wavelengths longer than 1400 km) in the upper atmosphere nudged toward the driving data. The nudging is applied every time step with a maximum value of 5% at the highest model level and decreases to zero at approximately 500 hPa.

Figure 1 presents the relative differences between the CRCM simulated and CRUTS2.0 (Mitchell *et al.* 2003) observed precipitation fields over both domains for winter 1995-96 (DJF). The relative differences are computed as

$$E = \frac{CRCM - CRU}{CRU}.$$

A mask was applied to oceans where precipitation observations are not available from CRU. In winter, large portions of both domains show relative errors within $\pm 25\%$. However, significant overestimation of precipitation (more than 200% over Alaska and the American prairies) is observed over areas receiving less than 1.0 mmd^{-1}. The CRCM, as many other models, has a tendency to generate fictitious low precipitation rates resulting in high relative errors over dry areas. The problem is not as strong over the European domain where the CRCM seems to perform better.

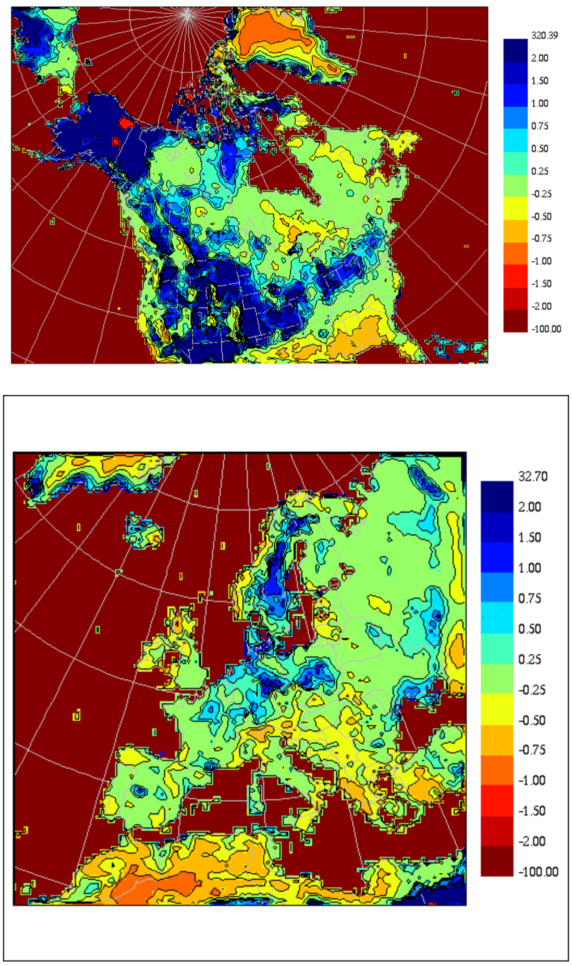


Figure 1. CRCM relative errors for winter precipitation over North America (top panel) and Europe (bottom panel).

Figure 2 presents the same analysis for the 1996 summer season (JJA). It can be seen that the CRCM is strongly overestimating the summer precipitation with errors larger than 200% over sizeable portions of both domains. Again, the performance seems better over Europe than over North America. This better performance over Europe is improved even more if we remove from the analysis the regions where observations are less than 0.25 mmd^{-1}. Results from such an analysis are presented in Figure 3 which is identical to the ones Figure 2 except that a mask is applied to the abovementioned regions.

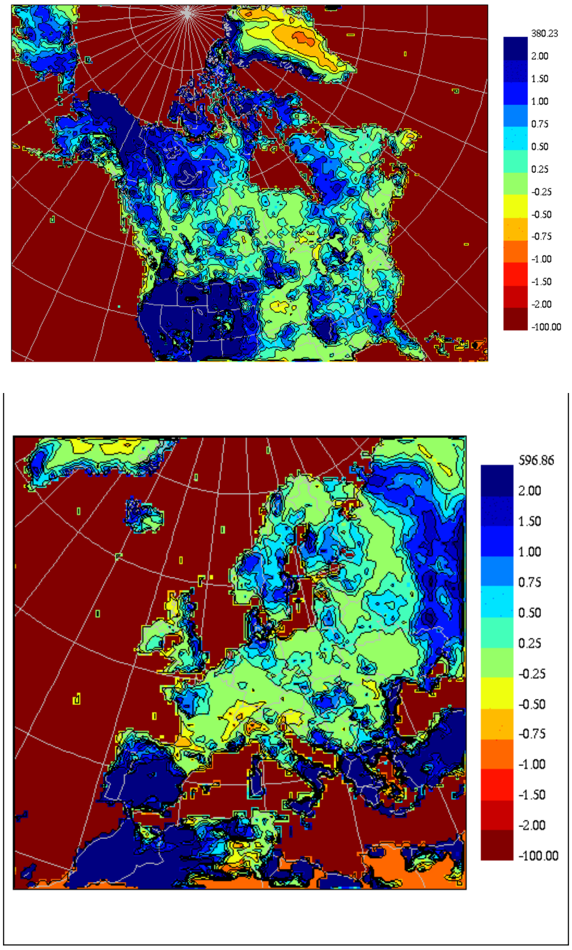


Figure 2. Same as Figure 1 for summer.

Conclusions

A pair of short one-year simulations has been generated with the Canadian RCM to compare its performance over two distinct climatic regions. It has been seen that the CRCM has a better performance over Europe than over North America. This is particularly true in summer where the CRCM shows strong overestimation of the precipitation over very large portions of the North American domain. This work has been made as a first step toward a full set of climate simulations over the European domain. This set of simulations will include a 30-year integration nested in reanalyses and time slices of perturbed climate driven by the Canadian CGCM3.

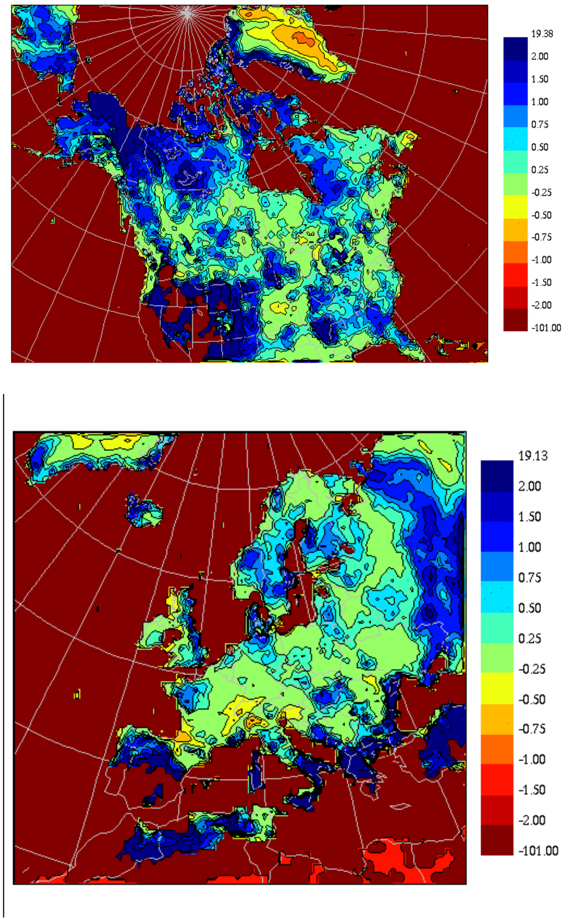


Figure 3. Same as Figure 2 with a mask over regions where observed precipitation are less than 0.25 mmd^{-1}.

References

Caya, D. and R. Laprise, 1999. A semi-implicit semi-Lagrangian regional climate model: the Canadian RCM. *Mon. Wea. Rev.*, Vol 127, 341-362.

Frigon, A., D. Caya, M. Slivitzky and D. Tremblay, 2002: Investigation of the hydrologic cycle simulated by the Canadian Regional Climate Model over Québec/Labrador territory. In: *Advances in Global Change Research*, vol. 10, *Climatic Change:*, Ed. M. Beniston, Kluwer Academic Publishers, 31-55.

Laprise R. , D. Caya, A. Frigon and D. Paquin, 2003. Current and perturbed climate as simulated by the second-generation Canadian Regional Climate Model (CRCM-II) over North-Western North America. *Climate Dynamics*. Vol 21, 405-421.

Laprise, R., D. Caya, M. Giguère, G. Bergeron, H. Côté, J.-P. Blanchet, G. J. Boer and N. McFarlane, 1998: Climate and Climate Change in Western Canada as Simulated by the Canadian Regional Climate Model. *Atmos.-Ocean* 36 (2), 119-167.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme,M., New, M., 2003: A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). J. of Climate: submitted (August 2003).

Moisture conservation in the Canadian Regional Climate Model.

Dominique Paquin[(1)] and René Laprise[(2)]
(1) Ouranos, (2) Université du Québec à Montréal (UQÀM), Montréal, Québec, Canada
paquin.dominique@ouranos.ca, laprise.rene@uqam.ca

Using the semi-Lagrangian time integration scheme in a numerical model introduces a small non-conservation. In order to correct this inaccuracy and to ensure moisture conservation in the Canadian Regional Climate Model (CRCM; Caya et Laprise, 1999), an in-line atmospheric moisture budget is performed to diagnose the correction to be applied.

