The study by Tsypin et al. aims to quantify future groundwater warming under various climate change scenarios. Its key novelty lies in the explicit consideration of heat advection by groundwater flow, an aspect often overlooked in previous research.

The manuscript is well written and presents a compelling approach. Several comments should be addressed to further strengthen its impact.

We would like to thank reviewer#3 for their feedback on our study, as well as for constructive suggestions aimed to improving the manuscript's clarity. In the following, we provide our point-by-point responses to each comment (our answers are marked in red).

General:

- It would be beneficial for the reader to make titles of different chapters more detailed.

We reviewed the structure and chapter titles in the original manuscript. As reviewer#3 did not provide specific suggestions, we made minor adjustments based on our own judgment:

4. Scenario Definition to *4. Climate scenario definition*

6.3 Effects of recharge projections on the thermal field to *6.3 Effects of recharge projections on the subsurface thermal filed*

- Figures and legends need more clarity.

We have adjusted the figures mentioned by reviewer#3 and implemented additional improvements based on suggestions from the other reviewers.

Specific comments:

L57 Regarding the impact of GW dynamic on subsurface temperatures, you may also check Klepikova et al., ERL, 2025.

Yes, we are familiar with the findings of Klepikova et al. (2025), who described thermal effects arising from shifts in groundwater dynamics caused by groundwater abstraction. While the focus of our paper is on climate-driven changes in advection rates, we agree that studies by Klepikova et al. (2025) as well as Bense et al. (2020) are highly compelling, as multi-year pumping exert a stronger influence on groundwater fluxes than comparatively slow climate-driven recharge reduction. This study will be cited in the revised manuscript.

L67 As for the impact of advection on temperature profiles, a review by Kurylyk, 2018 should be cited.

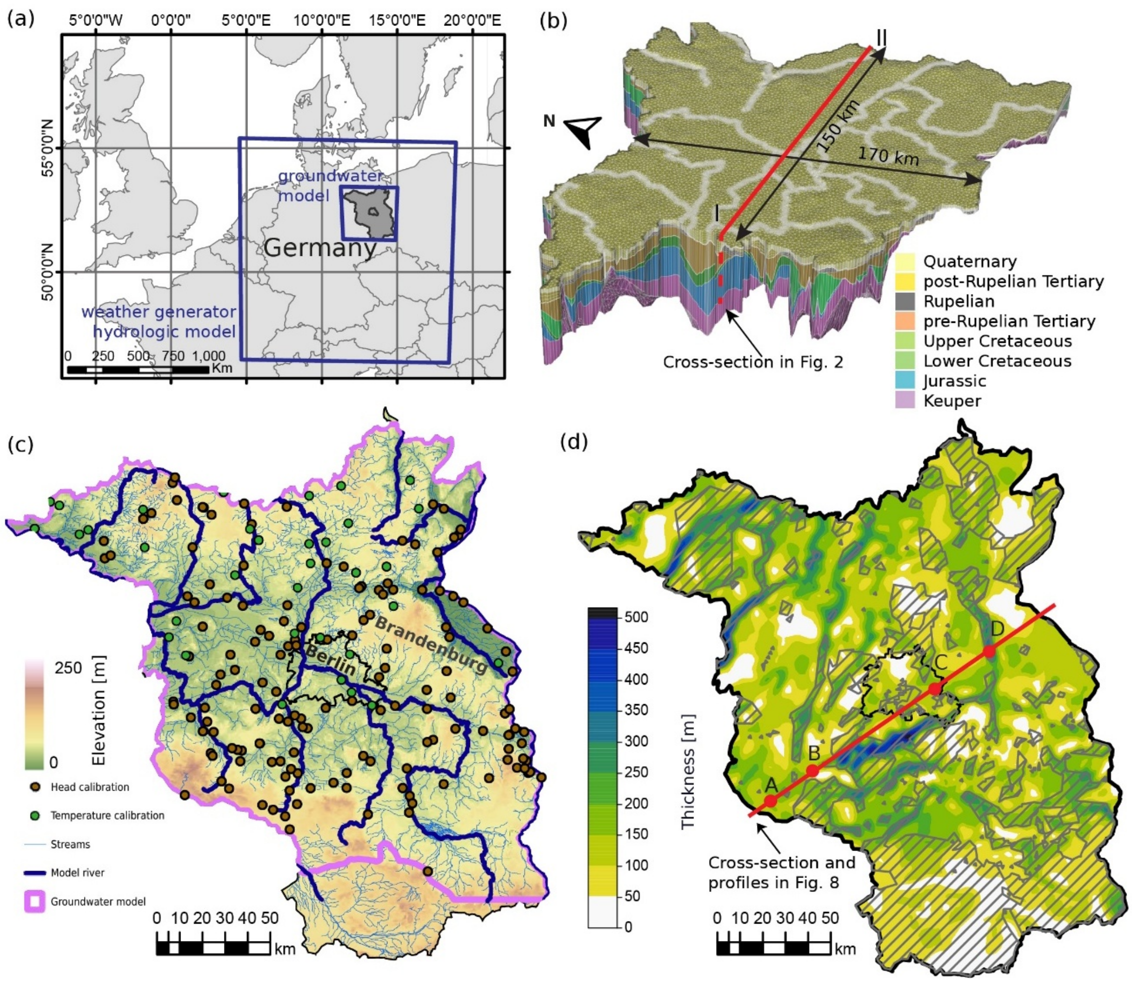
Thank you for the suggestion. We will add this reference in the introduction, in addition to already cited older works.

