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ESTIMATION OF CLIMATE CHANGE IMPACTS ON THE COUPLED SURFACE-SUBSURFACE HYDROSYSTEM OF THE UPPER RHINE GRABEN

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1 INTRODUCTION

The Upper Rhine Graben alluvial aquifer is an extensive water resource (45 billions m3), extended on 4650 km^2 north of the Swiss alpine part of the Rhine basin, and surrounded by two snowy mountain ranges, forming a 14,000km^2 basin. Most of its recharge is due to the river infiltration, while the remaining is due to effective precipitation and to some subsurface flows at the limit between the mountains and the plain. Climate change, by modifying the partition between snowfall and rainfall, and by increasing the evaporative demand can modify the water availability on the whole Upper Rhine basin and increase its vulnerability. To simulate such impact on an alluvial aquifer, it is necessary to have a fine representation of the surface-groundwater interaction[1,2]. Such application was developed with the MODCOU model, with an explicit representation of the uncertainty linked to key parameters involved in the surface-groundwater interactions, groundwater flow, or estimation of the effective rainfall[3]. In present day, the recharge from rivers was then estimated to represent 80 % +/- 14% of the 140 +/-17 m^3/s total recharge flow. This study focuses on the impact of climate change on the Upper Rhine Graben water resources by combining the uncertainties on the hydrogeological parameters and on the climate change projections. To do so, some climate projections from CMIP3[4] using the A1B greenhouse gas emission scenario were used.

2 MATERIAL AND METHOD

The Upper Rhine aquifer is modeled by the MODCOU hydrogeological model as a single aquifer layer tigthly connected to the river3. On river cells, the river-aquifer exchange flow is proportional to the head difference between the river (Ho) and the aquifer (H), to permeability and width of the riverbed, and inversely proportional to its thickness. As these characteristics of the river bed are mostly unknown, they are integrated in two parameters called the transfer coefficient (Tp), for the case when the aquifer and the river are connected, and the maximum river infiltration flow (Qlim) for the disconnected case. The exchange flow is therefore computed as follows:

$$Q = \max(T_p * (H - H_0), Qriv, Q\lim) \qquad (1)$$

Where Qriv is the simulated riverflow. The river height in MODCOU can so far only be simulated in the Rhine river, for the other rivers, the height is supposed to be constant.

