Climate change analyses used for river basin management in the rivers Danube and Elbe

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1 Introduction

Increasing global temperatures as indicated by the climate projections of the Fourth Assessment Report of the IPCC (2007) may lead to changes in the hydrological cycle. These changes could cause major changes in precipitation, water flow, water quality, and the ecosystem. This triggered a discussion among experts how aquatic systems and water-resources management practices can be adapted to become “climate proof”. Because all elements are interlinked in a complex way, an appropriate evaluation of adaptation options requires (1) the assessment of regional climatic and hydrological effects taking into account different sources of uncertainty in data and methods, and (2) the integrated assessment of the main impacts on water quality, water quantity as well as ecological and economic functions of waters.

Figure 1 shows the exemplary interrelationships of the system components of waterways influenced by external climate forcing, national and international policies and the economy to demonstrate the importance of considering system relationships and feedbacks in the discussion of adaptation strategies.

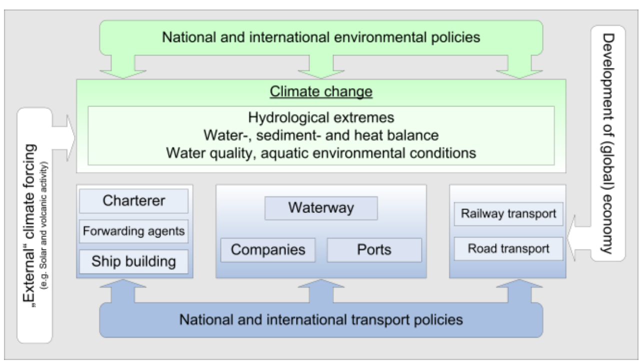

Figure 1. *Interrelationships of the system components of waterways influenced by external forcings (changed after Moser et al. 2008)*

These aspects are addressed by the interdisciplinary research projects “KLIWAS – Impacts of climate change on navigation and waterways – options to adapt” funded by the German Federal Ministry of Transport as well as by the two EU funded projects “AdaptAlp – Adaption to Climate Change in the Alpine Space” (INTERREG IV) and “ECCONET - Effects of climate change on the inland waterway networks” (EU FP 7) on the catchments of the Rivers Danube (Figure 2) and Elbe (only project KLIWAS). The projects KLIWAS and AdaptAlp were mentioned as “good practice examples” in the just released

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“Guidance document No. 24: RIVER BASIN MANAGEMENT IN A CHANGING CLIMATE” (European Communities 2009).

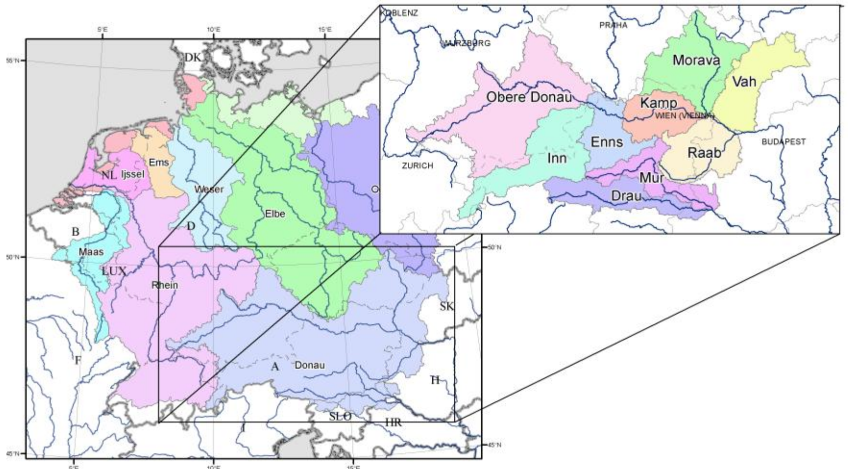

Figure 2. *Study areas in the catchment of the River Danube, AdaptAlp: German Danube and Inn, ECCONET: Rhine/Danube, KLIWAS: All international catchments shared by Germany*

2 Database and multi-model approach

In recent years, global and regional climate modelling achieved significant improvements, so that the results of the models are getting more and more reliable. Due to the low resolution, the simplification of processes and assumptions about initial and boundary conditions, the model results still have large bias and uncertainties which can be grouped in two categories (for a more detailed analysis of the different sources of uncertainty see Krahe et al. 2009):

1. Uncertainties inherent in the system (aleatoric), e.g. deterministic-chaotic behaviour of the climate system.
2. Uncertainties related to incomplete knowledge about the system (epistemic), e.g. measuring errors, simplification of the system (bias).

Due to these uncertainties, there is not a single “true” climate-model run, and most likely never will be. Hence, an ensemble, as e.g. generated via a “multi-model approach” using different global climate models, different regionalization models, and different hydrological models must be used to account for the uncertainties that lead to a range of possible changes.

