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, most large-scale hydrological models do not adequately consider subsurface heterogeneity.

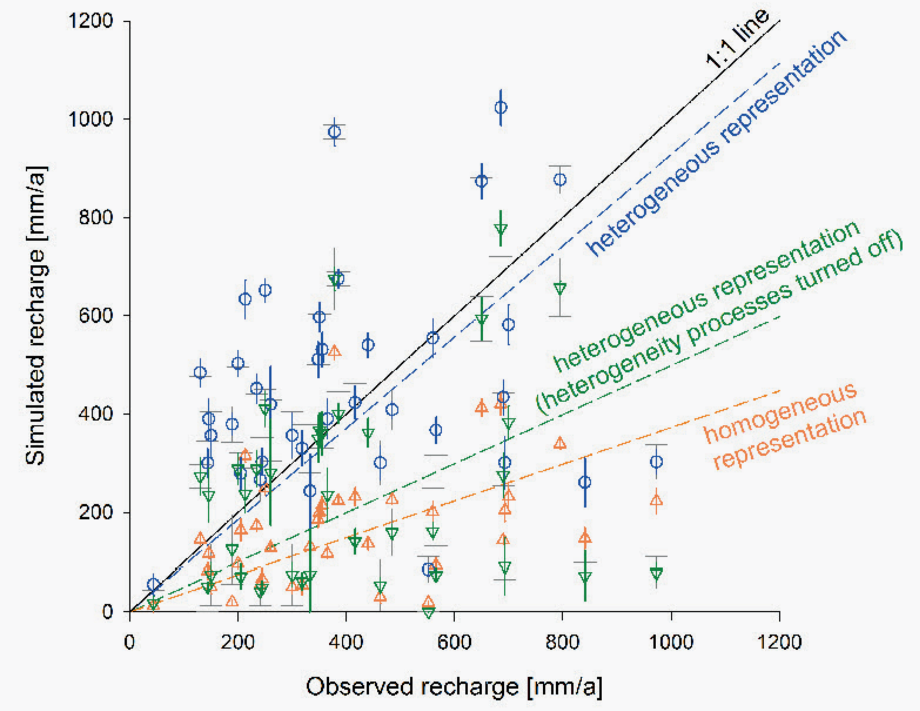
Here we show that regions with strong subsurface heterogeneity have enhanced present and future recharge rates due to a different sensitivity of recharge to climate variability compared with regions with homogeneous subsurface properties.

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.

