Evaluation of Central European and Eastern Alpine seasonal climate simulated with CCLM: double nesting vs. direct forcing techniques

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1. Introduction

Various types of Regional Climate Models (RCMs) have been applied for dynamical downscaling of low-resolution global climate (General Circulation Model - GCM) simulations or atmospheric reanalyses for different regions of the world (see for example Fu et al. 2005; Jacob et al. 2007; Rockel and Geyer, 2008). With increasing computational power the grid size of RCMs is decreasing, but new issues concerning the use of nested RCM as a climate downscaling technique arises. Many of them have received considerable attention in the scientific literature (Sun and Ward (2007) and references therein). For example, physical parameterization schemes were designed to mimic unresolved processes on the coarser GCM grid (50 - 200 km) and they are not adequate for convection permitting ($\sim 2km$) RCM simulations, but most of the RCMs apply the same parameterization schemes as the GCMs. Another example is the sensitivity to the spatial resolution and temporal update of lateral boundary conditions. Denis et al (2003) found that satisfactory results are achieved when spatial resolution is degraded by up to factor of 12, but their nested experiment was at 45 km resolution and today the RCM community is going towards approaching a convection resolving scale in regional climate simulations (see Hohenegger et al. 2009. for the Cosmo Climate Local Model (CCLM) example).

At the last CCLM Assembly (September 2009, Karlsruhe) a Convection Resolving Climate Simulations (CRCS) working group was established. One of the first issues that turns out at the working group session was, if there are some standard techniques, hints, and settings how to design an experiment in order to perform high resolution (grid scale 3 km or less) climate simulations? In the frame of the Local climate Model Intercomparison Project LocMIP (Gobiet et al 2009), we have performed several experiments at $0.09°(\sim 10km)$ and $0.025°(\sim 2.8km)$ grid resolution. Comparison of results for two various nesting techniques (direct and double) and evaluations against their forcing fields were performed. This newsletter, together with technical documentation (namelist, run scripts, and other input and output files) available on the CCLM community web site, might be considered as a first step towards setting standard rules for convection resolving climate simulations with the CCLM model.

The article is organized as follows. Three experiments, abbreviated as CEU (Central Europe), EA1 (Eastern Alps direct nesting) and EA2 (Eastern Alps double nesting), are presented and briefly described in the next section, followed by results in section 3. Summary and outlook are provided in the final section.

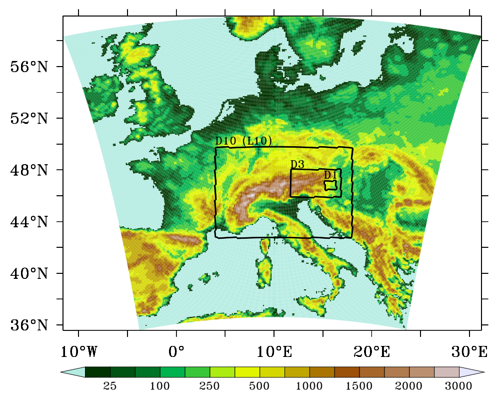
2. Experimental setup

Topography and evaluation domains are shown in figure 1. Relevant namelist parameter settings of int2lm and cclm are sumarized in the tables 1 and 2, respectively. The resolution of simulation CEU is 10 km and settings are similar to the COSMO-EU (Schulz and Schättler,

2009) standard configuration used at DWD for operational weather forecast at date, with different forcing and some modification specific for climate simulations[3].

Lateral boundary conditions (LBC) are interpolated from ECMWFs integrated forecast system (IFS) dataset (Untch et al. 2006) at 3h intervals. EA1 and EA2 are simulated at 2.8 km resolution and namelist settings are similar to COSMO-DE (Baldauf et al, 2009) setup with the same climate modifications as for the 10km simulation. Lateral boundary conditions for the EA2 are interpolated from the CEU simulation at 3h intervals, so this is an example of a double nested experiment, while the EA1 is directly driven by IFS lateral boundary conditions updated every 3h (figure 2). Some differences between CEU and COSMO-EU were necessary in the preprocessing step due to the fact that lateral boundary conditions are provided by different sources (IFS and GME). The same differences also apply for EA1, EA2 simulations in comparison to COSMO-DE. The main difference between 10 km (CEU) and the 2.8 km (EA1 and EA2) simulations is that former is performed with three time level (leap-frog) scheme, while the latter utilizes the two time level (Runge-Kutta) scheme (l2tls=.TRUE.). Convection parametrization in the former utilizes Tiedtke scheme and the latter shallow convection (itype_conv=3). The grid scale precipitation (itype_gscp) scheme used for both 2.8 km simulations includes all available components (rain, snow, ice and graupel), while CEU utilize only three of them (rain, snow and ice).

