

## 46 Simulating Forest Responses to Transient Changes in Climate and Atmospheric CO<sub>2</sub>: A Case Study for Saskatchewan, Central Canada

MUSTAPHA EL MAAYAR, DAVID T. PRICE, AND R. MARTIN SILTANEN

Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre, 5320-122 Street, Edmonton, Alberta, T6H 3S5, Canada.

**Abstract.** A transient climate scenario for the simulated period 1900–2100, derived from the CCCma coupled GCM (CGCM1) with IPCC IS92a greenhouse forcing was used to drive the IBIS Dynamic Global Vegetation Model (DGVM), applied to the region of Saskatchewan, Canada. Results indicate significant effects of atmospheric CO<sub>2</sub> increase on NPP, litter production and biomass. Our simulations also indicate a minor effect of temperature increases on the exchange of CO<sub>2</sub> between forest and atmosphere in this region. Projections for the period 2000–2100 using a ten year moving average, derived from this single scenario analysis include: increases in NPP, biomass, aboveground litter, belowground litter, soil carbon, soil nitrogen, transpiration, and evapotranspiration rate of approximately 90, 64, 60, 21, 13, 13, 32 and 5%, respectively. Over the same period, runoff decreased by ~23%.

### 46.1 Introduction

The terrestrial biosphere and the atmosphere interact in various ways, of which perhaps the most obvious demonstration is in the global distribution of vegetation. Over the last two decades, the scientific community has attached great importance to understanding the effects of increasing atmospheric CO<sub>2</sub> on global climate (as projected by General Circulation Models, GCMs) and the consequences of climatic change on the distribution and ecological function of terrestrial vegetation. More recently, the impacts of change on the many services provided by these ecosystems have also become an important concern (e.g., Mendelsohn and Neumann 1998)

Reproducing the complexity of most terrestrial ecosystems in the laboratory is extremely difficult, so field observation and computer modelling are widely accepted as appropriate ways to investigate these effects. Several types of ecosystem models have been developed and used to simulate global and regional forest responses to climate in terms of productivity and cycling of carbon and nutrients, at both global and regional scales (e.g. Melillo *et al.*, 1993; Parton *et al.*, 1995; Schimel *et al.*, 1997; Price *et al.*, 1999a,b). Examples include small-scale "patch" models [e.g., FORSKA (Prentice *et al.*, 1993)], global-scale equilibrium vegetation models [e.g., BIOME (Prentice *et al.*, 1992)], and terrestrial biogeochemistry models [e.g., TEM (Melillo *et al.*, 1993)]. Amongst many

researchers, Parton *et al.* (1995) and Xiao *et al.* (1997) found that net primary production (NPP) and carbon storage of terrestrial ecosystems may be significantly affected by changes in atmospheric CO<sub>2</sub> concentration and climate. At the regional scale, Price *et al.* (1999a) concluded that climate variability affects seasonal water balances and should be considered when using patch models to forecast vegetation dynamics during and following a period of climate transition. The climate data used in most earlier studies were derived from GCM equilibrium simulations. Hence the effects of short-term transient vegetation responses, both in canopy processes and in competition and phenology, have often been ignored. Because these responses are often highly nonlinear, simulation results are often questionable. Feedbacks between vegetation and atmosphere could also affect vegetation development during the transition between current and future climates (see Levis *et al.*, 1999), but these cannot be simulated unless the vegetation model and the GCM are coupled dynamically. To overcome these limitations, Dynamic Global Vegetation Models (DGVMs) attempt to provide greater consistency in simulating key vegetation processes (including growth, competition, death and decomposition as well as associated mass and energy exchanges with the atmosphere). These models also have the potential to simulate dynamic responses of terrestrial vegetation to changing climate, and can be coupled to transient-mode GCMs (see White *et al.*, 1999).

In this study we examined responses of the Integrated Biosphere Simulator (IBIS) DGVM of Foley *et al.* (1996), to a transient climate scenario for the period 1900-2100 derived from observed climate normals and output from the Canadian Climate Centre's (CCCma) CGCM1 model (Flato *et al.*, 2000). Atmospheric CO<sub>2</sub> concentration was assumed to increase following the IPCC IS92a scenario (Houghton *et al.*, 1996). The model was scaled down to simulate vegetation dynamics for the region of Saskatchewan in central Canada, and applied at a relatively high spatial resolution of 50 km.