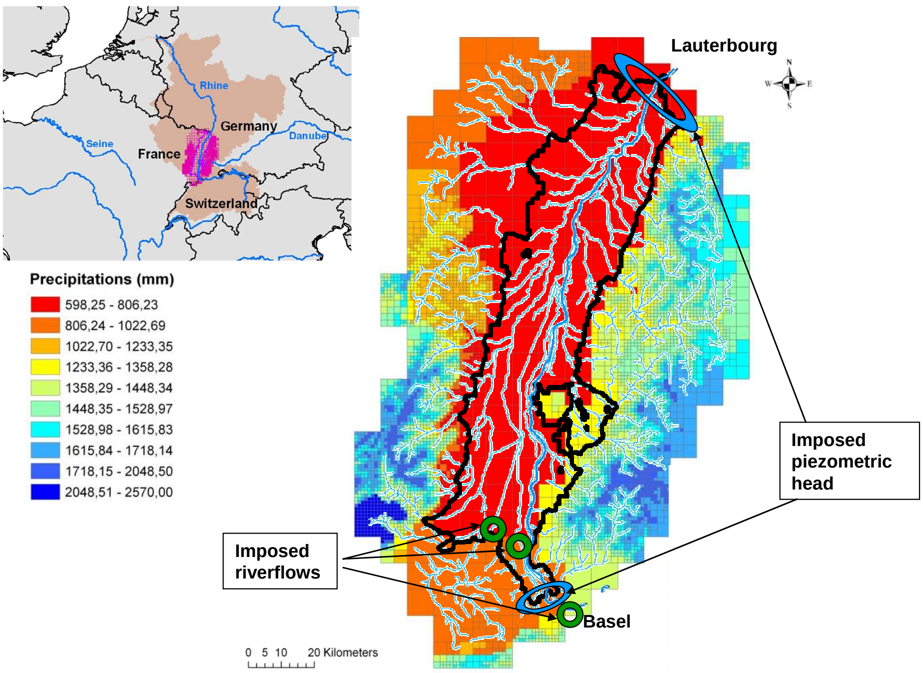

Figure 1: Simulated domain, with the extension of the Rhine alluvial plain in black, the hydrographic network in blue lines, and the mean annual precipitation from a refine version of the SAFRAN analysis in color. Boundary conditions with imposed riverflows and piezometric heads are plotted.

Several values of these parameters were tested in present day and were shown to provide similarly good results in terms of comparison with daily river flow and piezometric head. Therefore, for the climate change impact study, we have selected two sets of values for Tp, Qlim, and the porosity, that lead to quite contrasted estimations of the river infiltration, from 90 to 140 m^3/s in present day.

As only a part of the Rhine basin is modelled, it is required to impose the Rhine riverflows as a boundary condition. In present day, the observed dataset from Basel (Switzerland) are used. For the climate change impact study, the projected riverflow at Basel were provided by the Rheinblick project[4], using the HBV model and the ECHAM-REMO –A1B climate projection. Although there is no clear trend in the mean annual volume, these riverflows present a shift of the maximum riverflow from June to May, due to early snowmelt. The remaining imposed boundary conditions, ie, the riverflows of two canals used for irrigation and navigation, as well as the imposed piezometric heads are supposed unchanged, as well as the pumping pressure, and the land use.

3 CLIMATE CHANGE PROJECTIONS AND IMPACTS

3.1 climate change downscaled projections

Seven climate model projections using the A1B greenhouse gas emission scenario were downscaled using the DSCLIM method[6,7] based on a weather typing approach. All projections lead to an increase of the PET (from 7% to 20%) and most of them a decrease of precipitation in summer and an increase in winter, with an annual evolution ranging from +2 to -8 % (figure 2).

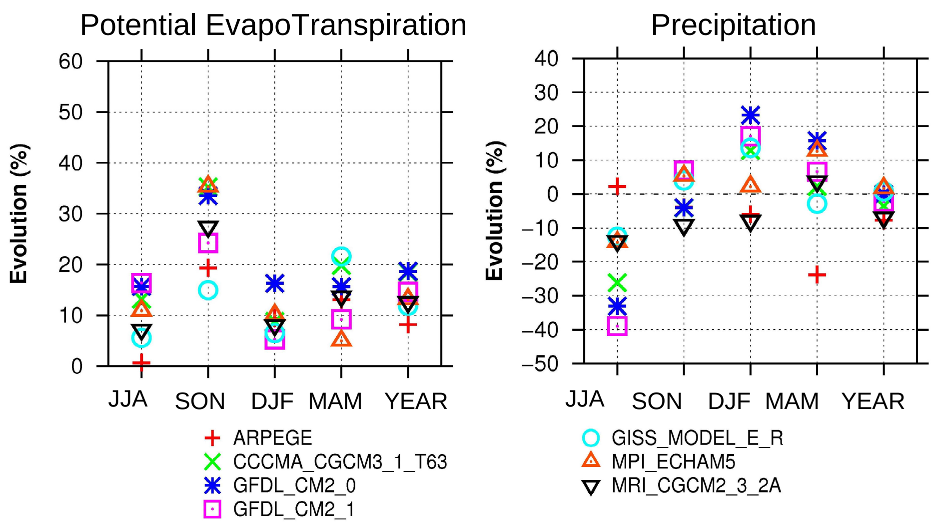

Figure 2: Evolution of the PET (left) and Precipitation (right) for each season and on an annual basis as projected by the seven downscaled climate projection in the period 2045-2065 compared to 1961-2000

The spatial patterns of the precipitation change are quite contrasted, with almost half of the projections indicating an increase of the precipitation in the mountain ranges (figure 3), where the precipitations is above 1500mm/year.

