

Projections of groundwater recharge changes in the Mediterranean: Uncertainties of simulating groundwater recharge in global hydrological models

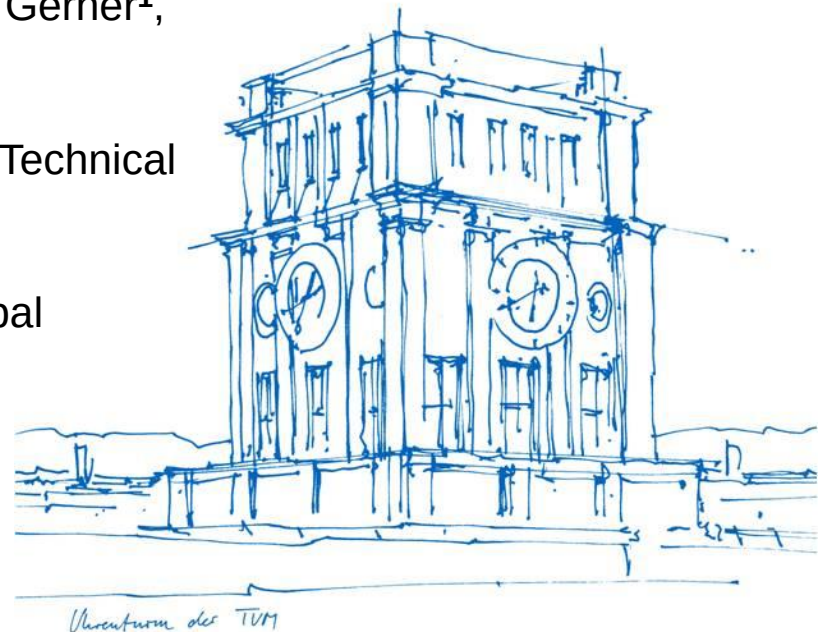
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1. Motivation

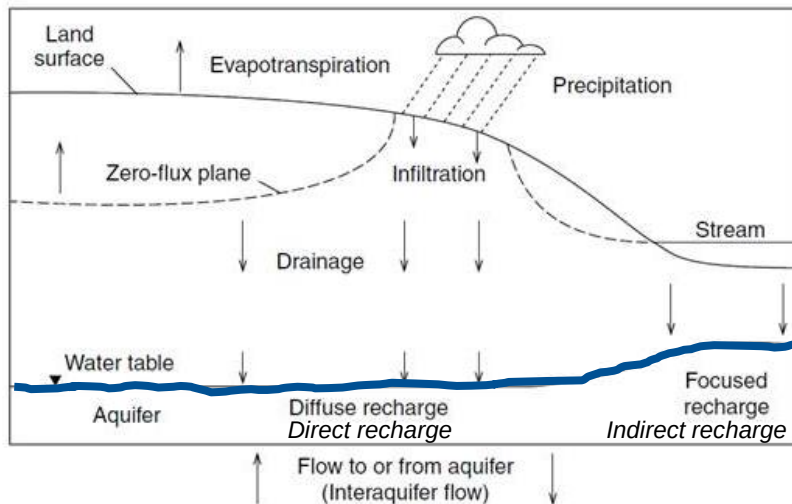
- Strong climate change impacts are projected in the Mediterranean region
- Effects on groundwater availability are unsure
- Goal of this research: enhance the understanding of past and future developments of large-scale groundwater recharge in the Mediterranean under climate change scenarios



