Hyper-resolution aquifer parameterization: estimating aquifer thickness, vertical structure, and conductivity for North-America

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Motivation

Groundwater is an important part of the freshwater cycle. Groundwater baseflows help to sustain river flows during times of drought, lateral groundwater flows crossing catchment boudaries support water butgets of the recieving catchments, and shallow water tables support evapotranspiration. Also, groundwater is the world's largest accessible freshwater resource and is critically important for irrigation and hence for global food security.

Despite the importance of groundwater most global-scale hydrological models do not include a groundwater flow component. The main reason of this ommision is the lack of consistent hydrogeological information at the global-scale.This information includes estimates of aquifer thickness,vertical structure, and condictivities. A realistic aquifer parameterization will lead to better estimates of groundwater dynamics and lateral flows, and is especially needed when moving to finer resolutions when groundwater flow between grid-cells can be more important (1,2,3).

Objective

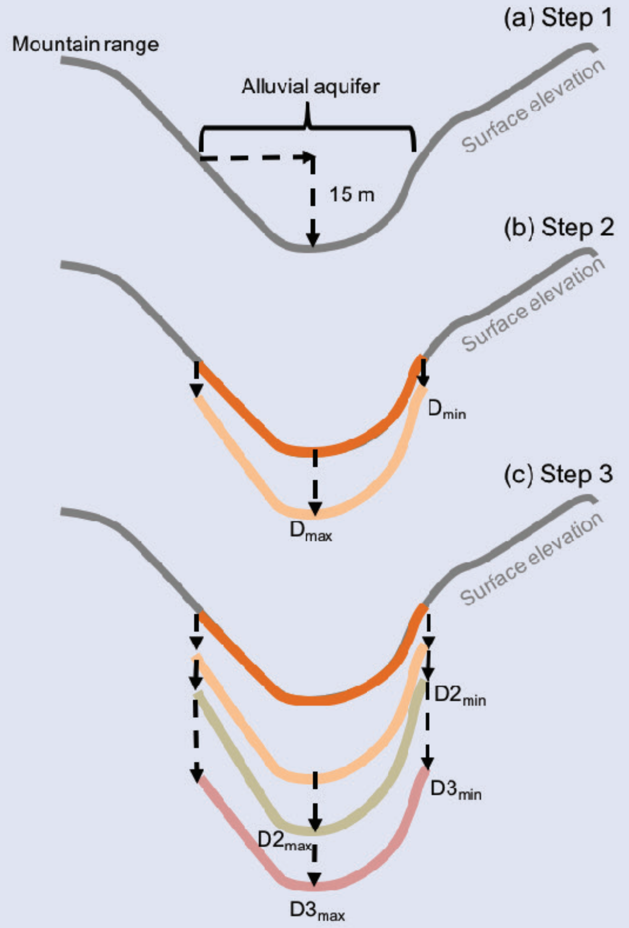
- To improve current aquifer parameterization spatial resolution and to develop a framework to include local available data in global-scale estimates.

Methods

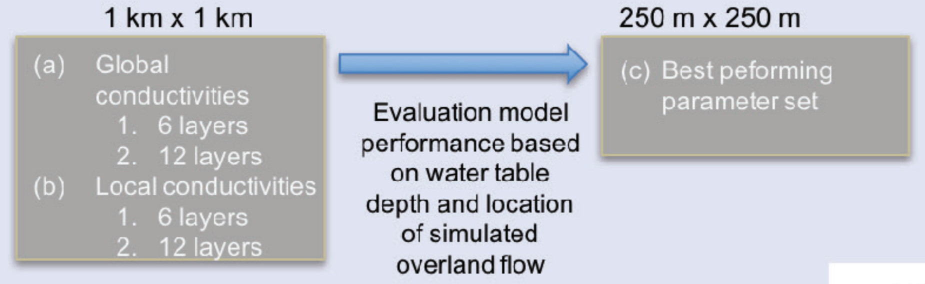
- Estimate aquifer thicknesses and vertical structure at **hyper-resolution** (**250 m x 250 m**, for North-America) by appying previously published methods (3,4) and **including local information** on spatial and vertical distribution, as well as conductivities.
- Test the new parametrization **hydrologically**, focussing on a smaller test area, and evaluating results against observed data, in order to make recommendations for steps forward in large-scale hyper-resolution hydrological modelling.