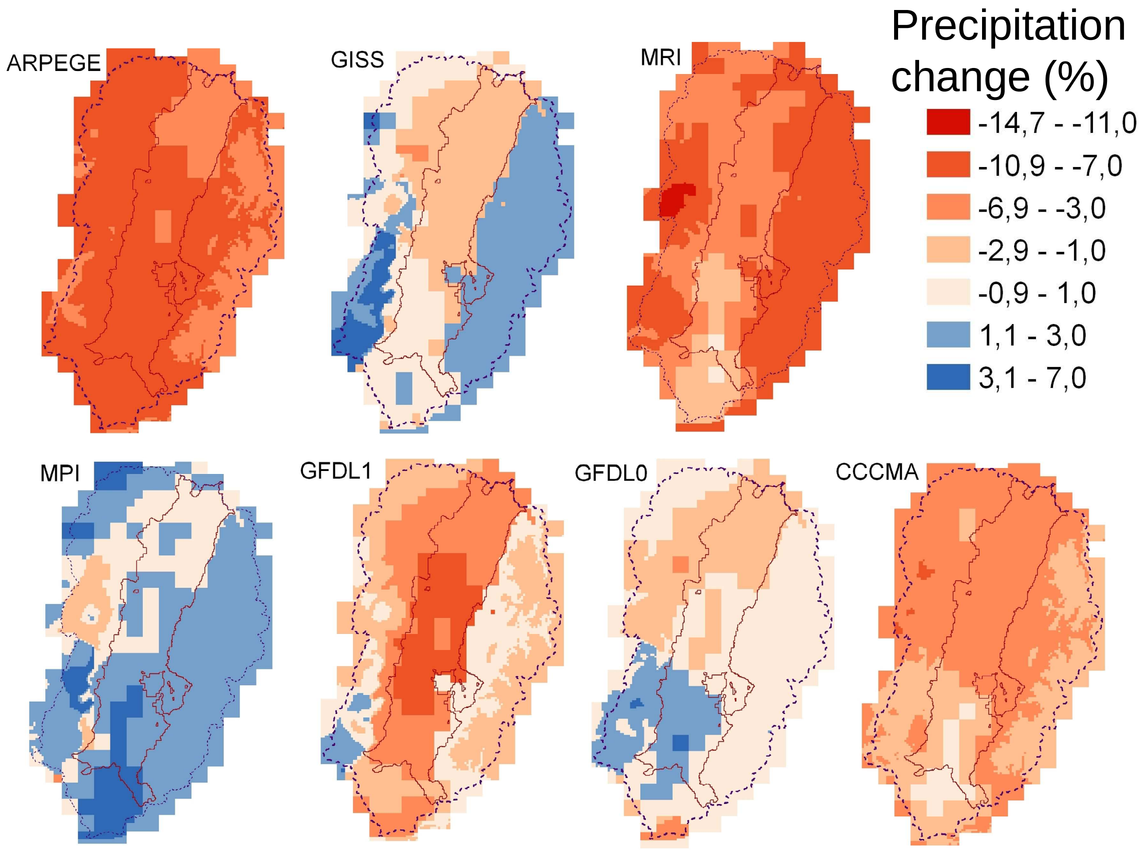

Figure 3: Annual evolution of the precipitations over the period 2045-2065 compared to 1961-2000 estimated by the seventh downscaled projections.

3.2 Climate change impacts on the water budget

All but one climate projections lead to an increase of the actual evapotranspiration (figure 4) associated to the warming air and increased potential evapotranspiration. The evolution of the annual runoff ranges from -1 to -8 %, while the effective rainfall decreases from -3 to -34%. However, the effective rainfall represents less than 20% of the aquifer recharge. Therefore, figure 5 focus on the dominant source of the recharge which is the river infiltration. For all climate projections and aquifer parameters sets, the river infiltration decrease from -1 to -7%. This flux is as sensitive to the climate projection as to the parameter sets.

