BOREAL ENVIRONMENT RESEARCH 7: 203–210 ISSN 1239-6095
Helsinki 2 October 2002

A numerical study using the Canadian Regional Climate Model for the PIDCAP period

Virginie Lorant[1)], Norm McFarlane[1)] and René Laprise[2)]

[1)] *3964 Gordon Head Road, Victoria, B.C., V8N3X3, Canada*
[2)] *UQAM B.P. 8888, Succ. Centre-ville, Montréal, Q.C., H3C 3P8, Canada*

Lorant, V., McFarlane, N. & Laprise, R. 2002: A numerical study using the Canadian Regional Climate Model for the PIDCAP period. — *Boreal Env. Res.* 7: 203–210. ISSN 1239-6095

Simulations of summertime conditions over the BALTEX region using the Canadian Regional Climate Model (CRCM) are compared with observations for the PIDCAP period. A systematic cold bias of the surface temperature was found in a reference simulation made with a version of the CRCM which uses the physical processes package of the third generation global climate model of the Canadian Centre for Climate Modeling and Analysis. This cold bias is found to be due to excessive cloud near the surface. Revision of the cloud scheme, which was originally designed for use in conjunction with relatively coarse resolution of the AGCM, results in a reduction of the cloud cover, improved net radiative flux at the surface and substantial reduction of the cold bias. An associated result is that the lower atmosphere becomes more conditionally unstable which increases the number of convective events. Nevertheless the incidence of convective precipitation events remains unrealistically low.

Introduction

A major goal of climate studies using high resolution, limited area models to study regional climates is to reproduce small scale features associated with localized forcing effects such as may be associated with complex terrain. If limited area models can achieve this task it is reasonable to expect that they may be used as a tool for downscaling climate simulations made with global climate models. The present study aims to evaluate the Canadian regional climate model (CRCM) skill with respect to this task. This evaluation is motivated by the fact that the new version of the CRCM has been used in very few studies to date. A further concern is that the physical processes package of the CRCM, which was originally developed for an atmospheric general circulation model (AGCM), may not be entirely adequate for regional climate modeling.

The general lack of high resolution observation puts a serious limitation on RCM evaluation except under circumstance of the availability of intensive observing programs. As part of the Baltic Sea Experiment (BALTEX), a high resolution database was assembled during the Pilot Study for Intensive Data Collection and Analysis of Precipitation (PIDCAP) carried out

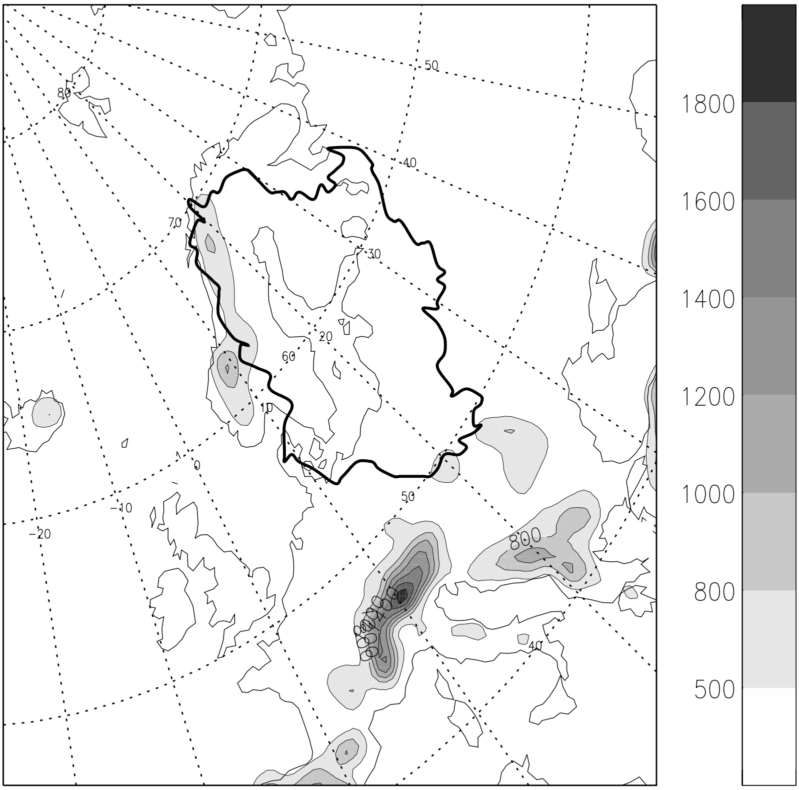

Fig. 1. CRCM domain. The thick line marks the BACAR domain. Contours depict the relief in meters.

over the Baltic Sea catchment area (depicted by the thick black line on Fig. 1) from August to October 1995. Advantage is taken of these data to evaluate the CRCM skill in reproducing realistic regional scale features. Thus special attention is given to the surface hydrological and energy budgets.

