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Hydrology and Earth System Sciences Discussions

Interactive comment on "The effect of downscaling on river runoff modeling: a hydrological case study in the Upper Danube Watershed" *by* T. Marke et al.

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The authors would like to thank reviewer 2 for contributing to the improvement of our manuscript.

——————— Comment: ———————

Surprisingly the authors dealing with downscaling use spatial and temporal scales in a very arbitrary manner. For example they use a model with a 1 hour 1 km x 1 km spatial resolution for which the correction of the precipitation input is derived from monthly distributions.

——————— Response: ———————

The temporal and spatial resolution of the hydrological simulations have not arbitrarily been chosen in the present study. High temporal resolution is required to account for the nonlinearity of hydroclimatological processes at the land surface and to adequately consider the diurnal cycle of temperature and radiation in order to allow for an accurate simulation of evapotranspiration and, in direct consequence, discharge. The spatial resolution of 1 x 1 km represents a compromise between the spatial resolution required to sufficiently account for heterogenities in the catchment area (e.g. landcover, topography, soil, climate) and the computational costs that somehow limit model applications when it comes to a simulation over large areas and climatological periods of time (as done in our study). The applied combination of temporal and spatial resolution has been evaluated and has proven to allow for an accurate simulation of discharge in the Upper Danube Watershed in the framework of various studies in the past (e.g. Hank, 2008; Mauser and Bach, 2009; Marke et al., 2011). The spatial patterns in precipitation distributions as well as those of biases in RCM-simulated precipitation in the catchment considered are often related to the prevalence of convective or orographically induced events as well as their realistic representation in climate models (at least in case of biases induced by different RCM convection shemes or those resulting from an overestimation of the frequency of cyclones in Central Europe and the Mediterranean region found in the global boundaries, this has been demonstrated and discussed in our paper). Hence, to account for the seasonality in precipitation patterns the application of monthly correction factors seems entirely appropriate. This is confirmed by the accurancy of simulated discharge resulting from the application of monthly correction factors in PROMET as done in the uncoupled (observation-driven) model setup. Furthermore, the application of monthly corrections of simulated/observed precipitation with the aim to derive hourly distributions has been proposed and carried out by other authors in the past with very good results (e.g. Liston and Elder, 2006). The authors do not see any contradiction or arbitrariness in the application of spatial and temporal scales in our study.

——————— Comment: ———————

Further model results are compared mainly on monthly means (or even long term monthly means) aggregated over the a large catchment of 76000 square km. There are many reasons which can lead to the same integral performance but with poor spatial details. The only higher frequency related evaluations are done in time using 1 day resolution flow duration curves and scatter plots of observations. These are all of different quality. Several comparisons are made on a monthly mean scale.

——————— Response: ———————

The statistical evaluation approaches applied have been chosen depending on the options and limitations that go together with the application of different meteorological drivers for the hydrological simuations. The following meteorological drivers allow evaluation based on different criteria and in different detail. They therfore clearly need to be distinguished:

Meteorological observations:

Here the hydrological model is driven with spatially distributed station observations (uncoupled setup). This run serves as a reference for all coupled (RCM-driven) hydrological simulations and shows the capabilities of the physically based hydrological model in the simulation of discharge, given that accurate meteorological drivers are supplied. As the applied station observations describe the real meteorological conditions in the catchment, it is possible to compare discharge simulations to discharge recordings on a daily basis (as has been done in our study). As this analysis is important before applying meteorlogical simulations as input for the hydrological model, the evaluation has been carried out as detailed as possible (on a daily basis). Reference for an even more detailed validation has been provided in the paper.

Global climate model ECHAM5, dynamically downscaled by different RCMs:

As the global climate model ECHAM5 reproduces climate only in a statistical man-

ner (mean conditions over climatological periods in the order of 30 years), a comparison of hydrological model results to hydrological observations e.g. for individual days or months is not feasable. We need to use hydrological criteria that allow to assess whether the hydrological model, driven with a climate that statistically compares well with observed climate (over 30 years), is able to reproduce discharge that statistically compares well with observed discharge (over 30 years). This can be done by analyzing mean monthly conditions and by comparing the mean number of days with discharge above a certain discharge value (flow duration curves) over climatological periods of time (both approaches have been applied in our study).

