Enhanced recharge rates and a greater sensitivity to climate variations in regions with heterogeneous subsurface

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MOTIVATION

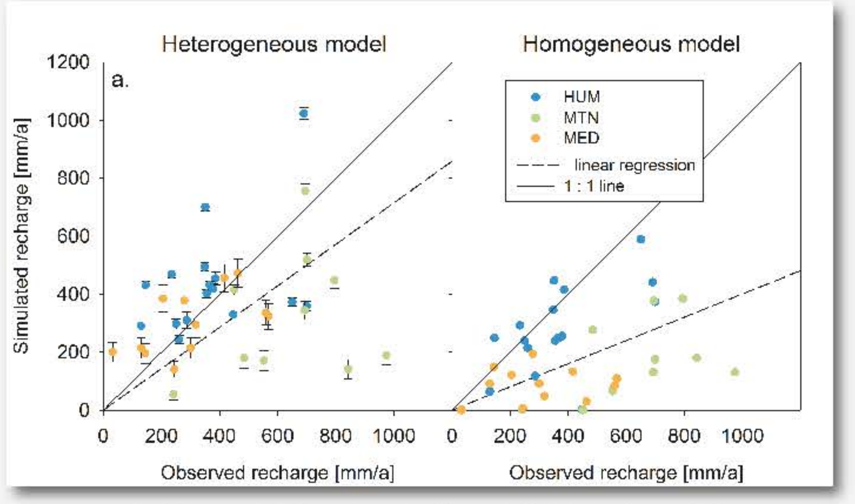
In hydrology, subsurface heterogeneity exerts an important control on water balance. This notably includes groundwater recharge, which is an important factor for efficient and sustainable groundwater resources management. Currently, large-scale hydrological models do not adequately consider subsurface heterogeneity.

Here we show that regions with strong subsurface heterogeneity have enhanced recharge rates and greater sensitivity to future climate variability compared to regions with homogeneous subsurface properties. This enhanced sensitivity translates into potentially significant differences in projections for future water balance estimates.

Our study domain is comprised of the carbonate rock regions that cover ~25% of Europe and the Mediterranean. Aquifers from these regions contribute up to half of the drinking water supply for some European countries.

EVALUATION

We compare the simulated historic recharge volumes of our model with recharge volumes assessed from independent and published karst studies over Europe and the Mediterranean. Even though there is a considerable spread across the simulations, their bulk plots well around the 1 : 1 line. When we compare the same observations to the simulated recharge volumes of the PCR-GLOBWB model we find a strong tendency of underestimation that is strongest for the mountain and Mediterranean landscapes but still significant for the humid landscapes.