Because regional model simulations may be adversely affected by deficiencies encountered in the lateral forcing data, National Centers for Environmental Prediction reanalyses (NCEP_REA) rather than GCM simulations are used to provide lateral forcing.

Canadian Regional Climate Model (CRCM)

The CRCM is a non hydrostatic, limited-area, nested atmospheric model developed at l'Universitée du Québec à Montréal (UQAM). Its earlier version, described by Laprise *et al.* (1998) includes a physical processes package that is based on the second generation AGCM of the Canadian Centre for Climate Modeling and Analysis (CCCma), AGCM2 (McFarlane *et al.* 1992). However the new version of the CRCM used in the present study uses the physics package developed for the third generation CCCma AGCM (AGCM3). The main differences between this package and the previous one are that it includes the more sophisticated and complete Canadian Land Surface Scheme (CLASS, Verseghy *et al.* 2000), the penetrative convection scheme described in Zhang and McFarlane (1995), and a more up to date version of the radiation scheme which includes additional solar and terrestrial bands and a revised treatment of the water vapor continuum. Representation of surface fluxes follows the formulation of Abdella and McFarlane (1995). The subgrid scale vertical mixing of momentum, heat and moisture is, as in the AGCM2, modeled using eddy diffusivities that are based on shear and stability through the local gradient Richardson number. An additional non-local vertical mixing

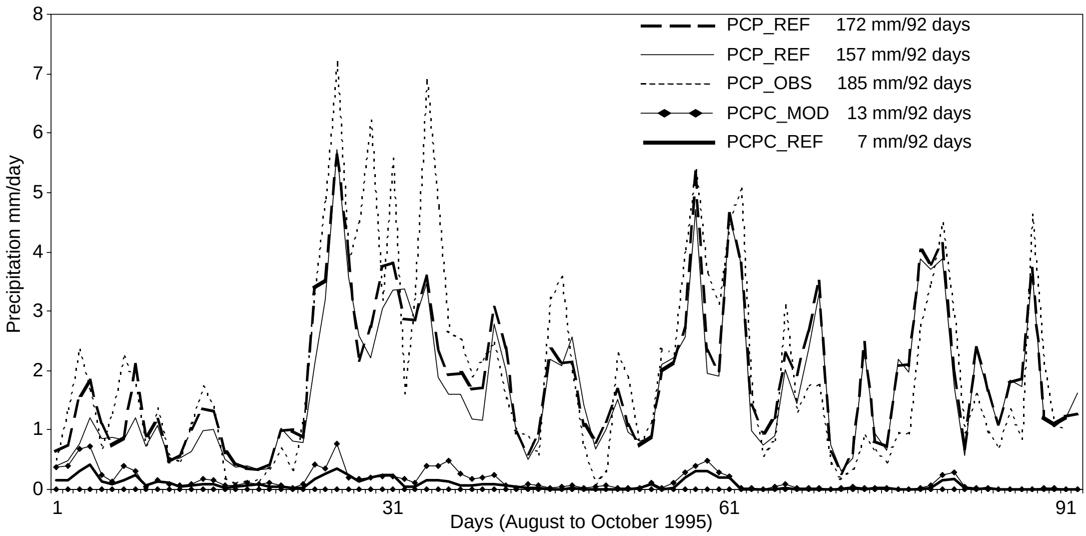

Fig. 2. Daily timeseries of total and convective precipitation from August to October 1995 averaged over BACAR_L for model results and observation analyses. Values shown on the upper left corner are the pcp. accumulated over the period.

of heat and moisture is performed within the boundary layer when it is convectively active so as to prevent the occurrence of statically unstable vertical profiles in response to surface heating. The treatment of clouds in AGCM3 is qualitatively similar to that of AGCM2 but differs in details.

A two-year simulation, starting 1 January 1994 was conducted over a 101 × 101 grid points computational domain centered over the Baltic Sea (Fig. 1). The horizontal grid spacing is fixed at 45 km on a polar-stereographic projection. The vertical resolution comprises 29 layers in the terrain following Gal-Chen coordinate system. Lateral boundary conditions were extracted from the NCEP_REA as projected to a 145 WE × 73 NS, global grid. The AMIP2 sea surface temperature fields are used to prescribe the temperature at the surface over oceans. Initialization data for soil variables are extracted from a 17-year AMIP2 simulation that was made with AGCM3. An extended four-year simulation indicates that the 19-month period before the PIDCAP period is a reasonable spin-up period to remove obvious trends in soil variables.