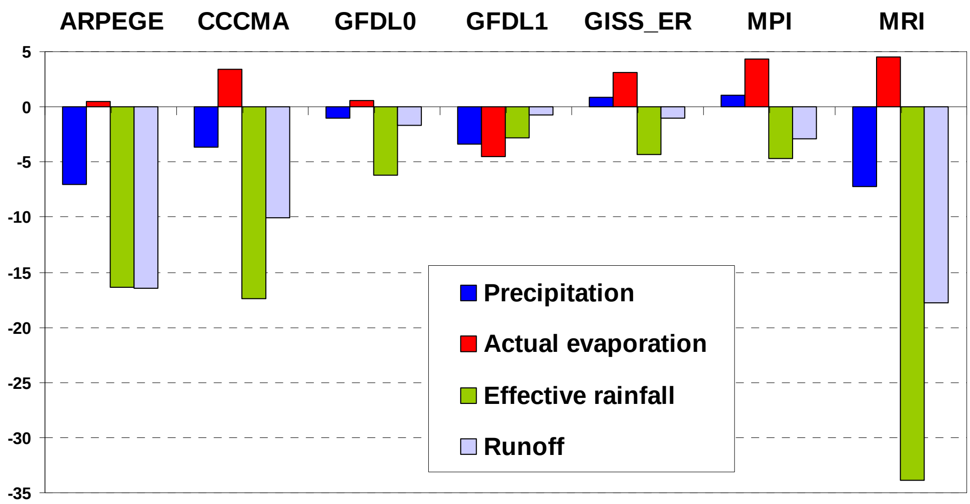

Figure 4: Evolution of the water budget simulated by MODCOU using the seventh downscaled projections for the period 2045-2065 compared to 1961-1990. The effective rainfall corresponds to the part of the precipitation that infiltrates to the aquifer.

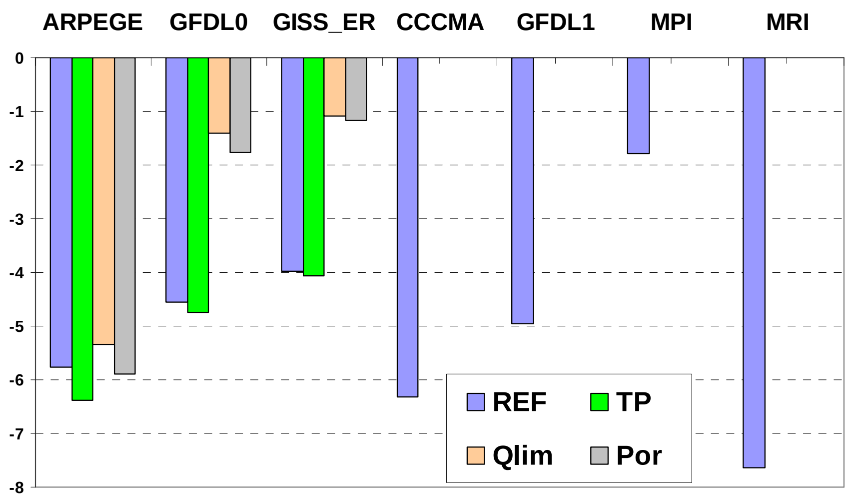

Figure 5 Evolution of the river infiltration for the seven climate projection and the 4 sets of parameters (for only 3 climate projection) on average on the periods 2045-2065 compared to 1961-1990.

3.3 Climate change impacts on riverflows and piezometric head

Although the annual riverflows decrease for most of the climate projections, there are some areas where the mean annual river flow increases essentially due to the increase of winter rainfall and the decrease of the snow part. Consequently, the 10-year return period food is expected to increase in most part of the basin, while the 5-year return period low flows are expected to decrease, leading to an increase of the variability of the water resource (figure 6).