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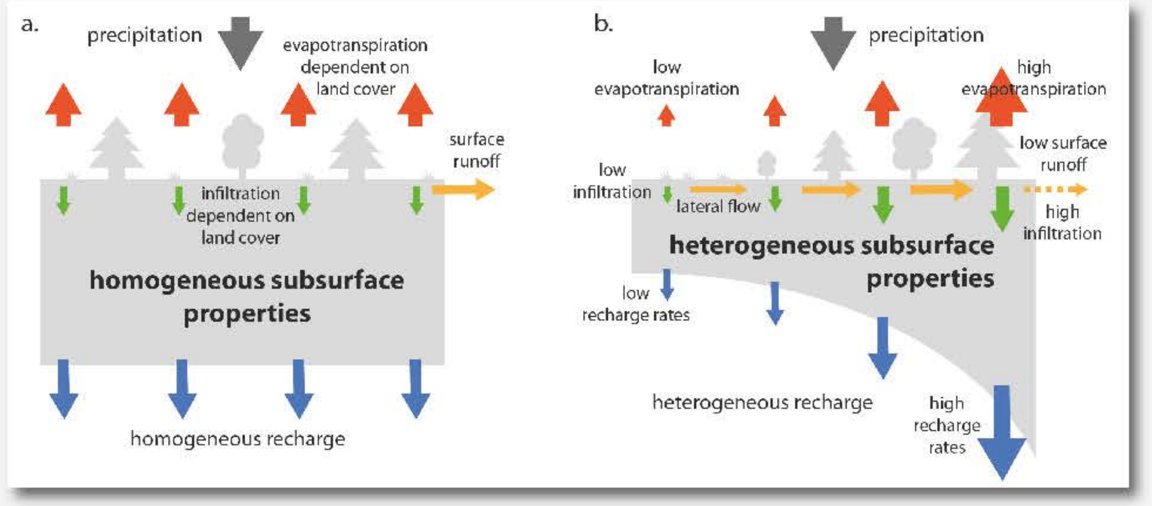
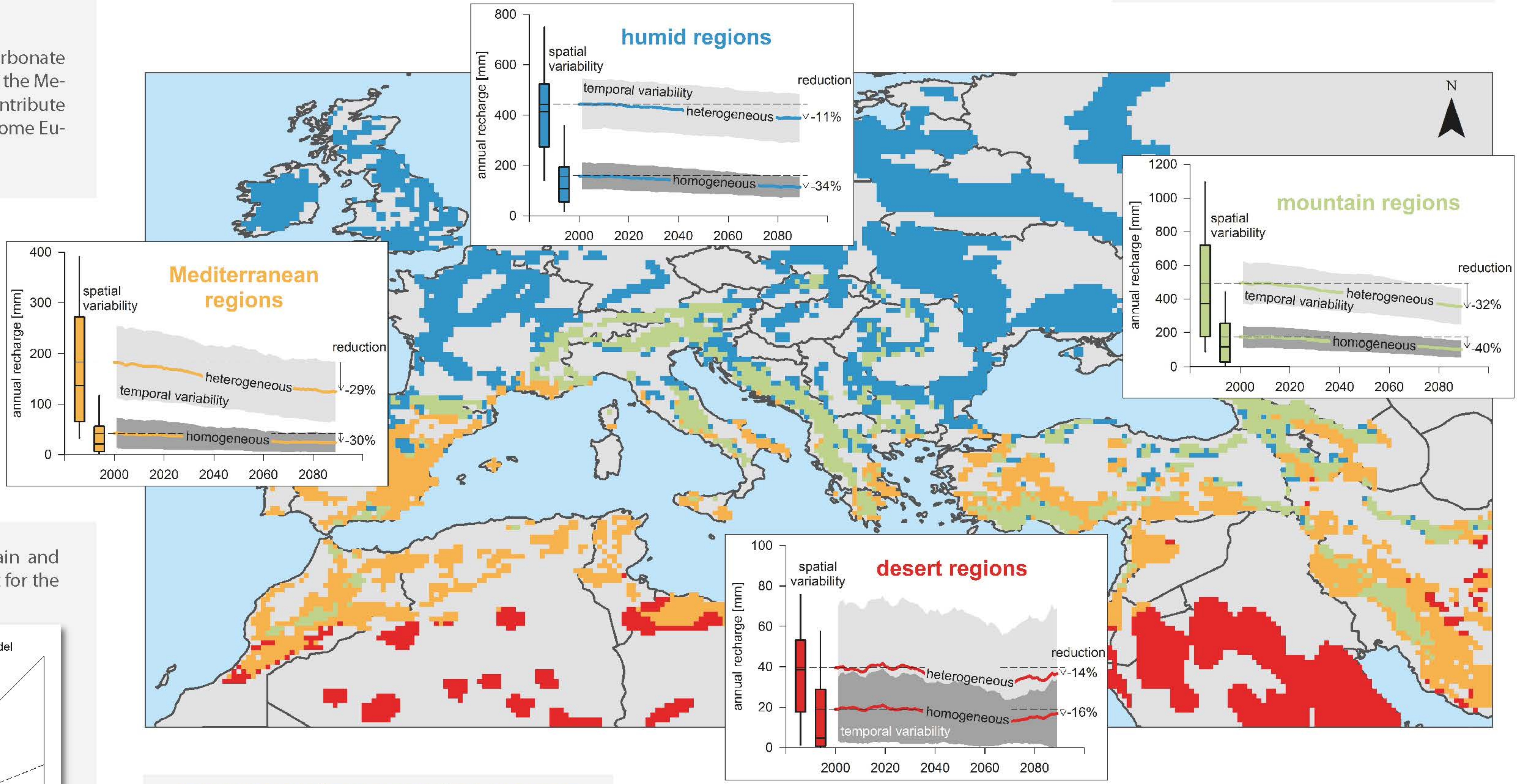
APPROACH