I. ESTIMATING AQUIFER THICKNESS

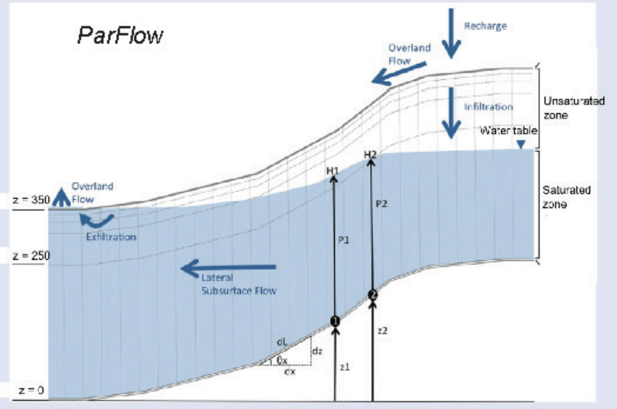
- We distinguish between 1) **mountain ranges** with negligible sediment thickness, 2) **local aquifers** present in the valleys of streams, and 3) **extensive alluvial quifers,** present in the major deltas and piedmont belts.
- Aquifer thickness is estimated to thin further away from the stream towards the edge of the alluvial aquifer.
- Maximum and minimum aquifer thickness (Dmax and Dmin) are based on USGS aquifer studies (water.usgs.gov).
- Thickness of deeper aquifer layers are estimated for extensive aquifers only.



