Simulation of Regional Climate over East Asia using Dynamical Downscaling Method

Jai-Ho Oh
Prof., Dept. of Env. & Atmos. Sci., Pukyong National University, Busan, Korea

Tae-Kook Kim
Graduated Student, Dept. of Env.& Atmos. Sci., Pukyong National University, Busan, Korea

Young-Mi Min
Graduated Student, Dept. of Env.& Atmos. Sci., Pukyong National University, Busan, Korea

ABSTRACT

In this study, we have simulated regional climate over East Asia using dynamical downscaling method. For dynamic downscaling experiments for regional climate simulation, MM5 with 27 km horizontal resolution and 18 layers of sigma-coordinate in vertical is nested within global-scale NCEP reanalysis data with $2.5^{o}x2.5^{o}$ resolution in longitude and latitude. In regional simulation, January and July, 1979 monthly mean features have been obtained by both continuous integration and daily restart integration driven by updating the lateral boundary forcing at 6-hr intervals from the NCEP reanalysis data using a nudging scheme with the updating design of initial and boundary conditions in both continuous and restart integrations.

In result, we may successfully generated regional detail features which might be forced by topography, lake, coastlines and land use distribution from a regional climate. There is no significant difference in monthly mean features either integrate continuously or integrate with daily restart. For climatologically long integration, the initial condition may not be significantly important. Accordingly, MM5 can be integrated for a long period without restart frequently, if a proper lateral boundary forcing is given.

1 INTRODUCTION

Although the resolution of Atmosphere-Ocean General Circulation Models (AOGCMs) is still coarse, simulations of present day climate with the AOGCMs become quite comparable to the observed atmospheric general circulation features in general since the IPCC WGI Second Assessment Report (IPCC, 1996) (hereafter SAR). Meanwhile, the development of high resolution Atmospheric General Circulation Models (AGCMs) shows that the models' dynamics and large-scale flow improve as resolution increases, though this is not uniformly so geographically or across models (e.g., Stratton, 1999; Cubasch et al., 1995; Deque and Piedelievre, 1995). In some cases, however, systematic errors are worsened compared with coarser resolution models although only very few results have been documented. The direct use of high-resolution versions of current AGCMs, without some allowance of the dependence of models physical parameterizations on resolution, leads to some deterioration in the performance of the models. At the regional scale, in particular, the models display area-average biases that are highly variable from region-to-region and among models, with sub-continental area-averaged seasonal temperature biases typically within 4 ℃ and precipitation biases mostly between -40 and +80% of observations (IPCC, 2001).

Regional Climate Models (RC5Ms) based on the concept of "downscaling" implying that the regional climate is conditioned but not completely determined by the larger scale state consistently improve the spatial detail of simulated climate compared to General Circulation Models (GCMs) since SAR. The conclusions reported in SAR were that (a) both RCMs and downscaling techniques showed a promising performance in reproducing the regional detail in surface climate characteristics as forced by topography, lake, coastlines and land use distribution; and (b) high resolution surface forcing can modify the surface climate change signal at the sub-AOGCM grid scale. RCMs driven by observed boundary conditions show area-averaged temperature biases (regional scales of 10^5 to 10^6 km^2) generally within 2 ℃ and precipitation biases within 50% of observations (IPCC, 2001).

2 REGIONAL CLIMATE MODELS (RCMs)

In general, AGCMs will evolve their own planetary scale climatology with the impact on the atmosphere of the sea surface and radiative forcings compared to that given by the driving AOGCM. This may lead to inconsistency with the AOGCM-derived forcing. It would be of less concern if a model simulation of the resolved planetary scale variables were asymptotic to a solution as resolution increased. A current weakness of high resolution AOGCMs is that they generally use the same formulations as at the coarse resolution for which these have been optimized to reproduce current climate. Some processes may be represented less accurately when finer scales are resolved and so the model formulations would need to be optimized for use at higher resolution. Another issue to be mentioned is that the use of high resolution and variable resolution global models is computationally very demanding, which poses limits to the increase in resolution obtainable with this method.