All simulations are performed for two seasons: summer 2007 (May, June, July, and August - MJJA) and winter 2007/2008 (November, December, January, and February - NDJF). Analysis is performed for three evaluation domains as defined in the framework of the LocMIP project (figure 1 adopted from Gobiet et al, 2009). Domains D10 and L10 (land only inside D10 domain) are chosen since they represent the entire Alpine region. Domains D3 and D1 represent regions of interest for which high-resolution observations should be available in the near future.



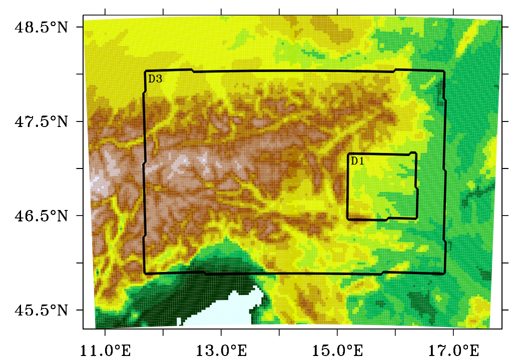


Figure 1: Model domains with topography and evaluation domains for experiment CEU (top) and experiments EA1 and EA2 (bottom). Results will be discussed for the 3 black rectangular evaluation domains: L10 (land only inside D10 domain), D3 and D1. The largest domain L10 only exist for the CEU experiment.

[3] There are two main differences between climate simulations and weather prediction: (*i*) the discretization of the soil layers and (*ii*) the CO_2 concentration. Usually 9 soil layers with grid stretching (ratio between two neighbouring layers) 2 are used in climate simulation instead of 7 layers in weather prediction mode with grid stretching 3 and CO_2 concentration is set to default 360 ppm constant value, while in climate mode equivalent CO_2 increasing in time is considered.

experiment	CEU	EA1	EA2
LBC and SST data	IFS 0.225°	IFS 0.225°	CEU 0.09°
lmgrid	252 × 260 × 40	192 × 132 × 50	192 × 132 × 50
hincbound	3h	3h	3h
irefatm	1	2	2
ivctype	1	2	2
dlon, dlat	0.09°	0.025°	0.025°
lvertwind_ini	T	T	T
lvertwind_bd	F	F	F
lprog_qi	T	T	T
lprog_qrqs	F	F	T
lprog_qg	F	F	F
lprog_rho_sno	F	F	F
lboundaries	F	F	F
itype_w_so_rel	1	1	1
itype_t_cl	1	1	0
itype_rootdp	3	3	3
lmulti_layer_lm	T	T	T
lmulti_layer_in	F	F	T
lbdclim	T	T	T
lforest	T	T	T
lsso	T	F	F
l_cressman	T	T	T

Table 1: Relevant int2lm namelist parameter settings. Preprocessing is performed with int2lm_1.9_clm3 version.

experiment	CEU	EA1	EA2
dt	60s	25s	25s
l2tls	F	T	T
lhdiff_mask	F	T	T
ldyn_bbc	F	T	T
rlwidth	Not used	30000 m	30000 m
irunge_kutta	Not used	1	1
lgsp	T	T	T
lprogprec	T	T	T
itype_conv	0	3	3
lconv_inst	F	T	T
ltype_gscp	3	4	4

Table 2: Relevant cclm namelist parameter settings. All simulations are performed with cclm_4.8_clm6 version.

3. Precipitation and temperature at 2m

We analysed and evaluated the monthly mean air temperature at 2m (T_2m) and the monthly sum of precipitation averaged over the evaluation domains described in the previous section. The results are compared with three reference data sets: (*i*) IFS, (*ii*) E-OBS (Haylock et al, 2008) and (*iii*) GPCC (precipitation only for summer season and November to December 2007) data (see Schneider et al 2008 for the description of the GPCC dataset).