## 46.2

### Method

#### 46.2.1

##### Model

Version 2.1 of IBIS (Kucharik *et al.*, 2000) was used to simulate potential vegetation distribution in each 50 km square grid cell, forced by climate data described below. This model simulates the presence/absence of different Plant Functional Types (PFTs), where each PFT represents a group of plants with similar ecological characteristics (e.g., deciduous forest, coniferous forest, grasses and shrubs). Competition processes, influenced by inter-annual climatic variations, then lead to changes in vegetation structure and distribution. Trees (which form the simulated upper canopy vegetation) compete with grasses and shrubs (lower canopy) for water and light. Within each vegetation layer,

competition is driven by differences in the annual carbon balance resulting from different ecological strategies, including differences in phenology (evergreen vs. deciduous), leaf form (needle vs. broadleaf), and photosynthetic pathway (C<sub>3</sub> vs. C<sub>4</sub>). Potential vegetation was initialized in the first year of the simulation using climatic rules derived both from known physiological plant responses and observed vegetation distribution. These included the constraints imposed by: absolute minimum temperature, temperature of the warmest month, and cumulative degree-days above 0 and 5 °C.

For efficient simulation of vegetation responses when coupled to GCMs, the model integrates different processes at appropriate time-scales. Fluxes of energy, water and carbon between vegetation and atmosphere are calculated at high frequency (typically hourly) using the LSX land-surface scheme of Pollard and Thompson (1995), modified to account for simultaneous transfer of carbon and water based on the photosynthesis model of Farquhar *et al.* (1980) as modified by Collatz *et al.* (1991, 1992). Biomass accumulation and leaf area index are computed daily in the phenology module. The remaining model components are integrated on a yearly time-step, and include estimation of annual carbon balance and spatial changes in vegetation biomass and species composition.

For our simulations, two modifications were made to the original model. Firstly, the geographic (latitude/longitude) projection normally used for global simulations was replaced by the Lambert Conformal Conic projection (Snyder, 1987). This provides a more even sampling of the land surface at mid-latitudes, while greatly reducing the computation invested in simulating vegetation at high latitudes where relatively little exists in any case. Secondly, much of Canada's land-surface is composed of organic soils, which have important effects on surface-atmosphere exchanges (El Maayar *et al.*, 2001). For this reason, the IGBP soil data used in global simulations (see Kucharik *et al.*, 2000) was replaced by data on both mineral soil texture and carbon content derived from the Canadian Soil Information System (CanSIS, Agriculture Canada).

#### 46.2.2

##### Transient Climate Change and CO<sub>2</sub> Scenarios

Monthly time series of "pseudo-anomalies" of mean daily temperature, temperature range (Tmax - Tmin), and total precipitation were first created by subtracting the monthly averages of the values simulated for 1961-1990. These anomalies were then interpolated to a 10 km grid as functions of latitude and longitude using the GIDS approach (Price *et al.*, 2000; Nalder and Wein 1998), and added to the observed 1961-90 climate normals (Environment Canada, 1994) interpolated to the same grid using ANUSPLIN (Hutchinson 1999; McKenney *et al.*, 1996). Finally, the 10 km resolution data were reaggregated to 50 km by simple averaging. A mask was created for the spatial domain, corresponding to the area of Saskatchewan, and used to determine the grid cells to be simulated by IBIS. Changes in atmospheric CO<sub>2</sub> concentration for 1900-2100 were estimated as 1% per year compounded from 290 ppm, following the IPCC-IS92a emissions

scenario (Houghton *et al.*, 1996) which suggests that it will reach ~710 ppm by 2100.

From 1900 to 2000, simulated annual mean temperature increased by about 1 °C (Fig. 46.1a) which is consistent with the observational record for western central Canada (e.g., see Environment Canada, 1995). Between 2000 and 2100, the simulated temperatures increase by approximately 6, 10, 8, and 5 °C for autumn, winter, spring, and summer, respectively. During this period, monthly mean temperature range is projected to decrease by approximately 1 °C in spring and summer, and by as much as 4 °C in winter (Fig. 46.1b). Over the same period, monthly precipitation is projected to increase slightly in autumn, winter and spring, but decrease by approximately 20 mm in summer (Fig. 46.1c).

The climate data created for the first year of simulation (1900) were used to spin-up the model for three hundred simulation years, primarily to ensure that soil and litter carbon pools were adequately stabilized before beginning the simulation of climate change effects (see Kucharik *et al.*, 2000). The pool values obtained at the end of the spin-up period were then used to initialize the runs for which results are reported below.

### 46.3 Results and Discussion

The simulated distribution of vegetation for present-day climate conditions (i.e., as simulated for the period 1900–2000; Fig. 46.2a) agrees with observations reasonably well. In general, the pattern of both upper storey (trees) and lower storey (grass and shrubs) vegetation is reproduced successfully, with boreal forest vegetation appearing in the northern region of the Province and grasslands in the south. Less successfully, the model also simulates the presence of temperate deciduous forest between these two regions. This seems incorrect because none of Saskatchewan's vegetation is properly classified as temperate forest. Much of the landscape in this region is dominated by stands of deciduous aspen (*Populus tremuloides* Michx.), however, which suggests that the model's discrimination of deciduous vegetation between temperate and boreal regions could be improved. The most likely factor is the sensitivity to drought: either the boreal deciduous PFT is too sensitive, or the temperate deciduous PFT is not sensitive enough—which results in the latter being too successful when competing with the boreal vegetation. For the year 2100, the model predicts almost total dominance of the region by temperate deciduous trees in the forested regions (Figs 46.2b,o).

