Impacts of spectral nudging on the simulation of present-day rainfall patterns over southern Africa

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Abstract

Regional climate models (RCMs) provide finer-scale simulations than those of Global climate models (GCMs), whilst being forced by the output of the host GCMs. In this study, we examine the influence of various strengths of spectral nudging on the simulation rainfall patterns in Southern Africa. We use the Conformal-Cubic Atmospheric Model (CCAM) as RCM to downscale ERA-interim reanalysis data to a resolution of 50 km in the horizontal over the globe. A scale-selective filter (spectral nudging technique) is used for nudging the CCAM simulations. The filter is applied at length scales of 9000 km, and 4500 km. The model simulations of rainfall are compared against CRUTS3.2. Both the experiments realistically simulate the present day rainfall patterns.

Keywords: Regional climate models, Rainfall, Spectral nudging ,

Introduction

Regional Climate Models (RCMs) are used to obtain detailed simulations of present-day or future climate by dynamically downscaling large-scale atmospheric circulation from Global Climate Models (GCMs), or reanalysis data. RCMs are expected to provide finer scales that are absent in the course resolution driving field, but with the condition of maintaining the large scale circulation of the driving field over the high-resolution domain (Jones et al 1995). Traditionally the way to downscale reanalyses datasets or GCM outputs has been through the application of limited-area models (LAMs), with forcing of the host simulation applied at the lateral boundaries of the LAM (Davies 1976). Such methods make use of relaxing the model variables to the driving fields in a buffer zone several points wide along the borders of the high-resolution domain, effectively damping numerical noise and physical inconsistencies that accumulate in the vicinity of the lateral boundaries.LAMs forced by host models/reanalysis following this procedure are sometimes referred to as nested RCMS. However, numerous studies have demonstrated that lateral boundary conditions as described above are associated with a number of problems. These include the spurious reflection of atmospheric waves leaving/entering the high-resolution domain of the LAM, and the occurrence of spurious precipitation in the viscinity of the lateral boundaries. These problems are sufficiently large to cause spurious small-scale variability in [1]the LAM simulation thereby limiting the downscaling applicability of the nesting technique. For example, Miguez Macho et al (2004) investigated the ability of an RCM to simulate precipitation and established that the simulations were distorted by misrepresentations of the large scale atmospheric circulation produced by the interaction of RCM simulations with the imposed lateral boundary conditions of the nested domain. Consequently, the spatial distribution of precipitation generated by their RCM varied unrealistically across the domain. There are several studies of the view that large scale atmospheric fields are not realistically communicated to the downscaling RCM. To maintain coherence of the large scale between the host GCM and the LAM, another method known as grid point nudging was developed. It relies on nudging each and every grid cell for example, Castro et al (2005) established that nudging the entire domain interior helps in retaining the value of the atmospheric large scales, which happens to lose variability during the specific period they studied.

Another nudging technique that has gained interest is spectral nudging (Von Storch et al, 2000). In this technique a nudging term is introduced in both the meridional and zonal direction and a selective filtering is done to select only the waves under the selected wave number. Through the process of selective filtering, Miguez-Macho (2005) has outlined that by keeping long scale waves in the

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nudging term large scale precipitation bias is eliminated, hence while the small scale features are maintained. In order to maintain the balance between the large scale forcing from the GCM and the change brought by smaller scale features introduced by the RCM appropriate wave numbers need to be selected appropriately through the use of sensitivity tests (Liu et al, 2012). For the southern African region, it is important to specify the nudging appropriately for the key synoptic-scale forcings to be communicated appropriately over the high-resolution region. However, simulateneously, the RCM should be left with sufficient degrees of freedom to simulate deep convection and internal model-domain dynamics. It is the aim of this study to determine the appropriate filter which improves the model's ability to simulate rainfall patterns over Southern Africa.

Methodology

The model

The Conformal Cubic Atmospheric Model (CCAM) is a variable-resolution global atmospheric model, developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) (McGregor, 1996, 2005; McGregor and Dix, 2001). It employs a semi-implicit semi-Lagrangian method to solve the hydrostatic primitive equations. The model includes a fairly comprehensive set of physical parameterizations. The GFDL parameterizations for long-wave and short-wave radiation are employed, with interactive cloud distributions determined by the liquid and ice-water scheme of Rotstayn (1997). A stability-dependent boundary layer scheme based on Monin Obukhov similarity theory is employed (McGregor, 2005), A canopy scheme is included, and it has six layers for soil temperatures, six layers for soil moisture (solving Richard's equation) and three layers of snow. The cumulus convection scheme uses a mass-flux closure, as which includes downdrafts, entrainment and detrainment.

Experiment design

We use the Conformal-Cubic Atmospheric Model (CCAM) as RCM to downscale ERA-interim reanalysis data at a resolution of 50 km in the horizontal over the globe. The simulations are performed for the period 1979-2012. A scale-selective filter (spectral nudging technique) is used for nudging the CCAM simulations (Thatcher and McGregor, 2009, 2010). The filter is applied at length scales of 9000 km, 4500 km. The filter is applied at six-hourly intervals and from 900 hPa upwards. Use of this spectral-nudging technique ensures that observed synoptic-scale circulation patterns a represented with increasing realism as the length-scale at which the filter is applied decreases. The model simulations of rainfall are compared against CRUTS3.2 observed data set.

