Research for Climate Protection:  
Model Run Evaluation  
Project Year2  
Reclip:more – Boku-Met

Precipitation evaluation of the one year model runs


by

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1 Introduction

Main part of the first half of this project year was the production and analysis of the sensitivity tests, for defining the final set up of the Regional Climate Models (RCM) for the ten years runs. In the second half, the focus was on the analysis of the results from several one year model experiments for the year 1999. As the Reclip-team agreed on a final set up, which are described in the reports of the modelling groups, the BOKU-Met report focuses on the precipitation analyses and comparison of the one year integrations for 1999 of the several models.

Aim of this precipitation analyses is to highlight the skills and deficits of the specific model – and set ups – in the different regions in and around the Alps. The analysis of the one year runs are a prototype of the analyses planed to be carried out for the ten year runs, forced with ERA-40 boundary conditions. The GCM forced model runs will be analysed with the same tools, but the results will be aggregated to allow a climatological comparison of the several time slices. For the 1999 runs no statistic for daily precipitation is done, because no appropriate observational dataset on daily time step is available for this year. These daily statistical measures will be an additional feature for the ten year integrations.
2 Database

2.1 Observation

For comparison of the RCM precipitation with observations, the grided HISTALP (Auer et. al, 2005) dataset was used. HISTALP is based on long term homogenised meteorological station data within a “greater alpine region”. The data set has a monthly temporal resolution and the data are grided on a 10 km grid. In Fig. 1 the analysis domain and the specific analyses regions, based on the Steinacker regions used in the VERA analyses with an additional Alpine region, are shown.

The analysis domain is the maximum area, which is covered from all model inner domains and the grided precipitation data set of Frei (Frei et al, 1998). The HISTALP data set is aggregated to the grid of the “Frei” dataset with ~25 km resolution. This was done, to allow a direct comparison of the daily statistics that will be performed in the ten years runs using the Frei dataset, with the results from HISTALP.

As only long term high quality stations are used for compiling the HISTALP data set, the station density is rather coarse, which leads to smooth interpolated precipitation fields, that to not really represent the variability on a ten km scale. In Fig. 2 the annual precipitation field for 1999 is shown. Especially the maxima and the variability within the main alpine chain seem to be underestimated (e.g. local maxima in the “Berner Oberland” and minima in the Tessin). Therefore, the HISTALP precipitation must be interpreted as a low estimate of the real precipitation with a reduced spatial variability within the Alp.

Fig. 1: Precipitation analysis domain using the HISTALP dataset and the adapted Steinacker-regions with an additional Alpine region (7).
2.2 Used model results

Within the project, 11 one year runs for 1999 have been performed. A detailed description of the model setups can be found in the reports of the responsible modelling group. The following names were used for the different model runs. In parenthesis are the names of the responsible group and the resolution of the inner domain:

- MM5_noa (ARC-sys, 15 km)
- MM5_plx (ARC-sys, 15 km)
- Alad_no (IMGW, ~ 12 km)
- Alad_sur (IMGW, ~ 12 km)
- Alad_rad (IMGW, ~ 12 km)
- MM5_21d1 (WGEN, 15 km)
- MM5_21d2 (WGEN, 15 km)
- MM5_24d1 (WGEN, 15 km)
- MM5_24d2 (WGEN, 15 km)
- MM5_34d1 (WGEN, 15 km)
- MM5_34d2 (WGEN, 15 km)
In the MM5 _noa and _plx runs, the same MM5 set up was used, but in one run the “NOAH” land surface model was used and “Pleim Xi” in the other. In the MM5 runs from WGEN, d1 denotes the coarse outer domain with 45 km resolution and d2 the inner domain with 15 km resolution.

After performing 6 runs with MM5, a bug in the model setup was detected leading to a wrong sea surface temperature (SST) in these runs. In the standard setup of MM5 the SST average of all time steps of the integration is used as SST input. This might be useful for weather forecasts, but leads to problems in our one year integrations. In the MM5 runs from ARC-sys and in the runs MM5_21x and MM5_24x, therefore the annual mean SST was used for the integration. To test the impact of this wrong SST, the MM5_34x run was performed with the same MM5 configuration (but with a newer MM5 version and with one way nesting technique) as the MM5_21x run.