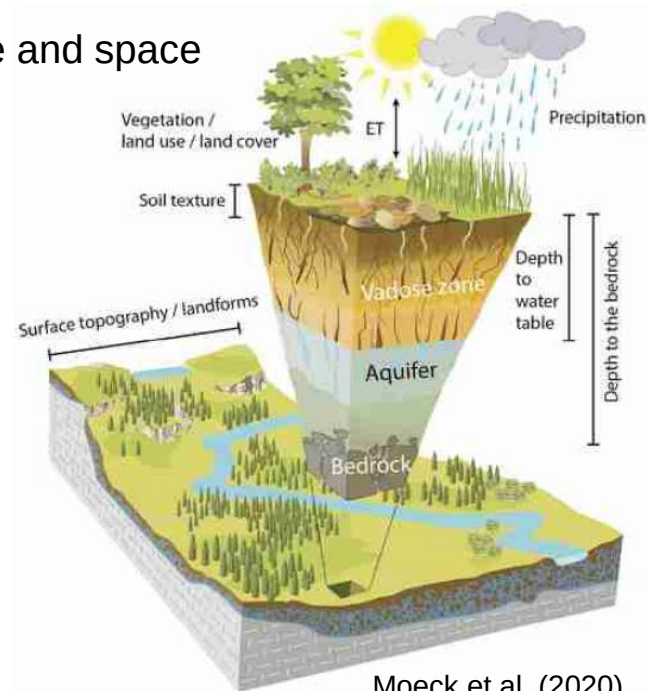
2. Groundwater recharge is a complex process

Variables involved (excerpt): precipitation, evapotranspiration, infiltration (soil characteristics, depth to groundwater table, sealing), percolation, vegetation, roots, vadose zone, bedrock type, topography, slope

→ Generally interconnected, strong variation in both time and space



modified after Healy & Scanlon (2010)



Moeck et al. (2020)

Definitions:

Groundwater: subsurface water in the saturated zone of the soil or bedrock (NRC, 2004)

Groundwater recharge: "water reaching the groundwater table by downward, lateral or upward movement, adding to the groundwater reservoir" (de Vries & Simmers, 2002)

3. A vast amount of data is available through ISIMIP

Inter-Sectoral Impact Model Intercomparison Project simulation round 2B ISIMIP2B:

- **four** global circulation models (*IPSL-CM5A-LR*, *HadGEM2-ES*, *GFDL-ESM2M*, *MIROC5*) used as climate drivers, at different climate and CO₂ concentration scenarios making up some of the input data for the...
- **eight** global hydrological models (*WaterGAP2*, *CLM4.5*, *H08*, *JULES-W1*, *LPJmL*, *PCR-GLOBWB*, *CWatM*, *MATSIRO*) evaluated here.

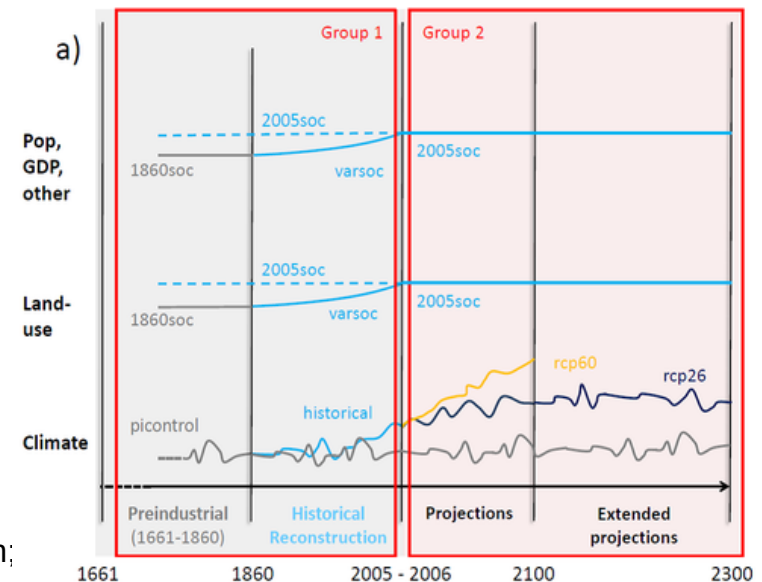
Climate and CO₂ concentration scenarios (distinguished in this study):

- **picontrol**: preindustrial “baseline” (no industrial revolution)
- **historical**: with emissions from industrial revolution 1861-2005
- **Representative concentration pathways (RCPs)**: projections from 2005-2099/2100-2299, rcp26, rcp60, rcp85

Human influence and land use scenarios (not distinguished in this study):

assumption of identical/ variable land use, population and GDP for societies in (identical: 1860soc & 2005soc representing state of 1860 & 2005; variable: varsoc representing state of 1860-2005)