Since SST are specified, this study focuses on results over land where surface and atmospheric processes are free to interact.

CRCM simulation in the PIDCAP period over the BALTEX region.

An analysis of CRCM simulation carried out during the PIDCAP period shows that in general the nested model reproduces the observed spatial distribution of atmospheric variables near the surface and lower troposphere in response to the more highly resolved representation of the surface forcing. However, the tendency for underestimation of the precipitation is evident over most of the land part in the domain. Figure 2 illustrates this bias over the land surface grid point of the Baltic Sea Catchment Area (BACAR_L) over which total simulated precipitation is averaged and compared to analyses of daily rain gauge data localized in this sub area (Rubel and Hantel 1999). Marked on the upper right corner of the figure is the total precipitation accumulated over the PIDCAP period for the model reference simulation (thin solid line) and the observations analyses (thin dotted line). The CRCM shows some good skill in reproducing the temporal variability of regional precipitation. However it underestimates the amplitude of most of these events resulting in a general underestimation of precipitation over this region. Lower than observed values of precipitation diagnosed

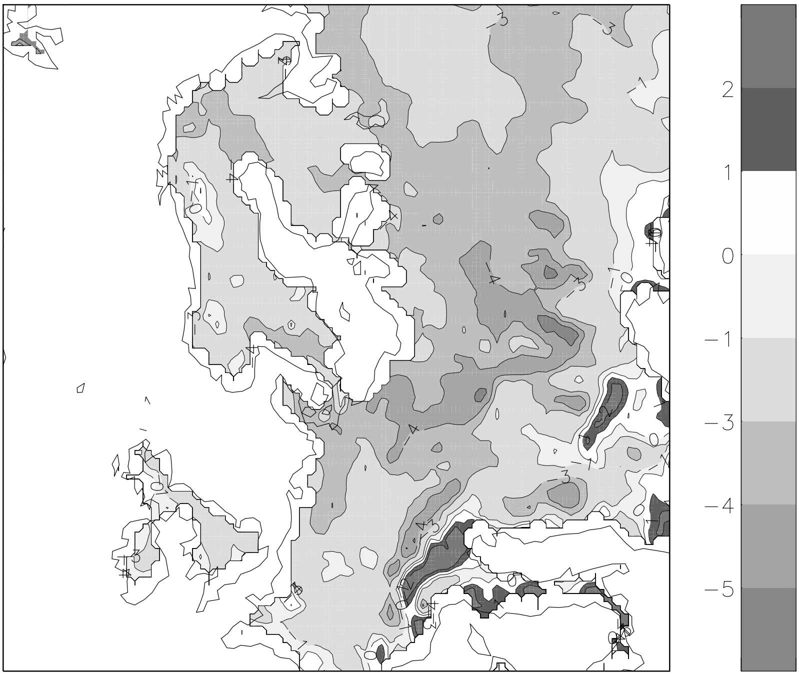

Fig. 3. Screen temperature difference between reference model experiment and CRU_ST analyses for August 1995 in °C.

from the NCEP_REA during this period suggests that part of this underestimate may be associated with the lateral boundary conditions used for the simulation.

During summer a substantial fraction of the observed precipitation is believed to be convective in nature. However, only six percent of the simulated precipitation during this period is convective (Fig. 2, thick solid line). The convective precipitation occurs whenever the atmosphere has a positive amount of convective available potential energy (CAPE) as defined for the reversible moist adiabatic ascent from the boundary layer. Thus a cooler than observed land surface temperature estimated by the CRCM would reduce the CAPE and inhibit the onset of moist convection.

Table 1. Components of the energy and hydric balance averaged over BACAR_L for CRCM simulations, observation analyses and Earth Radiation Budget Experiment (ERBE) climatology. The cloud cover is in % times the mapping scale factor, the energy fluxes in W m^{-2}, the hydric fluxes in mm day^{-1}. The TOA represent the top of the atmosphere fluxes. The surface energy balance is given by the difference between the surface radiative balance and turbulent flux.