The starting point is the general formulation of the atmospheric balance equation for water vapour (vap), cloud water (cw) and cloud ice (ci). For budget calculation, the Eulerian form of the equation is natural, even if the CRCM is a semi-Lagrangian numerical model.

Applying the leapfrog scheme to the vertically integrated Eulerian form of atmospheric moisture budget equation gives:

$$\partial_t q \approx \frac{q^n - q^{n-2}}{2\Delta t} = S\left(q^{n-2}\right) + A^{n-1} \qquad (1)$$

forward sources

centred difference on $2\Delta t$ *centred advection*

where n is the time index, q is the vertically integrated specific humidity, S is the source term (equivalent to Evaporation – Precipitation), and A the vertically integrated transport equivalent to

$$A^{n-1} = -\vec{\nabla}\cdot\left(r_{vap}\vec{V}\right)_z + -\vec{\nabla}\cdot\left(r_{cw}\vec{V}\right)_z + -\vec{\nabla}\cdot\left(r_{ci}\vec{V}\right)_z \qquad (2)$$

using the vertically integrated flux divergence with $\vec{V}$ the horizontal wind and r the local specific humidity. The complete moisture budget equation takes the form of (1) and includes a term taking account of the semi-Lagrangian inaccuracy, the residual term ε:

$$\frac{q^n - q^{n-2}}{2\Delta t} = S\left(q^{n-2}\right) + A^{n-1} + \varepsilon_{[n,n-2]} \qquad (3).$$

The calculation of the residual term ε follows equation (3) formulation, but it is complicated by the fact that all required terms are not available at the same timestep in the model. The corrective factor will be applied to q^n, giving q^{*n}, which will be saved in memory for the calculation of the $n-2$ residual term, giving

$$q^{*n-2} \equiv q^n - 2\Delta t\varepsilon_{[n,n-2]} \qquad (4).$$

At timestep n, ε is obtained with

$$\varepsilon_{[n,n-2]} \equiv \frac{q^n - q^{*n-2}}{2\Delta t} - S\left(q^{n-2}\right) - A^{n-1} \qquad (5)$$

such that the equation with q^* is conservative ($\varepsilon = 0$):

$$\frac{q^* - q^{*n-2}}{2\Delta t} = S\left(q^{n-2}\right) - A^{n-1} \qquad (6).$$

The correction will prorated to the specific humidity values at each grid point in order to obtain a residual integration over the free domain equal to zero (which has been verified). This gives a new specific humidity:

$$r^* = r(1 + FAC)$$

$$\text{where} \quad FAC = -2\Delta t\frac{\sum \varepsilon_{[n,n-2]}}{\sum q^n} \qquad (7).$$

The internal moisture budget conservation and correction has been tested with CRCM version 3.6.1 on a 4-month simulation, from May to August 1988. The domain is covering the USA and Mexico with 141 x 121 grid points at 45-km and 29 levels in the vertical. The model is driven by NCEP reanalyses-1 and SSTs are following AMIP-II. Diagnostic atmospheric moisture budget following equation (3) for JJA 1988 has been performed over the domain (excluding the sponge zone) to analyse the differences between the simulations with (CORR) and without (NO) the correction. The left term of (3) is called DRDT. On the right-hand side, the source term is decomposed in precipitation (PCP) and evaporation (QFS), while the second and third terms are DFQ and EBQ.

As seen in Figure and Table 1, the general behaviour of the two simulations is quite similar. The application of the correction does not make the model closer to the pilot, as seen in the DFQ terms of Table 1. The main feature of the CORR simulation is to reduce the error term of the diagnostic humidity budget. The error cannot be exactly equal to zero in the diagnostic evaluation for reason of archival time of the variables.

In conclusion, the empirical application of conservation to internal moisture budget is to correct the semi-Lagrangian inaccuracies, imposing the internal conservation of moisture in the model, with apparently little side effects on the performance of the model.

Table 1. Diagnostic atmospheric moisture budget for NCEP, NO and CORR runs. (mm/day)

	PCP	**QFS**	**DRDT**	**DFQ**	**EBQ**
NCEP			0.08	0.09	
NO	2.34	1.90	0.07	-0.35	0.16
CORR	2.12	1.79	0.07	-0.41	-0.01

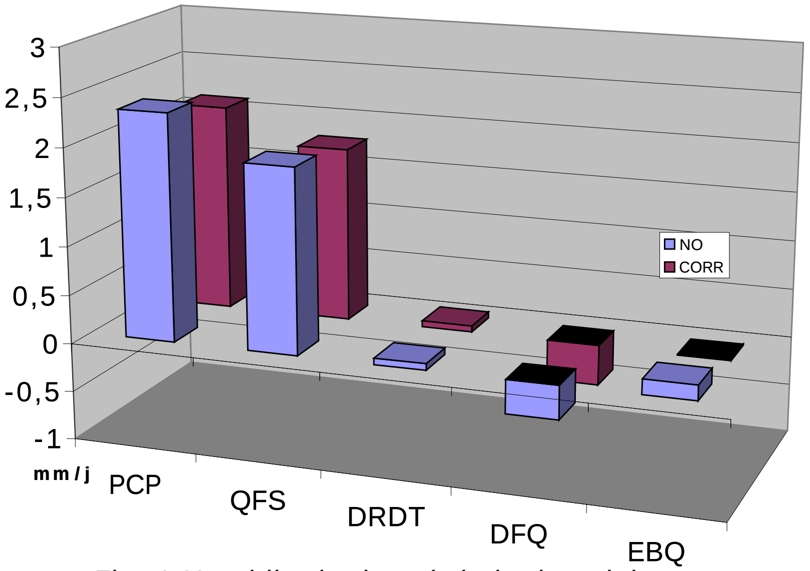


Fig. 1 Humidity budget (whole domain)

References:

Caya, D. and R. Laprise, 1999. A semi-implicit semi-Lagrangian regional climate model: the Canadian RCM. *Mon. Wea. Rev.*, **127,** 341-362.

Paquin, D. and R. Laprise, 2003. Traitement du bilan d'humidité interne au MRCC. Ouranos, Groupe simulations, Rapport interne No. 2, 26 p.

Cyclone and Anticyclone Synoptic Climatology and Variability

Alexandre B. Pezza and Tércio Ambrizzi. University of São Paulo, Brazil. E-mail: alepezza@model.iag.usp.br

Introduction

Automatic procedures can be applied for finding and tracking high and low surface pressure centers from operational numerical analyses. The most important advantages are the possibility of handling a large amount of information in a shorter time frame and generating results that can be easily compared between them.

Murray and Simmonds (1991) developed one of the first automatic procedures available nowadays to find and track surface pressure systems. They were able to reproduce and complement some previous results found in the literature.

In this work, wintertime SH synoptic climatology of cyclone and anticyclone tracks using the NCEP Reanalysis data applied to the Murray and Simmonds (MS henceforth) automatic scheme is presented for the 1973 – 1996 period. A climatological map with the total synoptic tracks superposed was produced in order to have a precise hemispheric signature for these systems. The total amount of tracks and orphan systems were counted in order to analyze possible climatic trends.

Methodology

The MS automatic scheme was used to find and track high and low pressure centers near the surface. Mean sea level pressure data from the NCEP Reanalysis was used every 12 hours from 1973 to 1996. Although some studies suggest that the automatic schemes performance would increase for data set every 6 hours, our tests did not show any significant improvement in that case. Therefore, the 12 hour analyses seem to be suitable for climatological applications. The area of study is the Southern Hemisphere, and track analyses have been carried out during the wintertime, i.e., June, July and August (JJA).

Results

Figure 1 shows a superposition of systems indicating the geographical track regions of anticyclones (tracks and "orphan systems") with central pressure above 1020 hPa (violet) and cyclones (tracks and "orphan systems") with central pressure below 1015 hPa (pink color), and the regions overlapped by both systems (yellow), according to the automatic MS scheme for the 1973 – 1996 JJA period, using the data every 12 hours. The purple color on the subtropical belt indicates a high anticyclone concentration over the oceans corresponding to the well known pressure centers of action, particularly in the Subtropical Atlantic High. The Subtropical Pacific High and the Subtropical Indian High are not too evident because they are embedded in regions of high cyclone activity (transient region showed in yellow color). A high concentration of orographic anticyclones, especially over the Andes and over the Antarctic plateau is also observed.

Some migratory extratropical anticyclones appear in the center of Australia and southeastern South America, but most of the transient hemispheric activity between 30^{o} and 60^{o}S is characterized by the passage of both cyclones and anticyclones represented by the yellow color in the map. The pink color shows a marked cyclone concentration around the Antarctic continent which is approximately the position of the SH storm tracks. Several heat and orographic lows (and highs) can be observed over the continents as well.