The nested regional climate modelling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution RCMs. To date, this technique has been used only in one-way mode, i.e., with no feedback from the RCM simulation to the driving GCM. The basic strategy is, thus, to use the global model to simulate the response of the global circulation to large-scale forcings and the RCM to (a) account for sub-GCM grid scale forcings (e.g., complex topographical features and land cover heterogeneity) in a physically-based way; and (b) enhance the simulation of atmospheric circulations and climatic variables at fine spatial scales.

The nested regional modelling technique essentially originated from numerical weather prediction, and the use of RCMs for climate application was pioneered by Dickinson et al. (1989) and Giorgi (1990). RCMs are now used in a wide range of climate applications, from paleoclimate to anthropogenic climate change studies. They can provide high resolution (up to 10 to 20 km or less) and multi-decadal simulations and are capable of describing climate feedback mechanisms acting at the regional scale. A number of widely used limited area modelling systems have been adapted to, or developed for, climate application. More recently, RCMs have begun to couple atmospheric models with other climate process models, such as hydrology, ocean, sea-ice, chemistry/aerosol and land-biosphere models.

3 CONSIDERATIONS IN THE REGIONAL CLIAMTE MODELLING

There is strong evidence that RCMs consistently improve the spatial detail of simulated climate compared to GCMs because of their better representation of sub-GCM grid scale forcings, especially in regard to the surface hydrologic budget. The regionally averaged biases in the nested RCMs are not necessarily smaller than those in the driving GCMs. However, Leung et al. (1999a, b), Laprise et al. (1998), Christensen et al. (1998) and Machenhauer et al. (1998) clearly show that the spatial patterns produced by the nested RCMs are in better agreement with observations because of the better representation of high-resolution topographical forcings and improved land/sea contrasts. For example, in simulations over Europe and central USA, Giorgi and Marinucci (1996) and Giorgi et al. (1998) find correlation coefficients between simulated and observed seasonally averaged precipitation in the range of +0.53 to +0.87 in a nested RCM and -0.69 to +0.85 in the corresponding driving GCM.

IPCC(2001) has reported that the uncertainty in regional climate information are coming from following reasons:

intrinsic factors

1) imperfect knowledge and/or representation of physical processes,
2) limitations due to the numerical approximation of the model's equations,
3) simplifications and assumptions in the models and/or approaches,
4) internal model variability,

5) inter-model or inter-method differences in the simulation of climate response to given forcings.

theoretical factors

1) effects of systematic errors in the driving fields provided by global models,
2) lack of two-way interactions between regional and global climate.

Here, it is also important to recognize that the observed regional climate is sometimes characterized by a high level of uncertainty due to measurement errors and sparseness of stations, especially in remote regions and in regions of complex topography. Multi-year to multi-decadal simulations must be used for climate change studies to provide meaningful climate statistics, to identify significant systematic model errors and climate changes relative to internal model and observed climate variability, and to allow the atmospheric model to equilibrate with the land surface conditions (e.g., Jones et al., 1997; Machenhauer et al., 1998; Christensen 1999). For a practical application, consideration needs to be given to the choice of physics parameterization, model domain size and resolution, technique for assimilation of large-scale meteorological conditions, and internal variability due to non-linear dynamics not associated with the boundary forcing (e.g., Giorgi and Mearns, 1999; Ji and Vernekar 1997), and initialization of surface variables.

The choice of appropriate domain is not trivial. Depending on the domain size and resolution, RCM simulations can be computationally demanding, which has limited the length of many experiments to date. The influence of the boundary forcing can reduce as region size increases (Jones et al., 1995) and may be dominated by the internal model physics for certain variables and seasons (Noguer et al., 1998). This can lead to the RCM solution significantly departing from the driving data, which can make the interpretation of down-scaled regional climate changes more difficult (Jones et al., 1997). The domain size has to be large enough so that relevant local forcings and effects of enhanced resolution are not damped or contaminated by the application of the boundary conditions. The location of boundaries over areas with significant topography may lead to inconsistencies and noise generation (e.g., Hong and Juang, 1998).