The **spatio-temporal resolution** of groundwater recharge: **monthly**, **0.5°x0.5°** → at southern boundary (lat=29.75°), cells are ~96 km in lon direction, at northern boundary (lat=45.25°), cells are ~78 km in lon direction; lat direction length is approx. 111 km over the Mediterranean region



Conceptualization of the ISIMIP2B scenarios

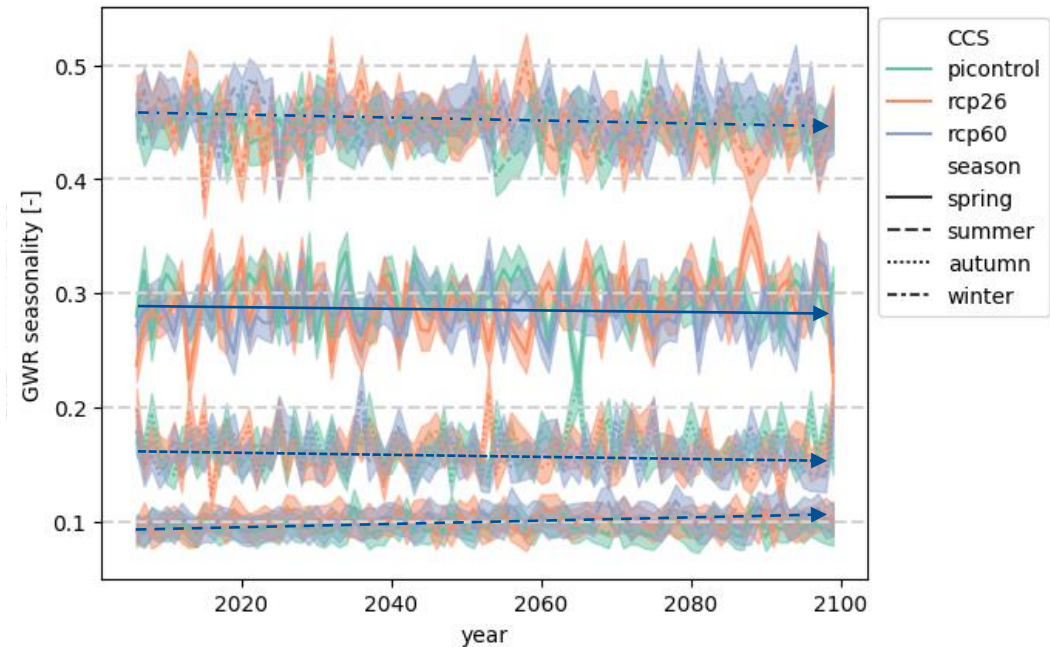
4. Seasonality of recharge is predicted to change

In this research: seasonality = percentage of annual recharge occurring in a season

On average, winter is by far the season with most recharge, followed by spring.

Summer is the season with least recharge, but on average its contribution increases in the 21st century, while the importance of winter, autumn and spring is slightly decreased at rcp60 compared to picontrol.

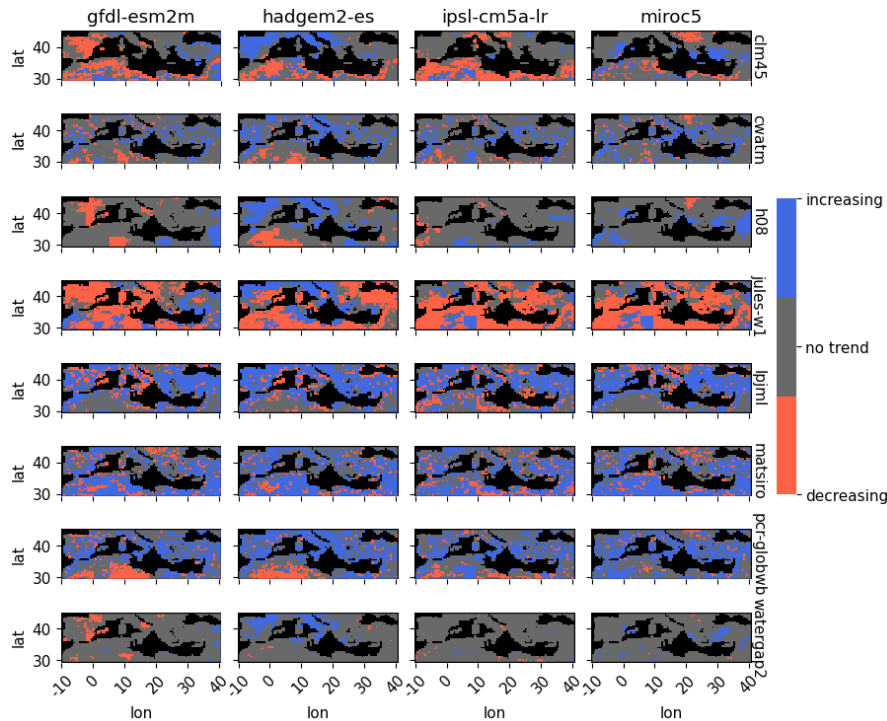
The 95% confidence interval shown around the lines indicate how uncertain the results are, especially the small changes of the average over time.