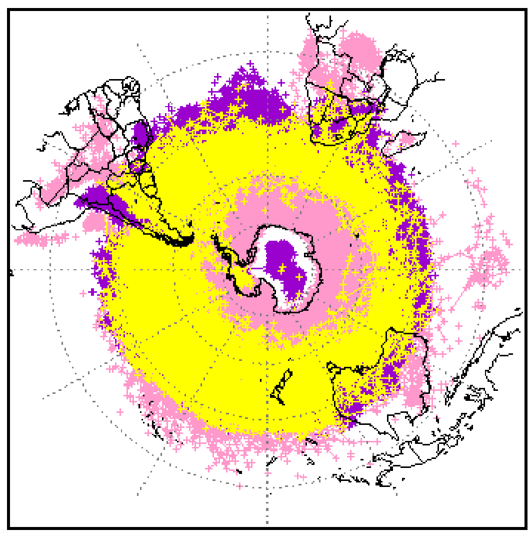


Figure 1: Superposition of systems indicating the geographical track regions of anticyclones with central pressure above 1020 hPa (violet) and cyclones with central pressure below 1015 hPa (pink color), and the regions overlapped by both systems (yellow), according to the automatic MS scheme for the 1973 – 1996 JJA period. "Orphan" tracks are indicated by crosses. See text for further details.

Figure 2 shows the Southern Hemisphere winter (JJA) total number of cyclone and anticyclone tracks with no restriction to pressure ranges (figure 2a), for cyclones below 1010 hPa and anticyclones above 1020 hPa (figure 2b), and for cyclones below 980 hPa and anticyclones above 1035 hPa (figure 2c) according to the MS automatic scheme using data every 12 hours for the 1973 – 1996 period. The linear regression lines and the square linear correlation coefficients according to the least square method are shown in each case. The confidence level according to the T-Student Test is above 99% for the regressions in figures 2a and 2c, excluding the anticyclones in figure 2c which presented no tendency with a near zero square linear correlation coefficient, and slightly above 95% for figure 2b. Tracks with one point, i.e., those that disappeared in the following analysis (defined here as orphan systems) were included as well.

From figure 2a, the regression indicates a significant overall decline of cyclones and anticyclones. Nevertheless, the percentage of the total variance explained by the fit, which is given by the square correlation coefficients, is about 55% for the anticyclones and 44% for the cyclones, indicating a high variability. The trends are less noticed in figure 2b, where the variability is much higher (only 17% and 19% of the total variance are explained by the linear fit for the anticyclones and cyclones respectively). Finally, figure 2c shows a different pattern, with an overall increase of cyclones below 980 hPa which indicates an opposite behavior at the intense end of the spectrum. About 46% of the total variance is explained by the linear regression in this case, as shown by the square linear regression coefficient. Nevertheless, no tendency has been observed for the intense anticyclones above 1035 hPa, with a near zero coefficient. These strong cyclones are frequently seen in association with polar air masses when passing over the southern tip of South America (Pezza and Ambrizzi 2003).

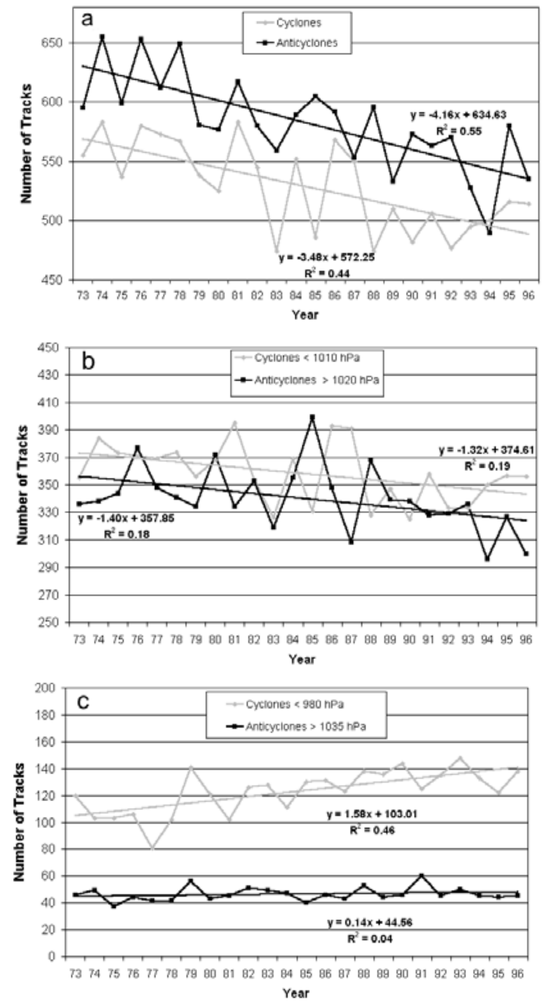


Figure 2: Number of cyclone and anticyclone tracks every 12 hours during JJA (1973 – 1996), according to the automatic scheme of MS for the Southern Hemisphere (a) without pressure restriction, (b) for cyclones of central pressure below 1010 hPa and anticyclones of central pressure above 1020 hPa and (c) for cyclones of central pressure below 980 hPa and anticyclones of central pressure above 1035 hPa.

Conclusions

Our results suggest another perspective for the downward trends in the cyclone numbers proposed earlier in the literature (Simmonds and Keay 2000). It is shown that when a “synoptic” selection is applied to the central pressure in order to prevent the inclusion of weak systems, the trends considerably change. Analyses at both ends of the spectrum show a lower total number of cyclones with a decrease in the number of weak systems and an increase in the number of intense systems, particularly for those with central pressure below 980 hPa. For the anticyclones, there is also an overall decrease in their number due to a decrease in the number of weak systems, but the strong ones are not undergoing any change.

Acknowledgements

This work was supported by FAPESP (Fundação de Amparo à Pesquisa do Estado de São Paulo), under grant 99/04105-2. A.B.P. would like to thank Dr. Rene Laprise, Dr. Harry Lankreijer and WMO for supporting his participation at Lund’s RCM conference.

References

Murray, R.J., and I. Simmonds, 1991: A numerical scheme for tracking cyclone centres from digital data. Part I: Development and operation of the scheme. *Aust. Metero. Mag*., **39**, 155-166.

Pezza, A.B. and T. Ambrizzi, 2003: Variability of Southern Hemisphere Cyclone and Anticyclone Behavior: Further Analysis. *J. Climate,* **16**, 1075-1083.

Simmonds, I., and K. Keay, 2000: Mean Southern Hemisphere Extratropical Cyclone Behavior in the 40-year NCEP-NCAR Reanalysis. *J. Climate*, **13**, 873-885.

Simulations of Precipitation in Iceland - Comparison with Glaciological Mass Balance Data

Rögnvaldsson, O. and H Ólafsson

University of Bergen, Iceland

Precipitation in the complex terrain of Iceland has been simulated with a numerical model (MM5) for a period of 12 years. The simulations are made with a horizontal resolution of 8 km and they are forced with boundaries from the ECMWF. Validation of precipitation simulations is

particularly difficult where precipitation falls largely as snow in strong winds, because of significant underestimation of true ground precipitation by conventional observations. In view of this, precipitation has been estimated from observations of snow accumulation on major glaciers in central and eastern Iceland. This glaciological dataset is compared to the simulated precipitation. The numerical simulations reproduce with quite good accuracy the amount of precipitation and the observed interannual variability. The results are promising for the use of glaciological data for precipitation mapping and for validation of numerical simulations. The usefulness of high-resolution numerical simulations for mapping precipitation in data-sparse regions is confirmed. This is important for downscaling results from general circulation models simulating future climate and for predicting changes in regional precipitation.

Simulating Arctic and European climate variability with a coupled regional atmosphere-ocean-sea ice model

Sein, D., Mikolajewicz, U. and D. Jacob

Max Planck Institute for Meteorology, Hamburg, Germany

The Arctic Ocean and the Nordic Seas are one of the key regions for climate. This area shows a high sensitivity to climate change (e.g. anthropogenic greenhouse warming), furthermore North Atlantic deep water ,one of the main constituents of the deep oceans, is formed here. Beside this, strongly nonlinear processes (like e.g. sea ice or deep convection) are essential and make climate research in this region more challenging (and interesting).

In this paper the results from a coupled regional atmosphere-ocean-sea ice model are presented. The model consists of the regional atmosphere model REMO and the ocean model MPI-OM. The model area includes the entire Arctic Ocean, the Nordic Seas, Europe, and a large fraction of the North Atlantic. The ocean model is formally global, but through the application of conformal mapping regionally high resolution around the Nordic Seas is achieved. The grid is focussed on the Nordic Seas and the adjacent areas, where some of the climatically most interesting processes in the ocean take place. The model has been driven with forcing data from the NCEP Reanalyses for the years 1958 to 2002 (lateral boundary conditions for REMO and input for bulk formula forcing outside the coupling domain for the ocean model). An ensemble of 4 members with slightly perturbed initial conditions has been carried out. The setup allows to investigate the question which part of the regional climate variability is forced by global signals (represented here by the boundary conditions at the model domain) and which part is regionally generated (represented by the differences between the different ensemble members). Whereas large scale climate indices like e.g. the NAO index closely resemble the observations in all ensemble members, does the sea ice export through Fram Strait show a substantially different behaviour: The large-scale atmospheric circulation seems to modulate the ensemble mean, but the different members of the ensemble show a substantial spread. Here regional processes obviously are of equal importance.