	Ref	Mod	Clim&Ana
Cld cov. 12UTC	95	61	63 ERBE
OLR	221	242	231 ERBE
Pl. albedo	0.45	0.38	0.40 ERBE
TOA rad. bal.	–21.43	–14.00	
Surf. rad. bal.	65.80	86.56	
Surf.energy bal.	5.38	7.05	
Pcp	1.3	1.6	1.9 CRU
Screen temp.	12.5	14.0	14.5 CRU

Figure 3, which shows the difference between the CRCM simulated screen temperature (ST) and the Climate Research Unit (CRU) observations analyses for August 1995, illustrates that such a cold bias exists in the CRCM simulation. Analyses of the two years simulation used for the present study shows that this bias, also evident for the ground and the lowest level of the model, is a persistent characteristic of the CRCM.

The surface radiation balance simulated by the CRCM is not in accord with observations (Table 1). This is associated with an apparently excessive cloud cover estimate. The mean analyses total cloud cover shown in this table is an average over BACAR_L of the 12 UTC cloud analyses used in D. Jacob *et al.* (2001) which is based on satellite imagery, radiosonde and sur-

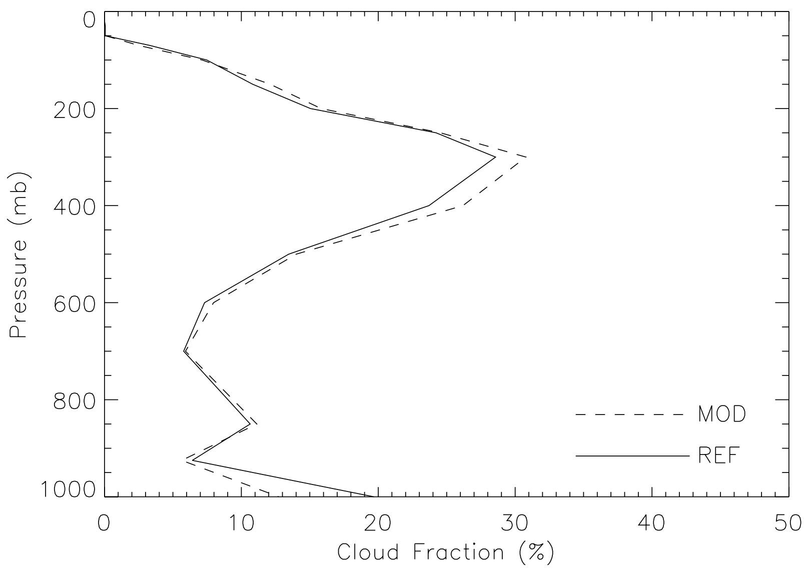

Fig. 4. Vertical profile of cloud fraction averaged over BACAR for August 1995 for the reference (dotted line) and modified (solid line) simulations.

face synoptic network observations. The simulated 12 UTC total cloud cover used here for comparison is that which is vertically accumulated from the values of fractional cloud cover for each of the model layers using the overlapping assumptions employed in the radiation code for the model (total overlap for adjacent cloud layers, random for separated layers). The vertical distribution of the simulated cloud cover for August 1995 over BACAR_L, as obtained from the six-hourly sampled model output shows (Fig. 4, solid line) that there are typically three maxima in the simulated could cover, the largest one being in the upper troposphere, centered near the 400 mb level with a typical magnitude of 25%–30%.

The uncertainties in comparing modeled cloud cover with estimates obtained from ground based and satellite observations are discussed by van Meijgaard *et al.* (2001). These authors have examined results from several regional models, for simulations over the Netherlands for a period in late summer. These models tended to produce excessive cloud cover in the lower troposphere and to develop an upper tropospheric maximum that was not clearly supported by observations. The upper tropospheric maximum and that near the 850 mb level in the lower troposphere shown in Fig. 4 are similar to their results. Yet the CRCM reference simulation develops an additional maximum in cloud cover near the surface that results in nearly 100% cloud cover over the BACAR_L with very little temporal variability (Fig. 5, solid line). This excessive total cloud cover occurs over most of the model domain and is qualitatively similar to the behavior found for the earlier version of the CRCM (Laprise *et al.* 1998). More recently, using the present version, a similar tendency has been found in simulations carried out over the Mackenzie Basin within the GEWEX-MAGS region (M.D. McKay, pers. comm.). Thus it is concluded that, as for the previous version, revisions to the AGCM cloudiness scheme are needed for CRCM applications, as described below.