Annual mean seasonality of the ensemble at the climate and CO2 scenarios, in the entire Mediterranean (arrows added to visualize the approximate trend at rcp60)

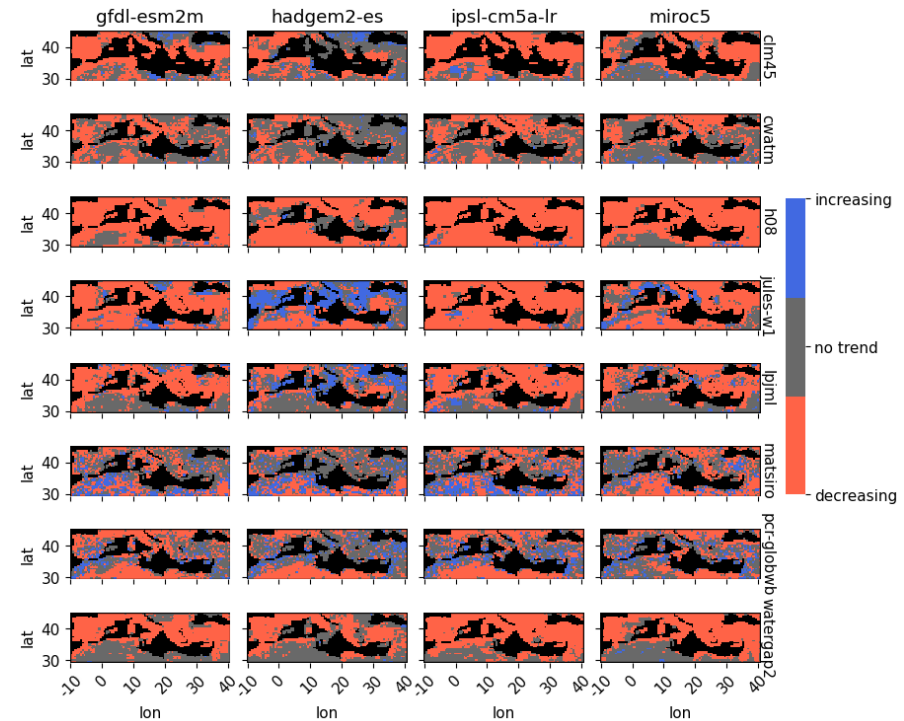
5. Trends shift from varying to mostly decreasing

At piconrol: varying results



Spatial plot of the seasonal Mann-Kendall Trend test of groundwater recharge at piconrol for each ensemble member

At rc60: predominantly decreasing



Spatial plot of the seasonal Mann-Kendall Trend test of groundwater recharge at rc60 for each ensemble member