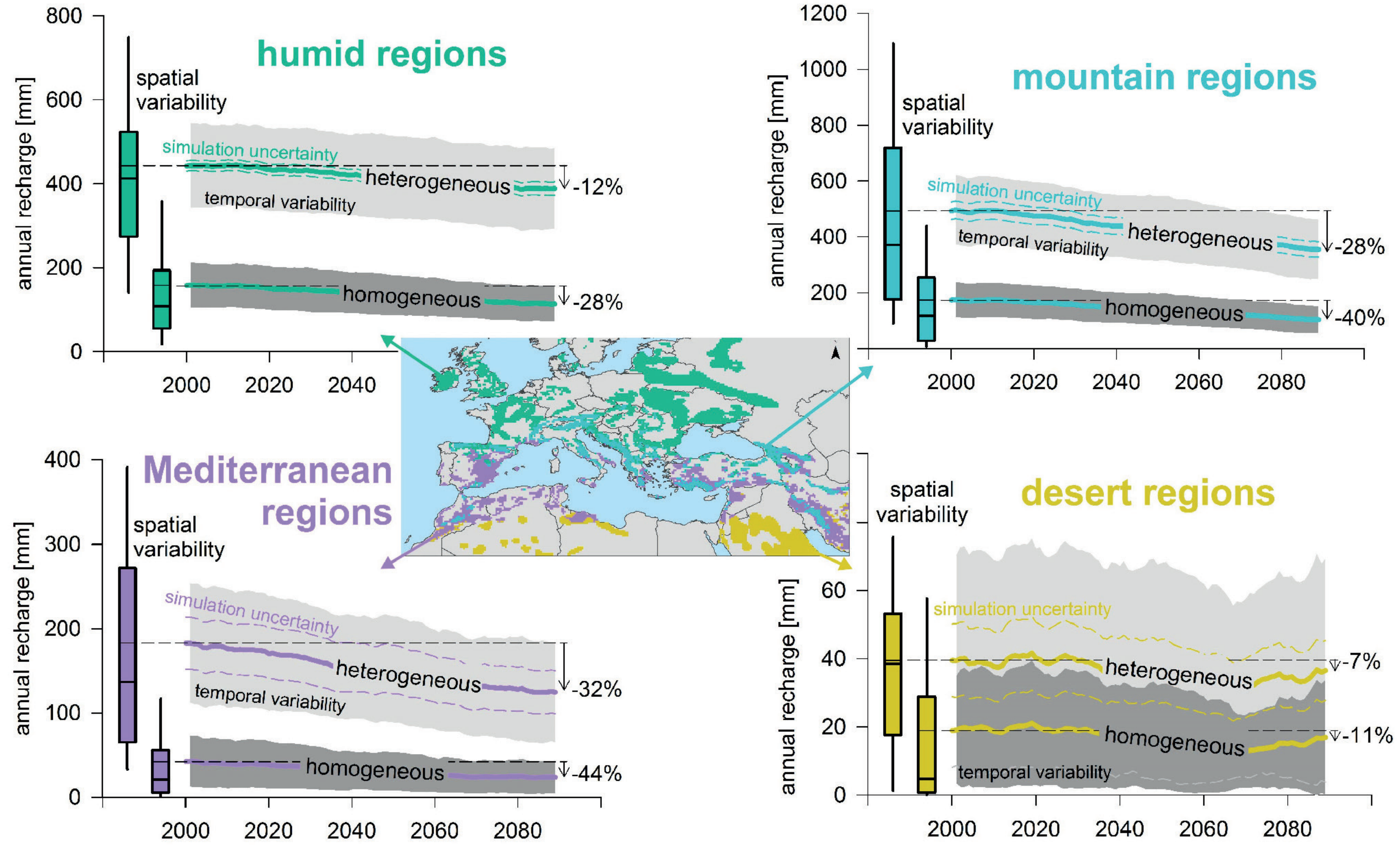
EVALUATION

Comparison with observations indicates that the heterogeneous model provides more realistic simulations of recharge than the homogeneous model because it includes heterogeneity processes.

When we turn off the heterogeneity processes of the heterogeneous model, its simulations also fall in large parts below the 1:1 line, plotting closer to the simulations of the homogeneous model.