The choice of RCM resolution can modulate the effects of physical forcings and parameterizations (Giorgi and Marinucci, 1996; Laprise et al., 1998). Analysis of some RCM experiments indicates that this is in the direction of increased agreement with observations. The description of the hydrologic cycle generally improves with increasing resolution due to the better topographical representation (Christensen et al., 1998; Leung and Ghan, 1998). The increased resolution of RCMs also allows the simulation of a broader spectrum of weather events, in particular concerning higher order climate statistics such as daily precipitation intensity distributions. Resolving more of the spectrum of atmospheric motions at high resolution improves the representation of cyclonic systems and vertical velocities, but can sometimes worsen aspects of the model climatology (Machenhauer et al., 1998; Kato et al., 1999).

Surface forcing due to land, ocean and sea ice greatly affects regional climate simulation (e.g., Giorgi et al., 1996; Christensen, 1999; Pan et al., 1999; Pielke et al., Rinke and Dethloff, 1999; Maslanik et al., 2000). In particular, RCM experiments do not start with equilibrium conditions and therefore the initialization of surface variables, such as soil moisture and temperature, is important. Christensen (1999) reported, for example, it can require a few seasons for the rooting zone (about 1 m depth) and years for the deep soils to reach equilibrium.

4 REGIONAL CLIMATE SIMULATION EXPERIMENTS

Simulations of current climate conditions serve to evaluate the performance of RCMs. The regional climate simulation with RCMs can be driven both by observed boundary conditions and by GCM boundary conditions. Observed boundary conditions are derived from either European Centre for Medium Range Weather Forecast (ECMWF) reanalysis (Gibson et al., 1997) or National Center for Environmental Prediction (NCEP) reanalysis (Kalnay et al., 1996), which may give accurate representation of the large-scale flow and tropospheric temperature structure over most regions (Gibson et al., 1997). Although errors are still present due to poor data coverage and to observational uncertainty, these analyses may be used to drive RCM simulations for short periods, for comparison with individual episodes, or over long periods to allow statistical evaluation of the model climatology.

For dynamic downscaling experiments for regional climate simulation, MM5 (version 3.4) with 27 km horizontal resolution and 18 layers of sigma-coordinate in vertical is nested within global-scale NCEP reanalysis data with 2.5^{o}x2.5^{o} resolution in longitude and latitude. In regional simulation, January and July, 1979 monthly mean features have been obtained by both continuous integration and daily restart integration driven by updating the lateral boundary forcing at 6-hr intervals from the NCEP reanalysis data using a nudging scheme of Davis (1976) as shown in Fig. 1. Fig 1. illustrates the updating design of initial and boundary conditions in both continuous and restart integrations, which are named as Exp 1 and Exp 2, respectively:

Exp 1. Continuous run from 00 UTC Jan. 1, 1979 00 UTC Feb. 1, 1979 and from 00 UTC Jul. 1, 1979 to 00 UTC Aug. 1, 1979 without restart

Exp 2. Restart run from 00 UTC Jan. 1, 1979 to 00 UTC Feb. 1, 1979 and from 00 UTC Jul. 1 1979 to 00 UTC Aug. 1, 1979 with daily restart

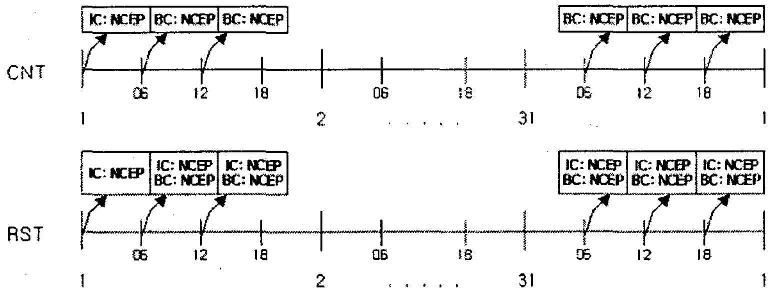

Fig 1. Updating design of initial and boundary conditions in both continuous and restart integrations

Figs. 2 and 3 present the January and July monthly mean precipitation and surface air temperature of 1979 obtained from Exp 1 and Exp 2, respectively. In both experiments many localized features have been generated, and somewhat different localized features between Exp 1 and Exp 2 has been found, although it may need further analysis to determine which one has better representation of the observed climate.