6. Climate change might cause groundwater recharge to decline by 30% in 2100

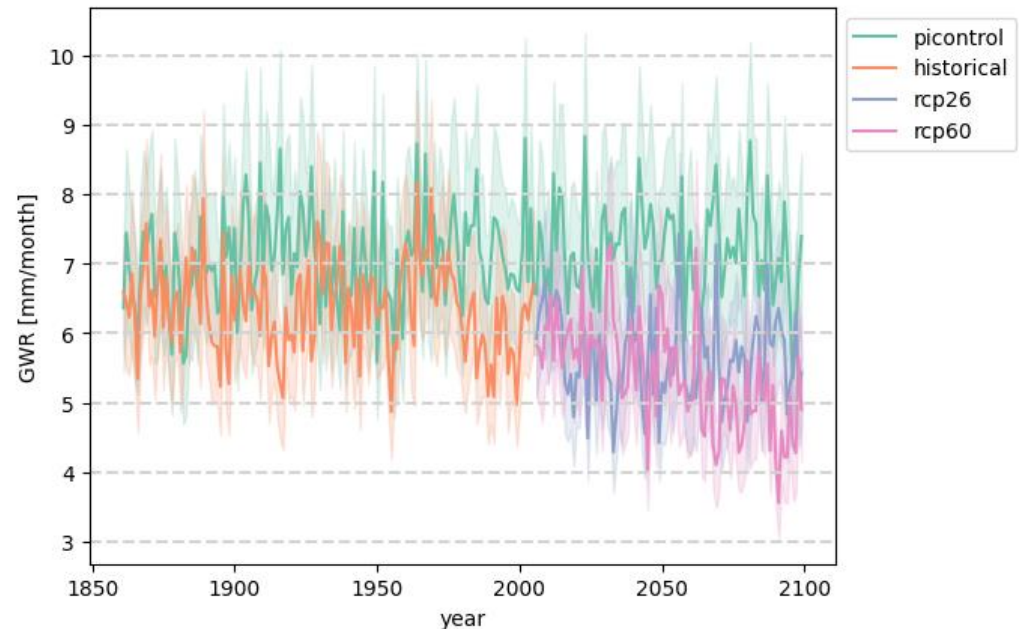
Declining groundwater recharge is found in the mean (spatially and among the models) monthly values of historical, rcp26 and rcp60, compared to the preindustrial scenario

→ ~20% decline by 2100 at rcp26

→ ~30% decline by 2100 at rcp60

Strong variation between the models, both spatially and between each other is indicated by the 95% confidence intervals around each line

→ approx. +/- 15%



Mean monthly groundwater recharge (GWR) and precipitation (P) for each year of the evaluation period, the climate and CO2 concentration scenarios are depicted by line style, each line is shown with 95% confidence interval

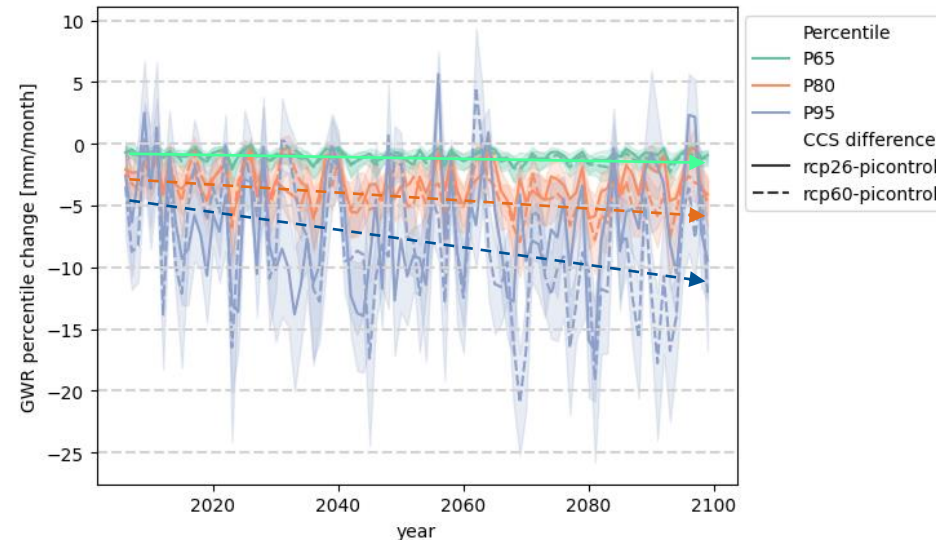
7. Recharge projected to drop significantly at several percentiles

Percentile	Absolute recharge change at rcp60 [mm/month]
65 th	approx. 0.5
80 th	approx. 3
95 th	approx. 6

While the absolute recharge change is larger at higher percentiles, the relative recharge change is larger at lower percentiles.