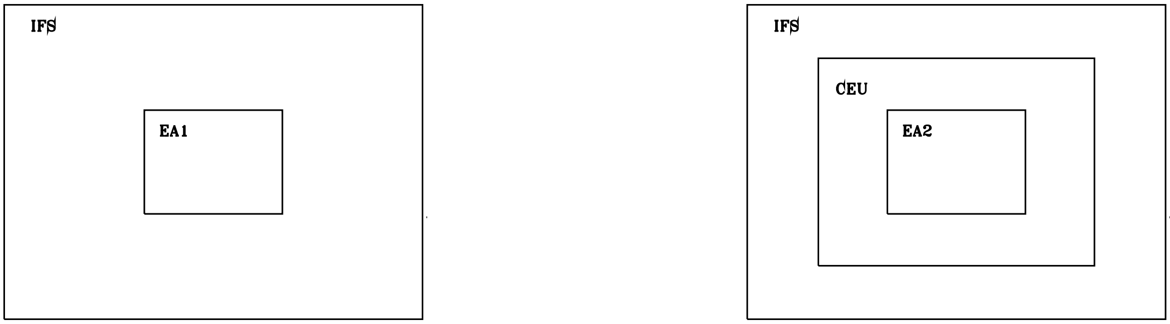


Figure 2: Nesting schemes: direct nesting scheme (on the left hand side) IFS data are used for forcing EA1 experiment; double nesting scheme (on the right hand side) IFS data are used for forcing CEU experiment, and then CEU simulation is used as the forcing for EA2 experiment.

Figure 3 shows monthly precipitation sums (left), and T_2m monthly means (right). Both averaged over L10 evaluation domain (figure 1, top). During the summer months (MJJA) CEU has less ($\sim 15mm/month$) precipitation than the IFS dataset, but it has the same amount as GPCC interpolated observed precipitation for May and August, slightly more ($\sim 20mm/month$) in June, and less ($\sim 10mm/month$) in July. In total (4 month sum) CEU generates only 13 mm less than GPCC and is closer to the climatological observation than IFS analysis which has 40 mm higher value than GPCC. The other observational dataset E-OBS is the driest one, up to 20 mm/month less precipitation then GPCC. During winter CEU is up to $20mm/month$ wetter than IFS dataset and even $25-30mm/month$ than the observed GPCC (November and December only) precipitation, and up to $40mm/month$ wetter than E-OBS. During February, the difference between CEU and IFS reduces to $5-10mm/month$, but this is still $\sim 20mm/month$ more than E-OBS, while the GPCC precipitation was not available for January and February. CEU obtained T_2m averaged over the L10 domain shows a small cold bias of up to $1K$ during the July and most of the winter months (November, January and February) in comparison to IFS driving data. In comparison with E-OBS observation, CEU has even more pronounced cold bias during winter since E-OBS is about $0.5K$ warmer than IFS dataset. During summer, there is no significant difference between IFS and E-OBS dataset.

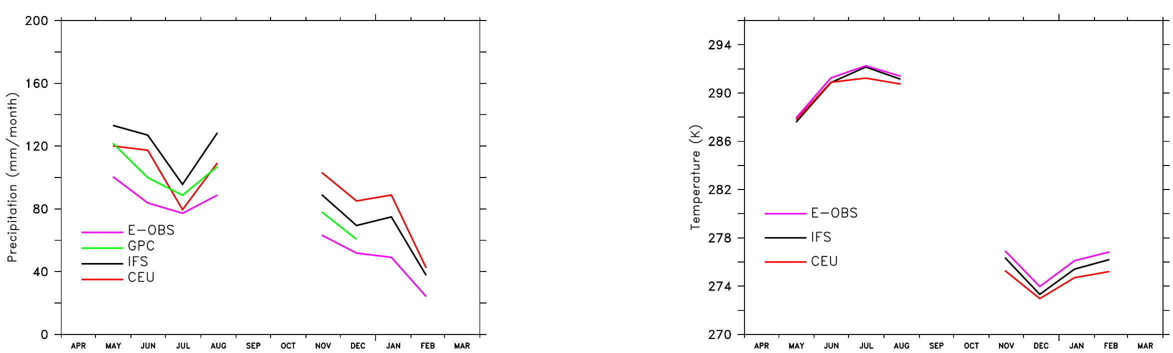


Figure 3: Precipitation in $mm/month$ (left) and T_2m in K (right) for the L10 domain (land points of D10, figure 1).