L104 "representative of EU geology" sounds weird.

We re-phrased this sentence as follows: *The study area spans Germany's federal state of Brandenburg and the city of Berlin and exhibits climatic and geological conditions typical of north-central Europe.*

Fig.1 please provide scale reference on all subfigures.

Thank you for pointing this out. The corrected figure is shown below:



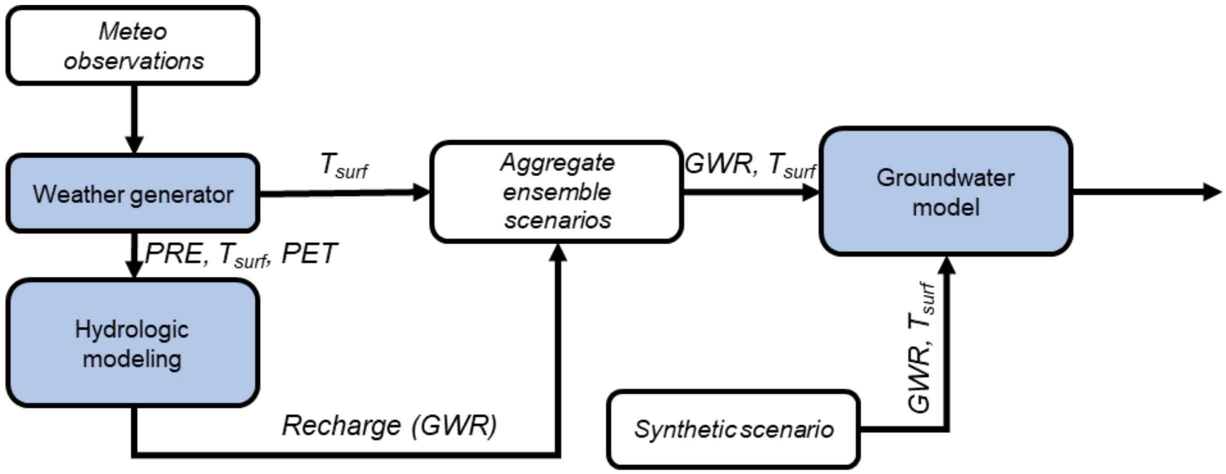
Section 3: In order to improve the clarity I believe that general conceptual models should be described first.

The Methods section organized according to the order in which the components of the integrated workflow were applied:

3.1 Simulation of downscaled weather time-series with the non-stationary Regional Weather Generator

3.2 Recharge estimation with a mesoscale Hydrologic model

3.3 Groundwater flow and transport modeling with the finite element method.



We are not entirely sure which "general conceptual models" reviewer#3 is referring to. If this comment is related to the advective-conductive heat transport in porous media, we find its description in Section 3.3 to be appropriate.

It could be argued that, given the objective of the study, the subsurface component should be introduced first, while the modeling of recharge and temperature time series, serving as boundary conditions for the groundwater model, could be described afterwards. However, we still prefer the current sequential structure of the Chapter and find it most appropriate for HESS journal, which targets a broad hydrology-oriented community.

L167-168 The main difference in between these scenarios should be already mentioned here.

We believe that the main difference between the scenarios is already described in the text: "*SSP245, a moderate-emission pathway where mitigation efforts balance sustainability measures with economic growth, and SSP585, a high-end emission scenario driven by fossil fuel development with minimal mitigation (IPCC, 2023)*". One consequence that should have been stated here more explicitly is that estimated global warming levels under SSP585 are substantially higher than under SSP245. More detailed quantitative differences between the two scenarios are region- and model- specific, and therefore discussed in detail in a dedicated chapter (Chapter 4).

L254 D of fluid?

