Convergence behavior of convection-resolving simulations of summertime deep convection over land

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1. Introduction

The truncation of the continuous energy cascade at scales of $\mathcal{O}(1\,\mathrm{km})$ poses a challenge for convection-resolving models, as the size and properties of the simulated convective features are often determined by the horizontal grid spacing Δx. Several idealized studies have shown that *structural convergence* of statistics and scales of individual clouds and updrafts is not yet achieved at the kilometer scale. On the other hand, *bulk convergence* of domain-averaged and integrated variables related to a large ensemble of convective cells was found in real-case simulations over the Alps (Langhans et al., 2012). This study compares bulk and structural convergence in idealized and real-case simulations of the diurnal cycle of convection over land. Different experiments are conducted to identify those physical processes and parameterizations which foster convergence.

2. Idealized simulations

Model and setup

- COSMO v5.0, $\Delta x = 8$, 4, 2, 1 km and 500 m
- Domain $200 \times 200\,\mathrm{km}^2$, simulation length 5 days
- Initialized with idealized T and RH profiles
- 5 ensemble members per experiment
- Explicit convection, 1.5-order TKE scheme for vertical eddy viscosities, Smagorinsky closure for horizontal eddy viscosities, interactive soil model

Experiment List	
CTRL	standard setup
MOUNTAIN	CTRL + 3D gauss mountain
WIND	CTRL + env. wind shear
PRESCR	CTRL w. prescr sfc. fluxes
PRESCR_NORAD	PRESCR w.o. rad. scheme

- Smaller and more numerous clouds at smaller Δx.
- More than 50 % of simulated clouds at $\Delta x = 2$ km and coarser grid spacings are only one grid box in size.
- More vigorous convective cells with finer grid spacing.

$\longrightarrow$ Structural convergence is not yet achieved.

- Although the resolution sensitivity ($NRI^*_{\Delta x}$) varies between the experiments, it generally decreases toward smaller Δx.

$\longrightarrow$ Bulk convergence is achieved.

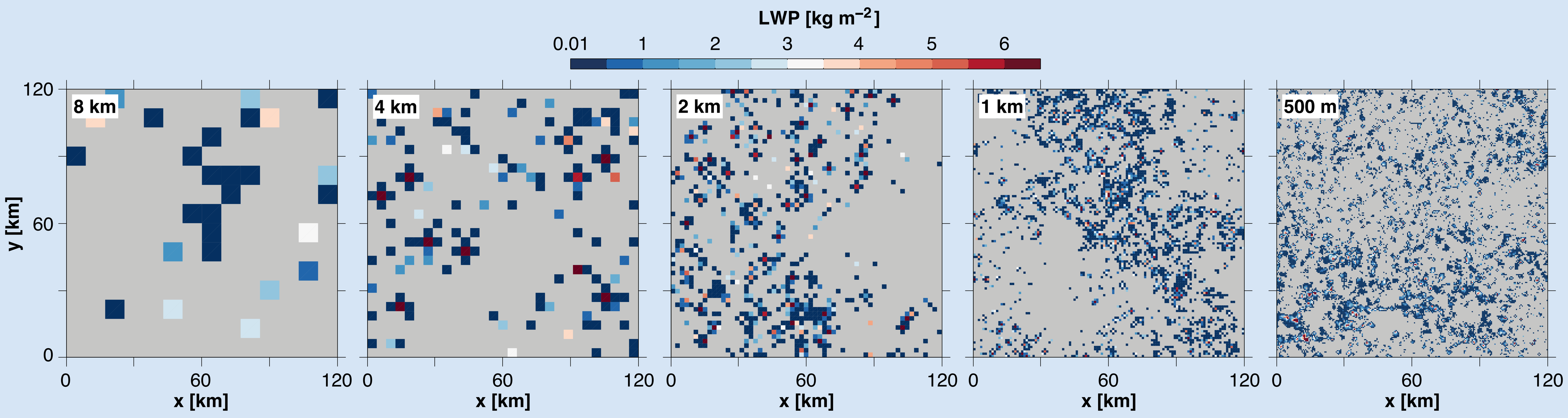

Fig. 1: Liquid water path (LWP [kg m^{-2}], threshold of 0.01 kg m^{-2}) in a $120 \times 120\,\mathrm{km}^2$ subdomain located at the bottom left corner of the model domain simulated at different horizontal grid spacings at the peak time of precipitation of the first simulation day in CTRL.