Transferability Experiments for Addressing Challenges to Understanding Global Water and Energy Budgets

Eugene S. Takle[1,2], William J. Gutowski, Jr.[1,2], and Raymond W. Arritt[1]

[1]Department of Agronomy, [2]Department of Geological & Atmospheric Sciences, Iowa State University, Ames

Introduction

At the Sixth Annual GEWEX Hydrometeorology Panel (GHP) meeting in Lüneberg Germany a proposal was presented to form a Transferability Working Group (TWG) under the GHP of the World Climate Research Programme to advance the science of regional climate modeling.

Rationale

The proposed working group (WG) addresses GEWEX Objective 3: Develop the ability to predict the variations of global and regional hydrological processes and water resources and their response to environmental change. Furthermore, it will contribute tools and understanding toward addressing all the Updated GEWEX Science Questions:

- Are the Earth's energy budget and water cycle changing? *Is the water cycle accelerating?*
- How do processes contribute to feedback and causes of natural variability?
- Can we predict these changes on scales up to seasonal to inter-annual?
- What are the impacts of these changes on water resources?

At a basic level, this WG will contribute to the WCRP objective of "developing the fundamental scientific understanding of the physical climate system and climate processes needed to determine to what extent climate can be predicted and the extent of man's influence on climate."

A GHP Opportunity

There are a number of international regional simulation and prediction efforts in progress or recently completed that will facilitate establishing this WG:

- ArcMIP (Arctic)
- AMMA (Africa)
- BALTIMOS (northern Europe)
- GKSS/ICTS (Europe)
- GLIMPSE (Arctic)
- IRI/ARCs (Brazil)
- La Plata (South America)
- PIRCS (US)
- PRUDENCE (Europe)
- QUIRCS (Southern Europe)
- RMIP (Asia)
- SGMIP (US)

Likewise, there are numerous intensive observing field campaigns organized under the Coordinated Enhanced Observing Period (CEOP, 2004) program jointly coordinated by GEWEX, Clivar, and CliC. This coordinated observing period is "…from 2001 through 2004, with a primary focus on developing a 2-year data set for 2003-2004 to support research objectives in climate prediction and monsoon system studies" (CEOP-IP, 2004). Data from these experiments are archived at the Joint Office for Science Support (JOSS, 2004) at the University Corporation for Atmospheric Research in Boulder, Co. Data sites listed in the archive include 14 sites in eastern Asia (GAME/CAMP), six in central South America (LBA), five in the continental US (GAPP), four in northern Europe (BALTEX), two in Africa (CATCH), one each in the Mackenzie Basin in northern Canada (MAGS) and the Murray Darling Basin of Australia (MDB). Three additional ARM sites are also listed (Darwin, Barrow, and Manus).

The GHP has opportunity to advance the agendas of WCRP, GEWEX, and GHP by coordination and extension of these international regional modeling activities by establishing a Transferability Working Group (TWG). Recent intercomparison experiments under PIRCS (Takle et al., 1999; Anderson et al., 2004; PIRCS, 2004) with international modeling teams provide a model for establishing the TWG.

Overall Objective of TWG

The overall objective of the TWG is

> *"To understand the physical processes underpinning the global water and energy cycles and their predictability through systematic intercomparisons of regional climate simulations on several continents and comparison of these simulated climates with coordinated continental-scale observations and analyses."*

Specific objectives

More specifically, TWG will provide a framework for systematic evaluation of simulations of dynamical and climate processes arising from different climatic regions. An important aspect of this intercomparison is to evaluate transferability of regional climate models and their components, for example the extent to which a model developed to study one region can be applied to other, "non-native", regions. Since several models will be used for each regional domain, TWG will perform a "meta-comparison" by examining individual and ensemble performance between domains as well as on particular domains. Anchored by coordinated observations from continental scale experiments, modeling studies under TWG will examine influences of physical parameterization choices (clouds, convection, precipitation, surface processes), resolution and nesting dependencies, modeling choices (grid point, spectral, stretched grid), and boundary condition influences on the quality of predictions.

Comparison of model output with water and energy budget observations in a variety of climates will provide model developers with insight on the ability of models to capture a wider range of climatic conditions, thereby raising the probability that such models will be more able to capture climate extremes or unexpected feedbacks and processes associated with climate change.

Tasks

Some tasks associated with launching such a working group include the following:

- Organizational Meeting
- Designation of coordinating center
- Engagement of a wide range of modeling centers
- Benchmarking simulations
- Design of experiments
- Reporting and analysis strategy and time tables
- Interaction with continental scale experiments for dialog on observing priorities

Organizational Meeting

An organizational meeting would bring together representatives of major regional climate modeling laboratories and current and past intercomparison programs as well as representatives of the continental scale observational experiments.

Modeling Component

- What has been learned from past and current MIPs?
- What are the impediments and advantages for participation of "non-native" models and centers in international transferability experiments?
- Development of a set of modeling issues that will benefit from transferability experiments:
  - What do we mean by transferability?
  - What are transferability criteria?
  - What are the transferability accuracy expectations?
  - What simulation processes challenge the transferability criteria?
  - What environments challenge the transferability criteria?
- Develop consensus on a hierarchy of transferability (intercomparison) numerical simulations.

Observations Component

- Review what has been learned from past and current observations
- Review local unique features critical to accurate simulation of water and energy cycles
- Review datasets available or being collected
- Examine data accessibility issues and data format compatibility
- Review quality and differences of different reanalysis datasets
- Search for "meta-comparisons" from different continental scale experiments.

Milestones

- Organizational meeting (summer 2004)
- Request for GEWEX Project status (September 2004)
- Create review paper on status of regional modeling, future challenges (based on material presented at May meeting), announcement of future experiments (EOS or BAMS, December 2004)
- First experiment announced with BC available (October 2004)
- Results reported to organizational center (July 2005)
- First scientific results paper (July 2006)

References

Anderson, C.J., and Co-Authors, 2003: Hydrological processes in regional climate model simulations of the central United States flood of June-July 1993. *J. Hydrometeor., 4*, 584-598.

CEOP, 2004: http://www.joss.ucar.edu/ghp/ceopdm/

CEOP-IP, 2004: http://www.gewex.org/ceop/ceop_ip.pdf

JOSS, 2004: http://www.joss.ucar.edu/

PIRCS, 2004: http://www.pircs.iastate.edu

Takle, E.S., and Co-Authors, 1999: Project to intercompare regional climate simulations (PIRCS): Description and initial results. *J. Geophys. Res. 104*, 19,443 19,462.

Applicability of various versions of the pattern-scaling method in projecting local anthropogenic temperature and precipitation change

Kimmo Ruosteenoja, Heikki Tuomenvirta and Kirsti Jylhä

Finnish Meteorological Institute, P.O. Box 503, FIN-00101 Helsinki, Finland
E-mail: Kimmo.Ruosteenoja@fmi.fi

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. Utilizing HadCM3 GCM responses to A1FI, A2, B1 and B2 scenarios, we evaluate some methods by which local temperature and precipitation responses to A1FI and B1 scenarios for period 2070-2099 (relative to the baseline period 1961-1990) can be approximated by scaling of A2 (3 ensemble members) and B2 (2 members) runs.

All pattern-scaling methods to be presented assume that the *geographical pattern* of the temperature/precipitation change is independent of the forcing whereas the *amplitude* of the change is proportional to $\langle \Delta T \rangle$, $\langle\ \rangle$ denoting a global mean. $\langle \Delta T \rangle$ is calculated with a simple energy balance climate model MAGICC (IPCC, 2001). Unfortunately, the GCM-simulated climate response includes, besides the actual climate change signal, noise caused by natural variability. This noise is transmitted into the scaled temperature/precipitation response.

The simplest method consists in scaling from an individual GCM response, e.g.:

$$\Delta T_{A1FI,s} = \frac{\langle \Delta T_{A1FI} \rangle}{\langle \Delta T_{A2} \rangle} \Delta T_{A2,g} \qquad (1)$$

where the subindex g refers to the GCM-simulated, s to the scaled temperature change at an individual gridpoint.

One method to reduce the influence of noise is to perform the scaling in (1) from the ensemble mean instead of an individual GCM response. The effective ensemble size can be further increased by calculating the scaled value from a regression line fitted to the *entire set* of five GCM-simulated temperature changes:

$$\Delta T_{A1FI,s} = a_T \langle \Delta T_{A1FI} \rangle; \qquad (2)$$

$$a_T = \frac{\sum_{i=1}^{5} \langle \Delta T_i \rangle \Delta T_{i,g}}{\sum_{i=1}^{5} \langle \Delta T_i \rangle^2}$$

The principle of the method is illustrated in Fig. 1. N.B.: Since $\langle \Delta T \rangle = 0$ represents a zero climate change, the least-square regression line is constrained to pass through the origin.