The “Coupled Model Intercomparison Project” (CMIP 2009) has provided a large number of global climate projections of the Fourth Assessment Report of the IPCC (2007). For Europe, the European joint research projects PRUDENCE (2007) and ENSEMBLES (2009) provided a large number of regional climate projections based on different global climate projections and concepts for probabilistic evaluation and analysis of model results.

Besides the regional climate projections from these two projects, some additional projections are used from national and international climate-change projects. An overview of the emission scenarios, global climate projections, regional climate projections, bias-correction models, and water balance models considered in KLIWAS and other projects on the River Danube is presented in Figure 3.

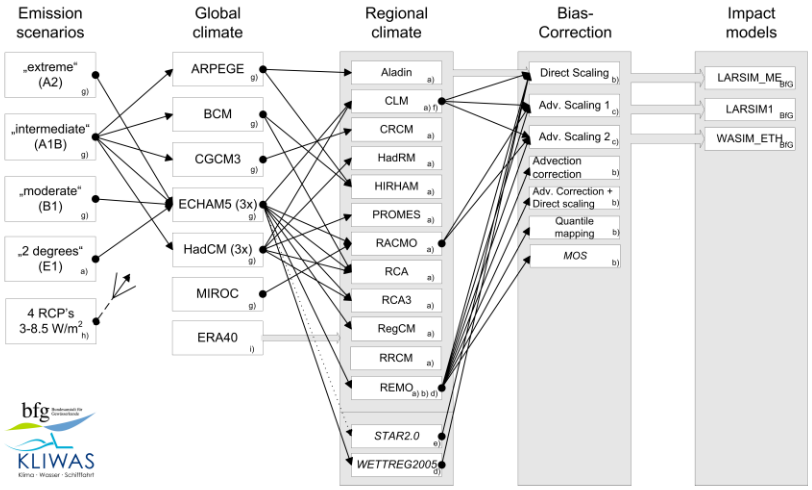

__Figure 3.__ Model chain and database for the multi-model approach in KLIWAS PJ 4.01 Hydrology and Inland Navigation. Sources: (a) EU-ENSEMBLES, (b) BMVBS-KLIWAS, (c) KHR-Rheinblick2050, (d) REMO_UBA, (e) PIK-STAR, (f) BMBF-CLM, (g) CMIP3/IPCC_AR4, (h) CMIP5/IPCC_AR5, (i) ECMWF (changed after Nilson et al. 2010).

Simulations of the climate of the 20th century show that all regional climate models have limitations in reproducing the present climate (Figure 4). Hence, many bias-correction methods are currently being developed. Current transboundary projects (KLIWAS, AdaptAlp, and RheinBlick2050) test different statistical bias-correction methods for various climate-model runs for the catchment of the River Rhine. These methods are applicable also in other catchments like that of the Danube.

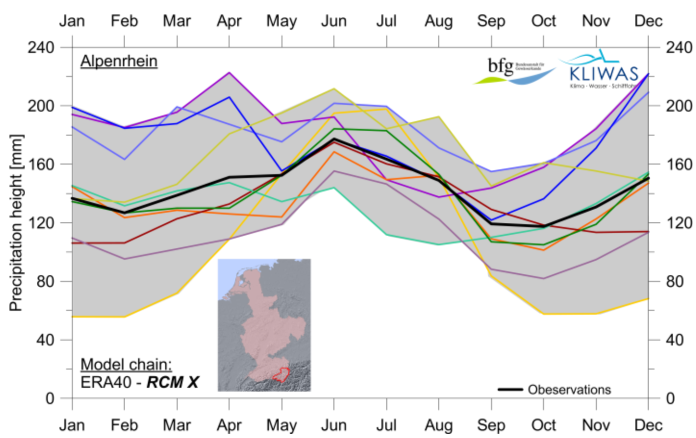

__Figure 4.__ Multi-annual (1971-2000) mean monthly precipitation sums in a subcatchment of the River Rhine with 10 different regional climate model runs (ENSEMBLES 2009). The black line is based on observations.(Bülow et al. 2009, Krahe et al. 2009)

To analyse the uncertainty of the water-balance models, several models with different spatial and temporal resolutions (Table 1) are used in the Danube Basin to calculate discharge projections using ERA40-data and bias-corrected climate-model runs as input data. The model LARSIM_ME is currently being developed in the context of the research project KLIWAS with a resolution of 3 km x 3 km, and it will cover the national and international tributaries of rivers in Germany. Only this model and the model WatBal (Danube Countries 2006) will cover the whole study area of the River Danube as shown in Figure 2.