II. SENSITIVITY ANALYSIS

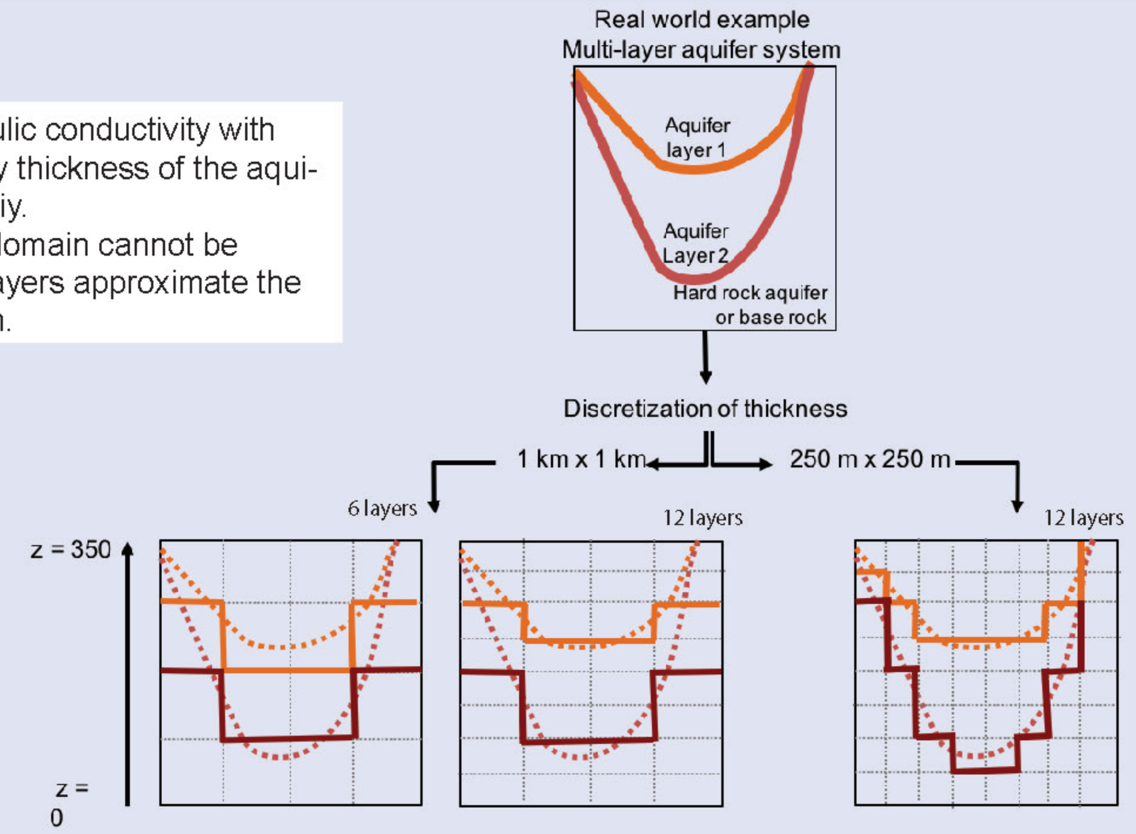


- We used the integrated hydrological model ParFlow (1) to simulate water table depths and overland flow.
- Five runs in total.
- Tested for a smaller case-study area.
- Model outcomes are evaluated against observed data of water table depths (5) and surface water locations(water.usgs.gov).



II a. VERTICAL DICRITIZATION

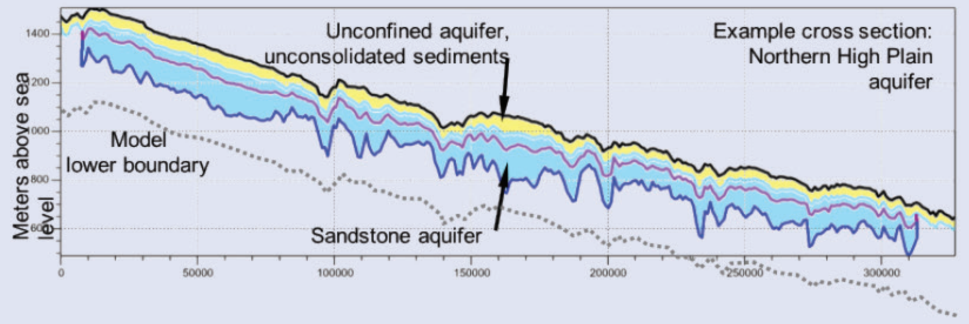
- Variation of hydraulic conductivity with depth is defined by thickness of the aquifer and conductivity.
- An infinite model domain cannot be solved, so fewer layers approximate the true model domain.