1.1 precipitation

In general, many localized features have been found in both simulations with reasonable geographical distribution compared to the GPCP data (Fig. 2). As expected, many of these localized precipitation feathers are much larger than the GPCP data. Here, it is notable that the GPCP data may not represent localized precipitation features in detail because of its coarse resolution. Two well organized branches of monsoon rain band have been found in both July simulations compared to the GPCP data. One is located from central China to southern Korean peninsula, and then extended to southern Japan, while another is positioned at northern China. The southern branch is more distinguishable in the continuous run (Exp 1) than the restart run (Exp 2). However, more organized local precipitation features have been generated by Exp 2 than Exp 1. In January, Exp 1 has produced more precipitation in Japan and northern Pacific than in Exp 2. It may need further detail analysis to determine which method is more reasonable for the downscaling for regional climate in terms of reproducibility of regional climate and requirement of computing resources.

1.2 temperature

The geographical distribution of simulated surface air temperature from both Exp1 and Exp 2 is not much different from the NCEP reanalysis data in general except that many localized features have been found in both simulations due to the similar reason discussed above (Fig. 3). The localized feature is more distinguishable over Asia continent than over Pacific ocean because surface air temperature depends highly on the topography in general. During January the temperature is somewhat warm at southern China and southern Korean peninsula compared to the NCEP reanalysis data. There is some difference in Exp 1 and Exp 2, but it may result from the difference in precipitation between two experiments.

4 SUMMARY AND FURTHER SUGGESTIONS

From a pilot regional climate simulation with MM5 driven by updating the lateral boundary forcing at 6-hr intervals from the NCEP reanalysis data, we may successfully generated regional detail features which might be forced by topography, lake, coastlines and land use distribution. There is no significant difference in monthly mean features either integrate continuously or integrate with daily restart. For climatological long integration, the initial condition may not be significantly important. Accordingly, MM5 can be integrated for a long period without restart frequently, if a proper lateral boundary forcing is given.

For a scenario run we have to evaluate the variability of regional model climatology compared to that in the observation to adjust model results with the difference in the variability to obtain more reasonable regional climatological information. If we are interesting in future climate (2xCO2), for example, the future temperate may obtained as

$$T_{2xCO_2} = T_{1xCO_2} + \Delta T_{2-1} \tag{1}$$

We may obtain from the model simulation for both 2xCO2 and 1xCO2 integrations. However, it may guarantee that the model climate variability is the same as that in the nature. Thus, we may write as

$$\Delta T_{2-1}^{nat} = \beta \Delta T_{2-1}^{\mathrm{mod}\,el} \tag{2}$$

where represents the ratio between natural variability and model variability. If we may assume is not quite sensitive so that we may write as

$$\beta = \frac{\Delta T^{nat}}{\Delta T^{\mathrm{mod}\,el}} = \frac{\Delta T_{2-1}^{nat}}{\Delta T_{2-1}^{\mathrm{mod}\,el}} \tag{3}$$

Then, we may obtain the future climate as

$$T_{2CO_2} = T_{1xCO_2} + \beta \Delta T_{2-1}^{\mathrm{mod}\,el} \tag{4}$$

Here, represents diurnal, seasonal, interannual, interdecadal variabilities, respectively. With above consideration we may produce more reasonable climate information for regional area.

ACKNOWLEDGEMENT

We thank Dr. Jinwon Kim for the discussion on the dynamic downscaling technique. This research was supported by a grant (code 1-3-1) from Sustainable Water Resources Research Center of 21st Century Frontier Research Program.

