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Simulation of South American wintertime climate with a nesting system

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Abstract A numerical nesting system is developed to simulate wintertime climate of the eastern South Pacific-South America-western South Atlantic region, and preliminary results are presented. The nesting system consists of a large-scale global atmospheric general circulation model (GCM) and a regional climate model (RCM). The latter is driven at its boundaries by the GCM. The particularity of this nesting system is that the GCM itself has a variable horizontal resolution (stretched grid). Our main purpose is to assess the plausibility of such a technique to improve climate representation over South America. In order to evaluate how this nesting system represents the main features of the regional circulation, several mean fields have been analyzed. The global model, despite its relatively low resolution, could simulate reasonably well the more significant large-scale circulation patterns. The use of the regional model often results in improvements, but not universally. Many of the systematic errors of the global model are also present in the regional model, although the biases tend to be rectified. Our preliminary results suggest that nesting technique is a computationally low-cost alternative for simulating regional climate features. However, additional simulations, parameterizations tuning and further diagnosis are clearly needed to represent local patterns more precisely.

1 Introduction

Current general circulation models (GCMs) with their coarse resolution are not able to provide reliable estimates of climate change and climate variability at the appropriate scales required for regional studies over the South American region. This problem has also been detected over other regions of the world as is documented in Giorgi and Mearns (1991), McGregor et al. (1993), Giorgi (1995) and McGregor (1997) where different revisions of earlier simulations with regional climate models are presented. The previous studies may broadly be divided into two main categories: those where a GCM simulation is used to drive a higher resolution regional model and those running a variable resolution GCM, without nesting a regional model (e. g., Déqué and Piedleivre 1995; Leslie 1997).

Aside from the technique used to develop higher resolution model-climatologies, southern South America simulations are not frequently found in the literature. The strong effect impinged upon atmospheric systems by the Andes constitutes a key factor for determining regional climate (Seluchi et al. 1998). This mountain range is characterized by a steep topography, reaching more than 5000 m, flanked by the Pacific Ocean on the western side and by Amazonia at the northeastern portion while a narrow continental region lies at its southern lee-side.

Previous experience denotes that areas influenced by terrain inhomogeneities are the ones where dynamical downscaling techniques are more helpful. Preceding studies guided our research endeavor aimed at the development of this downscaling technique for the eastern South Pacific-South America-western South Atlantic region that is now under way at the Centro de Investigaciones del Mar y la Atmosfera (CIMA). In the present work, we adopt a hybrid strategy, in which a regional model, covering almost all South America, is nested in a GCM with variable-resolution grid. As suggested by Caian and Geleyn (1997) this combined technique could be the most advantageous, since it surpasses the
limitations of traditional nesting and/or GCM zooming, with a lesser computational cost. Our nested modeling system is based on a newly developed version of the Laboratoire de Météorologie Dynamique General Circulation Model (LMD-Z), with a stretched grid irregularly spaced in the meridional direction, and a version of the GFDL/Limited Area HIBU Model (LAHM) (GFDL = Geophysical Fluid Dynamics Laboratory, HIBU = Federal Hydrometeorological Institute and Belgrade University). Such a nested model is known as the CIMA regional climate model (RCM). The one way nesting technique consists of using the output of LMD-Z simulations to provide driving initial and time-dependent lateral boundary conditions for LAHM simulations over South America and adjacent oceans.

A RCM simulation has been performed for multiple individual July months. The run was carried out on workstations at CIMA and was limited to six months in length by the computational resources available. This is the first time where LAHM is run for periods longer than several days. We consider that this climatology provides a first assessment to evaluate whether this nesting technique constitutes a plausible approach to describe regional climate features better than a GCM. The nested modeling system is presented in Sect. 2; Sect. 3 is devoted to the analysis of different features of the large-scale regional climate in terms of mean fields and standard model skill measures. Concluding remarks and future work are included in Sect. 4.