Figure 46.2c shows simulated forest biomass compared to observed values taken from inventory data of Penner *et al.* (1997). The model estimates only potential vegetation and hence estimates of biomass should be compared with observations for mature forest stands. Such a comparison shows that on average, the model exceeds observed data for this region by approximately 14 t ha<sup>-1</sup>. Some overestimation is to be expected, given that our simulation did not include effects of disturbances (fire, insects, diseases, harvesting and change in land use).

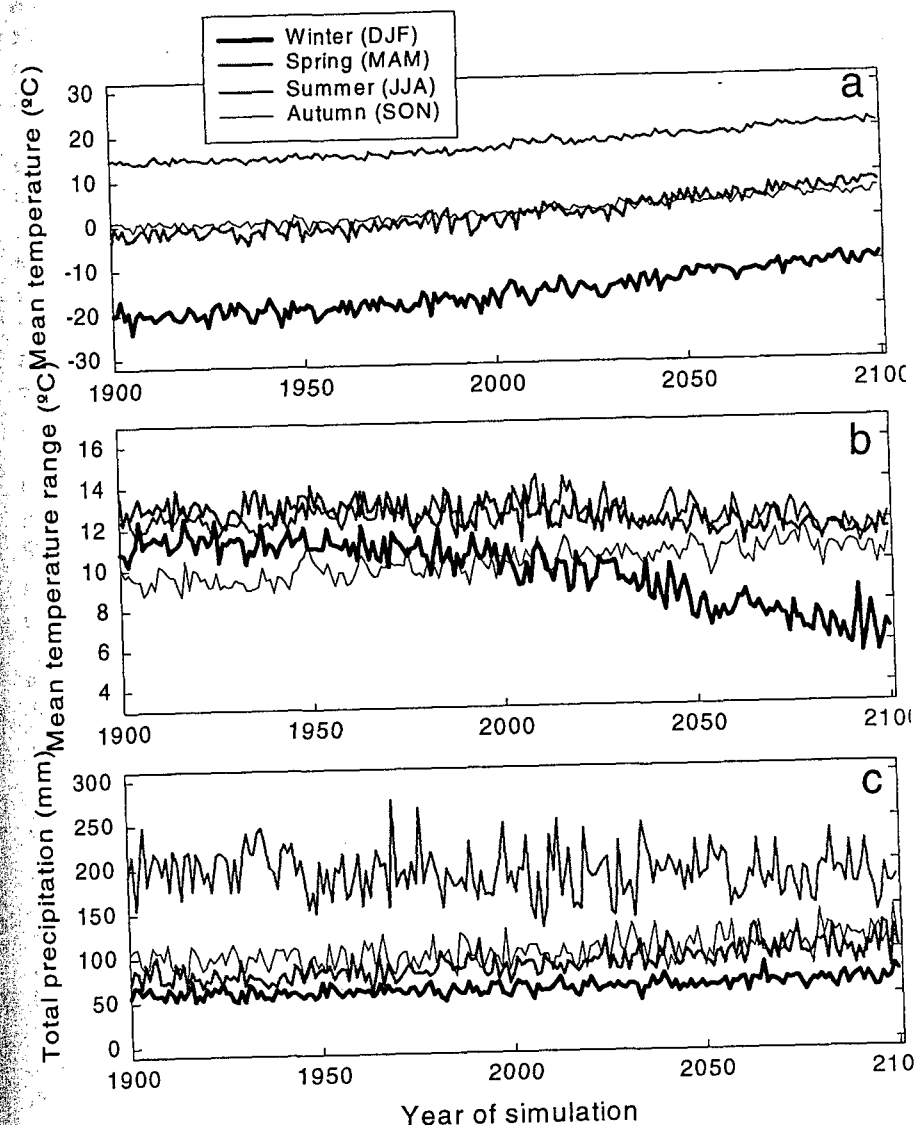


Fig. 46.1. Seasonal CCCma-GCM projected transient changes for the period 1900 to 2100 for Saskatchewan: a) temperature; b) temperature range (Tmax-Tmin); c) precipitation.