Figure 4 shows the same results for D3 domain. Both high-resolution simulations (EA1 and EA2) show a wet bias in summer compared to their forcing data (IFS and CEU, respectively) and both observational (GPCC and E-OBS) datasets. In extreme case the bias is up to $\sim 90mm/month$ (June compared to E-OBS). Such a huge discrepancy from reference data sets, especially compared to CEU simulation, indicates a considerable influence of the different settings (namelist parameters, table 2, domain and resolution) of the two high-resolution simulations compared with the CEU simulation. CEU fits nicely between the two (IFS and GPCC) reference datasets in May and June, but has a dry bias ($\sim 30mm/month$) in July and fits with E-OBS dataset. In August CEU precipitation is the same as GPCC reference data. Similar as for the L10 domain, E-OBS interpolated observation presents the driest climate for the D3 domain. During the winter months both high-resolution simulations precipitation are more or less the same as the precipitation of their corresponding forcing (EA1 driven directly by IFS and EA2 driven by CEU) indicating a substantial influence of convection on the wet summer bias. Since IFS precipitation fits better with both observational data sets (GPCC and E-OBS), EA1 (IFS driven simulation) shows better results than EA2 (double nested, CEU driven simulation). CEU performs similar as on L10 domain, it has a dry bias during summer and a wet bias during winter compared with IFS data. Similar as before T_2m (figure 4, right) of CEU has a weak cold bias of about $1K$ during July, November and February and agrees quite well with IFS data during the other months. EA2 shows warm bias compared to its forcing data (CEU), but fits better with IFS data. EA1 is slightly warmer than IFS forcing data. E-OBS is slightly warmer than IFS, therefore both high-resolution simulation during summer (especially EA1) are in good agreement with E-OBS.

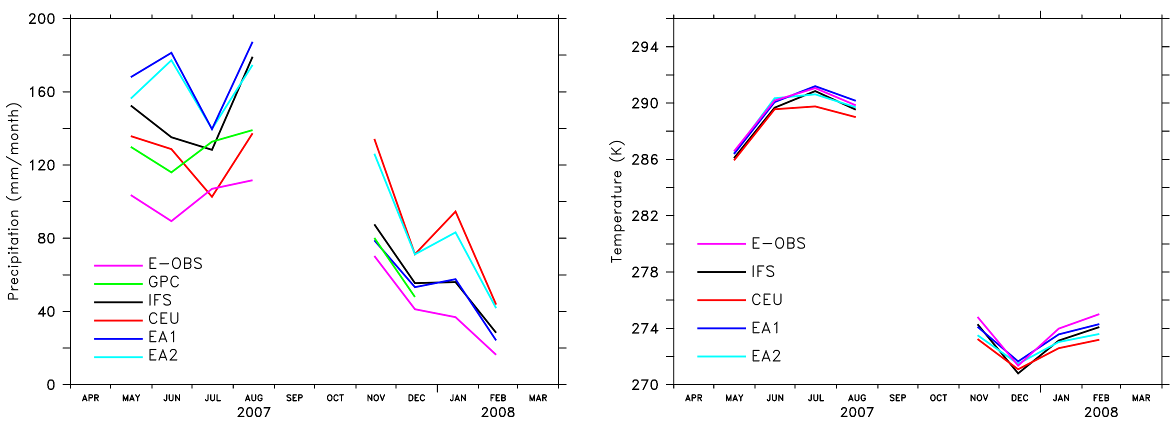


Figure 4: Precipitation in $mm/month$ (left) and T_2m in K (right) for the D3 domain.