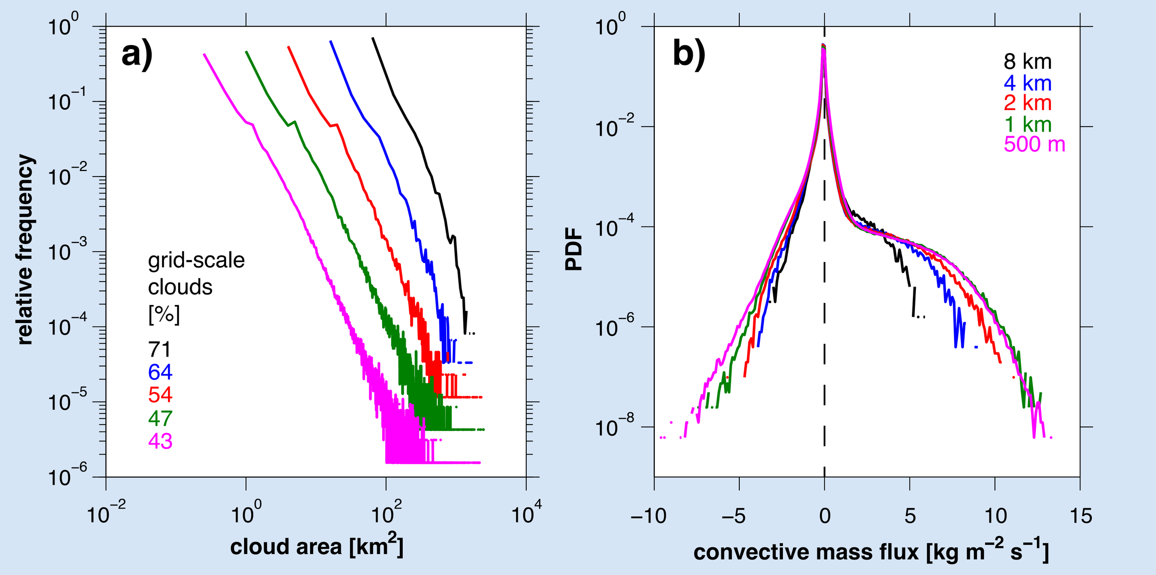

Fig. 2: Probability density functions of (a) cloud horizontal area [m^2] (cloud-size distribution) and (b) convective mass flux at 3000 m height in CTRL. The numbers at the bottom left corner in (a) indicate the percentage of grid-scale clouds (i.e. clouds that are only one grid box in size).

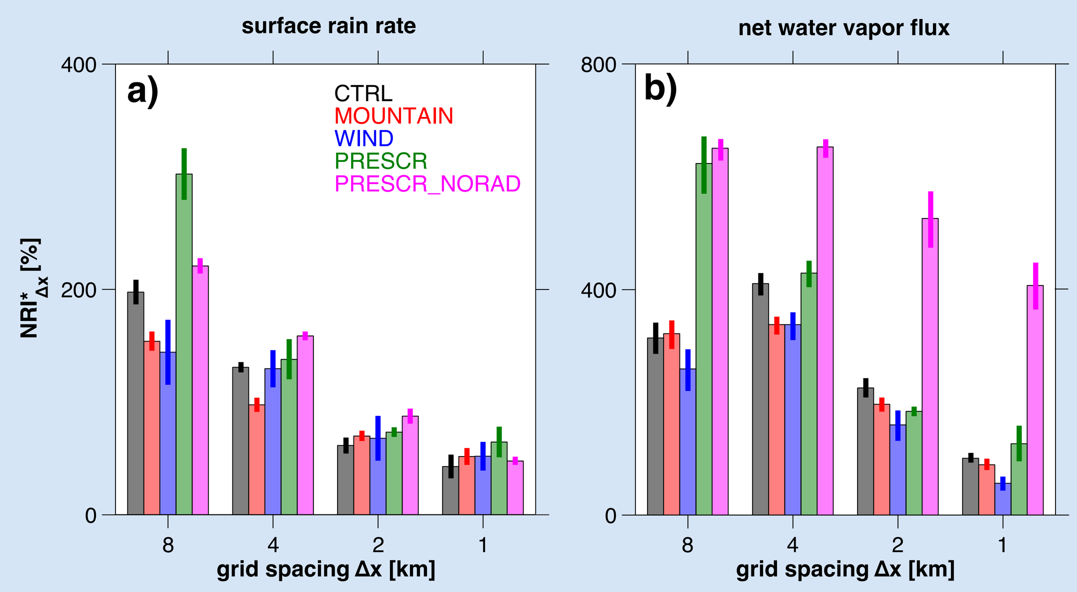

Fig. 3: Ensemble-averaged normalized resolution increment ($NRI^*_{\Delta x}$ [%]) versus the horizontal grid spacing Δx computed for the mean diurnal cycles of (a) domain-averaged surface rain rate and (b) net water vapor fluxes between the lower and mid-level troposphere. The bars illustrate the ensemble spread for each experiment. The $NRI^*_{\Delta x}$ is a measure of the relative differences between the diurnal cycles simulated at Δx and $\Delta x/2$.

