O. B. Christensen · M. A. Gaertner · J. A. Prego
J. Polcher

Internal variability of regional climate models

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Abstract Two regional climate models have been applied to the task of generating an ensemble of realizations of the year 1982 with observed boundary conditions in areas covering parts of the Mediterranean countries. These realizations were generated by applying boundary conditions from the ECMWF ERA reanalysis project consecutively, carrying over the soil variables from the regional models from one iteration to the next. Monthly mean fields for six iterations of each model have been used as statistical ensembles in order to investigate the internal variability of the regional model dynamics. This internal variability is a necessary consequence of the non-linear physical feedback mechanisms of the RCM being active. A small value of internal variability will give better statistics for climate sensitivity signals, but will make these results less credible. The internal variability is important for the quantitative assessment of a climate sensitivity signal. With the present choice of models and integration domains the internal variabilities of surface fields and precipitation do reach levels that are less than, but in summer of comparable order of magnitude to, corresponding atmospheric variabilities of an atmospheric general circulation model.

1 Introduction

When asking about local and regional effects of climate change, current general circulation models (GCMs) have a horizontal resolution that is inadequate. One possibility for downscaling GCM results to regional scale is to apply a nested regional climate model (RCM) (Giorgi 1990).

Several important mechanisms relating to a realistic simulation of present-day climate and climate sensitivity require high spatial resolution. Extreme values of fields like cyclone low pressure, intense precipitation and strong winds are generally more realistically described in nested RCMs than in driving GCMs (Giorgi and Mearns 1999 and references therein). The effect of anthropogenic greenhouse warming on the hydrological balance depends crucially on the ability to calculate a realistic snow pack and its melting (Christensen et al. 1998). Regional climate models driven by perfect boundaries (i.e., observation-based reanalysis fields) show quite realistic climate signals when compared to observations (Christensen et al. 1998), but are unable to “correct” systematic errors in large-scale circulation from driving GCMs in nested studies; often errors are amplified further by the RCM (Christensen et al. 1997). There are still improvements needed for RCMs, in particular due to the fact that RCM physical parametrization schemes are normally tuned for use in GCM resolution (Noguer et al. 1998). The WMO Working Group on Numerical Experimentation (WGNE) has recommended (WGNE 1999) an emphasis on research regarding resolution dependency of model physical parametrization and the ability of boundary conditions to determine the large-scale flow in RCMs.

At present no algorithm exists for the optimal choice of integration area for a nested RCM experiment. It is generally agreed that the area of interest should be well within the integration area (Seth and Giorgi 1998); on the other hand, very large integration areas suffer from inconsistency errors at outflow boundaries, as the RCM
starts developing its own large-scale dynamics different from the one of the driving model (Jacob and Podzun 1997).

In order for a regional model to add value to the driving model output and not merely act as a simple interpolator, the model should be able to simulate local atmospheric feedback mechanisms. These mechanisms have to be active for the downscaled results to be credible. They should describe the interactions between the large-scale forcing and the small-scale processes correctly at all temporal scales. Too small integration domains will not enable the model dynamics to act, resulting in erroneous feedback to perturbations of parameters (Seth and Giorgi 1998). It is a necessary but not sufficient test for the general validity of an RCM that it reproduces the large-scale flow which corresponds to the lateral boundaries and that realistic small-scale features are added. This test only holds for the given boundary conditions. The model can only have a general validity, if the physical processes are free to act in the regional model and are not forced onto it by the lateral boundary conditions.

The general validity of an RCM is for instance necessary in the case of climate sensitivity experiments where the parameters of the RCM are changed, possibly accompanied by changes in lateral or lower boundary conditions. In order to advance on this topic, which is essential for the application of RCMs to downscaling of climate sensitivity scenarios, we propose here to study and quantify the internal variability of RCMs. This quantity is tightly linked to the freedom of the model to generate its own realistic climate feedback mechanisms.

In the following section we will further discuss the concept of internal variability. Then we will describe the two regional climate models applied in the present study. After that the experimental setup will be treated, then the relevant output of the experiments will be presented and discussed; finally we will summarize our findings.

2 Definition of internal variability

In the present work an ensemble approach has been applied to study the internal variability of an RCM. Lateral boundary conditions for one year have been repeated consecutively for several realizations (iterations) of this year. Soil variables, being the prognostic variables with the longest time scales, have been carried over from one iteration of this year to the next. All the iterations simulated by this approach are allowed solutions to the lateral boundary conditions, and the ensemble samples the variability of the regional processes simulated by the RCM. The variability produced this way can be used to evaluate the consistency of the perturbed climate with the lateral boundary conditions, as it can be used in the comparison of RCM results with observations by providing a meaningful acceptance limit on the model biases. The physical meaning of this approach is that the results of the RCM are tested against the solution space the RCM provides for a given set of lateral forcing conditions. The size and structure of this space needs to be studied for each variable and configuration of the RCM.

Ensemble simulations with RCMs allow to identify variables and regions of high internal variability, which is essential for the validation of RCMs. The simulated internal variability comes from the non-linear physical processes which are described by RCM equations and develop under given large-scale conditions. Thus, these regions and fields may be identified as those where the model develops its own processes uninhibited by the lateral boundary relaxation process. Areas and variables of high variability correspond to cases where the RCM can be able to show skill and add value when compared to what a deterministic interpolation algorithm could provide, thus also enabling meaningful scenario signals that can be the subject of a statistical significance analysis. In other words: Though internal variability makes it more difficult to extract climate sensitivity signals, it is necessarily present in an RCM with realistic physical feedback mechanisms and a realistic sensitivity to the RCM parameterization.

The ensemble results can furthermore be used to calculate the significance of scenario results by standard methods. The different members of an ensemble of RCM simulations with the same set of boundary conditions can be considered as a sample of the solution space for the given lateral boundary conditions. This knowledge is of value in providing variability estimates for the validation of the model and its development. Indeed changes in the RCM, either for sensitivity experiments or parameterization tests, can only be analyzed in a meaningful way in areas where the solution space is sufficiently large to allow modification of the simulated processes for the given boundary conditions. The application of ensembles of RCM simulations to assess the significance of model perturbations has only begun recently (Ji and Vernekar 1997; Guertner et al. 2001; Weisse et al. 2000; Rinke and Dethloff 2000).

Provided that the RCM internal variability is sufficiently large, several designs of climate sensitivity studies are possible. A setup of regional climate experiments with varying model parameters between control and scenario, but common boundary conditions, may show local effects of changes in climate forcing, for instance from land-use changes or changes in atmospheric chemistry, but not changes in the large-scale circulation. A necessary condition for the success of the regional scenario approach is that the dominating climatic feedbacks to the perturbation are indeed regional. This is more or less equivalent to the condition that the resulting perturbed climate is an allowed solution to the lateral forcing applied to the RCM. Obviously, it is also desirable to test the statistical significance of the result. Another possibility of a climate sensitivity study with an RCM is letting boundary conditions for the two cases differ by applying “suitable” changes to the control