It’s all about scale: impact of uncertainty in surface water elevation and effects of grid size on water table depth in global groundwater modeling

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Abstract

Continental and global-scale groundwater models have been proposed recently to complete and improve the simulation of the hydrologic cycle. This development is still impeded by the resolution of these models either due to data availability and/or computational demands. One of the major challenges is determining the location of surface water bodies on the global scale based on land surface elevation data, as surface water elevation directly influences the model results. Closely connected to this problem is the comparison of simulated model results to observations of depth to groundwater. The models calculate hydraulic head so depth to groundwater is heavily influenced by how the variation in topography is reflected in one computational cell. This presentation demonstrates by means of the newly developed global groundwater model G\textsuperscript{3}M that depth to groundwater observations need to be contemplated in the context of the elevation of the surface water bodies to draw proper conclusions on the model performance. The impact of uncertainty in surface water body elevation is illustrated based on multiple grid size experiments (5 arcmin, 30 arcsec, and 3 arcsec resolution) for New Zealand.
It’s all about scale

Impact of uncertainty in surface water elevation and effects of grid size on water table depth in global groundwater modeling

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Introduction

Continental and global-scale groundwater models have been proposed recently to improve the simulation of the hydrologic cycle. This development is still impeded by the resolution of these models either due to data availability and/or computational demands. One of the major challenges is determining the location of surface water bodies on the global scale based on land surface elevation data, as surface water elevation directly influences the model results. Closely connected to this problem is the comparison of simulated model results to observations of depth to groundwater. The modelled calculated depth to groundwater is heavily influenced by how the variation in topography is represented in a computational cell.

Using the newly developed global groundwater model G'M (Fig. 1) we demonstrate that depth to groundwater observations need to be correlated in the context of the elevation of the surface water bodies to draw proper conclusions on the simulated model results. The impact of uncertainty in surface water body elevation is illustrated based on multiple grid size experiments 5°, 30’ and 5° resolution for New Zealand.

The global groundwater model G'M

![Image](https://example.com/image1.png)

Figure 1: Conceptual view of the coupling between WG/HM (WaterGAP Global Hydrology Model) (Döll et al., 2003) and G'M (Fraene et al., 2018). G'M provides calculated GW recharge (R) [Döll and Fiedler (2008)] and if the human impact is considered, net abstraction from GW (N). Döll et al., 2012). G'M spreads this input equally to all 5° grid cells inside a 0.5° cell and calculates hydraulic head and interactions with surface water bodies. Grey arrows show information flow that is not yet implemented.

Research Questions

- How big is the difference in water table depth if groundwater is simulated on different spatial resolutions (5°, 30’)?
- Is there a systematic error in the assumption of surface water body elevation in the existing 5° global groundwater model?
- Is the groundwater table in higher resolution models also a function of the surface water body elevation?
- Can we use the existing high resolution global DEMs to improve the conceptual 5° global groundwater model?

Approach

Groundwater recharge

Surface water body elevation

Conductivity

Available data

Clear boundary condition

New Zealand as ‘small’ world example

Models: 5° (9km) 30’ (3°x3°)

Surface water bodies in 5° model vs. 30° model

- Percentage area of lakes and wetlands of 5° model is distributed equally to 30° cells.
- River elevation and location is based on 30° HydroSHEDS (hydrosheds.org).
- Algorithm includes rivers from HydroSHEDS until width and length of 5° data is reached (dropping cells with lowest number of upstream cells).

Preliminary results: New Zealand on 5° and 30°

![Image](https://example.com/image2.png)

Figure 2: Results of a sensitivity analysis (method of Morris with n = 2000 model runs) [Paper submitted to HSSE] and previous model experiments (Fraene et al, 2018). showed that surface water body elevation is one of the three most sensitive parameters. We use New Zealand as a “small” world, because it is surrounded by mean sea level and includes complex topography. The goal is to investigate how the grid-scale affects the model outcome.

![Image](https://example.com/image3.png)

Figure 3: Elevation [m] and hydraulic head [m] profile through New Zealand including groundwater well observations. Due to the scale, the 5° model is missing a lot of the higher resolution topography. The groundwater table calculated by the 30” model is much closer to the topography. Well observations, especially of perched aquifers, may be off by more than hundred meters. The presented profile represents a cut with the most available observations. Unfortunately, there is a general bias towards flat areas where model performance is relatively good.

Surface water bodies

5° model

30° model

- Percentage area of lakes and wetlands of 5° model is distributed equally to 30° cells.
- River elevation and location is based on 30° HydroSHEDS (hydrosheds.org).
- Algorithm includes rivers from HydroSHEDS until width and length of 5° data is reached (dropping cells with lowest number of upstream cells).

Preliminary results: New Zealand on 5° and 30°

![Image](https://example.com/image4.png)

Figure 4: Comparison of simulated hydraulic head [m] on 5° and 30° to observed hydraulic head [m] (DEM - observed WTDS) left and surface water body (SWB) elevation [m] (right). Overall the 30° model seems to reduce overestimates of observed heads but still includes substantial underestimates of observed heads. In comparison to the surface water body elevation the simulated head has the opposite sign for each model, whereas the 5° head seems to correlate closer with the surface water body elevation.

Discussion and conclusions

- Simulated hydraulic heads and surface water body interactions are sensitive to the assumed elevation of the surface water bodies (e.g. the 30th percentile of the 30° land surface elevations). (Paper in review)
- G’M is able to simulate the groundwater for New Zealand on 5° and 30°.
- Estimates of 5° surface water bodies can be off by over 500 m in regions with complex topography.
- Available observations are biased towards flat regions where the model already performs well.
- The 5° model overestimates groundwater heads more than the 30° model.
- The 30° model is underestimating groundwater heads. It is unclear why.
- Simulated groundwater head in the 5° model is closer related to surface water body location than in the 30° model. This might be a function of number of rivers and the grid scale.

Forthcoming research

- Refinement of 30” and 3” model
- Comparison on 30” model with 3” model results
- Comparison to Westerhoff et al. (2018)
- Sensitivity analysis of grid scale resolution
- Development of an algorithm to optimize surface water body elevation per 5°

globalgroundwatermodel.org

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