Influence of regional scale information on the global circulation: A two-way nesting climate simulation

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[1] The influence of regional scale information on the global circulation has been investigated through the development and application of the so-called "two-way nesting" technique. The two-way nesting climate model system consists of a spectral atmospheric general circulation model and a grid point regional atmospheric model. Two simulations of 10 years each have been carried out with and without the feedback of the regional model to the global model. For the regional model domain the Maritime Continent covering the tropical area of the Indonesian islands has been selected as a key region influencing the global climate. The analysis of the global atmospheric temperature field shows a clear improvement through the regional model feedback; the systematic error with respect to re-analysis data can be reduced even in regions far away from the regional model domain. **Citation:** Lorenz, P., and D. Jacob (2005), Influence of regional scale information on the global circulation: A two-way nesting climate simulation, *Geophys. Res. Lett.*, *32*, L18706, doi:10.1029/2005GL023351.

1. Introduction

[2] The evolution of the global climate is strongly affected by regional differences and it seems that a few key regions can act as the main drivers of the global energy budget [e.g., *Neale and Slingo*, 2003]. Therefore it should be possible to enhance a global atmospheric general circulation model (GCM) simulation by a better representation of some important regions, i.e. by using a finer spatial and temporal resolution over these regions.

[3] In order to prove this hypothesis, a two-way nesting (TWN) climate model system has been developed using a GCM and an atmospheric regional climate model (RCM): within the RCM-domain(s) the GCM is updated continuously by the corresponding aggregated results of the finer resolved regional model. There is a feedback from the RCM to the GCM.

[4] The selection of proper domains is crucial for the impact of this approach on the global circulation. One such particular region is the "Maritime Continent" [*Ramage*, 1968], occupying the tropical region between 90°E and 160°E, with its complex formation of partly large islands; some of them covered with high mountains. In this region sea surface temperatures are one of the warmest worldwide with corresponding large heat fluxes; and there is a frequent occurrence of deep convection with associated high amounts of precipitation. A study of *Neale and Slingo* [2003] showed a strong global influence on geopotential height and surface temperature for a GCM experiment with the islands of the Maritime Continent removed. Therefore the first climate simulation was conducted using this region as a two-way nested domain.

[5] The aim of this paper is to present preliminary results of the effect of this approach on the global circulation. The two-way nesting model system is described in section 2. The setup and results of a 10-year integration are shown in section 3, and final conclusions are given in section 4.

2. The Two-Way Coupled Model System

[6] Two-way nesting means an interactive numerical model integration, where a part of the integration area is computed at a finer horizontal resolution than the coarser resolved residual area. The basic idea behind this technique is the reduced computing time compared to an integration at the finer resolution over the whole integration area. Two-way nesting techniques have already been applied between atmospheric limited area models at different horizontal resolutions [*Phillips and Shukla*, 1973; *Clark and Farley*, 1984; *Zhang et al.*, 1986].

[7] The two-way nesting approach presented in this paper for coupling a RCM with a GCM has been developed with the Max Planck Institute for Meteorology (MPI-M) models REMO [*Jacob*, 2001] and ECHAM4 [*Roeckner et al.*, 1996]. The ECHAM4 model is a GCM with a spectral representation of its prognostic variables (see Table 1) except for the water components, which are represented in grid point space.

[8] REMO is a hydrostatic RCM. A hybrid sigma-pressure vertical coordinate system [*Simmons and Strüfing*, 1981] with 19 vertical layers is used for both the ECHAM4 and the REMO model. REMO uses the lateral boundary formulation after *Davies* [1976]. The set of physical parameterizations of this model is absorbed from the global ECHAM4 model. Therefore both the GCM and the RCM have identical physical parameterization schemes, except for a few scale-dependent adjustments of some parameterization parameters; e.g. within the mass flux type convec-

Table 1. Characteristics of the Used Models

	ECHAM4	REMO
Horizontal resolution	~2.8° (T42)	0.5°
Time step	24 minutes	4 minutes
Set of physical parameterizations	ECHAM4	ECHAM4
Horizontal Representation		
Temperature	spectral	grid
Divergence and vorticity	spectral	—
Horizontal wind components	—	grid
Specific humidity and liquid water	grid	grid
Surface pressure	spectral	grid

