Determination of the Effective Resolution of Regional Climate Models

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R e L o C l i m

I. Brief Overview

Currently there are attempts to operate Regional Climate Models (**RCM**s) with spatial model resolutions (numeric grid spacings, Δx) of 10 km (e.g. Suklitsch et al., 2008 and Awan et al., 2010) and even smaller.

The effective resolution of a RCM is 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 (Pielke, 2002 and Grasso, 2000).

The present work is focused on the determination of the effective resolution of RCMs operated at small gridspacings. 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 gridspacings (1 km, 3 km, 10 km) are analysed on two altitude levels (at 700 hPa and near surface). The core study region (for intercomparison of high 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).

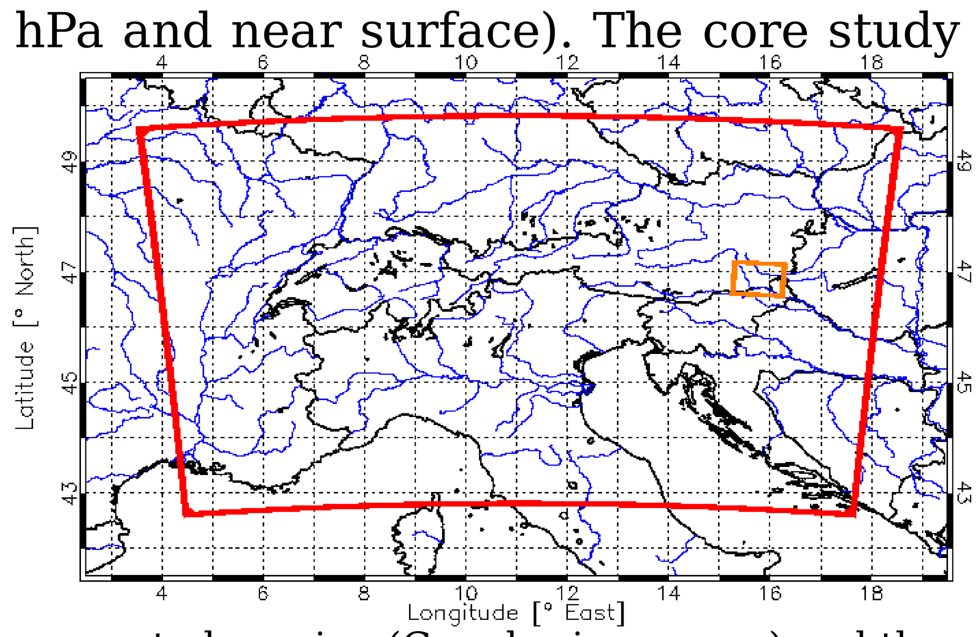


Fig. 1: Map of the core study region (Graz basin, orange) and the extended study region (Alpine area, red).

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**), (Denis 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.

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

$$\beta(m) = \begin{cases} \sqrt{\frac{1}{N_i}}, & \text{for } m = 0 \\ \sqrt{\frac{2}{N_i}}, & \text{for } m = 1,2,\ldots,N_i-1 \end{cases} \qquad \beta(n) = \begin{cases} \sqrt{\frac{1}{N_j}}, & \text{for } n = 0 \\ \sqrt{\frac{2}{N_j}}, & \text{for } n = 1,2,\ldots,N_j-1 \end{cases}$$

Eq. 1: Discrete Cosine Transform (m,i ... columns; n,j ... rows; N_i, N_j... total amount of gridpoints in east- and northward direction).

III. Results

In Fig. 2 a variance spectrum of a CCLM simulation (horizontal wind speed at 700 hPa) with 10 km gridspacing is compared to a spectrum of its driving data (IFS, 20 km gridspacing) to analyse the small scale variability gained by dynamical downscaling. The CCLM spectrum lies slightly above the IFS spectrum for wavelengths larger than ~110 km. At smaller scales CCLM adds additional variability.

In Fig. 3 the performances of MM5-, CCLM-, and WRF-simulations with three different gridspacings are compared in the core region. The spectra of 2 m air temperature (Fig. 3b) resemble the spectra of the altitude (Fig. 3a) at wavelengths >10 Δx and there is an expected coherence throughout the models. At wavelengths <4 Δx the spectra show diverging (Fig. 3b) and partly unrealistic behaviour (e.g., CCLM 1 km in Fig. 3b and 3d, MM5 1 km in Fig. 3b and 3 km in Fig. 3c). The spectra of air temperature at 700 hPa (Fig. 3c) are smoother and of lower amount than those at 2 m (Fig. 3b), because of less influence of the orography which is a main driving force for simulated variability. The spectra of air temperature and wind speed at 700 hPa (Fig. 3c and 3d) 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. In Fig. 4 spectra of MM5-, CCLM-, and WRF-runs with varying setups in the core region (wind speed at 700 hPa with 1 km gridspacing) are shown. At the smallest wavelength of 2 km the spectra have a range in the variances of three magnitudes.