ENHANCED RECHARGE

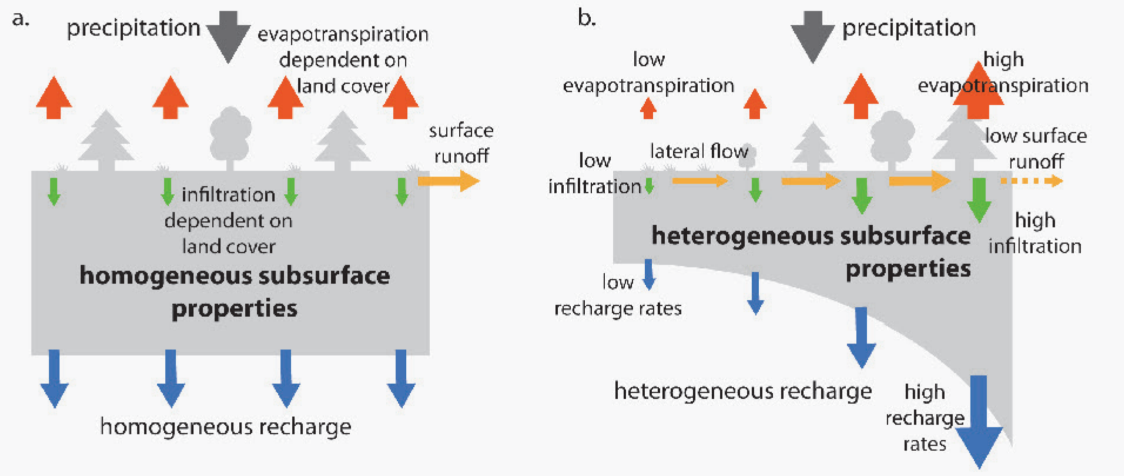


The differences in recharge sensitivity to variability in climate result in different simulated present and future recharge rates over Europe's carbonate rock regions. Compared with the ho- mogeneous subsurface representation, the heterogeneous sub- surface representation shows enhanced and more variable recharge rates for both present and future conditions. In the present period (1991–2010), the simulated recharge rates of the heterogeneous subsurface representation are **2.1–4.3× larger** than the recharge rates of the homogeneous representation.

As a result of the projected climatic change, we find a general reduction of recharge rates for both subsurface representations. The relative decrease of the two subsurface representations is in the same direction but the absolute reductions of simulated recharge rates of the heterogeneous representation are **2.2–5.3× larger** than the simulated reductions of the homogeneous representation.

APPROACH

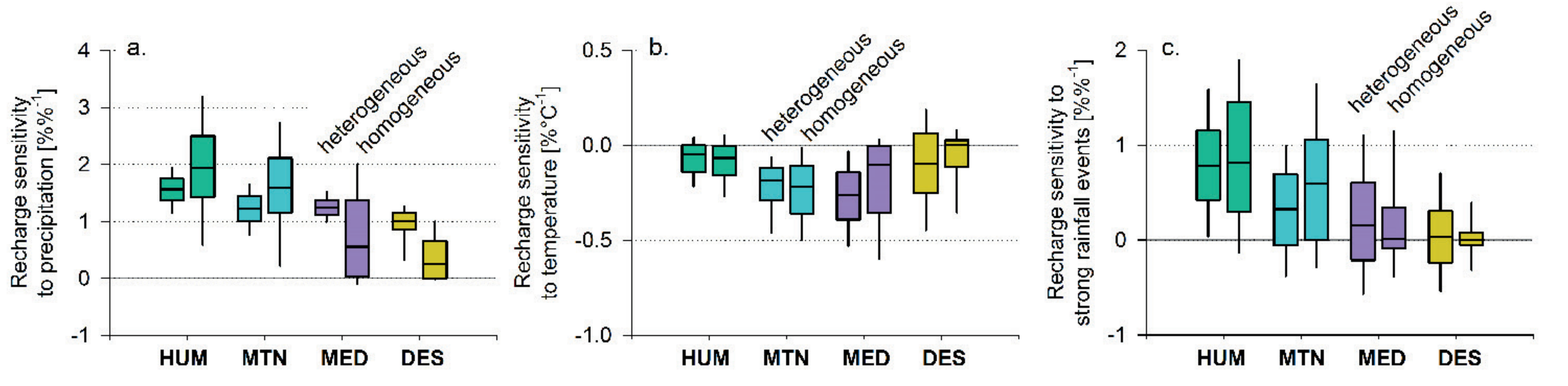
We simulate groundwater recharge with both a **homogeneous and a heterogeneous subsurface representation**. The global hydrological model PCR-GLOBWB is used for the homogenous representation, while the karst recharge model VarKarst-R is used for the heterogeneous . We use the output of five GCMs (ISI-MIP) to simulatefuture recharge 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:

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

ALTERED SENSITIVITY

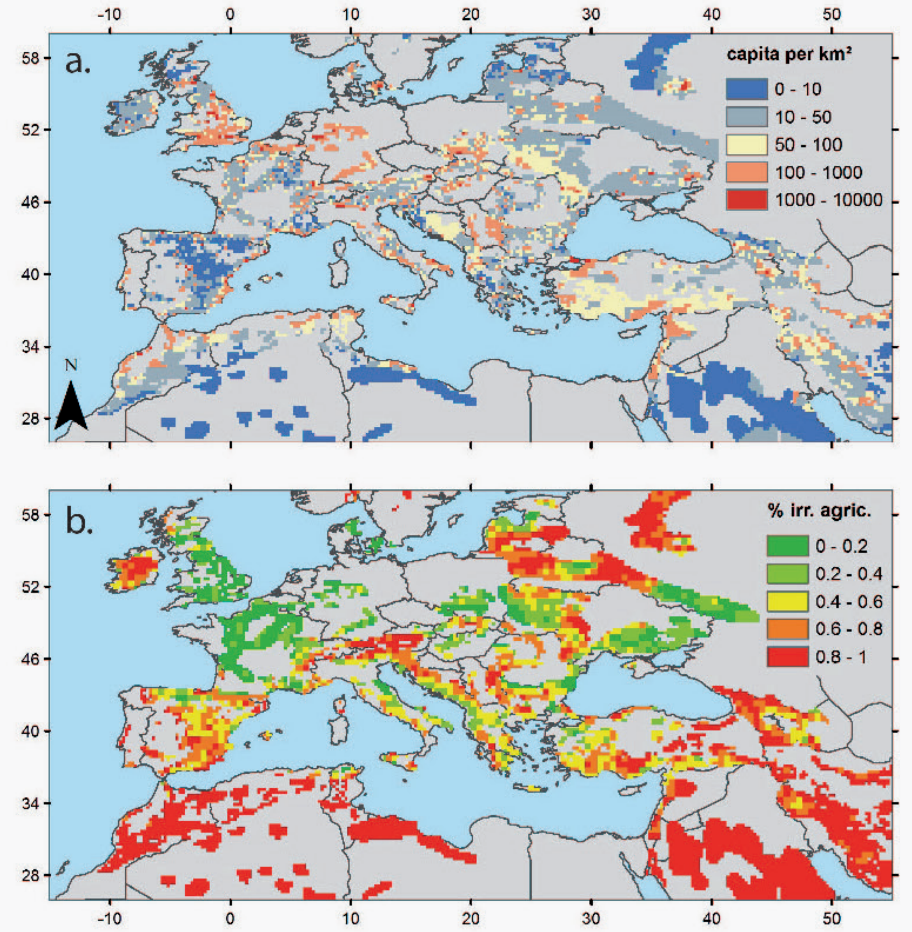


We find that the two subsurface representations exhibit different sensitivities to climate variability. The different recharge sensitivities with respect to climate variability for the two subsurface representations can be explained by the interplay of two different simulated processes: (i) variable fractions of surface runoff, which dynamically increase or reduce infiltration, and (ii) different dynamics of evapotranspiration that change the amount of water available for downward percolation.

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.

Our results imply that subsurface heterogeneity significantly alters groundwater re- charge and its sensitivity to climate variability at large spatial scales. They indicate that previous large-scale model applications may have reduced utility for groundwater management for regions with pronounced subsurface heterogeneity.



SYNTHESIS

Widely used global hydrological models generally assume simple homogeneous subsurface representations to translate climate signals into hydrological variables. We demonstrate that subsurface heterogeneity alters the sensitivity of recharge to climate variability and enhances recharge estimates, resulting in potentially more available water per capita, than previously estimated. Through our parsimonious simulation approach, we also provide a promising direction to include subsurface heterogeneity evolved due to karstification into any large-scale hydrological model to obtain more realistic simulations.

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See also Hartmann, A., Gleeson, T., Wada, Y., Wagener, T., 2017. Enhanced groundwater recharge rates and altered recharge sensitivity to climate variability through subsurface heterogeneity. Proc. Natl. Acad. Sci. doi:10.1073/pnas.1614941114