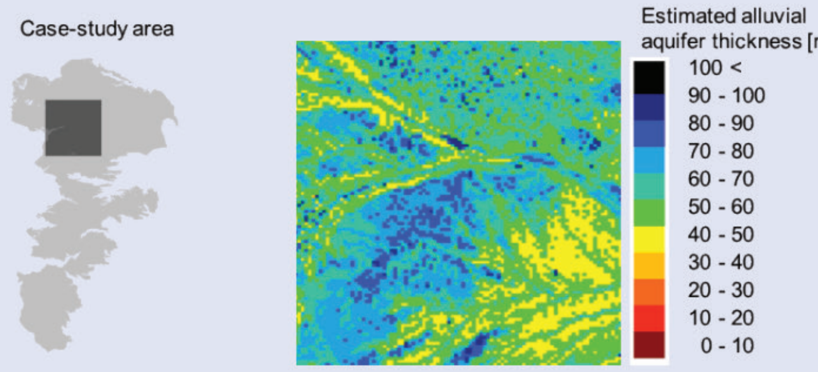


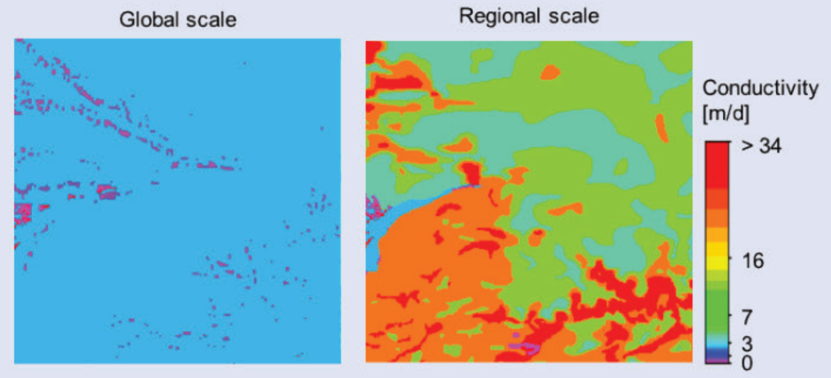
II b. CONDUCTIVITIES

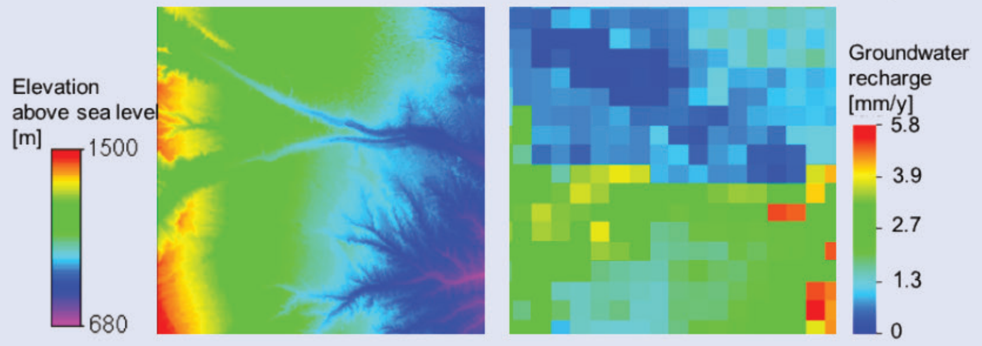
- Two types of datasets are used (see: III. Case study):
(a) globally available permeability (6), updated with regional scale data from aquifer studies, and (b) locally available data (water.usgs.gov).
- Both data-sets are very different and sometimes differ more than an order of magnitude.

