Future Pyrenees water cycle evolution combining hydrological model

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Introduction

The Pyrenees are a mountain range of great environmental importance, due to its considerable climatic variety, ranging from Atlantic to Mediterranean climates, and high vulnerability to climate change. In addition, this mountain range serves as a water source for more than 15 million people, as well as industry, agriculture, and valuable ecosystems.

Humans are altering the hydrological functioning of the Pyrenees. For instance, greenhouse gas emissions have a substantial impact on the climate, and hence all aspects of the water cycle, affecting it on both a spatial and temporal scale. As a result, understanding and studying the future evolution of the Pyrenean hydrological cycle is critical for its management, particularly in surface flows, which are the main source of water resources.

Hydrological modeling is a crucial tool to analyze possible hydrological changes over time, as well as trends in future water resources availability. But hydrological models need to be forced by climatic data for the simulation time period. Global Climate Models (GCM) are used to estimate scenarios of the future climate, which among other factors, depends on greenhouse gas concentrations, estimated for different Representative Concentration Pathways (RCP). The CLIMPY project provided these data for the Pyrenees region (Amblar-Francés et al. 2020). They have been used in this work.

Methodology

No hydrological model is able to perfectly simulate the hydrological system, so using a diversity of models can help to assess, to some extent, the uncertainty associated with this modeling. Thus, we studied the future evolution of the main components of the water cycle in the Pyrenees for this century using two hydrological models: the fully distributed model SASER (Quintana-Seguí et al. 2020), and the semi-distributed model SWAT (Douglas-Mankin, Srinivasan, and Arnold 2010). The comparison of simulations using six GCM and two RCPs (RCP45 and RCP85) allows us to detect, evaluate, and analyze changes in the main components of the water cycle, their trends, as well as the main sources of uncertainty.

SWAT simulations used the atmospheric forcing dataset provided by the CLIMPY project, applying a bias correction based on delta change. CLIMPY provides data of minimum and maximum temperature and precipitation, which is enough for SWAT. However, SASER needs more parameters, thus we completed the climatic dataset using an analogues methodology. The latter extends the method developed by Clemins et al. (2019) to build a multivariate high-resolution reanalysis dataset to infer projected ancillary variables from precipitation and temperature projections based on analogue resampling.

Results

The study shows that the future climate of the Pyrenees will be clearly warmer, throughout the study domain, and drier. However, there could be increases in mean annual precipitation in the southeast of the domain (southern Mediterranean area) (Fig. 1). It should be noted that there is a high uncertainty about this last aspect.

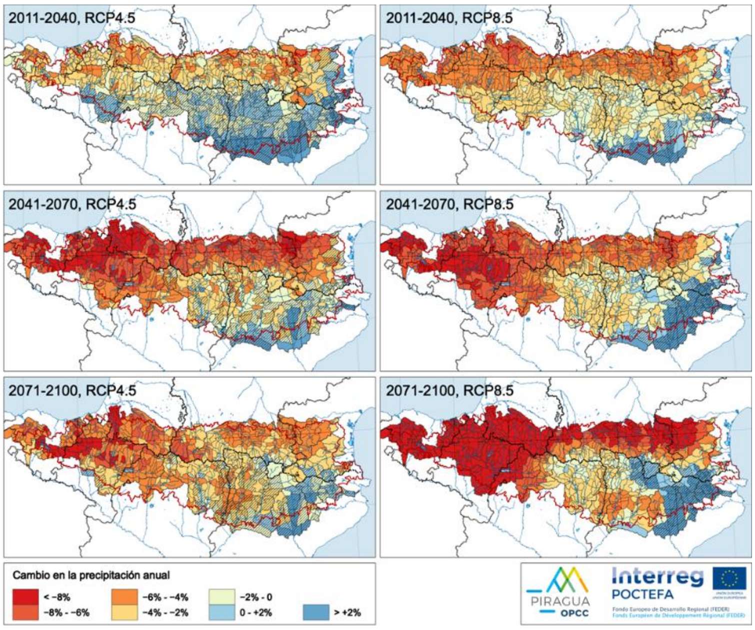

Figure 1. Change in mean annual precipitation relative to 1981-2010 for three time horizons and two emissions scenarios: median values from nine GCM models. Dashed lines indicate low agreement between simulations. Modified from Beguería et al. (2022)

Even though potential evapotranspiration will increase, actual evapotranspiration will decrease as the century progresses (Fig. 2), with high consensus among simulations at the end of the 21st century. This is explained by a decrease in soil water availability. This will result in a more arid climate throughout the domain, except at higher elevations where earlier and more pronounced snowmelt will contribute to increased soil moisture and thus water available for vegetation.