Results for D1 domain (figure 1) are shown in figure 5. During summer both high-resolution simulations produce more precipitation than the simulations providing the lateral boundary conditions (forcings data), with exception of EA1 in May, which is a bit dryer than IFS. However, CEU has a strong dry bias compared to its IFS forcing, therefore EA2, although wetter than its forcing (CEU), is drier than IFS and it shows about $50mm/month$ less than GPCC in July but exactly the same amount of precipitation in August. In total, during summer only directly nested high-resolution run EA1 produces more precipitation than IFS. However, note the large deviation between IFS and GPCC. Except for July IFS has much more precipitation than GPCC. E-OBS is up to $30mm/month$ dryer than GPCC interpolated observation. During winter EA1 has a dry bias compared to its IFS forcing. EA2 has equally distributed their positive and negative discrepancies from its forcing CEU data, but it is in very good agreement with IFS data. EA1 is in good agreement with E-OBS in November, January and February. Temperature shows similar distributions as for the D3 domain, except that D1 is about 3K warmer in summer, and about 2K in winter. In general it can be seen that during summer EA1 and EA2 show similar climate to each other, while during the winter each highly resolved simulation is more similar to their corresponding forcing. This is probably due to the predominating influence of large scale dynamics on the climate during the winter months, while during the summer local convective processes predominate the climate in the region

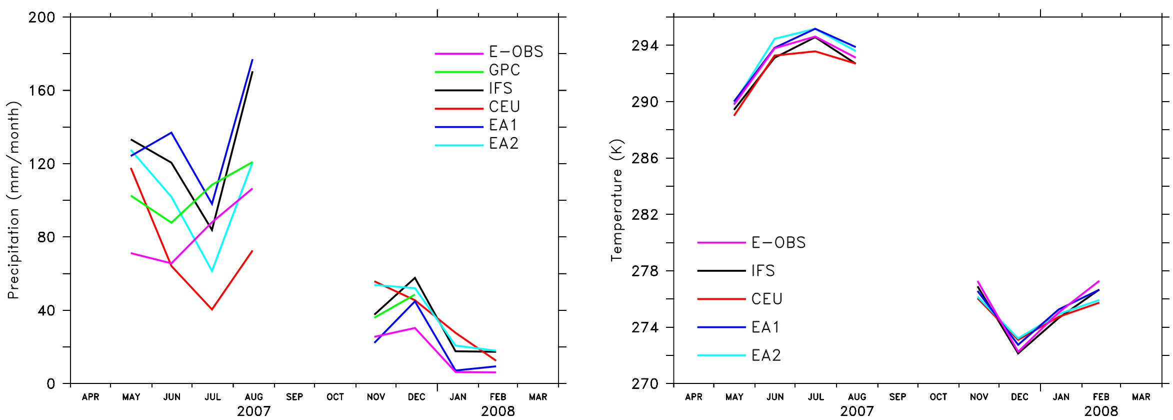


Figure 5: Precipitation (left) in $mm/month$ and T_2m in K (right) for the D1 domain.

The phenomenon can be even better seen on the spatial distribution of temperature and precipitation, therefore, in addition to the area-averaged values of the evaluation domains, the geographical distribution of model results compared to their forcing is presented. Our focus is on continental Central Europe, especially the Alpine region and the mid-range mountains. Figure 6 depicts the difference fields between CEU and IFS forcing for seasonal means of JJA 2007 and DJF 2007/2008. Summer is characterized with increased precipitation in CEU compared with IFS in the central region north of the Alps and along the eastern and above the ocean along the northern border of the domain. CEU produces a considerable decrease (more than $2mm/day$) in precipitation in flatland, especially in the Po valley and the Panonian basin. A decrease can also be seen along the north and north western coastlines of the Baltic Sea and the Atlantic ocean. During the winter CEU produces more precipitation in the northern and north-eastern region. Sea-land contrast can be seen especially along the southern Scandinavian coastline. Above the British island sea-land contrast and a better presentation of topographic features interferes and both effects contribute to the different precipitation pattern between the two models. Some features typical for better presentation of surface properties i.e. the downscaling effect could be also seen for some mid-range mountains and intermediate watersheds. See for example the region around Rhone valley, Vosges, and Jura mountain, or the region of the Pyrenees, together with the watershed of Ebro and Garone rivers. Furthermore, orographic precipitation (see Roe, 2005, for a comprehensive review) i.e. the shadowing effect behind Dinaric Alps and Apennine especially during winter seems to be by far better represented with CEU model due to a better horizontal resolution. Higher precipitation during winter on the south-eastern flank of the Alps is probably due to overemphasized mesoscale processes above the Adriatic Sea and corresponding cyclonic circulation in the CEU compared to IFS model. This is also in agreement with results from our work in progress, evaluation of CCLM simulations with IFS and Tiedke convection scheme. However, to make final conclusion, which model provide a better climate reproduction, a high-resolution observations are needed.