III. CASE STUDY



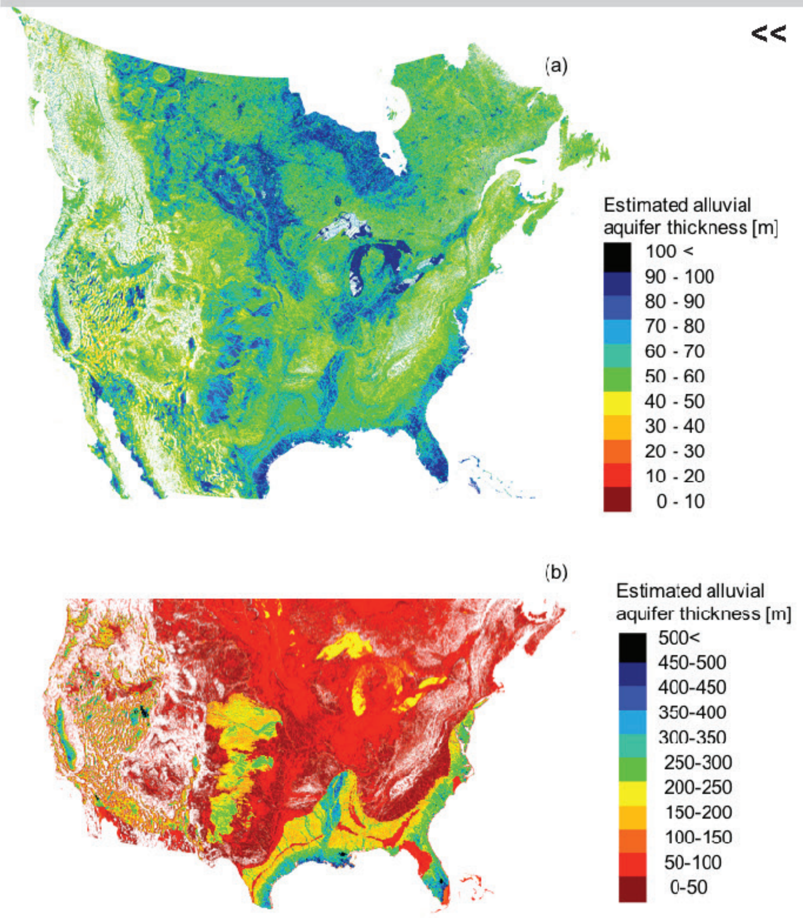






- Part of the **northern High Plains Aquifer** was choosen as a case-study area. Main motivation was the locally available conductivity data at the requested spatial resolutions.
- Model domain is 62500 km^2 (250 km x 250 km).
- The model domain covers part of an important aquifer systmem of the US, with complex structure.

Results: Hyper-resolution aquifer map

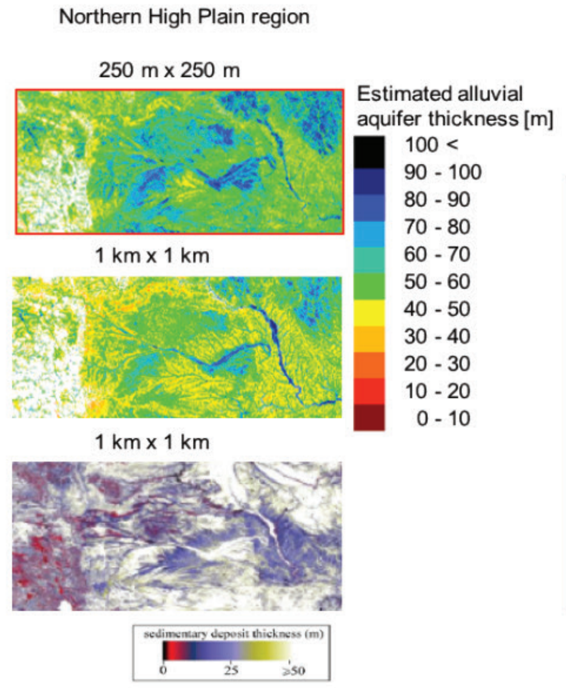


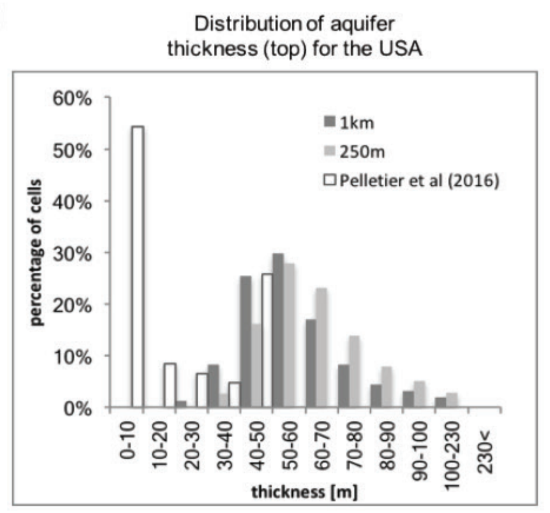
<< Estimated aquifer thickness of (a) the top layer, and (b) total aquifer thickness. Mountain ranges are presented in white.

- Thick aquifers are simulated for flat regions.
- Because of the hyper-resolution (250 m x 250 m), a level of detail is obtained not reached before (e.g. local aquifers higher up in the mountains).