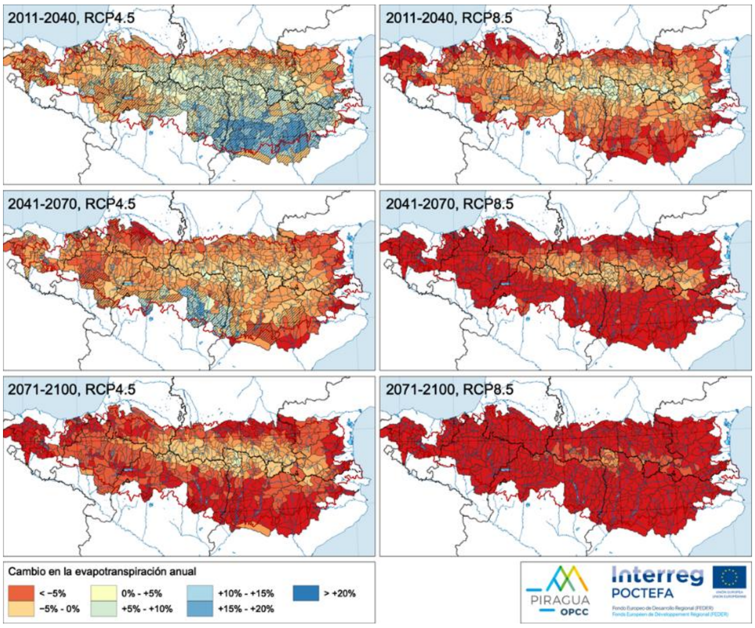

Figure 2: Change in mean annual evapotranspiration relative to 1981-2010 for three time horizons and two emissions scenarios: median values from nine GCM models. Dashed lines indicate low agreement between simulations. Modified from Beguería et al. (2022)

Snow has a great influence on the hydrological regime of the Pyrenean basins. The study shows that snow cover (Fig. 3) will decrease in the future throughout the domain with strong reductions, and snowmelt will decrease due to a decrease in snow cover and an increase in sublimation. Consequently, the future Pyrenean basins' regimes will be less nival and more pluvial. In terms of water resources, aquifer recharge will decrease, except in areas where precipitation may increase. Runoff generation will also decrease in a generalized way in practically all the domain. Especially in the northern slopes of the Pyrenees, with the exception of some sub-basins in the southeast of the Pyrenean area. The most marked changes will be those of temperature and snow reduction, which are closely related. These will modify the seasonality and therefore the hydrological regime of the studied basins.

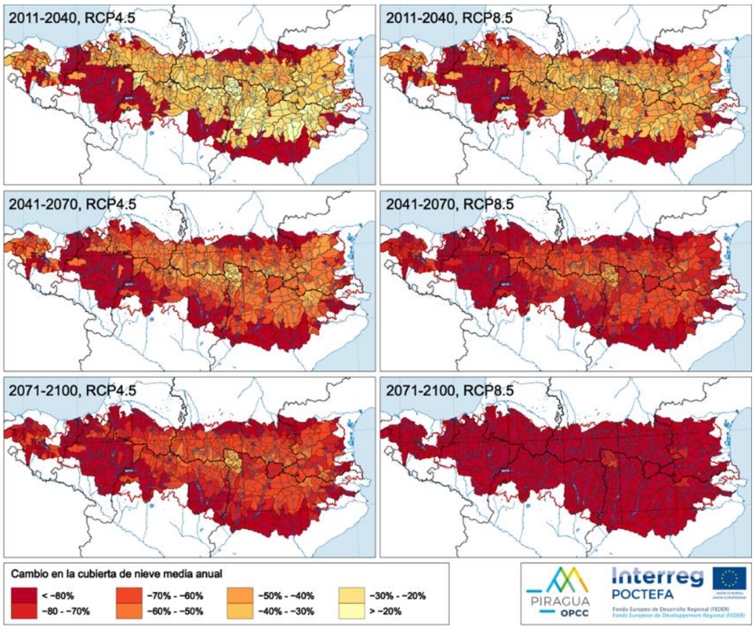

Figure 3: Change in mean annual snow cover (snow water equivalent) relative to 1981-2010 for three time horizons and two emissions scenarios: median values from nine GCM models. Modified from Beguería et al. (2022)

The contribution of the main rivers of the Pyrenees to the outlet of the massif will consequently be affected by significant reductions, which may reach more than 20% reduction of the annual contribution on the northern slope of the massif in the middle and end of the 21st century, although they will be more moderate (between 10 and 15%) on the southern slope, where the westernmost basins will be more affected than the eastern ones.

Conclusion

A complex geographical domain and climatically diverse as the Pyrenees requires to take into account uncertainties at different levels: emissions scenarios, global climate models, correction methods, and impact models, as has been done in this work. This gives us considerable confidence in the robustness of the results obtained.

In general, the exposed results show an evolution towards warmer and drier conditions, as well as a clear decrease in snow cover. This can have an impact on the availability of water resources which is an already difficult water management situation due to high demand and variable supply.

Acknowledgements

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