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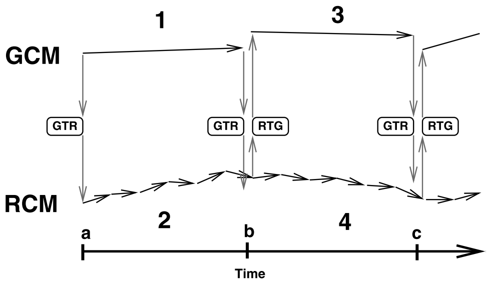

Figure 1. Schematic flow diagram of the two-way nested system. GTR: global to regional interpolation; RTG: regional to global aggregation.

tion scheme after *Tiedtke* [1989] with modifications after *Nordeng* [1994]. A summary of the characteristics of the used models is given in Table 1. The different representations of prognostic variables in the GCM and RCM require additional transformations contributing to the computational effort, since fields can be transformed between spectral and grid-point space and between divergence/vorticity and the horizontal wind vector, respectively.

[9] In the widely used one-way nesting technique a RCM is initialized and driven at the lateral boundaries using data from (re)-analysis products and global model output, respectively. In a one-way nesting mode there is no feedback from the RCM to the GCM, hence the GCM and the RCM simulations can be carried out sequentially.

[10] In contrast, within the presented two-way nesting approach there is a feedback from the RCM to the GCM at every GCM time step. This implies that both models as well as the procedures for the conversion between GCM grid and RCM grid have to be carried out simultaneously. The procedure to transform data from the global to the regional grid (GTR) was not modified with respect to one-way nesting; a reversed procedure (RTG) to accumulate RCM results on the GCM grid has been implemented additionally. Within this procedure the prognostic variable fields are first vertically interpolated to the GCM model levels and afterwards horizontally aggregated to the GCM grid. The horizontal aggregation is done by building the arithmetic average of the values of all RCM grid points located within the relative GCM grid box. These transformations are performed in grid-point space. A schematic flow diagram of the two-way nested system is shown in Figure 1:

[11] • In the beginning of a TWN simulation, the initial GCM fields (time a) are interpolated to the RCM grid via the GTR procedure.

[12] • One single 24-minutes time step is performed by the GCM (step 1); the results (time b) are also used in the GTR procedure.

[13] • The RCM is initialized within the whole RCM domain by the initialization fields (time a) and forced at the lateral boundaries with fields interpolated linearly in

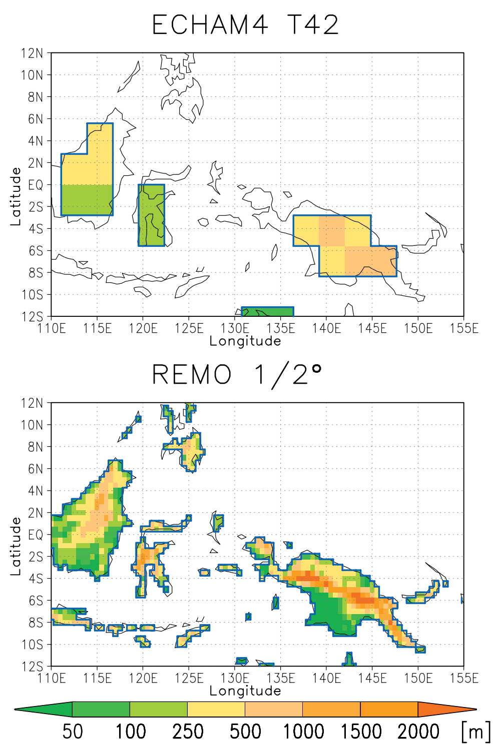

Figure 2. Orography [m] and land-sea-mask (blue line) of the two-way nested region (Maritime Continent) in the ECHAM4-T42 horizontal resolution (upper panel) and in the REMO 0.5° horizontal resolution (lower panel).

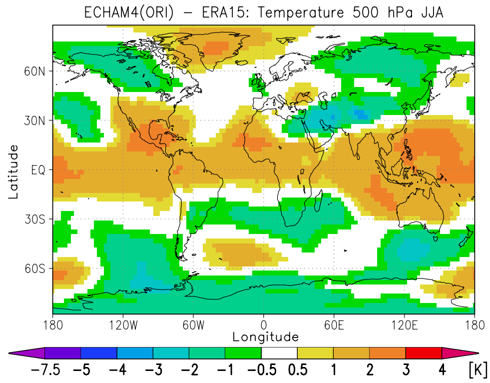

Figure 3. 10 year seasonal mean of the 500 hPa temperature difference [K] of ECHAM4-ORI minus ERA15 for boreal summer (JJA).