3 Methodology

3.1 Preparation of the precipitation fields for the analyses

To compare the precipitation results from different models with observations it is necessary, that all precipitation fields have the same spatial resolution and location. Otherwise a comparison of the variability of the fields and the maxima on single grids is not possible.

As the Aladin-model and the MM5 models are not using the same resolution, the MM5 runs were made with 45/15 km resolution and the inner domain in MM5 is finer than the outer, nearly the half of the 11 runs have their results on different locations and resolutions. It was decided to bring all these model precipitation fields and the HISTALP data set on the raster of the precipitation data set of Frei with a spatial resolution of ~ 25 km. This resolution is a little bit larger than all inner domain results from all models and therefore no downsampling is necessary.

To avoid a smoothing of the model results from an interpolation algorithm, the precipitation grids from the model were split-up in small sub-cells, with the same precipitation value, which were averaged on the Frei grid cells. So the value of a Frei grid cell is the average of ~100 sub-cells. This method allows a conversion of different cell sizes and locations to the analysis grid without losing information. The only smoothing is the up-scaling to the little bit coarser analysis grid size. This method works for the HISTALP data set only on land. For plotting purposes also values for the sea area was needed and here a Cressman algorithm was used.

3.2 Statistical measures used for the analyses

The precipitation analyses include statistical measures for the whole analysis domain and the seven analysis regions (see Fig. 1) on monthly base and for the whole year.

The statistical measures are:

- Average (region), minimum and maximum (grid cell in region)
- Spatial standard deviation (region)
- Relative bias (region)
- RMSE (region)
- Spatial correlation (region)
- Efficiency (region)
The Efficiency is defined as:

\[ \text{Efficiency} = 1 - \frac{\text{MSE}}{\sigma^2} \]

An Efficiency of 1 represents a perfect model, not only in spatial distribution, but also in absolute values. An Efficiency of 0 means, that the mean square error of the model is equal to the variability of the observations. In this case the model is as good as if the average of the observations within the region is used as prediction. The Efficiency is not only sensitive to the spatial distribution like the correlation, but also to the absolute bias of the model.

Except the first two bullets, all statistical measures depend also on the quality of the observations. As stated in chapter 2.1, the HISTALP data set seems to underestimate the spatial variability and the absolute values within the Alpine region on the 10 km, but also on the 25 km analysis scale. This must be kept in mind, when interpreting the analysis results.

4 Analysis results

4.1 Annual precipitation sums

For the whole analysis domain the average precipitation sums of all MM5 runs are within 10 % deviation from HISTALP (see Fig.3). The ALADIN runs have all more precipitation, especially the version Aladin_rad is much too wet. The spatial variability is also quite similar between HISTALP and MM5 and higher in ALADIN. In Fig. 4 and Fig. 5 the precipitation field from Aladin_no and MM5_34d2 are shown. Compared with the HISTALP precipitation, both models show an over-estimation at the Alpine chain.

In Fig. 6 the spatial correlation and the Efficiency for the whole Analysis domain is shown. Except the MM5_34d1 run (which reflects the potential of a model with 45 km resolution), all models show a similar correlation of ~0.7. Calculating the spatial correlation on monthly base and averaging for the year leads to a reduction to ~0.55. The Efficiency is clearly higher in the MM5 than in the ALADIN runs and is around 0.3 for MM5 and below 0 for ALADIN. This is due to the too high precipitation sums within ALADIN.

In Fig. 7 the relative bias within the seven analyses regions is shown. Except the Aladin_rad run, all models show an underestimation of the precipitation in the Po basin (6) and the south east region (4). Within the Alpine region, only the two runs from WGEN with average SST show good results, all other models are too wet.

In Fig. 8 the maximum grid cell values within the 7 analyses regions is shown. Generally, ALADIN shows too high values in all regions (up to more than 5000 mm in the Alpine region). MM5 is only a little too high in the Alpine region and similar or lower than HISTALP in all other regions.
Fig. 3: Yearly precipitation sum and spatial standard deviation (red line), observed and all models, in the whole analysis domain in 1999.

![Graph showing yearly precipitation sum and spatial standard deviation](image)

Fig. 4: Annual precipitation sum in 1999 from Aladin_no.

![Map showing annual precipitation sum](image)
Fig. 5: Annual precipitation sum in 1999 from MM5_v34d2.