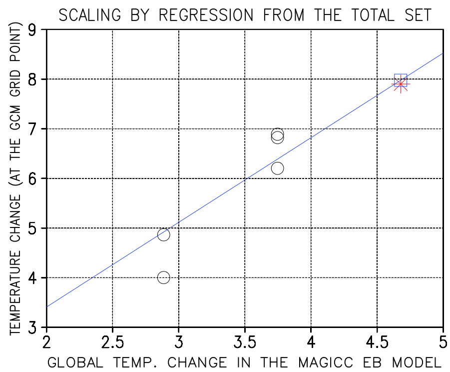


Fig 1. Scaling of $\Delta T_{A1FI,s}$ from the regression line (2) calculated from 3 A2 and 2 B2 temperature responses. Black circles depict the GCM-simulated temperature changes under B2 and A2 scenarios at 57.5°N, 26.25°E as a function of the global mean temperature change $\langle \Delta T \rangle$. The scaled temperature response is marked by a blue square, the GCM-simulated reference value with a red asterisk.

In this data set, the scaling method based on fitting a regression line to the entire set of A2 and B2 responses (2) appeared to be approximately as good as the scaling from the A2 ensemble mean (results for scaling of the A1FI response are given in Fig. 2). In a situation with only one A2 and one B2 simulation available, the regression method tended to work better than scaling from an individual response. Note that there is noise in the reference GCM-simulated A1FI and B1 responses as well, which hampers ranking the methods. Moreover, the ensemble sizes are so small that all findings presented here are tentative.

In principle, however, pattern scaling based on a regression line has several advantages. First, if responses to more than one scenario have been calculated by a sophisticated GCM or RCM, the method utilizes all available information in calculating the scaled response. Second, the method reduces the influence of random noise. This is particularly advantageous if some of the GCM runs happens to be very anomalous due to an extreme phase of internal natural variability. Third, many more simple versions of the scaling method (e.g., (1)) are obtained as special cases of the regression method.

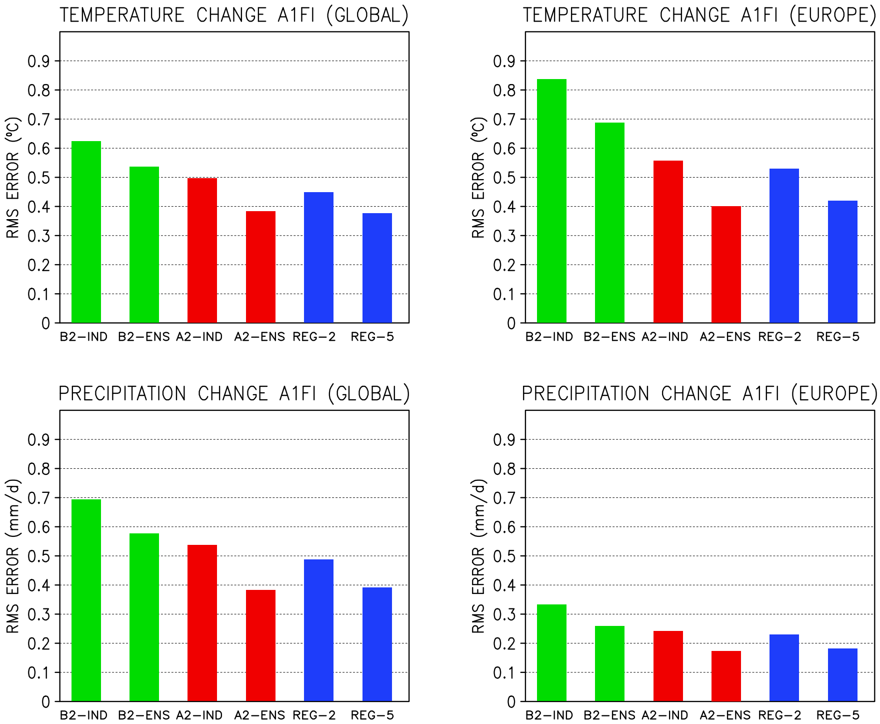


Fig 2. Rms difference between the GCM-simulated and scaled A1FI temperature (upper panels) and precipitation (lower panels) responses over the entire Earth (left) and European land areas west of 35°E (right). Various columns represent scaling from the following set of GCM-simulated responses:

(i) *Left-hand green: an individual B2 simulation*

(ii) *Right-hand green: the B2 ensemble mean*

(iii) *Left-hand red: an individual A2 simulation*

(iv) *Right-hand red: the A2 ensemble mean*

(v) *Left-hand blue: regression from a pair consisting of one A2 and one B2 ensemble member*

(vi) *Right-hand blue: regression from the set of 3 A2-simulated and 2 B2-simulated responses (see Fig. 1)*

(i) is a mean of two rms values that are obtained by comparing the patterns scaled from the two individual B2 responses with the GCM-simulated field. Analogously, (iii) is a mean of three rms values. (v) is a mean of 6 rms errors, each corresponding to scaling by a regression line fitted to a pair consisting of one A2 and one B2 ensemble member.

Effects of the Andes on Eastern Pacific Climate: A Regional Atmospheric Model Study

Haiming Xu, Yuqing Wang and Shang-Ping Xie
International Pacific Research Center, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, USA

Introduction

The Andes are a steep and narrow mountain range running across the South American continent along the west coast from 10^{o}N to its southern tip. At typical resolutions of 300 km or coarser, global climate models severely under-represent the height of the Andean mountains, with smoothed orography less than 1 km high between 10^{o}S and 10^{o}N while in reality, they rarely fall below 3 km. In this paper, we use a regional atmospheric model that affords high resolutions in a limited domain. Particularly we will focus on the effect of the Andes on boundary layer stratocumulus clouds in the cold season and deep convection in the warm season of the equatorial Pacific.

Model and experimental design

The regional atmospheric model developed at International Pacific Research Center (IPRC), University of Hawaii, is used in this study. It is a primitive equation model with sigma as the vertical coordinate solved on a longitude-latitude grid system. The model domain covers the eastern Pacific and tropical parts of North and South Americas (150^{o}W-30^{o}W, 35^{o}S-35^{o}N). The model uses a grid spacing of 0.5º in both longitude and latitude, and has 28 vertical levels with 10 levels below 800 hPa. We refer to Wang et al. (2003) for a full description of the model and summarize briefly only its physics.

The initial and lateral boundary conditions are obtained from the NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) global reanalysis available at a horizontal resolution of 2.5^o by 2.5^o with 17 vertical pressure levels. Over the ocean, the Reynolds weekly SST dataset with horizontal resolution of 1^o × 1^o is used as the lower boundary condition. Two sets of experiments are performed separately for the austral warm and cold. The warm and cold season runs are initialized at 00 GMT on 1 March and 1 September 1999, respectively, each lasting for three months. For each season, the following three experiments are carried out to examine the effects of the Andes. (1) Control run: The model topography is based on the 5×5 minute ETOPO5 Navy bathymetry. (2) T42 topography run: This experiment is identical to the Control run except that the topography is replaced with a smoother one taken from a GCM with triangular truncation at zonal wavenumber 42. (3) No-Andes run: The mountains on western South America including the northern, central, and southern Andes are removed by setting land elevation at 0.5 m.

Cold season

In the cold season, the model well simulates the season-mean precipitation and column-integrated cloud liquid water compared to TMI observations. The model also successfully captures the rich vertical structures of marine boundary layer over the Southeast Pacific with a low-cloud layer capped by a strong temperature inversion. Both the temperature inversion and cloud layer rise in height toward the west. The high Andes separate warm land air mass from one on the Pacific side that is kept cool by underlying SSTs. With the Andes removed, the low-level warm continental air now flows into the Pacific, causing large warming in the coastal region. Without the meridional barrier, zonal winds accelerate, especially near the coast. Figure 1 shows the control minus No-Andes difference of the column-integrated cloud liquid water content. Positive values extend from the coast off South America to about 95ºW between the equator and 25^{o}S. Overall, the Andes leads to 30%-50% increase in cloud liquid water content in the coastal region east of 95ºW. Consistent with the increase in stratocumulus clouds, the mean downward shortwave radiation fluxes at the sea surface are reduced by as much as 45 W m^{-2}, exerting a cooling effect on the ocean. The difference field of column-integrated liquid water content between the control and T42 is quite similar to that between the control and No-Andes runs except for smaller magnitudes. This suggests that the poor representation of the narrow and steep Andes in most AGCMs is partially responsible for the poor simulation or underestimation of stratocumulus clouds over the southeastern Pacific although proper

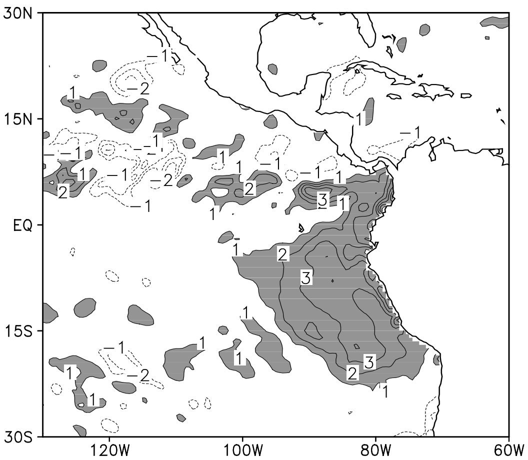


Fig. 1. Difference of vertically integrated liquid water content between the control and No-Andes runs, averaged for August-October 1999. Contour interval is 10^{-2} mm. Values greater than 10^{-2} mm are shaded.