Including these effects (see Figure 3 in Kurz and Apps, 1999) would presumably lead to closer agreement between simulated and observed average biomass (Fig. 46.2c), and work is currently underway to test this hypothesis. Other validations (runoff, NPP, soil carbon) for the region of the study can be found in

Kucharik *et al.* (2000) where agreement between observed and simulated data is particularly high for runoff and NPP. Our NPP simulation results (Fig. 46.2g) are also in good agreement with those obtained from the HYBRID-3 DGVM driven by the Hadley Centre's HadCM2 and HadCM3 transient climate scenarios (White *et al.*, 1999).

Figure 46.2g (grey line) shows that changes in temperature alone have little effect on NPP, even though the projected temperature increases in autumn and spring (Fig. 46.1) would lead to a longer growing season, and presumably, increased annual net photosynthesis (Black *et al.*, 2000). The explanation might be that NPP as simulated by IBIS is not very temperature sensitive, perhaps because any increases in photosynthesis with temperature are balanced by higher respiration rates. Even if mean temperatures were to increase in spring and autumn during the period 2000–2100 (Fig. 46.1), they would remain suboptimal for photosynthesis for much of the growing season. Increase in water stress (Fig. 46.2l), that would lead to reduced transpiration and photosynthesis, could also offset any gains due to the longer growing season. Comparison of Figs. 46.2d and 46.2e suggests that fluctuations in simulated NPP are driven more by variations in precipitation than temperature. The major factor causing large increases in NPP obtained in these simulations was the steady increase in atmospheric CO<sub>2</sub> concentration (Fig. 46.2g, black line). The combined effect of climate and CO<sub>2</sub> increase resulted in an approximate doubling of NPP over the period 2000–2100.

Part of the explanation for this increase was that the model also predicted an increase in the coverage of temperate deciduous forest with higher simulated NPP. The increased NPP generated in turn a greater fraction of woody biomass, contributing to an approximate doubling of simulated biomass over the same period (Fig. 46.2f). Note that biomass increases more in the absence of CO<sub>2</sub> increase in the early years of the simulation (Fig. 46.2f), which is due to NPP increase during this period (Fig. 46.2g). These results are not really plausible, however, not least because the model assumes that there are no nutrient controls on photosynthesis. If nitrogen limitations on plant growth were simulated, it is likely that NPP and total biomass would increase much less dramatically. Schimel *et al.* (1997) found from analysis of three model simulations, that water and nutrient controls on NPP become correlated at steady state, because the water budget strongly influences both the carbon and the nitrogen cycles. More recently, Jarvis and Linder (2000) have shown the importance of nitrogen limitations on tree growth based on measurements in two boreal forest regions.

Aboveground and belowground litter production followed the steady changes in total biomass simulated by the model (Figs. 46.2f,h,i). The increase was more rapid during the period 2000–2100, which caused soil carbon content to increase appreciably. (Fig. 46.2j). Increases in precipitation and temperature (Figs. 46.1a and 46.2e), also caused litter decomposition to increase, which stimulated an increase in soil N (Fig. 46.2k). The model also predicts increases in average transpiration (Fig. 46.2l), and a smaller increase in evapotranspiration (AET, Fig. 46.2m). When combined with the projected small decreases in precipitation, these

changes resulted in a 20% decrease in runoff (Fig. 46.2n), during the period 2000–2100. Study of Figs. 46.2g and 46.2l indicates that projected water use efficiency increased over the simulation period, mainly because of the feedback effect of increasing CO<sub>2</sub> concentration on leaf conductance.