ERA40 reanalysis, dynamically downscaled by different RCMs:

In this setup, the RCM aims at reproducing real weather conditions allowing a comparison of discharge conditions to observations for individual days or months, as has been done in a recent study by Marke et al. (2011). As this very detailed evaluation of the hydrometeorological model chain using ERA40 data has already been published, but also to go beyond a validation of the downscaling approaches and rather compare the performance of the hydrological model under different meteorological input, a statistical analysis has been chosen that can be applied to all combinations of global boundrary conditions and regional climate models in the same manner and detail. The publication Marke et al. (2011) has been cited in the paper of discussion. However, it was maybe not clear that it includes very detailed information on the validation of the model chain. We have corrected this in the updated version of the manuscript making it easier for the reader to find the information requested by reviewer 2. Moreover, we have added information on the options and limitations for evaluation as connected to the different meteorological boundary conditions, making clear the reasons why the applied evaluation approaches have been chosen (see manuscript, p. 5).

——————— Comment: ———————

The annual cycle of different discharge statistics shows reasonable agreement with observations, but unfortunately this is mainly caused by the natural annual cycle.

——————— Response: ———————

While the application of the global climate model ECHAM5 does not allow an analysis on a finer than long term monthly basis out of the reasons explained in the previous paragraphs, a more detailed analysis has been carried out for the boundaries of the ERA40 reanalysis in Marke et al. (2011). The analysis in Marke et al. (2011) compares simulated and observed discharge at a daily time basis separately for the different months of the year using different efficiency criteria. Averaging the performance over all months of the year leads to a mean performance that compares well to the overall performance resulting from a consideration of daily conditions over the whole year. These circumstances suggest that the reasonable agreement of simulated and observed discharge is not only due to the seasonal course that is included in discharge observations and simulations. In the updated version of the manuscript we have pointed out to this publication with more emphasis to allow easy access to further information (see manuscript, p. 5). Furthermore, we are discussing the daily evaluation for the different months (Marke et al., 2011) together with the fact that this approach systematically excludes biases that might be induced by the seasonal cycle in discharge observations and simulations in the updated manuscript.

——————— Comment: ———————

All these statistics show that the modeled peak is in May which is earlier than observed. As one would expect such a change with increasing temperature this error decreases the credibility of the prediction of the model chain if applied for changed climate.

——————— Response: ———————

The present paper does not only aim at showing the potential but also the limitations of the coupled model system for climate change investigations. The reviewer is totally right with the observation that the modeled peak is in May, which is earlier than in the

discharge recordings. This is, however, also observed in the uncoupled (observation-driven) model setup and can therefore not (fully) be attributed to biases in the meteorological input. As pointed out in the paper, discharge at gauge Achleiten is predominantly governed by snow melt in May suggesting that inaccuracies in the calculation of snow melt might be responsible for this effect. The implementation of a sub-pixel snow simulation approach that is currently carried out, might help to improve model performance in spring in future model versions. In case of MHQ, the fact that large floods tend to be overestimated (the frequent inundation of riparian areas during peak flow events, as well as the measures taken by reservoir management to reduce extreme floods are not implemented in the hydrological model yet) also contributes to the overestimation in May. Although further development of models in order to more accurately reproduce reality is highly desirable and is continuously carried out, present generation global climate models, regional climate models as well as the physically based hydrological model applied in our study (despite of the biases in the results of all these models) are the best tools currently available to investigate the effects of climate change. We do not think the biases that have been presented in a very transparent manner forbid the models' application in climate change research. These biases just have do be transparently discussed together with the model results – just like it is required and done in case of climate simulations.

——————— Comment: ———————

In fact the time period would have allowed an investigation of results from a time series perspective. This would have lead to more information on whether the model chain can capture climatic signals.

——————— Response: ———————

The evaluation proposed by reviewer 2 has been carried out by Marke et al. (2011) for the hydrometeorological model chain using the global boundary conditions of the ERA40 reanalysis. The study shows that the hydrological model is capable to simulate discharge with good accurancy if ERA-driven regional climate simulations are downscaled and bias corrected. In case of the present paper, the application of ECHAM5 does not allow a time series analysis. To perform a statistical analysis based on criteria that are applicable for all combinations of global boundary conditions, RCMs and downscaling approaches, but also as the proposed analysis has already been published in Marke et al. (2011), the comprison of discharge simulations and observations is not carried out for ERA40 forcings on a daily basis in the paper under discussion. The current paper focuses on the analysis of the influence of different statistical downscaling methods, different dynamical downscaling approaches (=RCMs) and different global boundaries (ERA40 and ECHAM5) on the results of the hydrometeorological model chain. In the updated version of the manuscript we point out to the publication with the detailed validation under ERA40 boundaries with more emphasis making it easier for the reader to find the information requested by reviewer 2.

——————— Comment: ———————

It is not clear from the paper if it was worth to make the large effort of detailed modelling with the available observation and climate model output uncertainty or whether a simpler approach could do as well. Especially the claim that this approach can capture climate change signals correctly is not sufficiently supported.