Modified cloud scheme

Within the AGCM3, cloud cover is determined as a function of the local (layer-mean) relative humidity and the static stability (relative to that on a moist adiabat passing through the layer mean temperature and pressure). Cloudiness is assumed to occur at a threshold relative humidity, which differs for ice (75%) and water (95%) clouds. The dependence on relative humidity once the threshold is exceeded is assumed to vary with the local static stability. An additional important parameter is the relative humidity threshold for the onset of precipitation and latent heat release, fixed at 95% for the AGCM.

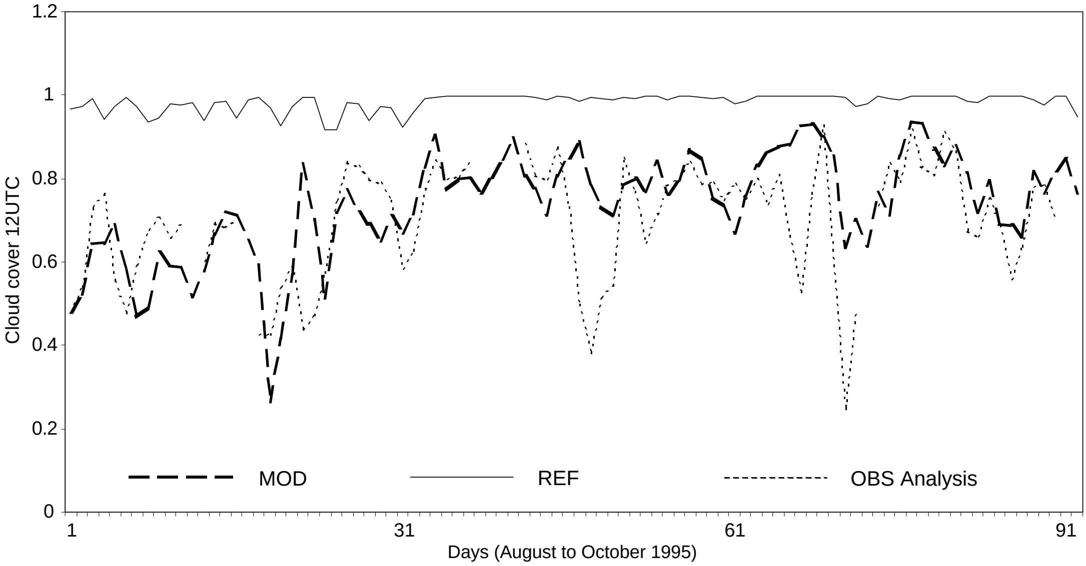

Fig. 5. Timeseries of cloud cover at 12 UTC during PIDCAP. Observations analyses (dotted line), reference (solid line) and modified CRCM (dashed line) simulation are averaged over BACAR.

Cloud water content and optical properties are specified as functions of local temperature and static stability, similar to AGCM2 but differing in details.

In the modified cloudiness scheme we have retained many of the basic features but simplified the dependence on relative humidity. The threshold humidity, H_0, is fixed at 95%, making the onset of cloudiness and large-scale condensation coincident. The dependence of the (layer mean) cloud cover on the local relative humidity is:

$$C^* = \frac{\eta^2 + \eta F^2}{1 + F^2}$$

with

$$\eta = \mathrm{Max}\left(\frac{H - H_0}{1 - H_0}, 0\right)$$

and

$$F = \mathrm{Max}\left(\frac{\Gamma - \Gamma_s}{\Gamma_s}, 0\right)$$

where Γ is the vertical gradient of potential temperature and Γ_s is the value on a moist adiabat. The specification of cloud water and effective depth is retained in the same form as is used in the AGCM3.

Sensitivity of the CRCM surface energy balance to the cloud scheme

A new experiment (referred to hereinafter as MOD), conducted with the aforementioned modified cloud scheme, shows a substantial reduction in cloud cover and an increased temporal variability as illustrated over BACAR_L in Fig. 5 (dashed line).

The reduction in total cloud cover is mainly associated with a substantial reduction near the surface (Fig. 4, dashed line). The associated increase solar radiation reaching surface leads to a net increase in the net downward radiative flux by about 20 W m^{-2} (Table 1), partly offset by higher values of the upward sensible and latent heat flux, resulting in an increased net downward flux of 1–2 W m^{-2} at the surface. The associated ST increase corresponds to a reduced cold bias over the entire CRCM domain (Fig. 6).