Fig. 6: Spatial correlation and Efficiency of the annual precipitation sum 1999 for the whole analysis domain.

Correlation [R]  
-1.5 -1 -0.5 0 0.5 1
Efficiency

Correlation
Efficiency

0.25 0.3 0.23 0.26 0.37 0.33 0.34 0.29 0.4
4.2 Monthly precipitation sums

The spatial correlations on monthly base are lower than the correlations on annual base and show an interesting fluctuation between the months, independent of the used model (see Fig. 9). The best correlations are reached in February. The February 1999 was characterised by nearly no precipitation in the Po basin (HISTALP 14 mm) and much precipitation in the Alpine region. The precipitation in this month seems to be produced only by Atlantic systems. Besides this February the correlation shows an annual cycle, with a maximum in summer and a minimum in winter. It seems that the model can reproduce Atlantic systems more realistically in terms of spatial distribution than Mediterranean systems.
The relative bias for the whole analysis region and all months and models is shown in Fig. 10. In general the ALADIN runs are too wet from May till August and the MM5 runs are too dry, especially from August till October.

The results of these monthly analyses are too manifold to plot them appropriate on single charts. Some examples will be given in the interpretation chapter and all results can be found in the attached tables (kennz_j_1999.pdf and kennz_m_1999.pdf).

Fig. 9: Spatial correlation of the monthly precipitation for the whole analysis domain in 1999 (averaged over all models and minima and maxima).

Fig. 10: Relative bias of the monthly precipitation sums for the whole analysis region in 1999.
5 Interpretation

5.1 Average SST versus correct SST in MM5

The use of a yearly averaged SST should mainly affect the water vapour transport from the Mediterranean Sea to the analysis domain, with an underestimation during summer and an overestimation in winter. The water vapour flow from the Atlantic should not be affected as much, because this is dominated by the lateral boundary conditions.

Comparing the annual precipitation sums of the model runs MM5_v21d2 (average SST) and MM5_v34d2 (correct SST), the precipitation for the whole analysis domain increases from 1064 mm to 1171 mm (HISTALP 1168mm) or ~ 10 % (see also Fig. 3). The precipitation shift shows a clear seasonal cycle with a good agreement with the anticipated changes. Fig. 11 and 12 show the change in the monthly relative bias for the Po basin and the Alpine region is.

In the Po basin the dry bias of the MM5_v21 run vanishes totally using the correct SST and the precipitation is in good agreement with the HISTALP data. The high relative underestimation in February is a consequence of the low precipitation (14 mm HISTALP) in this region and month, but the absolute bias is only a few mm. A decrease in precipitation can be found in November and December, but in January an increase is found. This can be explained by the factor, that SST in the Mediterranean Sea not only affects the availability of water vapour for precipitation, but also the cyclogeneses in this region.

A similar effect as in the Po basin can be seen in the Alpine region, with a reduction of the wet bias during winter and an increase of precipitation during late summer, reducing the dry bias.

Fig. 11: Relative precipitation bias in MM5 with average and correct SST and Aladin_no in the Po basin 1999
Fig. 12: Relative precipitation bias in MM5 with average and correct SST and Aladin_no in the Alpine region in 1999.

5.2 NOAH versus PLEIM-XIU

The land surface model (LSM) mainly affects the precipitation via local water vapour supply and the effect of the soil temperature to convective processes. Both effects should be most prominent under warm and dry conditions. For the whole analysis domain, the precipitation increases using the Noah scheme by 72 mm (see also Fig. 3), but the effect is strongest in the Po basin during summer. In Fig. 13 and 14 the results for the relative bias in the Po basin and the Alpine region are shown.

Fig. 13: Relative precipitation bias in MM5 runs with Noah and Pleim Xiu land surface model in the Po basin in 1999.
In the Po basin the Pleim Xiu shows a very strong dry bias, which is reduced using the Noah scheme. A similar but not so strong effect can be seen in the Alpine region. The regional and monthly analyses confirm the decision to use the Noah scheme for the long runs. But it must be stated, that this experiment was performed, using the average SST. Maybe the differences between Noah and Pleim Xiu are not so pronounced under less dry conditions.