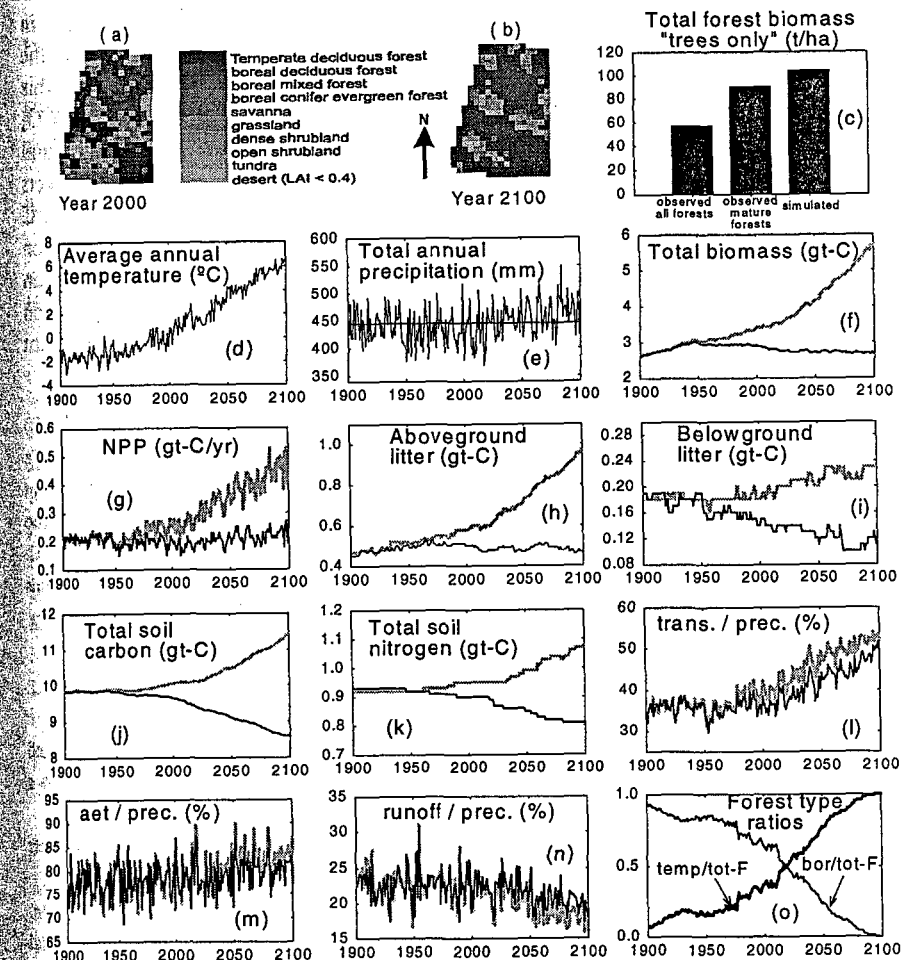


Fig. 46.2. IBIS simulated results for: a) vegetation distribution at year 2000, b) at year 2100, c) total forest (trees only) biomass at year 2000; and evolution of f) total biomass, g) NPP, h) aboveground litter production, i) belowground production, j) total soil carbon, k) soil nitrogen, l) ratio of transpiration to total precipitation, m) ratio of total evapotranspiration to total precipitation, n) ratio of runoff to total precipitation, o) temperate [temp/tot-F] and boreal [bor/tot-F] forest areas ratios. The thin (black) line refers to effect of changes in climate only. The thick (grey) line refers to combined effects of changes in climate and atmospheric CO<sub>2</sub>. Mean annual temperature (2d) and precipitation (2e) are shown for illustration.

## 46.4

## Conclusions

Although designed for application at the global scale, when suitably parameterised, IBIS was able to reproduce the general distribution patterns of vegetation type and forest biomass in a higher resolution study of a region in Canada. Improvement of the simulation of the competition processes driving the vegetation dynamics could lead, however, to a better reproduction of this distribution. The simulation results suggest an important effect of increasing CO<sub>2</sub> on NPP, causing related increases in forest biomass, litter production and soil carbon accumulation. Projected increases in mean temperature have small effects on growth, but increased decomposition of litter and soil carbon affects the C balance, as well as increasing soil nitrogen. Increases in evapotranspiration without a significant increase in precipitation combined to greatly reduce the mean annual water balance. These results should, however, be treated with some caution because ecosystem disturbances, and the effects of nitrogen limitations on plant production, were not considered in this study.

**Acknowledgments.** We acknowledge funding from the ENergy from the FORest (ENFOR) program of the Canadian Federal Panel on Energy Research and Development (PERD). We thank the organizing committee of the scientific meeting "Detection and modelling of recent climate change and its effects in a regional scale" held in Tarragona (29-31 May 2000) who provided financial assistance for the senior author's participation. We are grateful to J. Foley, C. Kucharik, and an anonymous reviewer for their valuable comments on an earlier version of this manuscript.