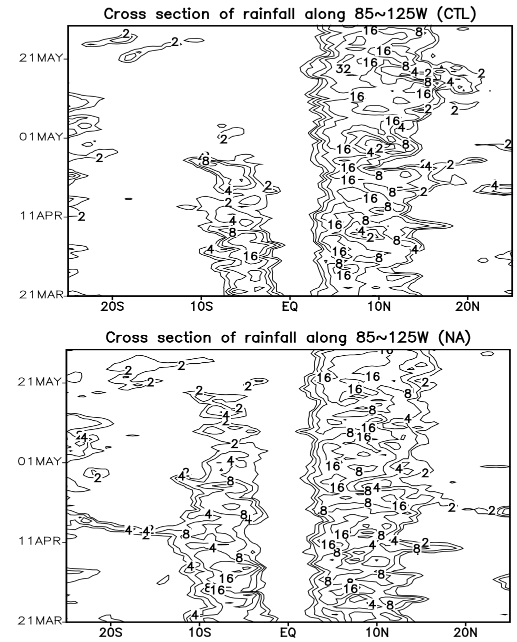


Fig. 2. Time-latitude section of precipitation (mm day^{-1}) zonally averaged between 85ºW and 125ºW for control (upper) and No-Andes (lower) runs.

model physical parameterizations are critical to the realistic simulation of these clouds.

Warm season

Warm season (March-May) climate over the eastern tropical Pacific differs markedly from the cold one, featuring one ITCZ on either side of the equator. The control run captures key features of the double ITCZs, including their positions and precipitation rate. The removal of the Andes causes the southern ITCZ to persist till mid-May, almost 20 days longer than in the control run (Fig. 2). The ITCZ is not a band of constant precipitation in time, but instead is made of rainfall events associated with pronounced westward propagating dynamic disturbances. Without the Andes, dynamic disturbances initiated over the continent can propagate into the Pacific and develop there, and interact with precipitation along the ITCZ. The westward propagation of these disturbances and the precipitation-dynamic feedback involved appear to be the reasons why the warm-season response to the Andes extends far away westward from the mountains while the cold-season response is much more zonally confined.

Summary

A regional atmospheric model is used to study the effects of the narrow and steep Andes on eastern Pacific climate. In the Southern Hemisphere cold season (August-October 1999), the model reproduces key climatic features including the intertropical convergence zone (ITCZ) north of the equator and an extensive low-level cloud deck capped by a temperature inversion to the south. In an experiment where the Andean mountains are removed, the warm advection from the South American Continent lowers the inversion height and reduces the low-level divergence off shore, leading to a significant reduction in cloud amount and an increase in solar radiation that reaches the sea surface. In March and early April 1999, the model simulates a double ITCZ in response to the seasonal warming on and south of the equator. The removal of the Andes prolongs the existence of the southern ITCZ for three weeks. Without the mountains, the intrusion of the easterlies from South America enhances the convergence in the lower atmosphere, and the transient disturbances travel freely westward from the continent. Both effects of the Andes removal favor deep convection south of the equator.

References

Wang Y., O.L. Sen, and B. Wang, 2003a: A highly resolved regional climate model (IPRC–RegCM) and its simulation of the 1998 severe precipitation event over China. Part I: Model description and verification of simulation. *J. Climate*, **16**,1721-1738.

ECHAM5 T106 TIME SLICE SCENARIOS USING PRUDENCE SST AND SRES FORCINGS

Martin Wild, Andreas Roesch, Peter Tschuck, Atsumu Ohmura, Chrtistoph Schaer, Pierluigi Vidale
Institute for Atmospheric and Climate Science ETH, Swiss Federal Institute of Technology (E-mail: martin.wild@env.ethz.ch)

Erich Roeckner
Max Planck Institute for Meteorology, Hamburg

Time slice experiments with ECHAM5 at T106 (1.1°) resolution have been performed at the Swiss Centre for Scientific Computing (CSCS) for the present day and end of the 21th century using SRES Emission Scenarios A2 and B2. The present day experiment uses observed sea surface temperature (SST) and sea ice distributions for the period 1960- 1990. The SST and sea ice anomalies superimposed on the observed fields to obtain the SST and sea ice distrbutions for the periode 2070-2100 were inferred from a coupled transient experiment carried out at the Hadley Centre with HadCM3 as used in the EU Project PRUDENCE. This enables an assessment of the response of high resolution versions of the different European GCMs to identical forcings in sea surface temperature, sea ice, and antropogenic emissions. A first analysis focuses on the potential change in mean summer temperature variability in the ECHAM5 T106 SRES Scenario A2.

In line with Schär et al. (2004), an increase in summer mean temperature variability is found over central Europe (Fig. 1). The increase is, however, less pronounced than in Schär et al. (2004). A month-wise analysis indicates that the increase in the temperature variability is limited to the end of summer (Fig. 2). This may be partly related to the fact that ECHAM5, unlike other models, shows only little drying during much of the summer over Europe under both present day and scenario A2 conditions. This becomes evident from annual cycles of latent heat fluxes for present and scenario conditions as well as observations. Unlike other GCMs, the latent heat flux is hardly water limited under present day conditions (in good agreement with observations) as well as in the scenario, where the latent heat flux is further enhanced (Fig. 3). Also, convective precipitation is increased in summer, again indicating no significant drying in the scenario (Fig. 3)

In contrast, the older version ECHAM3 showed an enhanced summer drying in the scenario experiment (Wild et al. 1996, 1998). More frequent periods with water limited evaporation in the scenario may then support an increase in temperature variability, due to more frequent offsets of evaporative cooling with associated feedbacks on temperature. This effect is found to a lesser extent in the present ECHAM5 experiments. Contributing to the lesser drying in ECHAM5 compared to ECHAM3 under present day conditions is a reduced surface insolation due to a more realistic radiation treatment (Wild et al. 1996, 1998).

References

Schär, C., Vidale, P.L., Lüthi D., Frei, C., Häberli, C., Liniger, M.A., Appenzeller, C., 2004: *Nature*, **427**, 332 – 336

Wild, M., Ohmura, A., Gilgen, H., and Roeckner, E., 1995: *Climate Dynamics*, **11**, 469-486

Wild, M., Dümenil, L., and Schulz, J.P., 1996: *Climate Dynamics*, **12**, 755-774.

Wild, M., Ohmura, A., and Cubasch, U., 1997: *J. Climate*, **10**, 3093-3110.

Wild, M., et al. 1998: *Climate Dynamics*, **14**, 853-869.

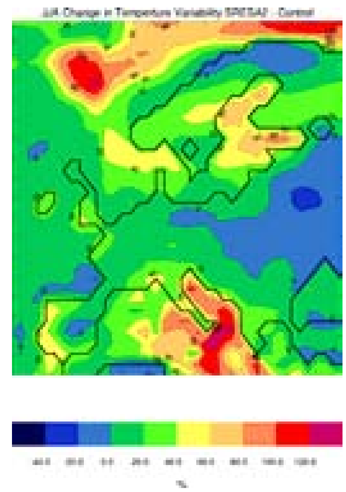


Fig. 1 Change in standard deviation of summer mean temperature SRES A2 – CONTROL calculated with ECHAM5 T106

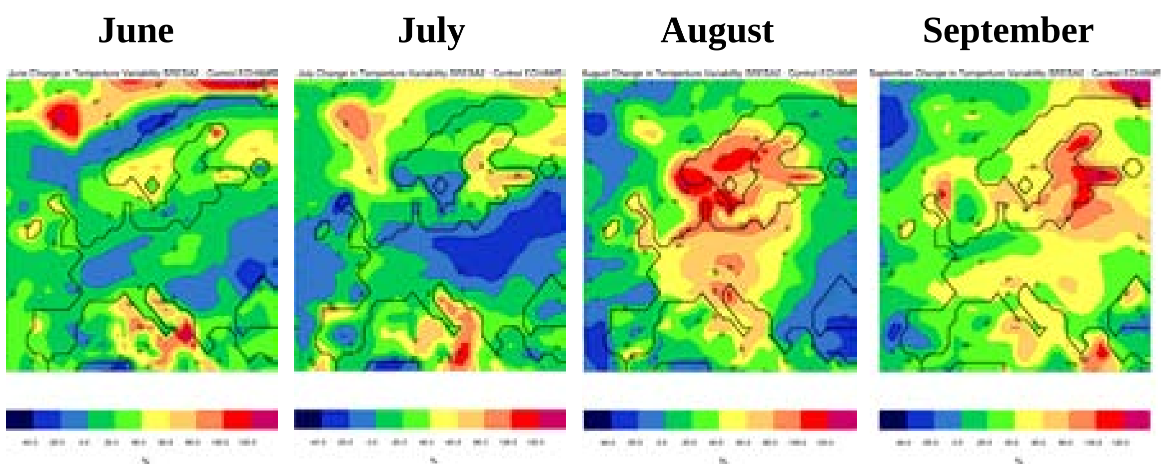


Fig. 2 Change in standard deviation of monthly mean temperature SRES A2 – CONTROL calculated with ECHAM5 T106