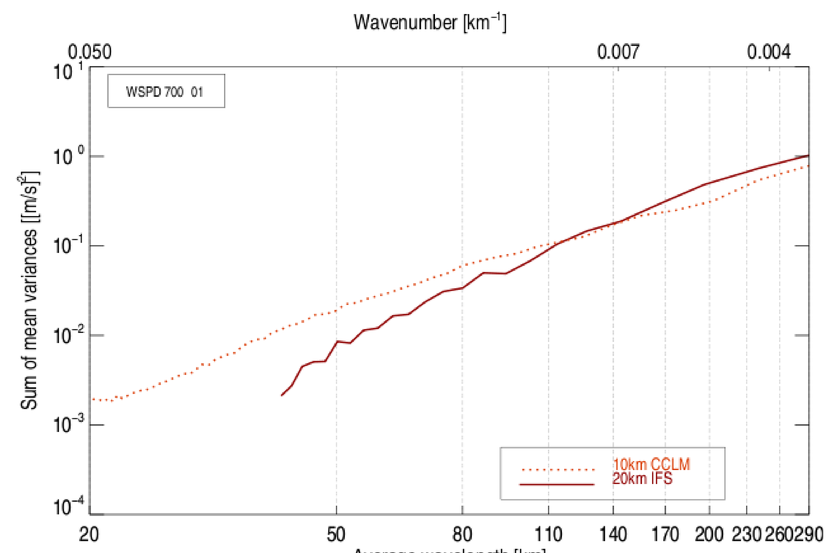


Fig. 2 (left): Variance spectra of wind speed at 700 hPa height in January 2008. Spectra of CCLM- (dotted), and IFS-simulations (continous) with 10 km and 20 km gridspacing are shown, referring to the model domain covering the Alpine region (Fig. 1).

Fig. 4 (right): Variance spectra of wind speed at 700 hPA height in July 2008. Spectra of a bunch of MM5- (red), CCLM- (green), and WRF-runs (blue) with 10 km, 3 km, and 1 km gridspacing are shown, referring to the model domain covering the Basin of Graz (Fig. 1).

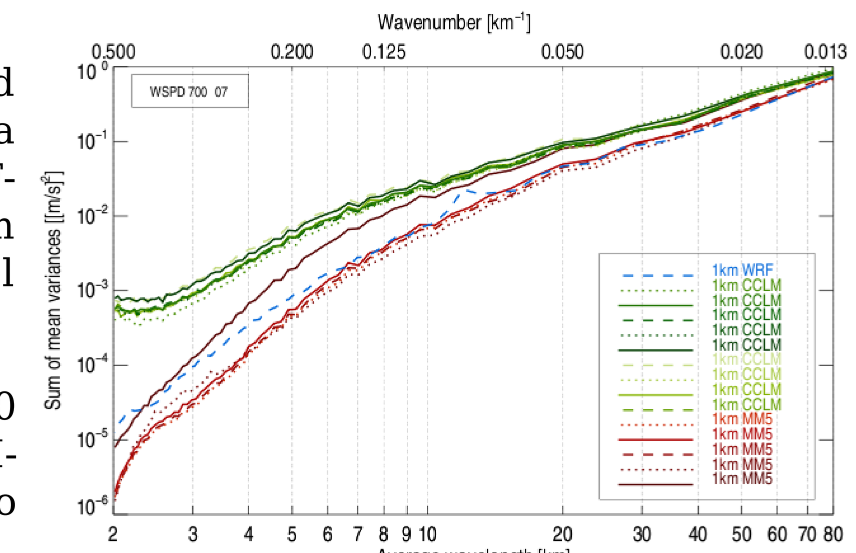
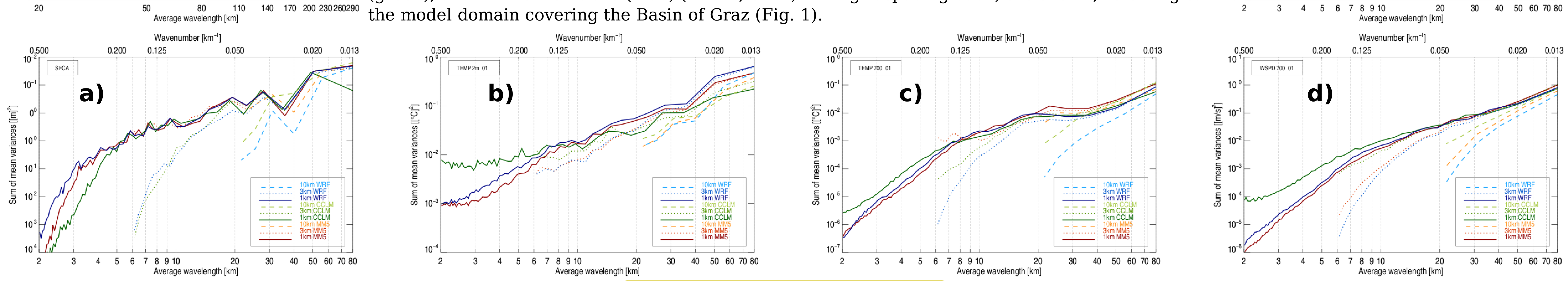


Fig. 3 (below): Variance spectra of **a)** surface altitude, **b)** air temperature at 2 m and **c)** at 700 hPA, and **d)** wind speed at 700 hPa height in January 2008. Spectra of MM5- (red), CCLM- (green), and WRF-simulations (blue) (10 km, 3 km, 1 km gridspacing each) are shown, referring to the model domain covering the Basin of Graz (Fig. 1).



IV. Conclusions and Outlook

Compared to the driving data the nested simulation (CCLM) shows more variability below 6 Δx for the wind speed at 700 hPA (Δx in terms of driving data) indicating an added value due to dynamical downscaling.

Comparing the three RCMs, the spectra of most parameters show consistent shapes for wavelengths larger then 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 an unrealistic increase of variability which indicates violations of the energy transfer from larger to smaller scales and a spread of variances depending on the model and its setup (wind speed spectra at 700 hPa). 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 system INCA (1 km gridspacing) of the Austrian Central Institute for Meteorology and Geodynamic (ZAMG) and to a dense observation network in Eastern Styria, Austria (Wegener Net, www.wegenernet.org).

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