## References

- Black, T.A., Chen, W.J., Barr, A.G., Arain, M.A., Nesic, Z., Hogg, E.H., Neumann, H.H. and Yang, P.C., 2000: Increased carbon sequestration by a boreal deciduous forest in years with a warm spring. *Geophy. Res. Letters* **27**, 1271-1274.
- Cihlar, J., and Beaubien, J., 1998: *Land Cover of Canada 1995 Version 1.1, Digital data set documentation*. Natural Resources Canada, Ottawa, Ontario, [www.ccrs.nrcan.gc.ca/ccrs/comvnts/rsic/rsicinde.html](http://www.ccrs.nrcan.gc.ca/ccrs/comvnts/rsic/rsicinde.html)
- Collatz, G.J., Ball, J.T., Grivet, C. and Berry J.A., 1991: Physiological and environmental regulation of stomatal conductance, photosynthesis and transpiration: A model that includes a laminar boundary layer. *Agric. For. Meteorol.* **53**, 107-136.
- Collatz, G.J., Ribas-Carbo, M. and Berry, J.A., 1992: Coupled photosynthesis-stomatal conductance model for leaves of C<sub>4</sub> plants. *Aust. J. Plant Physiol.* **19**, 519-538.
- El Maayar, M., Price, D.T., Delire, C., Foley, J.A., Black, T.A. and Bessemoulin, P., 2001: Validation of the Integrated Biosphere Simulator (IBIS) for Canadian deciduous and coniferous boreal forest stands. *J. Geophy. Res.*, Accepted.
- Environment Canada, 1994: *Canadian Monthly Climate Data and 1961-90 Normals on CD-ROM, Version 3.0E*. Canadian Meteorological Centre, Environment Canada, Downsview, Ontario.
- Environment Canada, 1995: *The state of Canada's climate: monitoring variability and change*. State of the Environment (SOE) Report 95-1, Atmospheric Environment Service, Downsview, Ontario.
- Farquhar, G.D., von Caemmerer, S. and Berry, J.A., 1980: A biochemical model of photosynthetic CO<sub>2</sub> assimilation in leaves of C<sub>3</sub> species. *Planta* **149**, 78-90.
- Flato, G.M., Boer, G.J., Lee, W.G., McFarlane, N.A., Ramsden, D., Reader, M.C. and Weaver, A.J., 2000: The Canadian Centre for Climate Modelling and Analysis Global Coupled Model and its Climate. *Clim. Dynamics* **16**, 451-467.
- Foley, J.A., I.C. Prentice, N. Ramankutty, S. Levis, Pollard, D., Sitch, S. and Haxeltine, A., 1996: An integrated biosphere model of land surface processes, terrestrial carbon balance, and vegetation dynamics. *Glob. Biogeochem. Cycles* **10**, 603-623.
- Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A. and Maskell, K., 1996: *Climate Change 1995. The science of climate change*. Contribution of working group I to the second assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 572 pp.
- Hutchinson, M.F., 1999: ANUSPLIN Version 4.0, <http://cres.anu.edu.au/software/anusplin.html>
- Jarvis, P. and Linder, S., 2000: Constraints to growth of boreal forest. *Nature* **405**, 904-905.
- Kucharik, C.J., Foley, J.A., Delire, C., Fisher, V.A., Coe, M.T., Lenters, J., Young-Molling, C., Ramankutty N., Norman, J.M. and Gower, S.T., 2000: Testing the performance of a dynamic global ecosystem model: Water balance, carbon balance and vegetation structure. *Glob. Biogeochem. Cycles* **14**, 795-825.
- Kurz, W.A. and Apps, M.J., 1999: A 70-year retrospective analysis of carbon fluxes in the Canadian forest sector. *Ecol. Applications* **9**, 526-547.
- Levis, S., J.A. Foley, and D. Pollard, 1999: Potential high-latitude vegetation feedbacks on CO<sub>2</sub>-induced climate change. *Geophy. Res. Letters* **26**, 747-750.
- Mackey, B.G., McKenney, D.W., Yang, Y.Q., McMahon, J.P. and Hutchinson, M.F., 1996: Site regions revisited: a climatic analysis of Hill's site regions for the province of Ontario using a parametric method. *Can. J. For. Res.* **26**, 333-354.
- Melillo, J.M., A.D. McGuire, D.W. Kicklighter, Moore, B., Vorosmarty, C.J. and Schloss, A.L., 1993: Global climate change and net terrestrial production. *Nature* **363**, 234-240.
- Mendelsohn, R., and Neumann, J., 1998: *The Market Impact of Climate Change on the U.S. Economy*. Cambridge University Press, Cambridge.
- Nalder, I.A. and Wein, R.W., 1998: Spatial interpolation of climatic Normals: test of a new method in the Canadian boreal forest. *Agric. For. Meteorol.* **9**, 211-225.
- Parton, W.J., Scurlock, J.M.O., Ojima, C.V., Schimel, D.S., Hall, D.O. and SCOPEGRAM Group Members, 1995: Impact of climate change on grassland production and soil carbon worldwide. *Glob. Ch. Biology* **1**, 13-22.
- Penner, M., Power, K., Muhairwe, C., Tellier, R. and Wang, Y., 1997. *Canada's forest biomass resources: deriving estimates from Canada's forest inventory*. Information Report BC-X-370, PFC, Victoria, 33pp.