Relative recharge changes at the 65th and 80th percentile show **decreases of over 50%** at rcp60

Note: The 50th percentile (median) of this recharge dataset mostly is close to or at zero in the Mediterranean

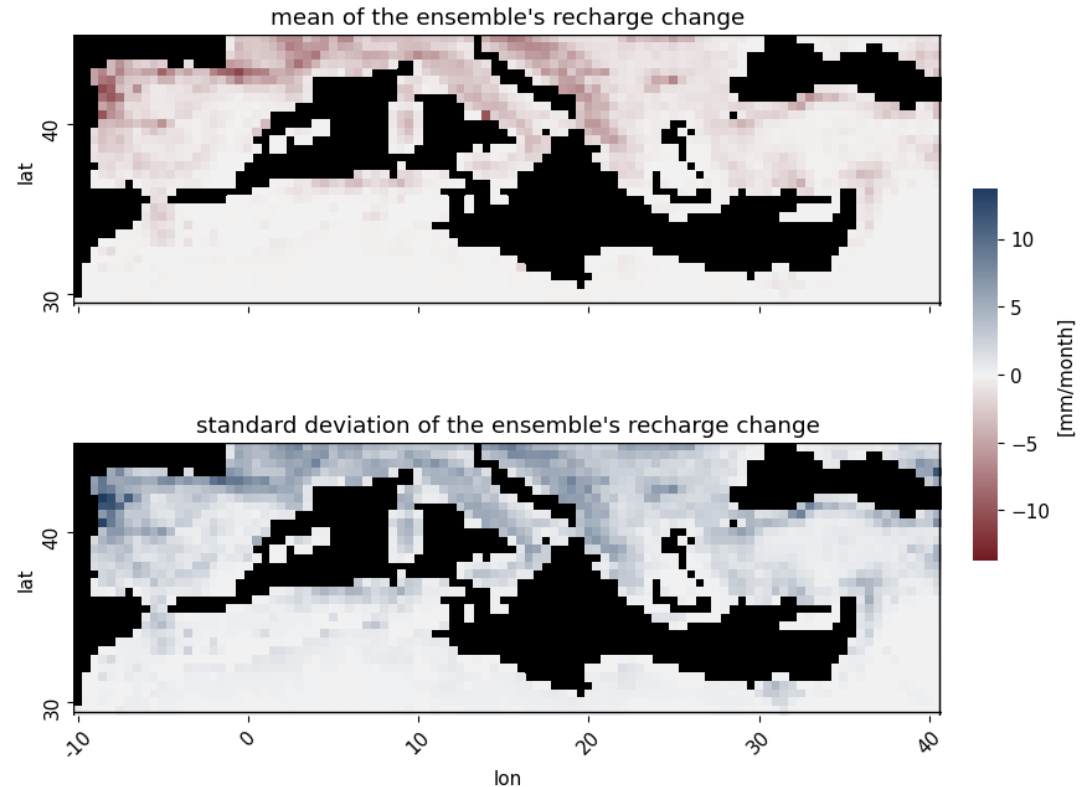


Absolute groundwater recharge change from picontrol to rcp26 and rcp60 at three percentiles (arrows added to show changes of 80th and 95th percentile from picontrol to rcp60)

8. Significant variation in groundwater recharge change – mean and standard deviation

The highest absolute recharge change is projected to occur in the northern Mediterranean.

Regions of high recharge change on average (over the ensemble members) are somewhat congruent with regions of high standard deviation.



Spatial plot of mean and standard deviation over the ensemble members of groundwater recharge change at rcp60 compared to picontrol (change = rcp60 - picontrol)

9. Lack of large-scale groundwater recharge databases perpetuates uncertainties

Uncertainties prevail as the documented projections of groundwater recharge cannot be verified.