Although a height correction is applied to the temperature fields, topographic signatures could be still seen in the temperature difference distribution. Mountain ranges which are better resolved in CEU and therefore higher, are colder than their counterparts in the IFS forcing dataset. During the summer, the Po watershed and the Pannonian basin are warmer than the corresponding areas in the IFS dataset. All of the central, north, and north-eastern Europe is characterized by a cold bias of up to $1.5K$ in the CEU simulation. During winter the situation is quite similar. One exception is the Po watershed which is colder then the corresponding area in the IFS dataset, indicating different regional and seasonal dynamics. Again, high-resolution observations are needed in order to make final conclusion which of the models provided a better presentation of the real conditions during the specific season.

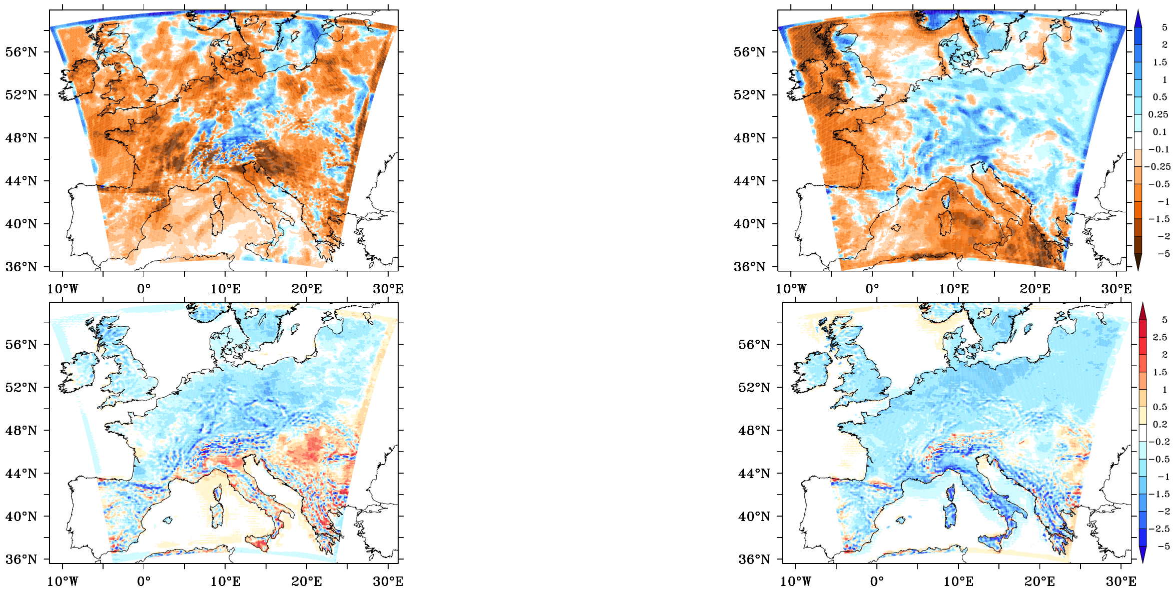


Figure 6: Precipitation (top) difference between CEU and IFS in mm/day and T_2m in K (bottom) for JJA 2007 (left) and DJF 2007/2008 (right).

The uncertainty caused by the nesting model technique (direct versus double nesting) is presented by the comparison of EA1 versus EA2 simulations (figure 7). The comparison of precipitation fields between both EA experiments indicates that a direct nested simulation overestimates precipitation at lateral boundaries, resulting especially during the winter in a dryer interior of the domain. During winter, both direct and the double nested simulations resemble features of their driving simulations. During summer overestimated precipitation in the direct simulation is limited only to the western and northern lateral boundary and it does not influence the results in the interior of the domain. This seasonaly different behavior is due to predominating influence of large scale dynamics on the climate during the winter months, while during the summer local convective processes predominate the climate in the region. A similar conclusion follows from the comparison of temperature field differences (figure 7, bottom) for summer and winter. It can be seen that the two simulations during the summer exhibit negligible difference in the interior of the domain, while during the winter differences are up to 1K. Problems for the EA1 experiment in the lateral boundary zone can be seen in the spatial distribution of total precipitation, especially during the winter (figure 8). For the EA1 experiment precipitation amount reaches extreme value of about 90 mm/day in the western lateral boundary zone (10.81E, 45.77N) and there are similar phenomana along the southern and northern domain border, while for the EA2 experiment precipitation values are not above 10 mm/day. This feature is probably due to the strong transition in topography fields from coarse ($\sim 25km$) to fine ($\sim 2.8km$) resolution resulting in a strong artificial vertical uplift and therefore an overestimated precipitation in that region. However, this still needs a further examination.