We simulate groundwater recharge with both a **homogeneous and a heterogeneous subsurface representation**. The global hydrological model PCR-GLOBWB is used for the homogenous subsurface representation, while the karst recharge model VarKarst-R is used for the heterogeneous representation. We use the output of five GCMs (ISI-MIP) to simulate groundwater recharge from 1991 to 2099 assuming a worst-case scenario (RCP8.5).



Climate sensitivity of groundwater recharge rates is assessed by a metric termed "elasticity". We define **recharge elasticity** E_R [-] as the median of the inter-annual changes of recharge rates R [mm a^{-1}] according to trans-annual changes of a controlling variable X, normalized by their annual means over a pre-defined period:

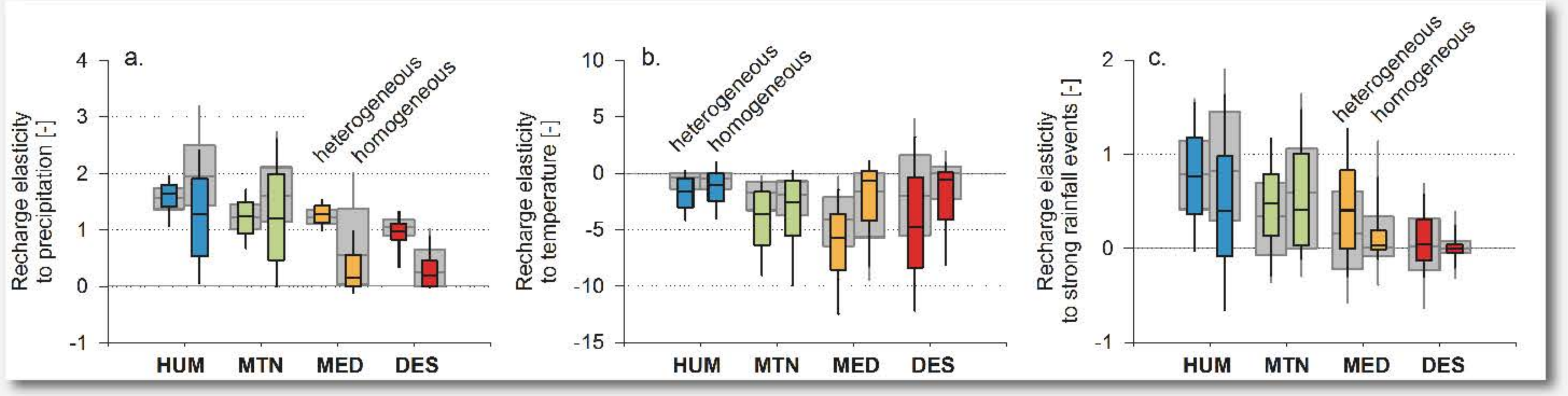
$$E_R = median\left(\frac{\Delta R}{\Delta X}\right) \cdot \frac{\overline{X}}{\overline{R}}$$



ENHANCED RECHARGE

In the **present period** (1991-2010), the more realistic representation of karst processes of **the heterogeneous subsurface model produces recharge rates that are 2.1 to 4.3 times larger than the recharge rates of the homogeneous representation**.
Towards the end of the century (2080-2099), simalar apparent fractional reductions in recharge rates of 11-32% for the heterogeneous subsurface and 16-40% for the homogeneous subsurface occur but the differences in absolute volumes of recharge rates from the present period even increase with **recharge rates of the heterogeneous representation 2.1 to 4.6 larger than the homogenous representation.**