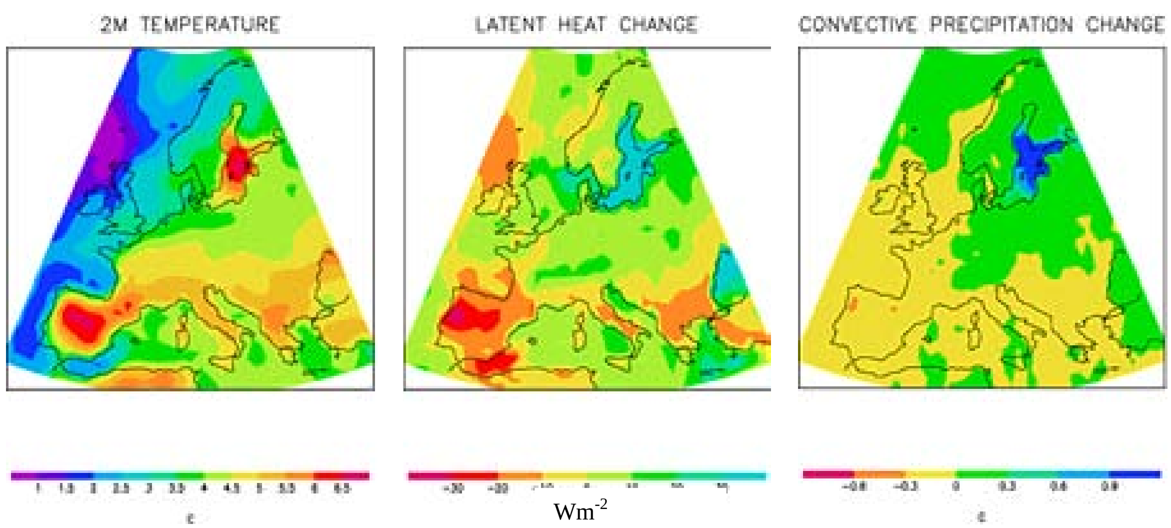


Fig. 3 Change in mean summer temperature, latent teat flux and convective precipitation in the ECHAM5 T106 SRS A2 scenario

Comparison of modeled and radar measured cloud fraction and overlap

Willén, U.

SMHI, Sweden

The vertical distribution of clouds has a large impact on the radiative heating and cooling rates of the atmosphere and the surface. Assumptions regarding the vertical cloud overlap in a grid column are required in climate models for the radiative transfer calculations. These various assumptions can lead to large differences in subsequent radiative heating rates of the atmosphere and the surface. The cloud overlap assumption and the cloud vertical structure can be assessed by comparing the model output with ground based cloud profiling radar data. We have evaluated the vertical cloud distributions of four European models (ECMWF, RACMO, RCA and LM) for the BALTEX BRIDGE campaign in August and September 2001 of the CLIWA-NET project. The four models of different horizontal and vertical resolutions overestimated high and low clouds and under estimated clouds at mid-levels. Clouds occurred more frequently in the models but with less amounts when present. The model cloud fraction frequency distributions were skewed compared to the observed distributions. These errors led to compensating errors in the overlap calculations which could adversely affect the temperature and circulations of the models. The radar derived cloud overlap was found to be in between maximum-random and random overlap. A new version of maximum-random overlap was tested with a random factor also for continuous clouds, which improved the agreement with the true overlap.

Modelling clouds and radiation in the Arctic

Wyser , K., Jones, C.G. and U. Willén

Rossby Centre, SMHI, Sweden

Recent observations and climate modelling results have highlighted the Arctic region as particularly vulnerable to potential anthropogenic climate change. Global model projections of the future climate show the largest surface warming over sea ice covered regions of the Arctic Ocean, where an initial climate warming is hypothesized to lead to sea ice melt, a reduction in the surface albedo and further melting and warming through increased absorption of solar radiation (i.e. positive feedback). However, Global Climate Model simulations of the Arctic vary widely in quality and many of the key physical processes that must be parameterised are poorly understood.

One of the areas with the largest uncertainties concerns the interaction between clouds and radiation. The radiation schemes of today’s climate models have often been developed with mid-latitude or tropical clouds in mind. In this study we will evaluate clouds and radiation from existing regional climate models that have participated in the Arctic Modeling Intercomparison project (ARCMIP). Model results are compared against observations from the SHEBA site.

Eight different regional climate models have participated in ARCMIP. All models have used a similar domain in the Western Arctic with approximately 50 km horizontal resolution and roughly 60 by 80 grid points. Lateral and lower boundary forcing was prescribed for the 13 month long simulation. Each modelling group has extracted cloud and radiation variables at the location of the SHEBA station.

The Surface Heat Budget of the Arctic Ocean (SHEBA) experiment has collected a large amount of observational data on clouds and radiation. A vessel was frozen into the pack ice north of Alaska and drifted with the ice for a year. We compare model simulated time series of clouds and radiation variables against observations from the SHEBA ship station and against satellite derived data.

The simulation of a full Arctic year with 8 different regional climate models has provided us with many interesting results. In general, we find a reasonable agreement in the radiation variables. However, when looking into details, we find large discrepancies between models and observations. For example, all models poorly reproduce cloud cover; there is basically no correlation between simulated and observed cloudiness. Other problems have been identified with the sensitivity of radiation to the amount of cloud condensate, or to the cloud base temperature. With these deficits in mind, we believe that the fair agreement between simulated and observed radiation follows from compensating errors. The differences between models and observations clearly demonstrate the need for improvements of the parameterisations, preferentially based on physical laws and realistic observations.

Applying a strong boundary layer mixing process in the Canadian Regional Climate Model

Yanjun Jiao[1], Daniel Caya[2] and Rene Laprise[1]

1. Department of Earth and Atmospheric Sciences, University of Quebec at Montreal, Montreal, Quebec, Canada
2. Ouranos Consortium, Montreal, Quebec, Canada
jiao.yanjun@uqam.ca

ABSTRACT

A strong boundary layer mixing process used in the third generation of the Canadian Atmospheric General Circulation Model (AGCM) is implemented into the third generation of Canadian Regional Climate Model (CRCM) as an effort to improve the CRCM performance in simulating summer land precipitation. The new strong mixing process imposes the latent and sensible heat fluxes on the whole boundary layers so as to directly mimic non-local mixing effects during strong surface heating events. After using new mixing scheme in the CRCM, the vertical distributions of water vapor and temperature in the boundary layer have been improved significantly; the intensity of convective precipitation is reduced drastically, which leads to the simulated total summer precipitation become more reasonable while compare with observation data.

INTRODUCTION

The structure and dynamics of the Planetary Boundary Layer (PBL) are of vital importance for weather and climate modeling. Inside the PBL, intense turbulent mixing caused by solar heating takes place on many temporal and spatial scales and tends to generate a well-mixed boundary layer, which has potential temperature and humidity nearly constant with height.

Owing to the sub-grid scale and chaotic nature, the mixing physical processes in the PBL have to be parameterized in current climate model. However, according to the report of the Intergovernmental Panel on Climate Change (IPCC, Houghton et al., 2001), most of the atmospheric models still have great difficulty in properly representing the turbulent mixing processes in the boundary layer, which is directly responsible for the poor quality of the model simulated convective precipitation over continental regions.

In this study, a simple and strong boundary layer mixing process used in the Canadian Atmospheric General Circulation Model (AGCM) is implemented into the third generation of Canadian Regional Climate Model (CRCM) (Caya and Laprise, 1999; Laprise et el., 1998; Laprise et al., 2003) as an effort to improve the vertical distribution of temperature and water vapor in the lower troposphere, further to improve the model performance in simulating summer precipitation over land.

DESCRIPTION OF MIXING PROCESS

In the original boundary layer parameterization scheme of the CRCM, the latent and sensible heat fluxes are imposed to the lowest model layer and then diffused upward according to the traditional K-diffusion scheme. Instead of exchanging latent and sensible heat fluxes only with lowest model layer, the new strong mixing process imposes evenly the surface fluxes on the whole boundary layers in accordance with the following procedure. First, the potential temperature and specific humidity increments caused by sensible and latent heat fluxes are added to the lowest boundary layer, which results in new potential temperature and specific humidity on the lowest model layer. The corresponding virtual potential temperature is then computed and compared with the original value. If newly obtained virtual potential temperature is greater than the old one (implying a statically unstable profile), the potential temperature and specific humidity are allowed to mix upward through an additional layer and the PBL top is raised accordingly. This process is repeated until the mixed virtual potential temperature becomes less than the old one. It is then assumed that the PBL top has been reached and the model potential temperature and specific humidity on all boundary layers are instantaneously adjusted to the newly mixed values.