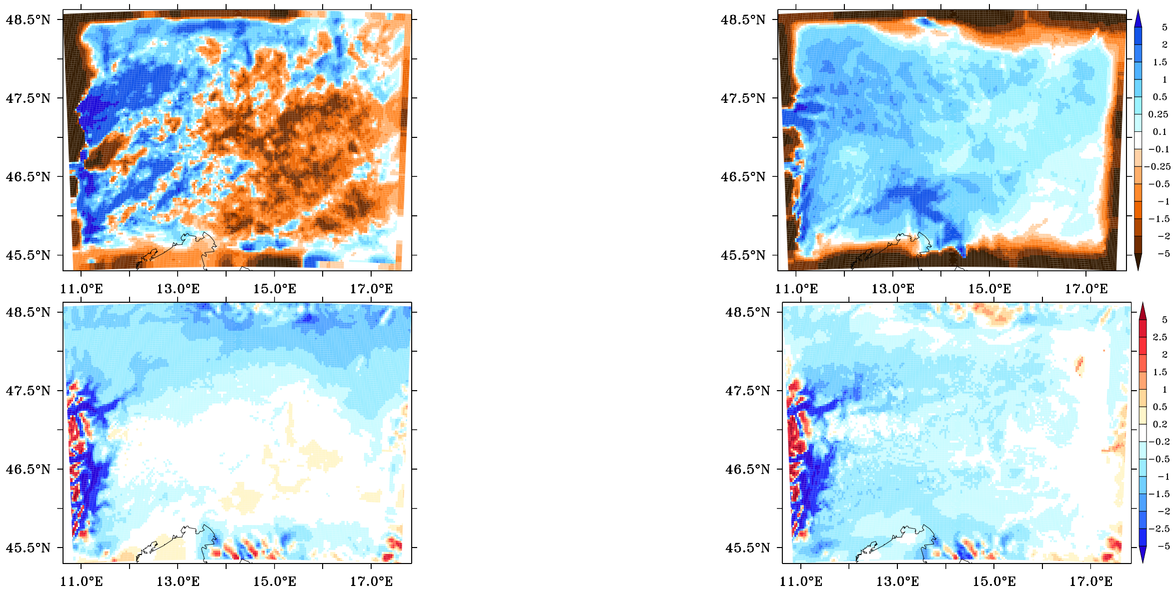


Figure 7: Precipitation (top) difference between EA2 and EA1 in mm/day and T_2m in K (bottom) for JJA 2007 (left) and DJF 2007/2008 (right).