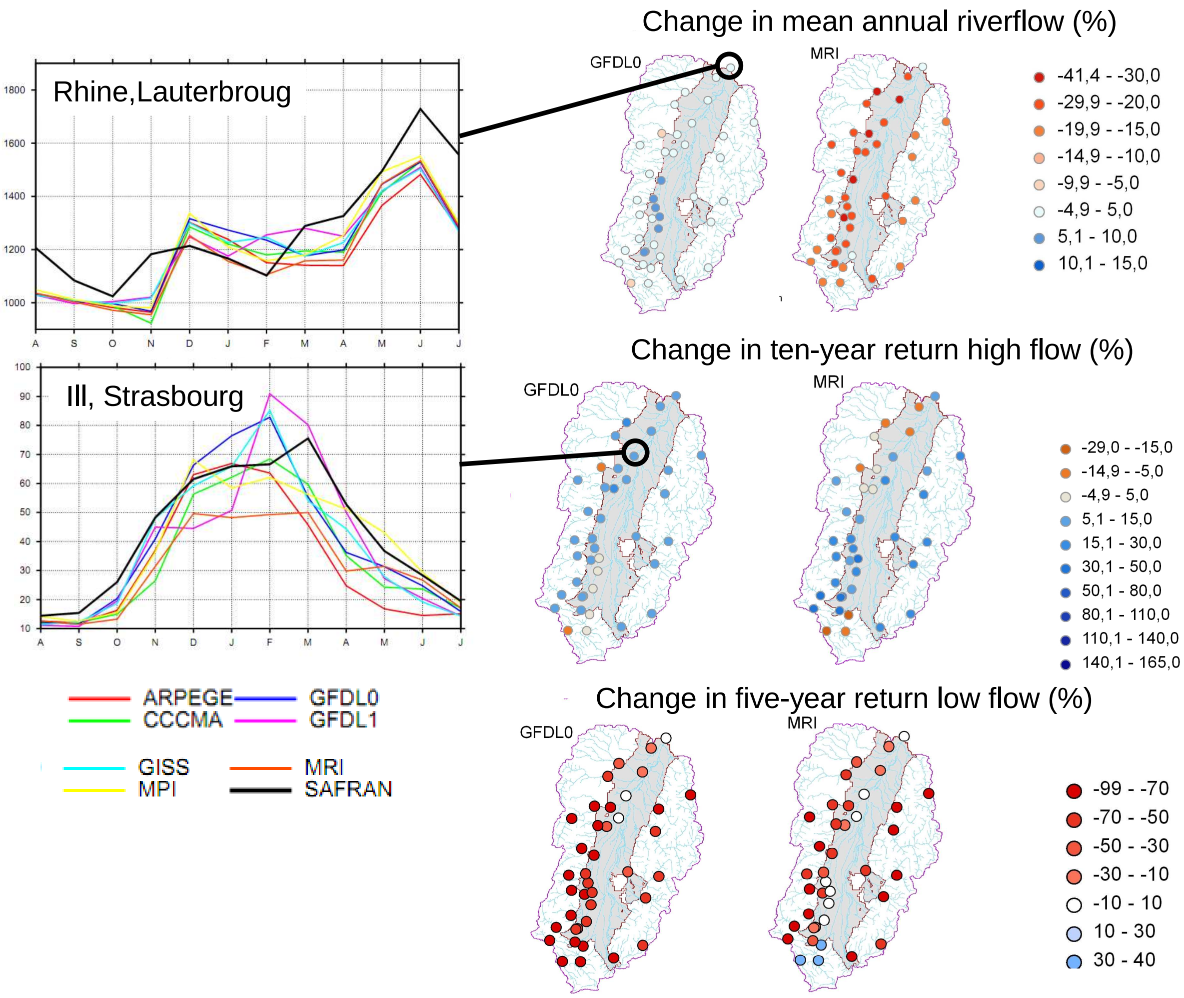

Figure 6: evolution of the mean annual riverflows, 10-year return high flow, and 5 year return low flow for two contrasted climate projections. The two boxes show the mean monthly riverflows in two places simulated with the seven climate projections over the period 2045-2065 (colored lines) compared to the simulation obtained with the current observed atmospheric forcing (black line.