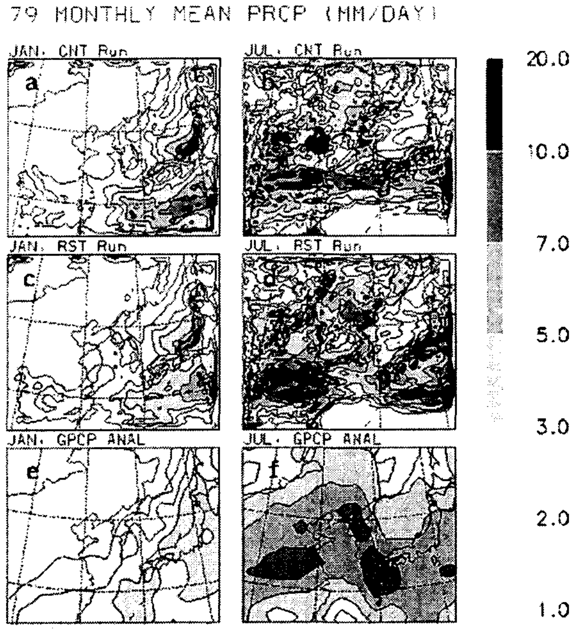

Fig 2 . Monthly mean precipitation (mm/day) of January 1979 (a, c, e) and July 1979 (b, d, f). The results are obtained by Continuous run (a, b) and Daily restart run (c, d), compared with GPCP analysis (e, f).

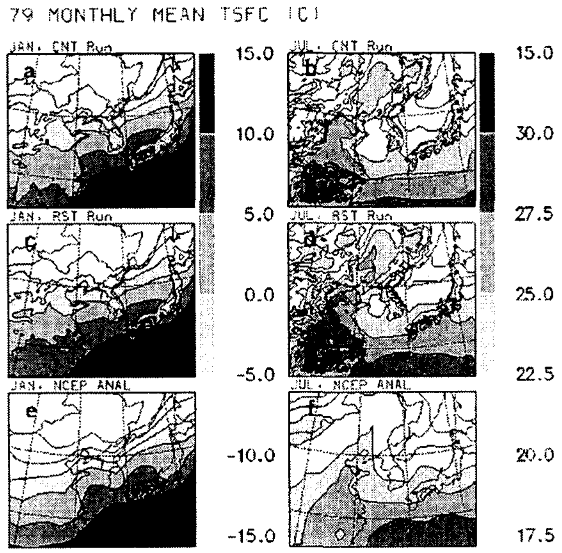

Fig 3. Monthly mean surface air temperature (℃) of January 1979 (a, c, e) and July 1979 (b, d, f). The results are obtained by Continuous run (a, b) and Daily restart run (c, d), compared with NCEP Reanalysis (e, f).

References

Christensen O.B., 1999: Relaxation of soil variables in a regional climate model. *Tellus*, 51A, 674-685.

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

Cubasch, U., J. Waszkewitz, G. Hegerl and J. Perlwitz, 1995: Regional climate changes as simulated in time-slice experiments. *Clim. Change*, 31, 273-304.

Davis, H., 1976: A lateral boundary formulation for multi-level prediction model. *Q. J. Roy. Meteorol. Society*, **102**, 404-418.

Deque, M. and J. P. Piedelievre, 1995: High resolution climate simulation over Europe. *Clim. Dyn.*, 11, 321-339.

Dickinson 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.

Gibson J. K., P. Kallberg, S. Uppala, A. Hernandez, A Nomura and E. Serrano, 1997, "ERA description." *ECMWF Reanalysis Project Report Series 1*, ECMWF, Reading, 66 pp.

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. and L.O. Mearns, 1999: Regional climate modeling revisited. An introduction to the special issue. *J. Geophys. Res.*, 104, 6335-6352.

Giorgi, F. and M.R. Marinucci, 1996: An investigation of the sensitivity of simulated precipitation to model resolution and its implications for climate studies. *Mon. Wea. Rev.*, 124, 148-166.

Giorgi, F., L.O. Mearns, C. Shields and L. McDaniel, 1998: Regional nested model simulations of present day and 2xCO2 climate over the Central Plains of the U.S. *Clim. Change*, 40, 457-493.

Giorgi, F., L.O. Mearns, C. Shields and L. Meyer, 1996: A regional model study of the importance of local vs. remote controls in maintaining the drought 1988 and flood 1993 conditions in the central U.S. *J. Climate*, 9, 1150-1162.