Increased CAPE induced by the warmer ST and moisture boundary layer and associated increased moist static energy provided an environment more favorable for convection. The two curves plotted in the bottom part of Fig. 2 compare the convective precipitation simulated by both the reference and modified experiments

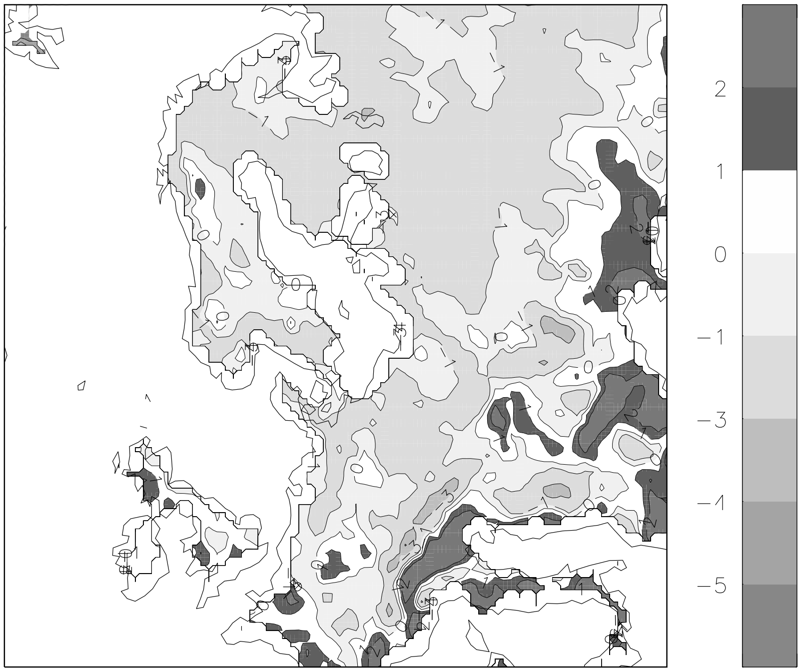

Fig. 6. Same as Fig. 3, but for the modified model experiment.

over BACAR_L during the PIDCAP period. Over the three months of the period convective precipitation amount is effectively increased 2-fold over this area. However this additional convective precipitation is insufficient to substantially increase the overall precipitation.

Conclusion

The goal of the investigation discussed in the present paper was to evaluate the ability of the Canadian regional climate model (CRCM) to downscale the large-scale information provided at its lateral boundary by the NCEP_REA within a domain centered over the Baltic Sea Catchment area. Results obtained from simulations carried out during the PIDCAP period show a cold bias in simulated screen temperature. Analysis of the surface energy budget reveals that this is largely due to the excessive low cloud cover. Adjustment of the cloud scheme parameterization results in much more realistic cloud cover, correcting the radiative forcing and removing the cold bias simulated in summer. As a consequence the vertical profile of moist static energy is generally more conditionally unstable. However, though increased, total convective precipitation remains underestimated in summer. Further investigations of the effect of alternative closure conditions for the convective scheme are being carried out to clarify why convective precipitation is generally underestimated in summer.

Acknowledgements: The authors thank D. Jacob, F. Rubel and B. van den Hurk as well as the Climate Research Unit for providing precipitation and cloudiness analyses. Constructive comments and suggestions from two anonymous reviewers are acknowledged.

References

Jacob D. & co-authors 2001. A comprehensive model intercomparison study investigating the water budget during the BALTEX-PIDCAP period. *Meteo. Atm. Physics* 77: 19–43.

Laprise R., Caya D., Guigere M., Bergeron G., Cote H., Blanchet J.-P., Boer G.J. & McFarlane N. 1998. Climate and climate change in Western Canada as simulated by the canadian regional climate model. *Atmosphere–Ocean* 36(2): 119–167.

McFarlane N.A., Boer G.J., Blanchet J.-P. & Lazare M. 1992. The canadian climate centre second generation general circulation model and its equilibrium climate. *J. Clim.* 5: 1013–1044.

Rubel F. & Hantel M. 1999. Correction of daily rain gauge measurements in the Baltic Sea drainage basin. *Nord.*

Hydrol. 30: 191–208.

van Meijgaard E., Andrea U. & Rockel, B. 2001. Comparison of model predicted cloud parameters and surface radiative fluxes with observation on the 100 km scale. *Meteo. Atm. Physics* 77: 109–130.

Verseghy D.L. 2000. The canadian land surface scheme (CLASS): its history and future. *Atmosphere–Ocean* 38: 407–446.

Zhang G.J. & McFarlane N. 1995. Sensitivity of climate simulations to the parameterization of cumulus convection in the canadian climate centre general circulation model. *Atmosphere–Ocean* 33: 407–446.

Received 23 January 2002, accepted 26 June 2002