Table 1. *Spatial and temporal resolutions of the Water-balance models WaSiM-ETH (Schulla & Jasper 2007), LARSIM (Ludwig & Bremicker 2006) and WatBal (Danube Countries 2006) applied in the projects AdaptAlp, KLIWAS, ECCONET*

Catchment	Model	Spatial Resolution	Temporal Resolution
Alz	WASIM	1 km	1 h
Alz	LARSIM1	1 km	1 h / 1 d
Inn	WASIM	1 km	1 d
Upper Danube	LARSIM_ME	3 km	1 d
Danube	WadBal	Basins	1 month

3 Climate change in the Upper Danube Basin

Figure 5 shows the changes of the multiannual (30 years) mean seasonal precipitation sums relative to the period 1961-1990 of 18 global climate projections. All simulations are based on the same emission scenario SRES_A1B. The span between the models results from the uncertainties described before. There is a large difference between the projected precipitation changes ranging from about 0% to possible decreases/increases depending on the season of about 20 %. These results confirm the importance of the multi-model approach in view of an uncertain future.

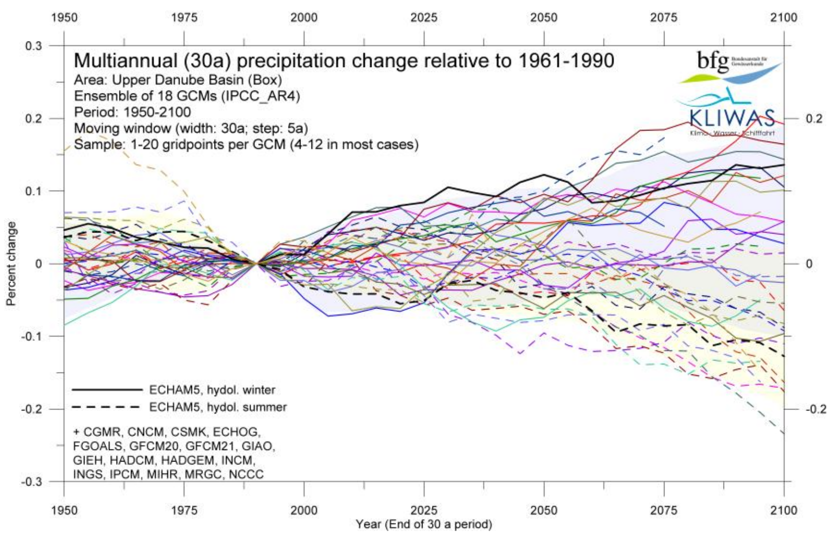

Figure 5. *Span of the seasonal (summer, winter) precipitation changes in the Upper Danube Basin (German part) between 1950 and 2100, simulated by 18 global climate models (AR4 of the IPCC 2007) using the emission scenario SRES_A1B. Shown are the changes of the multiannual (30 years) mean precipitation sums relative to the period 1961-1990.*

4 Outlook and conclusions

Despite all their uncertainties, climate projections should be used to improve river-basin management as these simulations are based on the best available scientific information. Especially for projections of the distant future they are more reliable than other methods as e.g. the extrapolation of the measured change into the future by statistical methods. Adaptation strategies in river-basin management should be based on a range of possible changes in the system to take all available information and the existence of uncertainty into account. Ideally, the whole ensemble of available projections should be considered in the impact models to evaluate the possible changes and adaptation options. As consequence of the large uncertainties the model results have to be analysed and evaluated to make them available to the different stakeholders involved in river-basin management. In KLIWAS and Rheinblick2050, a methodology was generated to select "representative projections" as scenarios based on the ensemble of discharge projections and the scenario horizon.

Figure 6 demonstrates this with focus on summer low flows at selected gauging stations on the River Rhine. The graph is based on an climate projection ensemble consisting of 20 members for the period 2021-2050. All members are bias-corrected and taken as input for a hydrological model (HBV134). The ensemble does not show a clear tendency of change. The main corridor spans changes from plus to minus 10%. The "representative projections" are selected subjectively on the outer rim of the main corridor as indicated by fat lines. The time series behind these projections will be used as a basis for investigations of other impacts on the aquatic system like water quality and ecology. A similar approach is currently under development for the Danube and Elbe, too.

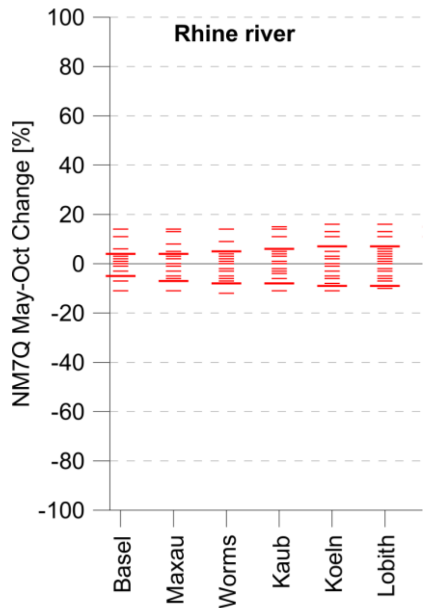

Figure 6. *NM7Q at major gauges along the River Rhine during the summer half year according to an ensemble of 20 discharge projections. NM7Q is lowest 7-day mean discharge. Values are expressed as percent change in period 2021-2050 (near future) compared to 1961-1990.*

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