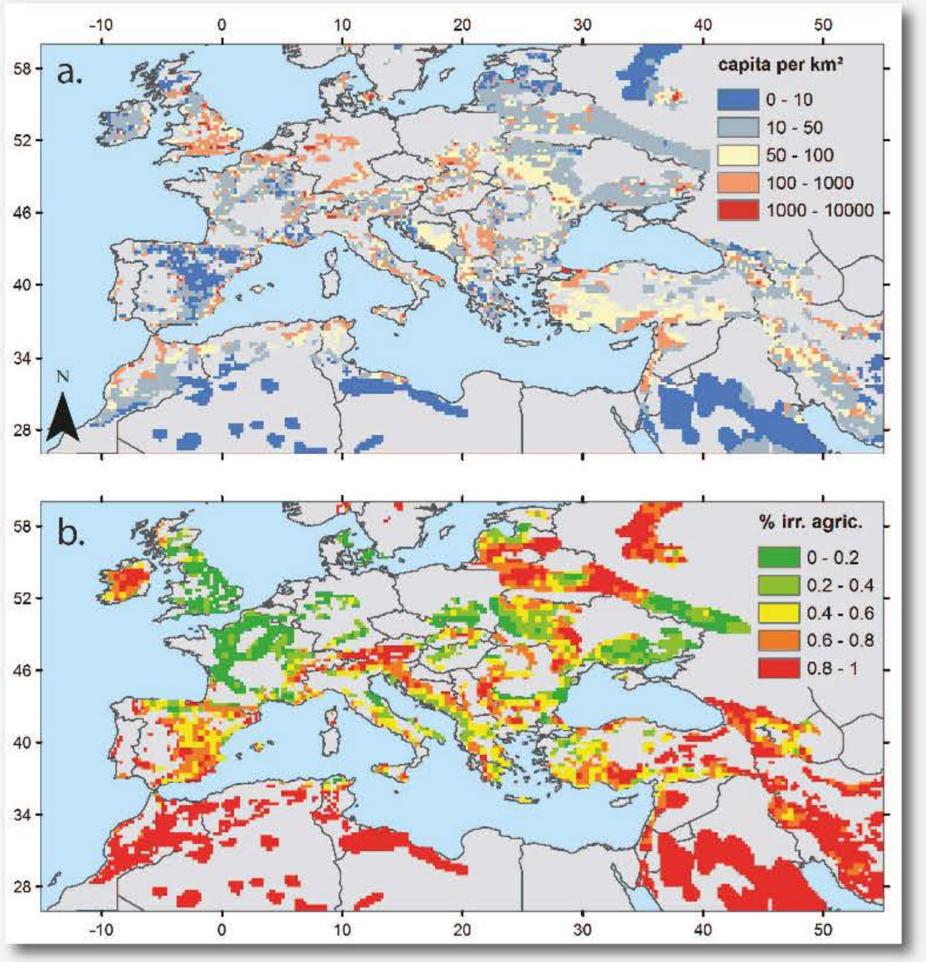
GREATER SENSITIVITY



An elasticity >1 or <-1 indicates that annual recharge is changing stronger than the input variable, i.e. a high sensitivity. Values closer to 0 indicate a low sensitivity. **The two subsurface representations exhibit different sensitivities to climate variability and predict that heterogeneous regions will have a generally higher sensitivity to climate variability in the future.** This is due to a more direct coupling of climatic variability and groundwater recharge variability predicted by the heterogeneous representation and shifts towrds more evaporation and surface runoff for the homogeneous representation.

RELEVANCE

Our study domain covers ~25% of the total land surface of Europe and the Mediterranean and it is home to ~560 Mio. people. Aquifers from these regions are major contributors to European water supplies and their agriculture depends 70% on irrigation. The high present-day recharge rates we found in these regions are considerably larger than estimates that assume homogeneous subsurface properties. These results explain why carbonate rock aquifers are considered highly important for Europe's national water supplies.
Due to the more direct coupling of climate and groundwater recharge those regions will remain with high recharge rates in the future but they will require flexible water management strategies that are able to cope with variable groundwater availability across different years.



SYNTHESIS

Overall, our results imply that subsurface heterogeneity alters water balance on a large scale. Considering it in hydrological projections is therefore relevant for present and future water management. The strong coupling of climate and recharge variability in heterogeneous regions produces more groundwater recharge than previously expected. However, **the increased inter-annual variability of recharge poses serious challenges for sustainable groundwater management and groundwater protection.**

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For future research also see **poster H11H-1448** of this session of this session.

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