Results and discussions

The seasonal Raifall patterns and monthly rainfall of selected areas over southern Africa are depicted on figures 1 and 2. The simulated CCAM_ERA-interim downscaling realistically represents the movement of the Intertropical Convergence zone. Both the experiments captures the south ward shift of the ITCZ during the DJF season and its northward shift during JJA season. Many regional features such as the west-east moisture gradient (rainfall gradient) across South Africa and the dry slot over the Limpopo basin are also well captured by the model. The decrease in the selective

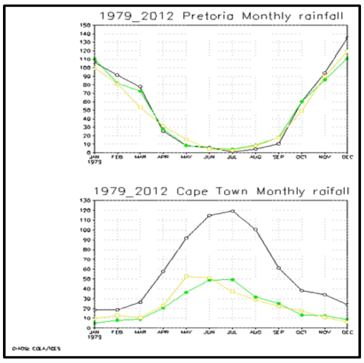

Figure 1: monthly rainfall (mm/day) in Pretoria and Cape Town as simulated by CCAM (yellow-9000 km, green -4500 km) and black line indicating CRU data .

Length scale of spatial filtering somewhat improves the model performance. The downscalings simulate the amplitude of montly rainfall totals well over the interior, but over coastal areas such as Cape Town the amplitude of the monthly totals are underestimated. Both the experiments indicate a pronounced rainfall during the DJF season of the mountainous eastern escarpment of South Africa and Lesotho. It should also be noted that CRU data may not realistically represent the present-day climate in areas with less monitoring stations. The rainfall spring onset period is well captured in Pretoria as well as the winter rainfall onset period in Cape Town. The Taylor diagram in figure 3 indicates how closely the two simulations represent the present-day rainfall pattern across southern Africa. The 4500 km length-scale spatial filtering (indicated by the black symbols) generally exhibits higher pattern correlations than in the case of the 9000 km length-scale spatial filtering. The standard deviations of both the simulations for all seasons and annually are larger than 1 (mostly below 1.5) indicating that there is great variability in space in the simulated compared to the observed climates.

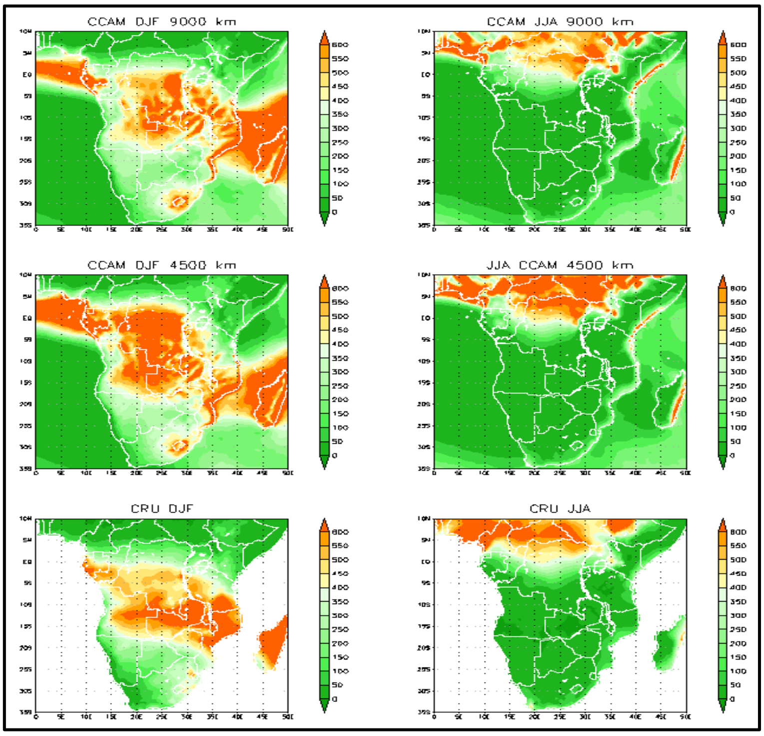

Figure 2: seasonal rainfall (mm/day) over Southern Africa as simulated by CCAM ERA-Interim downscaling (900km and 4500 spatial filtering length scale) compared against CRUTS 3.2 rainfall data.

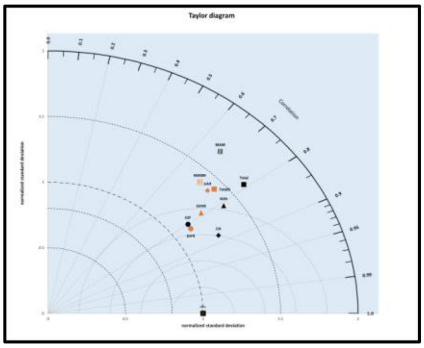

Figure 3 Taylor diagram depicting pattern correlation, normalized standard deviation and normalized root mean square error of the two CCAM-ERA downscalings and observations (cross on the x-axis) for southern Africa. The 4500 km length-scale spatial filtering is indicated by the orange symbols and the 9000 km length-scale spatial filtering is indicated by the black symbols.

Conclusions

Most of the southern Africa regional rainfall features are well captured by the model . A reduction in spatial filtering length scale somewhat improves model performance and further experiments need to be conducted for even shorter length scales of the forcing, in order determine the most optimum spatial filtering length scale.

Commented [A1]: The paper states "It is the aim of this study to determine the appropriate filter which improves the model's ability to simulate rainfall patterns over Southern Africa." However, the results are mostly just a description of a simulation's output, and little is said about the stated aim.

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