2 Description of the nested system

General circulation model

The driving atmospheric GCM is the LMD-Z, version 1. This gridpoint model is derived from the LMD standard GCM (Sadourny and Laval 1984). The code has been extensively rewritten, has more physical consistency, and is now organized in a more flexible manner for ease of use. Its horizontal discretization is a function of latitude and longitude, so a stretched grid can be applied to any region of the globe. The model’s physical parametrization is realized through a simple package containing main physical processes. The convection parametrization is a combination of the moist adjustment scheme (Manabe et al. 1965) and the Kuo (1965) scheme. Cloud liquid water is a prognostic variable of the model, which is calculated by considering the source and sink terms. At present, the clouds created by convection are not considered. Only those associated with stratiform precipitation are taken into account. Partial condensation is allowed through a statistical approach (Le Treut and Li 1991). The radiative transfer code has been designed by Fouquart and Bonnel (1980) for solar radiation and by Morcrette (1990) for terrestrial radiation. In the current simulation, the diurnal cycle of insolation is not taken into account. The calculation of surface temperature is incorporated in the boundary layer and based on the surface energy balance equation. For the soil moisture, a holding capacity is fixed at 150 mm of water, and all the water above this value is lost as runoff. A similar version of the model, differing in the resolution and in the zoom definition, has been used in Krinner et al. (1997) to simulate the climate of Antarctica.

GCM stretched grid

The version of the global model implemented at CIMA has a relatively coarse resolution: 72 points in longitude, 45 points in latitude and 11 vertical layers, with spatially variable horizontal resolution. The stretching scheme is introduced only in the northsouth direction in order to improve the resolution in the midlatitudes of the Southern Hemisphere (SH), a region where there are large gradients of circulation. The zoom is centered on 45°S where the meridional resolution is about 2°. Since the total number of grid points on the globe is constant, the enhanced meridional resolution in mid-southern midlatitudes is compensated by deterioration in the resolution of the Northern Hemisphere. On the contrary, zonal resolution remains constant everywhere (5°).

Among the problems that low-resolution atmospheric global models possess, one of the most serious is that they underestimate the horizontal eddy momentum flux. Held and Phillips (1993) suggest that it is the meridional, rather than zonal, resolution that is important for the simulation of the eddy momentum flux. They also suggest that a model with enhanced resolution in the meridional direction appears to be a natural choice particularly for studies in the Southern Ocean, where high zonal resolution in the atmosphere may not be essential. Therefore, a stretched grid irregularly spaced in the meridional direction seems to be a logical choice for the SH.

Limited area model

The LAHM/GFDL-CIMA hydrostatic model used in this study is a regional model that allows both horizontal resolution and domain to be arbitrarily chosen, with 18 fixed-sigma levels in the vertical. The numerical formulation and parametrization of radiative and boundary layer processes are similar to those described in Orlanski and Katzfey (1987). Surface drag is formulated via a Richardson number dependent Monin-Obukhov (1954) scheme, vertical diffusion is treated by a first order closure scheme with eddy diffusivity coefficients as functions of Richardson number (Saulo and Nicolini 1995). Moist convective parametrization is currently introduced using the cumulus cloud ensemble model developed by Arakawa and Schubert (1974). Radiation follows the Fels-Schwarzkopf (1975) algorithm and diurnal cycle is fully considered except for variations of the Sun’s azimuthal angle. Albedo is proportional to surface type and solar zenith angle. Surface hydrology is taken into account by a simple bucket scheme with 150 mm rainfall equivalent capacity. The soil moisture availability is a balance of evaporation, precipitation and snow melt. Surface temperature is evaluated based on the surface energy balance equation. This model has been widely used for research purposes applied to short range simulations over southern South America and Antarctica (Orlanski et al. 1991; Menéndez 1994; Saulo and Nicolini 1996; Seluchi and Saulo 1998, among others). It is also being used to provide experimental operative 72 h forecasts over Argentina and surrounding areas, with encouraging results.

The model domain covers almost all South America and the neighboring oceans at a gridpoint spacing of 1° × 1°. The orographies at the bottom boundary of both models are derived from the US Navy 10-min resolution data set, area-averaged to the required horizontal grids. Note that the regional model topography is narrower and much higher than the global model topography (Fig. 1). It can detect differences of more than 2000 m over certain regions at Central Andes.

Initial and boundary conditions

Global and regional models require the specification of sea surface temperatures and sea ice data throughout the simulation. Both models are forced by the climatological AMIP (Atmospheric Model Intercomparison Project) monthly mean values for the period 1979–88. The regional model also requires as initial condition the soil moisture, which is interpolated from the LMD-Z output. Initial and time-dependent atmospheric lateral boundary conditions are provided to the RCM from the global model simulation (one-way nesting). Temperature, horizontal wind components, specific humidity and surface pressure are interpolated from 6-hourly LMD-Z output. A bilinear interpolation is used to hori-