——————— Response: ———————

At present, the most sophisticated way of providing information on changing climate conditions for hydrological impact studies is the application of RCM data. RCM simulations are available as outcome of various projects, e.g. the ENSEMBLES project (van der Linden et al. 2009). The latter is providing various realizations of the A1B scenario to be used by the climate change research community free of charge. Hence, the application of RCM data for impact analysis is not necessarily connected to a major effort.

Considering the downscaling of RCM data, our study uses a pragmatic approach and

hence already minimizes the effort put into the preprocessing of RCM data.

The by far biggest effort was put in the detailed, physically based description of hydroclimatological processes at the land surface as implemented in the hydrological model PROMET. This model has specifically been designed for climate change impact analysis and has already proven to be capable of capturing climate change signals in many studies (e.g. Mauser and Bach, 2009; Hank, 2008; Marke, 2008; Prasch, 2010). Although simpler hydrological models might as well be able to reproduce observed discharge conditions on the basis of the downscaled and bias corrected RCM simulations applied in our study, their applicability for climate change research is questionable (Ludwig et al., 2009). This is particularly true, if the models have been calibrated to allow for optimum performance in the reproduction of past discharge conditions. Hence, in accordance with other authors (e.g. Ludwig et al., 2009), the application of distributed, physically based models is considered indispensable to maintain the predictive power of the hydrometeorological model chain. We have added information on this discussion to the conclusions section of the updated manuscript.

——————— Comment: ———————

The paper discusses the problem of observation data uncertainty. Blaming observations is a possibility to reduce the modeling errors of the RCMs, but if observations are wrong then the hydrological model which produces good output of bad input is also wrong.

——————— Response: ———————

The reviewer is totally right remarking that "... if observations are wrong then the hydrological model which produces good output of bad input is also wrong". However, the possibility to produce good results on the basis of bad meteorological input is high when using calibrated hydrological models, but is rather limited using uncalibrated, physically based hydrological models as done in our study. This particularly applies, when the model used has been successfully applied without any calibration under a variety of climatological and topographical conditions (e.g. Prasch, 2010; Ludwig et al., 2009, Mauser and Bach, 2009). Although we know that biases exist in meteorological observations and that further biases are induced by the application of methods used to spatially distribute these meteorological observations, the quality of the meteorological observations applied in our study seems reasonably high. The latter is confirmed by hydrological model results (Mauser and Bach, 2009) as well as by validation efforts carried out to evaluate the meteorological fields generated on the basis of point observations (e.g. Hank et al., 2007).

——————— Comment: ———————

Patterns of hourly precipitation are very different from patterns of monthly precipitation. Hourly precipitation has practically no correlation with elevation. How can the authors justify their correction approach?

——————— Response: ———————

The reviewer is right stating that hourly and monthly precipitation patterns differ and that hourly distributions correlate less with elevation. However, reproducing the general increase of precipitation with increasing elevation is crucial for achieving accurate hydrological simulations. Hence, many authors apply elevation corrections at hourly temporal resolution (Liston and Elder, 2006; Hank, 2008; Marke, 2008; Marke et al, 2011; Strasser and Mauser, 2001; Strasser, 2008; Mauser and Bach, 2009; Ludwig et al., 2009; Prasch, 2010; Prasch et al., 2011; Zabel et al., 2011) as done in our study.

——————— Comment: ———————

The frequency diagrams of hourly rainfall are unusual. Normally one produces either a histogram or a smoothed density. The figure is showing a mixture. Further the difference of dry/rain probability is of great importance and not given in the paper.

——————— Response: ———————

The frequency diagrams in our paper aim at displaying the frequency distribution of

hourly precipitation intensities for three data series (observations, MM5 simulations and REMO simulations) in just one plot for each of the different seasons in order to maximize comparability and avoid plotting/printing more graphs than necessary. To display different data series in a single histogram is not possible as the base of each histogram bar should be equal to the width of the class interval by definition. A smoothed density function, on the other, would go hand in hand with a loss of informative content. To combine the different data series in order to allow for better comparison and to give as much information as possible, a simple line plot has been chosen to display the data. As the illustration neither claims to be a histogram nor a smoothed density function, the authors do not see a problem here. However, we of course agree to switch to histogram plots (which would result in 12 further bar plots) if this is requested. That liquid and solid precipitation are not distinguished is right, but as the line of argumentation is built on the differences in summer intensities (and this is the only season where major differences between the RCM simulations and the observations exist), this distinction seems not really necessary here. Moreover, solid and liquid precipitation are not provided as input for the hydrological model separately. The decision between rain and snow fall is made in the hydrological model. Hence, including the phase would mix meteorological and hydrological simulations.

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We hope to have adressed your comment adequately and would like to thank you again for your valuable suggestions! Your endeavors are highly appreciated!

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 6331, 2011.