Currently there are attempts to operate Regional Climate Models (RCMs) with spatial resolution settings of 5 km gridspaces (Δx) of 10 km (e.g. Sulkitsch et al., 2008 and Awann et al., 2010) and even smaller. This effect is particularly important for RCMs that are larger than the gridspacing at which the model solves the governing equations. E.g., features of the size of 2 Δx and 3 Δx are filtered out to avoid numerical instabilities (e.g.aliasing effects). Also parameterizations in connection to advection, pressure gradient force, and subgrid-scale diffusion can only be well represented at dimensions of at least four times the gridspacing (Piekke, 2002 and Grasso, 2000).

The present work is focused on the determination of the effective resolution of RCMs operated at small gridspaces. Variance spectra of outputs of three models (PSU/NCAR model MM5, its successor WRF, and the German Community Model COSMO-CLM (CCLM)) operated at three gridspaces (1 km, 3 km, 10 km) are analysed on two altitude levels (700 hPa and near surface). The core study region (for intercomparison of high effective resolution model results) covers the Basin of Graz (South-East Styria) and has an area of about 74x74 km² (Fig. 1).

An extended study region for comparison of model results with their driving data (from the Integrated Forecasting System of the European Centre for Medium-Range Weather Forecast (IFS)) covers the entire Alpine area (Fig. 1).

I. Brief Overview

In Fig. 2 variance spectra of a CCLM simulation (air temperature at 2 m and at 700 hPa, wind speed at 700 hPa) with 10 km gridspacing are compared to spectra of its driving data (IFS, 20 km gridspacing) to analyse the small scale variability gained by dynamical downscaling. The CCLM spectra lie close to the IFS spectra for wavelengths larger than ~80 km (for 2 m air temperature, Fig. 2a) as well as ~110 km (for parameters at 700 hPa, Fig. 2b and 2c). At smaller scales CCLM adds additional variability.

The spectra of air temperature at 700 hPa (Fig. 2b) are smoother and of lower amount than those at 2 m (Fig. 2a), because of less influence of the orography which is a main driving force for simulated variability.

In Fig. 3 the performances of MM5-, CCLM-, and WRF-simulations with three different gridspaces are compared in the core region. The spectra of air temperature (Fig. 3a) resemble the spectra of altitude (Fig. 4) at wavelengths >10 Δx and there is an expected coherence throughout the models. At wavelengths <4 Δx the spectra show diverging (Fig. 3a) and partly unrealistic behaviour (e.g., CCLM 1 km in Fig. 3a and 3c, MM5 1 km in Fig. 3a and 3 km in Fig. 3b). The spectra of wind speed at 700 hPa (Fig. 3a and 3c) are close to each other for all three models for wavelengths >10 Δx. For smaller wavelengths the spectra are damped. Compared to the other models, the CCLM spectra (Fig. 3) have less damping over the whole wavelength range.

Compared to the driving data the nested simulation (CCLM) shows more variability below 4 Δx for the 2 m temperature and below 6 Δx for the parameters at 700 hPa (Δx in model downscaling lead to an added value due to dynamical downscaling at smaller scales).

Comparing the three RCMs, the spectra of most parameters show consistent shapes for wavelengths larger than 4 Δx to 10 Δx and the investigated models coincide at these scales. Going to smaller scales the variability decreases. At the smallest scales some simulations show a common spectral increase of variance indicating violations of the energy transfer from larger to smaller scales.

More comprehensive analyses (including summer, winter, and different parameters) have shown effective resolutions between 4 and 10 Δx depending on the investigated parameter. Currently the simulated data is compared to the analysis of the nowcasting simulation systems (1 km gridspacing) of the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) and to a dense observation network in Eastern Styria, Austria (WegenerNet, www.wegenernet.org).

References:
Awann, R. and T. Truhetz, and A. Gobiet (2010), Parameterization induced error characteristics of MM5 and WRF operated in climate mode over the Alpine Region: An ensemble based analysis.

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II. Effective Resolution from Variance Spectra

To determine the effective resolution spatial variance spectra are derived from the model results. To construct the variance spectra the fields are decomposed using the Discrete Cosine Transform (DCT) (Dennis et al., 2002). (Eq. 1).

The DCT is a sort of Fourier Transform, which can handle aperiodic fields.

The variances are calculated from the spectral coefficients F(m,n) which are gained from the decomposition (Eq. 1). To obtain the variance spectra the variances are displayed as a function of scale (spatial wavelengths) of the analysed atmospheric field.

In this study the effective resolution of a model is defined as the wavelength at which its variance spectrum deviates from a higher resolved simulation’s spectrum.

\[ F(m,n) = \frac{1}{2} \left[ \sum_{i=0}^{N_x/2-1} \sum_{j=0}^{N_y/2-1} f(i,j) \cos \left( \frac{(i+1/2)\pi}{N_x} j \right) \right] \]

\[ \sigma^2 = \frac{1}{2} \left[ \sum_{i=0}^{N_x/2-1} \sum_{j=0}^{N_y/2-1} (f(i,j) - \bar{f}(i,j))^2 \cos \left( \frac{(i+1/2)\pi}{N_x} j \right) \right] \]

\[ \bar{f}(i,j) = \frac{1}{N_x \times N_y} \sum_{i=0}^{N_x-1} \sum_{j=0}^{N_y-1} f(i,j) \]

Eq. 1: Discrete Cosine Transform (m...columns, n... rows, Ni, Nj: total amount of gridpoints in east- and northward direction).

Determination of the Effective Resolution of Regional Climate Models

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