Hong, S.-Y., and H. - M. H. Juang, 1998: Orography blending in the lateral boundary of a regional model, *Mon. Wea. Rev.*, 126, 1714-1718.

IPCC, 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 [J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K Maskell (eds.)], Cambridge University Press, Cambridge, 572 pp.

IPCC, 2001: *Climate change 2001*. The scientific Basis. J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson (Eds.), Cambridge University Press. Cambridge, 881pp.

Jacob, D. and R. Podzun, 2000: "In Research Activities in Atmospheric and Oceanic Modelling." (*CAS/JSC Working Group on Numerical Experimentation Report*) [Geneva]: WMO, February 2000, 30, 7.10-7.11

Ji, Y. and A.D. Vernekar, 1997: Simulation of the Asian summer monsoons of 1987 and 1988 with a regional model nested in a global GCM. *J. Climate*, 10, 1965-1979.

Jones, R.G., J.M. Murphy and M. Noguer, 1995: Simulations of climate change over Europe using a nested regional climate model. I: Assessment of control climate, including sensitivity to location of lateral boundaries. Quart. *J. R. Met. Soc.*, 121, 1413-1449.

Jones, R.G., J.M. Murphy, M. Noguer and A.B. Keen, 1997: Simulation of climate change over Europe using a nested regional climate model. II: Comparison of driving and regional model responses to a doubling of carbon dioxide. *Quart. J. R.. Met. Soc.*, 123, 265-292.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Am. Met. Soc.*, 77, 437-471.

Karl, T.R., W.C. Wang, M.E. Schlesinger, R.W. Knight, D. Portman, 1990: A method of relating general circulation model simulated climate to observed local climate. Part I: Seasonal statistics. *J. Climate*, 3, 1053-1079.

Kato, H., H. Hirakuchi, K. Nishizawa, and F. Giorgi, 1999: Performance of the NCAR RegCM in the simulations of June and January climates over eastern Asia and the high-resolution effect of the model, *J. Geophys. Res.*, 104, 6455-6476.

Laprise R., D. Caya, M. Giguere, G. Bergeron, H. Cote, 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.

Leung, L.R. and S.J. Ghan, 1998: Parameterizing subgrid orographic precipitation and surface cover in climate models. *Mon. Wea. Rev.*, 126, 3271-3291.

Leung, L.R., A.F. Hamlet, D.P. Lettenmaier and A. Kumar, 1999b: Simulations of the ENSO hydroclimate signals in the Pacific Northwest Columbia River Basin. *Bull. Am. Met. Soc.*, 80(11), 2313-2329.

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

Machenhauer, B., M. Windelband, M. Botzet, J.H. Christensen, M. Deque, R. Jones, P.M. Ruti and G. Visconti, 1998: Validation and analysis of regional present-day climate and climate change simulations over Europe. *MPI Report* No.275, MPI, Hamburg, Germany.

Maslanik, J.A., A.H. Lynch and M. Serreze, 2000: A case study simulation of Arctic regional climate in a coupled model. *J. Climate*. 13, 383-401.

Noguer M., R.G. Jones and J.M. Murphy, 1998: Sources of systematic errors in the climatology of a nested regional climate model (RCM) over Europe. *Clim. Dyn.*, 14, 691-712.

Pan, Z., E. S. Takle, M. Segal and R. Arritt, 1999: Simulation of potential impacts of man-made land use changes on U.S. summer climate under various synoptic regimes, *J. Geophys. Res.*, 104, 6515-6528.

Pielke, R.A., Sr., R.L. Walko, L. Steyaert, P.L. Vidale, G.E. Liston and W.A. Lyons, 1999: The influence of anthropogenic landscape changes on weather in south Florida. *Mon. Wea. Rev.*, 127, 1663-1673.

Rinke A. and K. Dethloff, 1999: Sensitivity studies concerning initial and boundary conditions in a regional climate model of the Arctic, *Clim. Res.*, 14, 101-113.

Stratton, R.A. 1999: A high resolution AMIP integration using the Hadley Centre model HadAM2b. *Clim. Dyn.*, 15, 9-28.