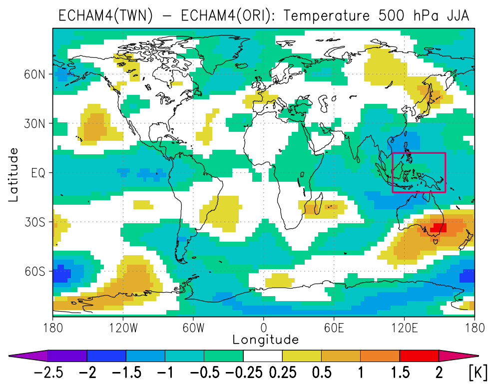

Figure 4. 10-year seasonal mean of the 500 hPa temperature difference [K] of ECHAM4-TWN minus ECHAM4-ORI for boreal summer (JJA). The red box is marking the two-way nested region.

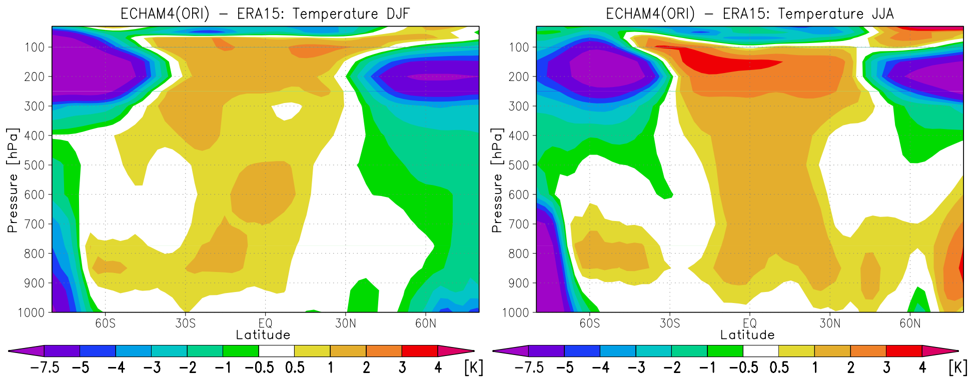

Figure 5. Latitude-height (pressure in hPa) cross sections of 10 year seasonal zonal mean temperature difference [K] of ECHAM4-ORI minus ERA15 for boreal winter (DJF; left panel) and boreal summer (JJA; right panel).

time between time a and time b; in this mode after 6 RCM time steps of 4 minutes time b is reached by the RCM (step 2); with modified results in the interior of the RCM domain.

[14] • These RCM results (time b) are aggregated to the GCM grid using the RTG procedure; the GCM values of all prognostic variables in all vertical levels are replaced by these aggregated values within the TWN domain. Due to the necessary need for horizontal averaging a major part of the small scale information introduced by the RCM is lost; but the GCM fields are still slightly modified.

[15] • With this modified state the GCM simulation is continued for the next time step (step 3); the results are in turn given to the GTR procedure.

[16] • The RCM simulation is continued for the next 6 RCM time steps (step 4). The RCM is integrated in so called “climate mode”: there is no additional initialization of the RCM within its domain; the only forcing from the GCM takes place through the lateral boundaries during the integration.

[17] • Now the last three worksteps are iterated for the complete integration time.

3. Setup and Results of a 10-Year TWN Integration

[18] An ECHAM4-only experiment (ECHAM4-ORI) as well as a two-way nested ECHAM4 simulation (ECHAM4-TWN) initialized at the 1st of January 1980 were integrated for 10 years using observed SST data from the Atmospheric Model Intercomparison Project AMIP [*Gates*, 1992]. As already mentioned the Maritime Continent/Western Pacific Warm Pool has been selected as the two-way nested region in the ECHAM4-TWN experiment. The TWN domain extends from 110°E–155°E and from 12°S–12°N (91 × 49 grid points at the 0.5° RCM resolution). As it can be seen clearly from Figure 2, in this region the rather poor representation of land-sea distribution and orography at the GCM resolution of ~2.8° (T42) is strongly enhanced by refining the resolution to the RCM grid (0.5°).