D is the bulk thermal diffusivity, which in our model accounts only for heat conduction, without including mechanical dispersion:

$D = k/\rho c_p$,

where *k* is thermal conductivity, ρ is density, and C_p is specific heat capacity. All three parameters are bulk properties, calculated as porosity-weighted average of the fluid and solid phases.

That being said, following a comment from reviewer#1, we decided to exclude the interpretation of *Pe* from the revised manuscript.

Figure 3. Expand and detail the legend.

A corrected figure with the expanded legend is provided below:

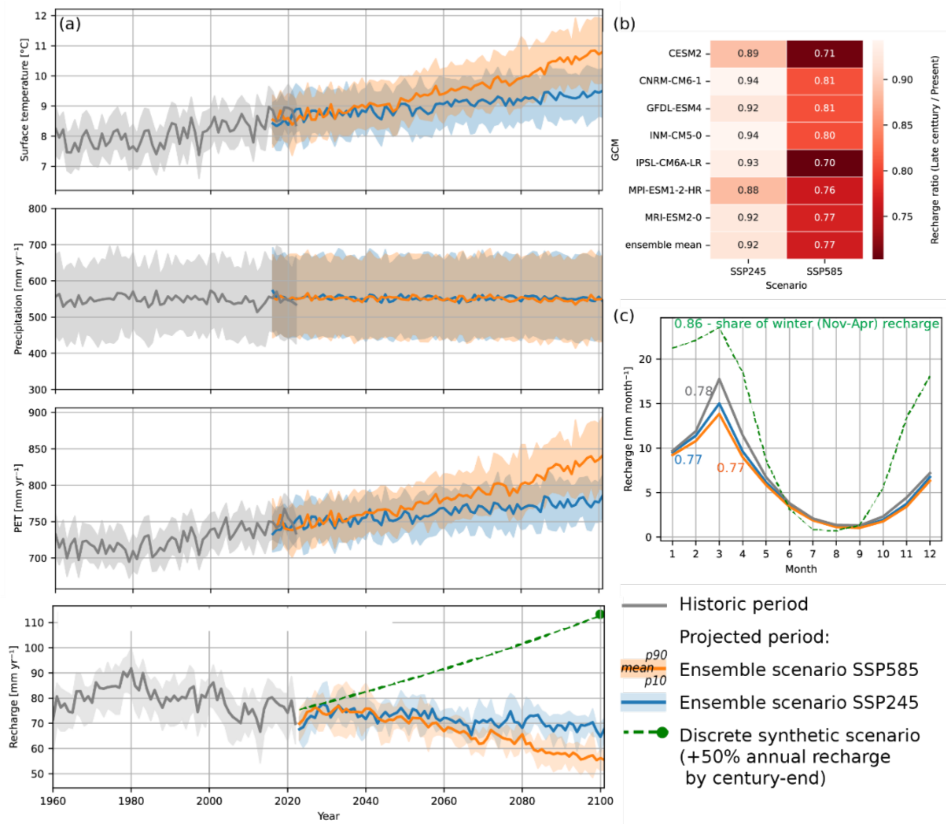
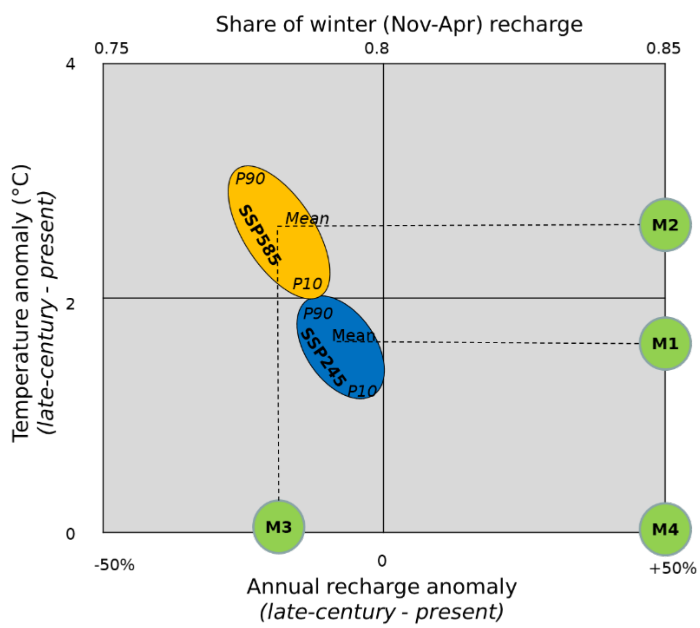


Figure 4. The clarity of this figure could be improved as well.