5.3 45 km versus 15 km

In the average regional precipitation sums are not much difference between the coarse outer domain and the fine inner domain, when using the two way nesting technique. The differences in the annual sum for the whole analysis domain are less than 1%. Even on monthly base and in the different regions the differences are not important. As an example, the relative biases for the Alpine region are shown in Fig. 15. Additional information can be found in Fig. 3, 6, 7, 8 and 10 comparing the results from d1 and d2 in MM5_v21 and MM5_v24.

The differences between the inner and outer domain can not be seen in the “large scale” behaviour of the model, but in the spatial variability near the grid scale. The precipitation fields from the inner domain (Fig17) show much more realistic structure than from the outer domain (Fig. 16), although both fields are aggregated on the same ~25 km grid. For example the separation of the south-western and south-eastern “Stau-region” is better pronounced in the inner domain (compare with Fig. 2) and the separation of the Jura or the Schwarzwald is much clearer.

The use of the fine resolutions clearly brings some improvement in the modelled precipitation. This should also improve other surface variables like soil wetness, snow cover and also soil and 2m air temperature and all components of the energy fluxes at the surface.

The full differences between a RCM run with 45 km and 15 km can be seen in the differences in the MM5_v34 d1 and d2 runs. In Fig. 18 the yearly sum of precipitation with “real” 45 km can be seen.
The structure of the precipitation is quite different to all other model runs and the observations. The added value of the fine resolution is also reflected in all statistical measures.

**Fig. 15:** Relative precipitation bias in MM5_v21 run with 45 km (d1) and 15 km (d2) resolution in the Alpine region in 1999.

**Fig. 16:** Annual precipitation sum in 1999 from MM5_v21d1 (45 km)
5.4 ALADIN versus MM5

Comparing the precipitation fields from ALADIN (Fig. 4) with that from MM5 with 15 km resolution (e.g. Fig. 5), ALADIN shows much more details, though the spatial resolution of the models are quite similar. Even compared with the HISTALP data (Fig. 2) ALADIN seems to be more realistic in the terms of precipitation distribution and spatial variability, as for example the minima in the Swiss Rhone valley is well detected with ALADIN and smoothed out in HISTALP. An another example is the precipitation at the “Koralpe” at the border from Styria to Carinthia. ALADIN locates this local precipitation maxima correct but it is nearly smoothed out in MM5 and HISTALP.

We assume that ALADIN uses a more advanced advection scheme than MM5, and/or a more realistic representation of the topography within the model. But this improvement in spatial distribution is associated with an overestimation of the precipitation, induced by lifting of the air masses at mountain ridges. Within the Alpine region for example, the relative bias in the Aladin_no run exceeds 50 % in 4 Months, and only in 2 months a small underestimation occurs (see Fig. 12). Within the Po basin the differences between ALADIN and MM5 are not so big (Fig.11). Additionally an overshooting of the precipitation on single grid points occurs. Within the Alpine regions all ALADIN runs have maximum annual grid cell precipitation around 5000 mm (see Fig. 8), for MM5 these values are around 3000 mm. It must be stated once again, that these statistical measures depend on the observations and that HISTALP is underestimating precipitation on this 25 km scale within the Alps, due to the low station density and the under-representation of mountain top stations.

Both effects, the smoothing of the precipitation in MM5 and the overestimating and -shooting in ALADIN can be corrected with statistical downscaling (e.g. MOS).
6 Conclusions

In general the RCMs can handle precipitation associated with frontal system from the Atlantic better than Mediterranean cyclones.

The model ALADIN shows a better spatial distribution of the precipitation in the near grid-cell scale than MM5, but has some problems with the precipitation amount.

On the large scale (differences between regions, seasonal cycle) the model results are quite realistic, but even with this high resolution of 12 / 15 km the RCM precipitation results are far from being used directly in impact studies. Some kind of “model output statistics” and “output localization” has to be done before.

The analysis of the 10 year runs will proof, if this findings here are biased by the specific situation in 1999 or if they are typical for the models. The additional analyses on daily scale will bring some further insight to the responsible processes.

The final assessment of the skills and weaknesses of the models for climate modelling can not be done before the 10 year control integrations forced by GCM boundary conditions are analysed.

7 References


A precipitation climatology of the Alps from high-resolution rain-gauge observations. Int. J. Climatol., 18, 873-900.