[19] For model validation the 15 years re-analysis dataset ERA15 [*Gibson et al.*, 1997] from the European Centre for Medium-Range Weather Forecasts (ECMWF) was used. The difference between the ECHAM4-ORI mean (climate) quantities (e.g. multi year seasonal zonal mean temperature) and the ERA15 dataset can be seen as a systematic model bias (or error). The 10 year mean bias is shown in Figure 3 for the seasonal 500 hPa temperature for boreal summer season (JJA). In the tropics there is a warm bias up to 3 K, while in higher latitudes there are biases in both directions. Figure 4 shows the effect of the TWN approach, namely the 10-year JJA difference of ECHAM4-TWN – ECHAM4-ORI. Throughout the tropics at all longitudes there is a systematic reduction of temperature (and therefore a reduction of the model bias) up to 1.5 K. Furthermore outside the tropics the influence of TWN on temperature is in most areas just diametrical to the model bias (Figure 3); therefore

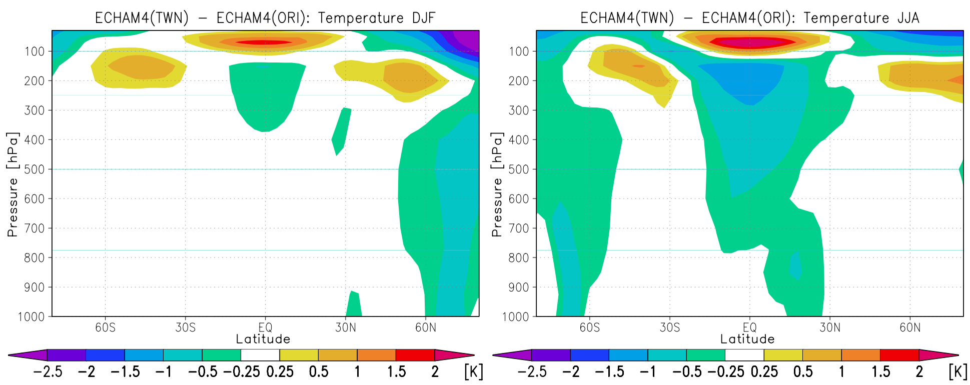

Figure 6. Latitude-height (pressure in hPa) cross sections of 10 year seasonal zonal mean temperature difference [K] of ECHAM4-TWN minus ECHAM4-ORI for boreal winter (DJF; left panel) and boreal summer (JJA; right panel).

the systematic 500 hPa temperature bias is globally reduced by the TWN approach.

[20] A similar analysis has been performed for the global zonal mean atmospheric temperature distribution. The analyzed 10-year seasonal (DJF and JJA) temperature bias with respect to the ERA15 dataset (Figure 5) is in accordance to prior studies [*Roeckner et al.*, 1996]: Throughout the tropical troposphere there is a warm bias for summer and winter season, strongest just below the tropopause. In the tropical stratosphere a cold bias is visible. Furthermore there is a significant cold bias at the upper troposphere at higher latitudes in both hemispheres (up to 8 K). The effect of the TWN approach with one nest over the Maritime Continent shows again a significant global reduction of this bias in both seasons (Figure 6). There is a clear cooling of the tropical troposphere that is more pronounced in JJA than in DJF. A warming in the tropical stratosphere as well as in the upper tropospheric regions at higher latitudes is caused by the two-way nesting approach.

4. Conclusions

[21] The two-way nested ECHAM4 – REMO atmospheric climate model system has been developed and integrated numerically stable for a 10-year period using one two-way nesting region covering the Maritime Continent. Preliminary results show a positive influence on the simulation of the global climate, even in regions not covered by the two-way nesting domain. There are indications that the systematic error can be reduced globally by a more detailed representation of this particular region, which is important for the global circulation. Until now a detailed analysis has not been completed to identify the physical processes which are leading to these improvements. However, analyses of horizontal patterns of precipitation in the experiments (not shown) suggest that the detailed representation of the complex land-sea distribution and topography within the Maritime Continent at RCM scale lead to a more realistic parameterization of convective processes in the two-way nested experiment. The conducted 10-year integration will be analyzed in more detail, in particular with regard to the identification of the mechanisms leading to the enhancements.

[22] Technically it is possible to implement one or more two-way nesting domains at any location of the globe. However, it is not clear if the application of this approach at other regions would also lead to an improvement of the global climate simulation, as the presented two-way nested simulation is the only one we have performed up to now. Consequently it is planned to investigate the influence of high resolution domains in different locations of the globe as well as the sensitivity to extension and number of RCM domains.

[23] Furthermore the effect of one-way nesting versus two-way nesting on the performance of an RCM simulation itself is under investigation.

[24] **Acknowledgment.** We would like to thank Erich Roeckner for providing the ECHAM4 model.

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