- Pollard, D. and Thompson, S.L., 1995: Use of a land-surface-transfer scheme (LSX) in a global climate model: the response to doubling stomatal resistance. *Glob. Planetary Change* **10**, 129-161.
- Prentice, I.C., W. Cramer, S.P. Harrison, R. Leemans, R.A. Monserud, and A.M. Solomon, 1992. A global biome model based on plant physiology and dominance, soil properties and climate. *J. Biogeography* **19**, 117-134.
- Prentice, I. C., M. T. Sykes, and W. Cramer, 1993: A simulation model for the transient effects of climate change on forest landscapes. *Ecol. Modelling* **65**, 51-70.
- Price, D.T., D.H. Halliwell, M.J. Apps, and C.H. Peng, 1999a. Adapting a patch model to simulate the sensitivity of Central-Canadian boreal ecosystems to climate variability. *J. Biogeography* **26**, 1101-1113.
- Price, D.T., McKenney, D.W., Nalder, I.A., Hutchinson, M.F. and Kesteven, J.L., 2000: A comparison of two statistical methods for spatial interpolation of Canadian monthly mean climate data. *Agric. For. Meteorol.* **101**, 81-94.
- Price, D.T., Peng, C.H., Apps, M.J. and Halliwell, D.H., 1999b: Simulating effects of climate change on boreal ecosystem carbon pools in central Canada. *J. Biogeography* **26**, 1237-1248.
- Schimel, D.S., VEMAP participants and Braswell, B.H., 1997: Continental scale variability in ecosystem processes: Models, data and the role of disturbance. *Ecol. Monograph* **67**, 251-271.
- Snyder, J.P., 1987: Map Projections—A Working Manual. U.S. Geological Survey Professional Paper 1395. Washington DC: U.S. Gov. Print. Off., 383 pp+poster.
- White, A., Cannell, M.G.R. and Friend, A.D., 1999: Climate change impacts on ecosystems and the terrestrial carbon sink: a new assessment. *Global Env. Change* **9**, S21-S30.
- Xiao, X., Melillo, J.M., Kicklighter, D.W., McGuire, A.D., Prinn, R.G., Wang, C., Stone, P.H., and Sokolov, A., 1997: Transient climate change and net ecosystem production of the terrestrial biosphere. *Glo. Biogeochem. Cycles* **12**, 345-360.

Manola Brunet India • Diego López Bonillo  
(Eds.)

# Detecting and Modelling Regional Climate Change

With 257 Figures

Springer

Berlin  
Heidelberg  
New York  
Barcelona  
Hong Kong  
London  
Milan  
Paris  
Tokyo



Springer

## EDITORS:

Dr. Manola Brunet India  
Dr. Diego López Bonillo  
University Rovira i Virgili  
Department of History & Geography  
Climate Change Research Group  
Physical Geography  
Pza. Tarraco, n 1  
43071 Tarragona  
Spain

ISBN 3-540-42239-0 Springer-Verlag Berlin Heidelberg New York

Library of Congress Cataloging-in-Publication Data  
Detecting and modelling regional climate change / M. Brunet and D. López, eds.  
p. cm. Includes bibliographical references and index.

ISBN 3540422390  
1. Climatic changes--Mathematical models. I. Brunet, M. (Manola), 1955- II. López, D. (Diego), 1936-  
QC981.8.C5 D45 2001 551.6'01'5118--dc21 2001042061

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitations, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

Springer-Verlag Berlin Heidelberg New York  
a member of BertelsmannSpringer Science+Business Media GmbH  
<http://www.springer.de>  
© Springer-Verlag Berlin Heidelberg 2001  
Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free general use.

Cover Design: Erich Kirchner, Heidelberg  
Typesetting: Camera-ready by the editors

SPIN: 10789876 30/3130xz - 5 4 3 2 1 0 - Printed on acid free paper

## Preface

Over the last 20 years great effort has been devoted to the understanding of the function and changes in the climate system, and the effects that an anthropogenically forced shift in the earth's climate could induce on the dynamics of environmental and socio-economic systems. Although climate change is global in nature, greater knowledge is required on smaller scales to identify its spatial structure and impacts. This book brings together, for the first time, the most prototypical and up-to-date analyses from the broad field of detection and modelling of regional climate change and the assessment of its associated natural and economic effects.

This volume is composed of a selection of papers from those presented to the International Scientific Meeting on the "Detection and Modelling of recent Climate Change and its Effects on a Regional Scale", which was held at Tarragona in May 2000. The meeting was co-organised by the Climate Change Research Group (Geography Unit) of the Rovira i Virgili University and the Catalan Meteorological Service (Servei de Meteorologia de Catalunya, SMC) of the Environment Department of the Autonomous Government of Catalonia (Spain).

The papers selected emphasise key advances in the fields of reconstruction, detection and modelling of regional climate variability and change and the current and potential impacts on environmental and socio-economic systems for a wide range of world regions.

To present, and provide and understanding of, the key issues in these fields, which requires the use of an integrated approach, the book has been structured into four sequentially related parts. The first part deals with the topic of quality control procedures and homogenisation of climate time-series. It is comprised of five chapters that provide a methodological approach to the assessment of the quality and homogeneity of climate data, and furnishes guidelines for achieving improved results. This part starts with the invited contribution of H. Alexandersson, which assesses past requirements of climate data homogeneity. The science of climate change requires, without doubt, reliable, quality controlled and homogenised datasets, with which to identify temporal and spatial climate variations and their patterns. Such data is also required to validate the numerical simulations provided by AOGCMs and for the different downscaling techniques.