3. Real-case simulations

Model and setup

- COSMO v5.0, $\Delta x = 8.8$, 4.4, 2.2, 1.1 km and 550 m
- Initialized and driven by $\Delta x = 12$ km simulation
- Model domain $1160 \times 1090\,\mathrm{km}^2$ centered over the Alps (ALP) and Central Germany (DE)
- 9 days of reoccurring convection with little large-scale forcing (11-20 July 2006 for ALP; 4-13 June 2007 for DE).
- External parameters filtered at $\Delta x = 8.8$ km
- Explicit convection, 1.5-order TKE scheme for vertical eddy viscosities, Smagorinsky closure for horizontal eddy viscosities, interactive soil model

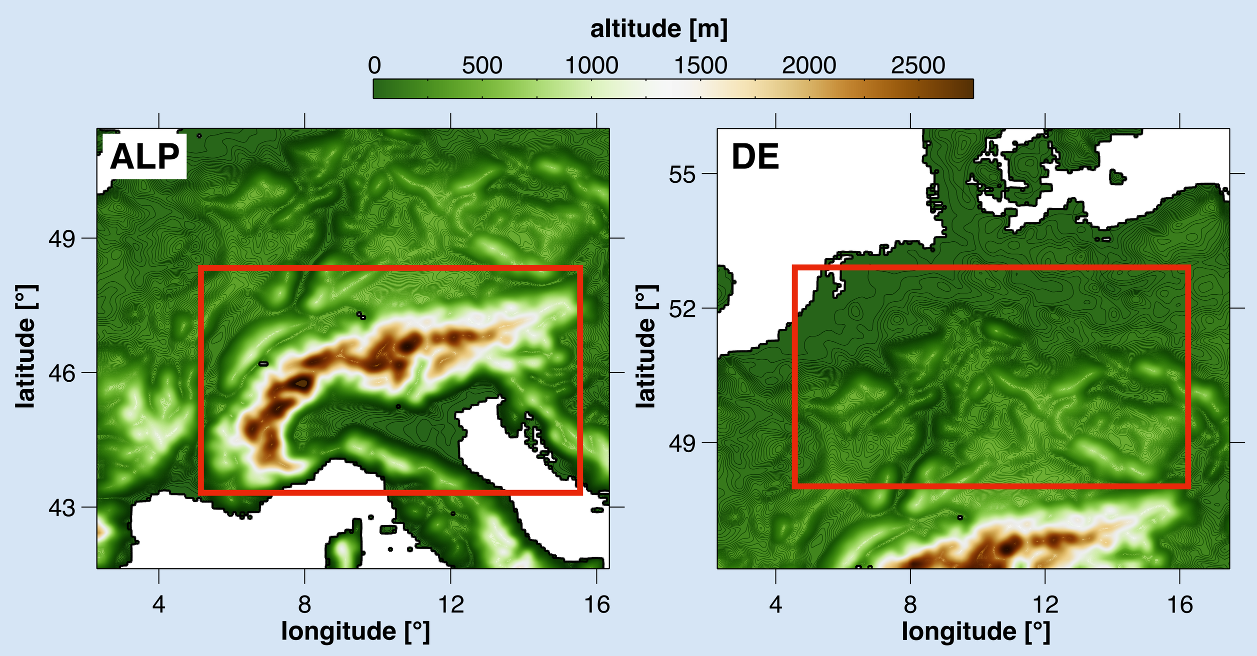

Fig. 4: Integration domain and topography in ALP (left panel) and DE (right panel) at $\Delta x = 2.2$ km. The analysis domain is illustrated by the red box.