The piezometric levels are lowered by only a few decimeters on the central and northern parts of the basin where the aquifer stays close to the surface, and are decreasing by more than a meter in the southern part where recharge through river infiltration is the main recharge process (figure 7).

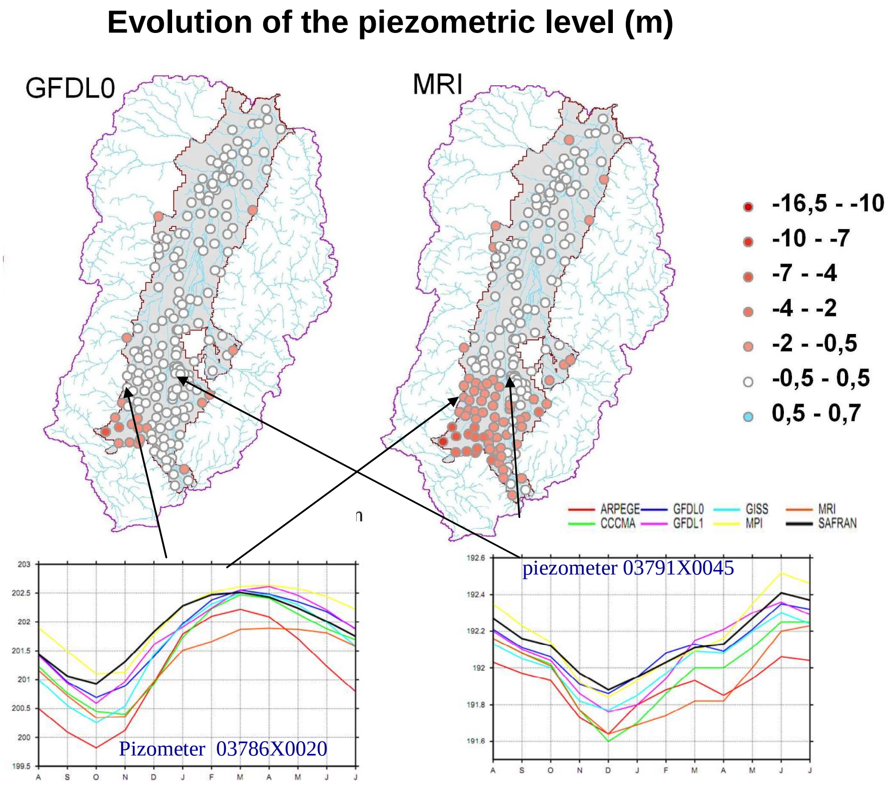

Figure 7: Evolution of the mean annual piezometric levels for two contrasted climate projections. The two boxes show the mean monthly piezometric levels in two places simulated with the seven climate projections over the period 2045-2065 (colored lines) compared to the simulation obtained with the current observed atmospheric forcing (black line)

4 DISCUSSION

Climate change is projected to enhance the seasonal contrast of the water resource of the Upper Rhine graben basin, with a moderate decrease of the piezometric level associated with a decrease of low flows and an increased of the high flows. In order to estimate the uncertainty associated to these projections, the impact of climate change on the groundwater recharge was analysed using the variance decomposition method[8,9]. Although the uncertainty on the hydrogeological parameters impacts the quantification of the river infiltration, it is far from being the main source of uncertainty, because it explains only 4% of the total variance. Indeed, the uncertainty associated with climate modeling is still dominant. However, the total uncertainty is underestimated in this study, since only one emission scenario of greenhouse gas emissions, one method of downscaling and a single hydrogeological model were used.

Moerover, a key process is not fully simulated by our modeling approach: the groundwater evaporation that occurs when the aquifer is close enough to the surface to interact with the root zone. It is expected that the actual evaporation in the plain is underestimated in the present study, and thus that the impact on the aquifer could be more important. To take into account such process, a fine coupling between the MODCOU hydrogeological model and the ISBA surface scheme[10] is in progress.

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