This is due to several reasons:

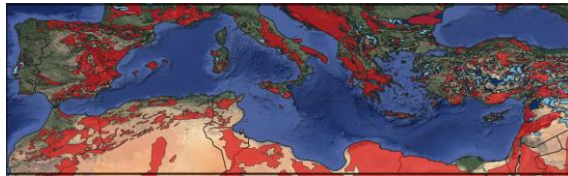
- Most groundwater recharge measurements made are influenced by groundwater abstractions
- While some authors gathered published annual recharge rates (e.g., Moeck et al. (2020), Mohan et al. 2018), these are point measurements which are not representative of large areas.
- Future developments of groundwater recharge in the Mediterranean region are rarely published → little information about recharge change due to climate change can be found in publications aiming at synthesizing existing research (e.g., MedECC reports by Cramer et al. (2019), Fader et al. (2020))

→ Large-scale groundwater and groundwater recharge databases are needed

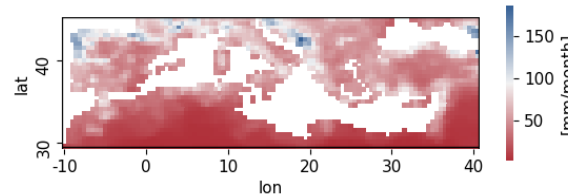
10. How hydrological models might be improved (without the use of large-scale databases)

1. Include hydrogeology in the models and improve soil representation

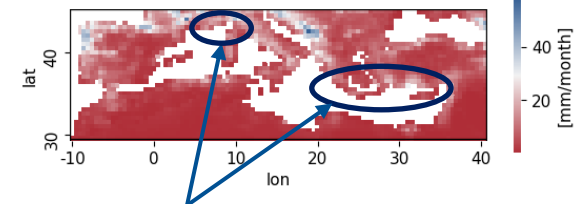
WHYMAP karst regions (red),
and IHME fissured aquifers (blue):



Precipitation mean at piconrol:



GWR mean of the ensemble at piconrol:



Considering precipitation and aquifer type in this area, more recharge could be expected here

2. Improve vegetation representation, including recent finding by Wang et al. (2020), who report lower CO₂ fertilization effects on photosynthesis

3. Finer spatio-temporal resolution could make calibration using recharge on basin-scale feasible)

11. Some concluding remarks

- An ensemble of 8 GHMs and 4 GCMs at 4 climate and CO₂ scenarios was examined
- The members show significant decreases of groundwater recharge in climate change scenarios, which are not found at picontrol.
- The uncertainty of absolute recharge change is especially high in regions with high recharge change
- Models could be improved by including hydrogeology, improving soil and vegetation representation and by refining the spatio-temporal resolutions

Further evaluations can be retrieved in the upcoming Master's Thesis (see slide 15 for research questions and evaluation methods), which will be submitted on May 31st.
Message Daniel Kretschmer to get a PDF.

Thank you for the attention!

Please contact us with any questions and suggestions.

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Alexander Gerner,
Markus Disse

Munich, 26 April 2021



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Master's Thesis - research questions & evaluation methods:

Research Questions	Evaluation methods
RQ 1: How do <u>trends</u> , <u>seasonal</u> recharge amounts, and regional <u>extreme</u> values vary between the GHM-GCM combinations?	Mean & median monthly recharge, trend evaluation with Mann-Kendall Trend Test, Sen's slope, „Innovative Trend Analysis“, extreme recharge (top 1 permil) evaluation
RQ 2: Do the models show similar <u>seasonal</u> groundwater recharge <u>patterns</u> and how do they differ in the climate change scenario simulations?	Mean & median monthly recharge, seasonality computation
RQ 3: How is the <u>variation</u> of monthly groundwater recharge distributed in both spatial and temporal terms?	Percentiles of recharge, variance introduction of GCMs vs GHMs
RQ 4: Are there recharge patterns induced by the occurrence of <u>extreme precipitation</u> events?	Kendall Correlation of precipitation with recharge
RQ 5: Do the findings correspond with <u>recent publications</u> and datasets? How do they differ and why?	Comparison and discussion of results with recent scientific publications