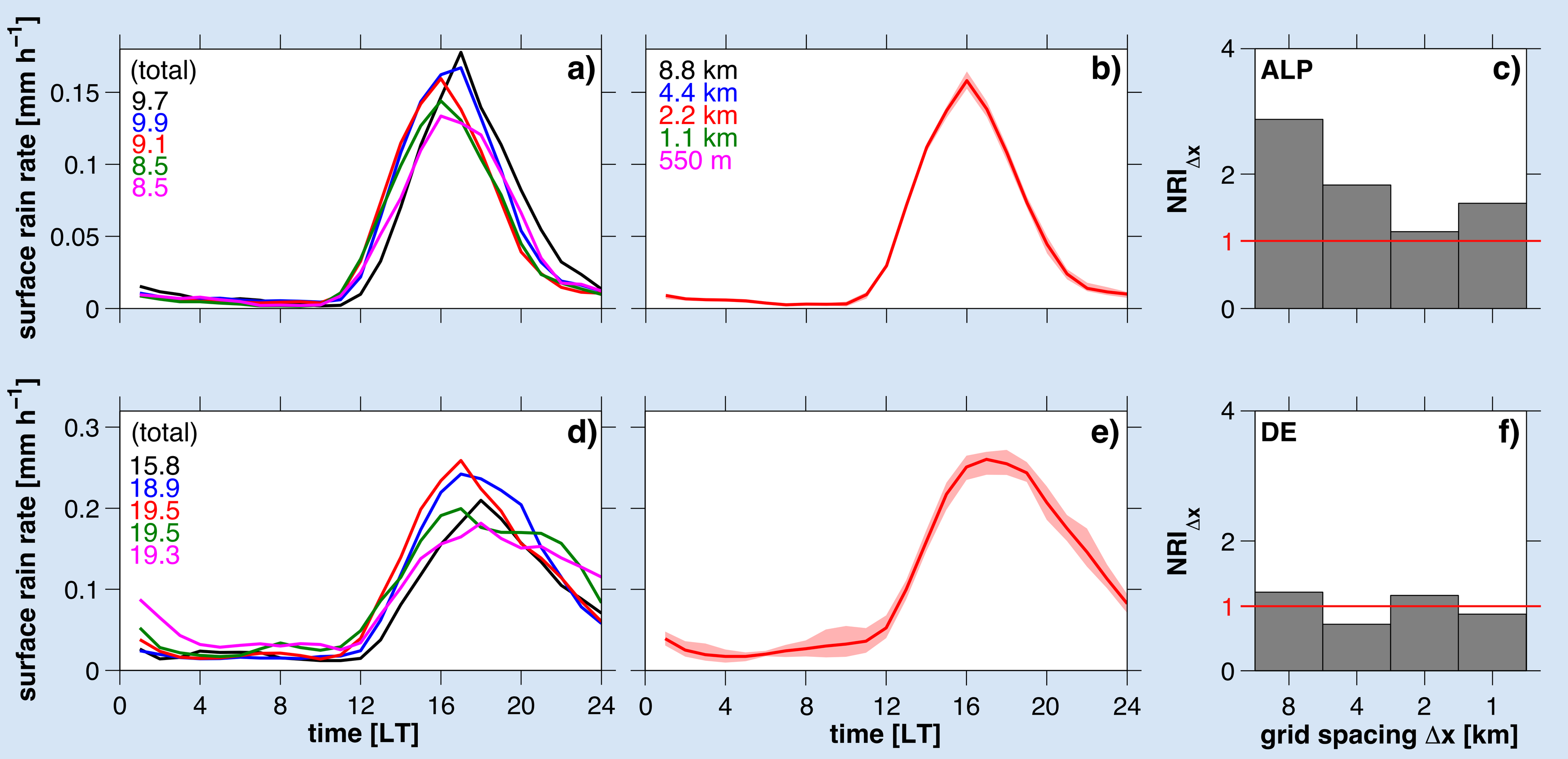

Fig. 5: (a, b, d, e) Mean diurnal cycles of domain-averaged surface rain rate [mm h^{-1}] at (a, d) different horizontal grid spacings and (b, e) in the $\Delta x = 2.2$ km ensembles and (c, f) normalized resolution increment (NRI$_{\Delta x}$) versus the horizontal grid spacing Δx computed for the mean diurnal cycle of surface rain rate in (a, b, c) ALP and (d, e, f) DE. In (a) and (d) the numbers at the top left corner indicate the total accumulated precipitation. In (b) and (e) the red shading illustrates the ensemble spread. In (c) and (f) the NRI$_{\Delta x}$ is computed as the root mean squared difference between the diurnal cycles simulated at Δx and at $\Delta x/2$ normalized by the mean ensemble spread, and the red lines indicate the point at which the two are equal.

- Resolution sensitivity and ensemble spread larger in DE than in ALP, owing to the lack of mesoscale orographic forcing.
- Bulk convergence observed in ALP until $\Delta x = 1.1$ km.
- Bulk convergence cannot be demonstrated when resolution sensitivity is comparable with ensemble spread.

6. Conclusions

- **Although structural convergence is not yet fully achieved at the kilometer-scale, bulk convergence is generally observed in idealized simulations.**
- **In real-case simulations bulk convergence can be demonstrated as long as the resolution sensitivity is larger than the model internal variability. The lack of mesoscale orographic forcing in simulations over Central Germany leads to a larger ensemble spread and thus makes it harder to assess bulk convergence compared to the Alpine domain.**

References

Langhans, W., J. Schmidli, and C. Schär, 2012: Bulk convergence of cloud-resolving simulations of moist convection over complex terrain. *J. Atmos. Sci.*, **69 (7)**, 2207-2228.

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