An updated version of the figure is provided below.



L343 Could you tell more about the T data (depth/profile or point?/range/precision)?

Temperatures from deep aquifers (>500 m) that we used to validate the initial thermal field, are a mix of (a) bottom-hole temperatures (BHT) obtained in wells shortly after drilling, thus representing perturbed borehole temperatures and (b) continuous temperature logs, mostly measured after the boreholes were cased (Förster, 2001). All BHT temperatures were previously corrected by Horner-plot correction and the exponential integral method based on a model simulating the temperature build-up during shut-in time of a well (Förster, 2001). The estimated error of the corrected measurements was ±3°C or ±10°C. Some temperature logs were also corrected using a simple empirical correction, with the error in final estimates of ±3°C (Förster, 2001).

Shallow groundwater temperature monitoring is available from a handful of wells in Berlin and is limited to 80 m below ground (SenStadt, 2020). Unfortunately, continuous vertical profiles and Distributed Temperature Sensing (DTS) are only available for the urban area. We chose to present them separately (Appendix B), due to strong land cover overprint.

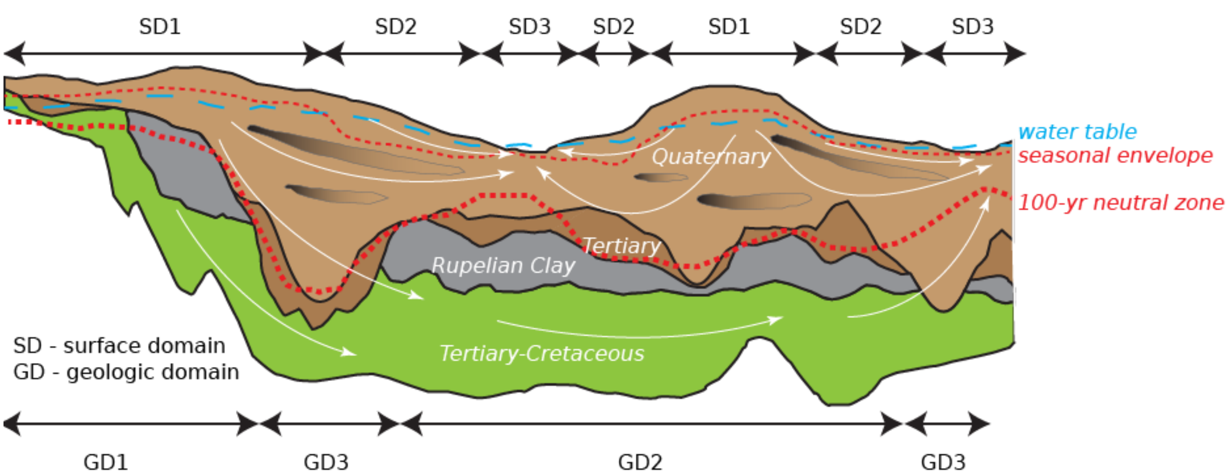
L370 Please explain “teleconnections”.

Our original sentence was imprecise and can be re-formulated without referring to teleconnections:

“Such behavior has been frequently observed in historical data and attributed to impact of intra-annual climatic fluctuations, such as North Atlantic Oscillation (Liesch and Wunsch, 2019).”

Figure 13. It is not really clear what do you want to highlight by horizontal arrows.

The black horizontal arrows delineate surface and geologic domains in the schematic cross-section. These domains have distinctions in shallow and deep groundwater dynamics. We agree that their recognition may be subjective. Therefore, in the figure caption we point reader to the detailed description of the domains in the main text. Slightly adjusted figure is presented below:

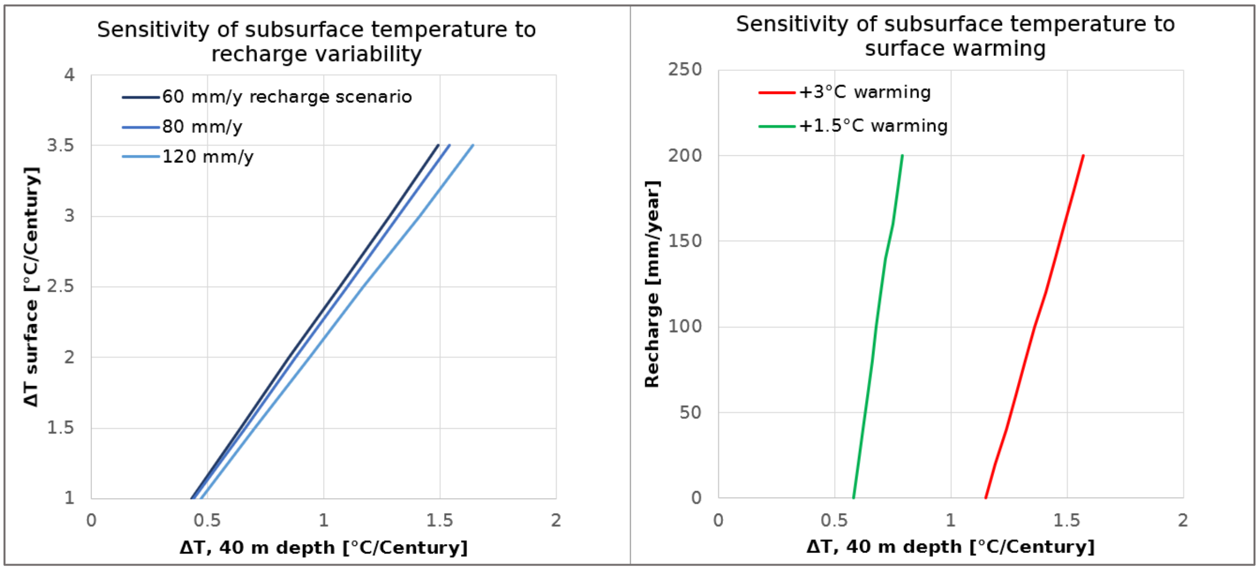


L535 This is confusing as the depth of penetration should be regulated by the GW flow rate and thermal properties of rocks.

We agree with reviewer#3 that the depth of warming penetration and the magnitude of temperature change at a given depth are regulated by flow velocities and thermal properties of rocks. However, they are also controlled by the magnitude of the applied surface forcing. For example, Kurylyk et al. (2015)

states: “*The thermal sensitivity formulae suggest that shallow groundwater will warm in response to climate change and other surface perturbations, but the timing and magnitude of the subsurface warming depends on the rate of surface warming, subsurface thermal properties, bulk aquifer depth, and groundwater velocity.*”

Our results indicate that, given the projected changes in surface temperature and the recharge rates, surface warming exerts a greater effect on the deviation of the geothermal gradient than shifts in recharge flux. To further support this, we present below the results from the analytical solution of Kurylyk et al. (2015) using the same degree of surface warming and recharge variability as applied in our numerical model.



L541-544 Rephrase this sentence to make it clearer (i.e. what is meant by “this response”?)

We rephrased this part as follows:

The contrasting sensitivity of surface domains to climate change supports the conclusions of Burns et al. (2017) and Taniguchi (2021) that the thermal response of groundwater to surface warming is amplified in topographically elevated recharge areas (SD1) and attenuated in low-lying discharge areas (SD3). Such spatial differentiation in the magnitude of subsurface warming is controlled by the downward and upward components of the regional groundwater flow field, respectively.

L544 differentiation of what?

See our response to the previous question.

L645 for which depth?

We thank reviewer#3 for pointing out this ambiguity. The corrected sentence now reads as:

The magnitude of groundwater temperature increase depends primarily on the global warming levels: the mean sensitivity to surface temperature scenario is approximately 1.4 °C ***at the water table****, while the difference between recharge scenarios contributes up to 0.4 °C between the present (2002-2021) and late-century (2081-2100) periods.*

References:

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Förster, A.: Analysis of borehole temperature data in the Northeast German Basin: continuous logs versus bottom-hole temperatures, Petroleum Geoscience, 7, 241-254, 10.1144/petgeo.7.3.241, 2001.

Klepikova, M., Bense, V., Le Borgne, T., Guihéneuf, N., and Bour, O.: Impact of groundwater extraction on subsurface thermal regimes, Environmental Research Letters, 20, 054048, 10.1088/1748-9326/adc8bb, 2025.

Kurylyk, B. L., MacQuarrie, K. T. B., Caissie, D., and McKenzie, J. M.: Shallow groundwater thermal sensitivity to climate change and land cover disturbances: derivation of analytical expressions and implications for stream temperature modeling, Hydrol. Earth Syst. Sci., 19, 2469-2489, https://doi.org/10.5194/hess-19-2469-2015, 2015.

Liesch, T. and Wunsch, A.: Aquifer responses to long-term climatic periodicities, Journal of Hydrology, 572, 226-242, https://doi.org/10.1016/j.jhydrol.2019.02.060, 2019.

SenStadt: Senatsverwaltung für Stadt-entwicklung, Bauen und Wohnen - Berlin Environmental Atlas, Berlin, https://www.berlin.de/umweltatlas/en/water/groundwater-temperature/, 2020.