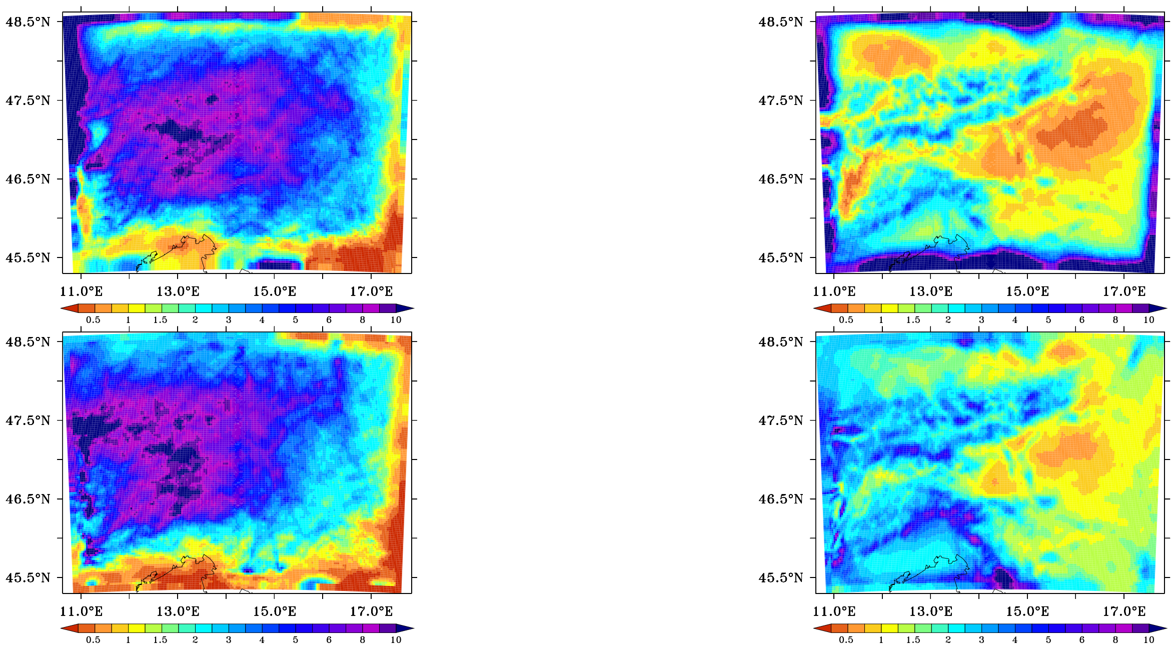


Figure 8: Total precipitation EA1 (top) and EA2 (bottom) in mm/day and for JJA 2007 (left) and DJF 2007/2008 (right).

4. Summary and Outlook

Results from three CCLM simulations have been presented and compared with available observational data sets. These results proved to be acceptable, since they are in the range of internal variability of the model. The simulation at 10 km for Central Europe (CEU) indicates that the model even in this version has some problems already known from previous versions, that is in particular a cold bias of about $1K$ compared with driving fields of IFS data. In the precipitation field, a dry bias of about $20mm/month$ is the predominate feature during summer and a wet bias in winter of similar amount if compared with the IFS data. However, perhaps the most striking feature of the total precipitation comparison are the discrepancies between all three reference data sets (the wettest IFS up to 40$mm/month$ more than E-OBS, and GPCC up to 20$mm/month$ more than E-OBS) and the fact that during summer CEU simulation fits in the middle of the range and agrees quite well with GPCC data set. However, during winter CEU is the wettest one. Two models (CEU and IFS) provide different seasonal means as a consequence of the dynamical downscaling (better surface features presentation within CEU simulation) and different physical parameterization (for example convection scheme).

The analysis of the two high-resolution simulations indicate that averaged temperatures do not deviate much from their forcing fields. However, total precipitation shows significant deviation from all the other datasets. In D3 domain during summer, both EA simulations have about the same amount of precipitation, up to 90$mm/month$ more than E-OBS. During winter EA2 is wetter than EA1, and the former has about the same amount of precipitation as its driving CEU simulation, and the latter has about the same amount of precipitation as its driving IFS re-analysis. An explanation for that is probably the predominant role of local convective processes during summer, and therefore similar performance of the two high resolution simulations with the same physical parametrizations, while during winter large scale dynamics dominate the climate system and therefore driving fields play a predominat role for the nested model performance. However, both EA simulations are wetter than interpolated observations (E-OBS and GPCC). When interpreting results in D1 domain, it has to be taken into account that this domain contains less then 10 grid points of coarse resolution reference data sets. However, double nested (EA2) simulation is drier than EA1 in summer and wetter in winter. The comparison of the precipitation fields of the two EA simulations indicates that the transition between the double nested and its driving simulation is much smoother than the transition between the direct nested and its driving simulation.

Although, the benefit of the double nesting can be seen against the results with direct driving (smoother transition and dynamical adaptation of forcing fields in the lateral boundary zone), it remains an open issue which of the two EA simulations gives a better presentation of climate since appropriate high resolution observations are not yet available. According to Denis et al (2003), satisfactory results for direct nesting are achieved when spatial resolutions degraded by up to a factor of 12 are imposed between forcing data and the nested experiment. In our case, the factor between IFS and EA1 resolution is 9, below but very close to the suggested critical value. Further examinations and new experiments are needed in order to confirm the factor of 12 or to provide a new critical value of the resolution factor between driving and nested simulation's resolutions. Until then, we suggest to perform double nesting when the ratio between forcing data and simulation is bigger than 9.

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