The second part focuses on identifying observed regional climate variability and change, together with the most useful and oft discussed climate reconstruction techniques. There are eighteen contributions to this part, starting with the P. D. Jones paper. This puts into context the last 150 years of instrumentally measured temperature changes with reference to the multi-proxy reconstruction of the last

9 North Atlantic Oscillation Projection on Romanian Climate Fluctuations in the Cold Season <i>I. Bojariu and D. M. Paliu</i> . . . . .	345
10 Spatial Winter Precipitation Distribution over the Iberian Peninsula and Greece and its Relation to the Large Scale 500 hPa Circulation <i>J. Gómez, J. Luterbacher, J. Martín-Vide, E. Xoplaki, M. J. Alcoforado, and H. Wanner</i> . . . . .	357
11 Wintertime Iberian Peninsula Precipitation Variability and its Relation to North Atlantic Atmospheric Circulation <i>M. Y. Luna, M. L. Martín, F. Valero and F. González-Rouco</i> . . . . .	369
12 Relationships between Iberian Rainfall Variability and the North Atlantic Oscillation <i>P. Tildes</i> . . . . .	377
13 Time-Frequency Variability of Spring Precipitation Associated with Teleconnection Indices over the Iberian Peninsula <i>M. D. Frias and C. Rodríguez-Puebla</i> . . . . .	389
14 Relationships between Dry and Wet Periods in Spring Precipitation over the Iberian Peninsula and Atmospheric Circulation <i>C. Rodríguez-Puebla, M. D. Frías and A. H. Encinas</i> . . . . .	397
15 Baroclinic Activity and Interannual Variability of Winter Precipitation in the Northern Iberian Peninsula <i>J. Sáenz, J. Zubillaga and C. Rodríguez-Puebla</i> . . . . .	405
16 First Order Markov Chain Model and Rainfall Sequences in several Stations of Spain <i>S. Conejo, A. Morata and F. Valero</i> . . . . .	417
17 Spatial and Temporal Variability of the Surface Air Temperature over the Duero Basin (Iberian Peninsula) <i>M. D. Manso and L. Caramelo</i> . . . . .	429
<b>Part IV: Modelling and Assessing Regional Climate Change and Associated Impacts</b> . . . . .	439
18 Uncertainties in Assessing the Impacts of Regional Climate Change <i>T. R. Carter</i> . . . . .	441

39 Local Climate Scenarios for Norway Based on MPI's ECHAM/OPYC3, a New DNMI Data Analysis, and the Common EOF Method <i>R. Benestad and E. J. Førland</i> . . . . .	471
40 Evaluation and Analysis of the ECHAM4/OPYC3 GSDIO-Integration Temperature- and SLP-Fields over Norway and Svalbard <i>I. Hansen-Bauer and E. J. Førland</i> . . . . .	483
41 Downscaling of the Global climate Change Projections: Some Approaches <i>R. Corobov</i> . . . . .	491
42 Modelling Climate Changes for Croatia <i>L. Srnec</i> . . . . .	501
43 Assessment of a Regional Climate for South America: A Dynamical Downscaling Approach <i>C. G. Menéndez, A. C. Saulo, S. A. Solman and M. N. Nuñez</i> . . . . .	515
44 Assessment of a Regional Climate Change Scenario for Central Argentina: A Statistical Downscaling Approach <i>S. A. Solman, M. N. Nuñez and C. G. Menéndez</i> . . . . .	525
45 Climate Change Effect on the Reforestation Potential of Russia <i>A. P. Kirilenko</i> . . . . .	537
46 Simulating Forest Responses to Transient Changes in Climate and Atmospheric CO <sub>2</sub> : A Case Study for Saskatchewan, Central Canada <i>M. El Maayar, D. T. Price and R. M. Siltanen</i> . . . . .	545
47 Climate Change and Fire Weather Risk <i>A. C. Carvalho, A. Carvalho, A. I. Miranda, C. Borrego and A. Rocha</i> . . . . .	555
48 Modelling Climate Change Impacts on Water Resources in the Swedish Regional Climate Modelling Programme <i>L. Ph. Graham, M. Rummukainen, M. Gardelin and S. Bergström</i> . . . . .	567
49 Irrigation Scenario vs Climate Change Scenario <i>J. Jorge and E. Ferreres</i> . . . . .	581
50 The Impact of Climate Change on Transport Conditions in Finland <i>H. Tuomenvirta, A. Venäläinen and J. Haapala</i> . . . . .	593