EXPERIMENT SET-UPS

Two experiments have been conducted without and with the new boundary layer mixing process (referred to as experiment CTL and MIX). Both of the experiments are initialed on May 1, 1991 and are conducted for 8 months with a time step of 15 minutes. The results presented here are the monthly mean for July and December in 1991.

The model domain covers the Pan-Canadian area. There are totally 193 by 145 polar steorographic grid points at a resolution of 45 km (true at 60°N) in the horizontal and 29 uneven Gal-Chen levels capped at 29 km in the vertical. The initial and lateral boundary conditions (LBC), including large-scale horizontal wind, temperature, specific humidity and surface pressure, are derived from the NCEP/NCAR re-analyses. The LBC are updated every 6 hours and are nested by one-way nesting with CRCM via 9-grid points buffer zone. The lower boundary forcings of the sea surface temperature (SST) and sea ice concentration are prescribed with observed monthly mean values from the Atmospheric Model Intercomparison Project (AMIP).

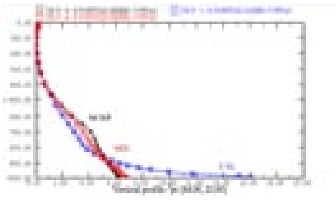


Fig 1. The vertical profile of monthly mean specific humidity on one CRCM grid point (the point is the intersection of Colorado, Utah and Wyoming; the blue, red and black lines are for experiment CTL, MIX and NCEP/NCAR reanalysis, respectively)

RESULTS

The profile in fig. 1 clearly shows that the moisture in the lower troposphere is not well mixed in experiment CTL (blue line). The air in the boundary layer is wetter while the air above the boundary layer is dryer than that of the NCEP/NCAR reanalysis; after new mixing process involved, the vertical distribution of the moisture in the lower troposphere, especially in the layers near the surface becomes more realistic although a slight wet (dry) bias still exist within (above) the boundary layer. For example, compare with the 16g/kg in CTL, the specific humidity in the lowest model layer is reduced to 6.8g/kg in MIX, very close to the NCEP/NCAR reanalysis value, which is 6.3g/kg. Fig. 2 presents the spatial distribution of the monthly mean specific humidity on the lowest mode layer, it clearly shows that the moisture distribution has significantly improved over whole model domain except in northeastern U.S. and southern Ontario and Quebec, where the specific humidity are slightly dryer than that of the NCEP/NCAR reanalysis.

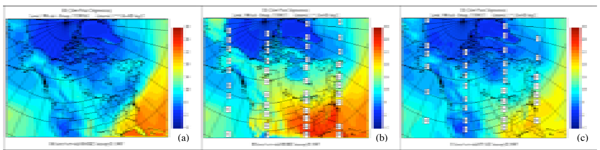


Fig 2. Monthly mean specify humidity on the lowest model layer (Gal-Chen coordinate) in July 1991. (a) MIX; (b) CTL and (c) NCEP/NCAR reanalysis

The comparison between model simulated total cloudiness and the observation from the International Satellite Cloud Climatology Project (ISCCP) indicates that the new mixing process also improves the simulation of the cloud over continent (not shown).

Fig. 3 is the monthly mean precipitation of July 1991 based on the model simulation and observation (Xie and Arkin, 1996). Comparison of fig.3a and fig.3b clearly shows the effect of the new mixing process on the precipitation. In CTL (fig. 3b), the CRCM overestimates too much precipitation over land, especially over western mountainous area in the United States. However, in MIX (fig. 3a), the total precipitation over land is reduced considerably. The model successfully captures the basic precipitation patterns over North America continent including the intensity precipitation in the southeast coast of the United States, the North America Monsoon precipitation over New Mexico and Texas, and the dry situation in the mountainous area over western United States.

Finally, the monthly mean result in December 1991 reveals that the new mixing process do not deteriorate the already good simulation of the CRCM on the winter precipitation (not shown).

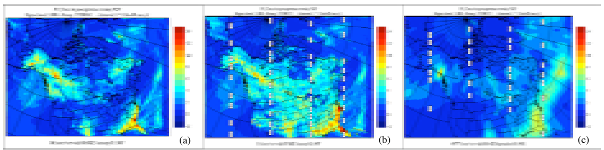


Fig 3. Monthly mean precipitation in July 1991. (a) MIX; (b) CTL and (c) Xie_Arkin observation

CONCLUSION

1) A strong boundary layer mixing process has been implemented into Canadian Regional Climate Model.
2) The new scheme significantly improves the vertical distributions of water vapor and heat in the boundary layer.
3) The new boundary layer mixing scheme reduces the amount of total precipitation over land by considerably reducing the intensity of the convective precipitation, the overall patterns simulated by CRCM become more realistic while compare with observation data.

REFERENCES

Caya, D., and R. Laprise, 1999: A semi-implicit semi-Lagrangian regional climate model: The Canadian RCM. *Monthly Weather Review*, 127(3): 341-362.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, D. Xiaosu, K. Maskell, and C. A. Johnson Eds. 2001: Climate Change: The Scientific Basis. *Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, 944 pp.

Laprise R., D. Caya, M. Giguère, G. Bergeron, H. Côte, J.-P. Blanchet, G.J. Boer and N.A. McFarlane, 1998: Climate and climate change in western Canada as simulated by the Canadian regional climate model. *Atmosphere-Ocean*, 36, 119–167.

Laprise, R., D. Caya, A. Frigon, and D. Paquin, 2003: Current and perturbed climate as simulated by the second-generation Canadian Regional Climate Model (CRCM-II) over northwestern North America. *Climate Dynamics*, 21(5-6): 405 – 421.

Xie, P., and P. A. Arkin, 1996: Analyses of global monthly precipitation using gauge observations, satellite estimates, and numerical model predictions. *Journal of Climate*, 9: 840-858.

reclip: more research for climate protection: model run evaluation

Johann Züger, ARC systems research, A-2444 Seibersdorf

A reliable assessment of future climate impacts in Austria makes necessary to provide Regional Climate Model (RCM) runs and additional tasks to deliver high resolution downscaled datasets for past and future climate targeting the entire eastern Alps covering Austria. The project ***reclip:more*** is designed to run those regional climate model runs, sensitivity analysis and model benchmarking of 2 different RCMs/LAMs and finally provide validated high resolution datasets for Austria.

The major scientific goals are:

- Quantify the uncertainties of regional climate simulations elated to observed climate data,
- Investigate the sensitivity of regional climate simulations and interpolated climate data to the influence of different model parameters and data processing techniques,
- Deliver regional climate change scenarios for the eastern Alps covering Austria.

To achieve this, data preparations, a set of common model experiments and data evaluations have to be carried out with sensitivity studies. The overall objective referring to data is to provide transient regional climate model (RCM) results of the daily weather conditions for a past decade (1990-2000) as control run and for model validation purposes and for some future decades (2040-2050 and/or 2070-2090) based on ECHAM 4 T106 GCM-results, first with a resolution of approximately 10 km for the Eastern Alps. A Model validation task shall provide a benchmarking of 2 different regional climate models MM5 and ALADIN.

To compare the model result with observation data high resolution monitoring data sets from 1990 to 2000 for Austria and synoptical data sets for entire Europe are necessary.

Further downscaling of the model results is required as the results will be derived for a horizontal resolution of 1 km. Former investigations have shown, that in some cases higher resolution nesting of numerical models may lead to less valid results. To overcome these disadvantages it is planned to continue downscaling from a 10 km level with help of terrain related response variables as already developed by the authors for regionalization of precipitation records and precipitation sums.

The tasks in detail:

(1) Development and application of methods and tests

- Model validation - statistical methods, indicators
- Up/Downscaling - regionalization of observation and gridded model results

(2) Dynamical regional climate modeling

- retrospective model runs with 2 RCMs & Re-analysis/GCM-data sets for 1990-2000
- prospective model runs with 2 RCMs & GCM-data sets for 2040-2050 and/or 2070-2100

(3) Up/Downscaling - regionalization of observation data and gridded model results

- for validation and for final delivery of model results

(4) Benchmarking of the retrospective model run results

- Comparative analysis of high resolution model results and monitoring data.
- Documentation of advantages and disadvantages of different settings of the RCMs

(5) Comparison of results of prospective model runs

(6) Delivery of high resolution model results for the future climate

- T-mean, T-max, T-min
- Humidity
- Radiation
- 6-hourly wind speed and direction
- daily precipitation

The project will be carried out by 6 teams:

ARC systems research:

- Project management
- ECMWF/GCM dataset preparation for MM5
- MM5 short runs
- Sensitivity tests
- Downscaling T-min, T-max, Rad

IMG-Univ.Vienna (i):

- EU-synoptic datasets
- Validation via VERA
- Sensitivity tests

IMG-Univ.Vienna (ii):

- ECMWF/GCM dataset preparation for ALADIN
- ALADIN short runs
- Sensitivity tests
- ALADIN long runs

IMP-Univ.f.Agric.Vienna:

- Sensitivity tests concept
- Model validation concept
- RCM benchmarking

IGAM – Univ. Graz:

- MM5 long runs
- Downscaling wind

ZAMG-Vienna:

- Austrian monitoring data
- Downscaling T-mean, P, Snow