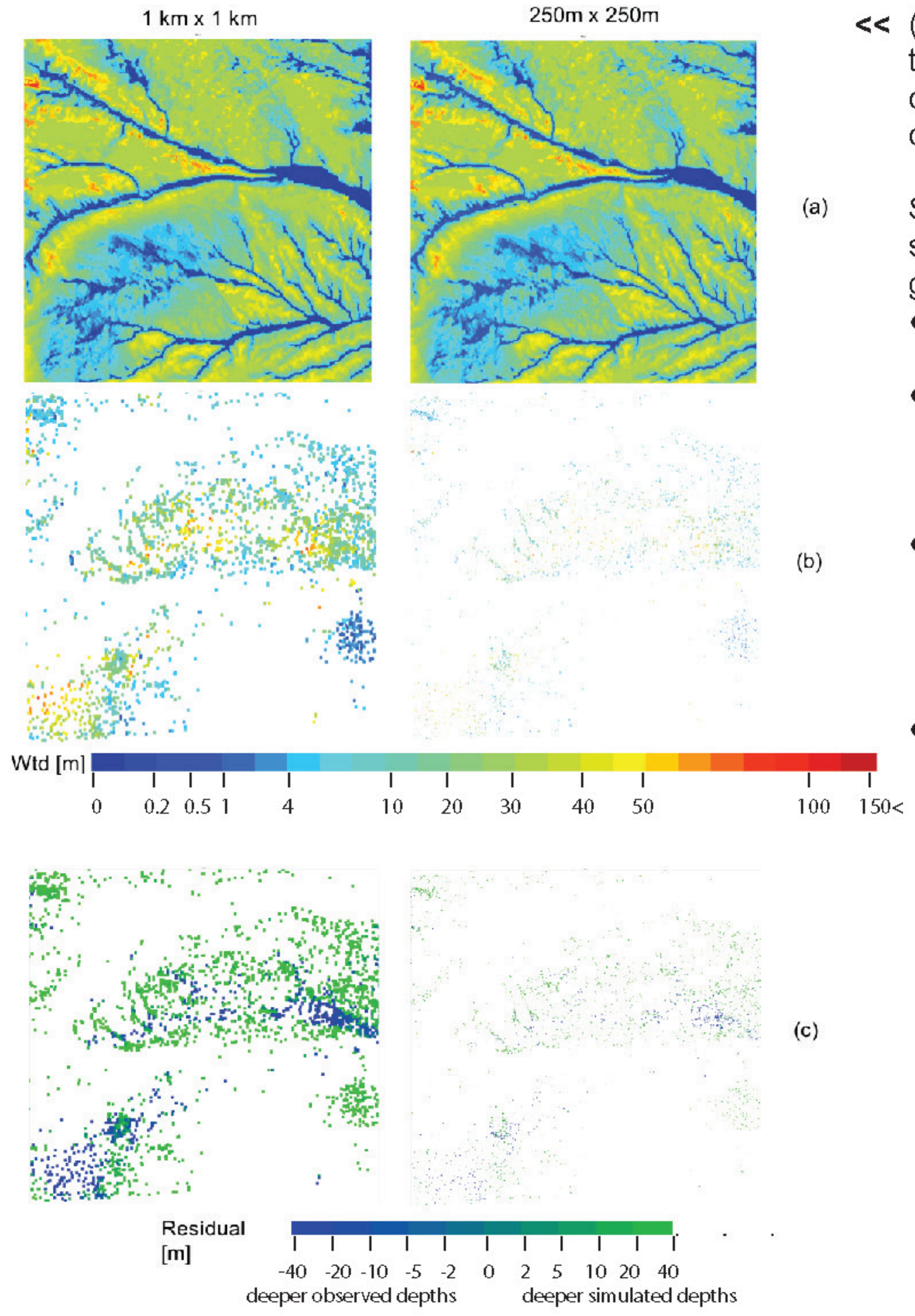
Comparison of thickness estimate of the top layer, comparing the 250 m x 250 m to 1 km x 1 km estimate and a previously published estimate (7). >>

- With increasing spatial resolution, spatial variability of thickness within the aquifer is better captured than before, so are local aquifers higher up in the mountains.
- Our estimate captures both shallow and deep aquifer systems.





Results: Sensitivity analysis

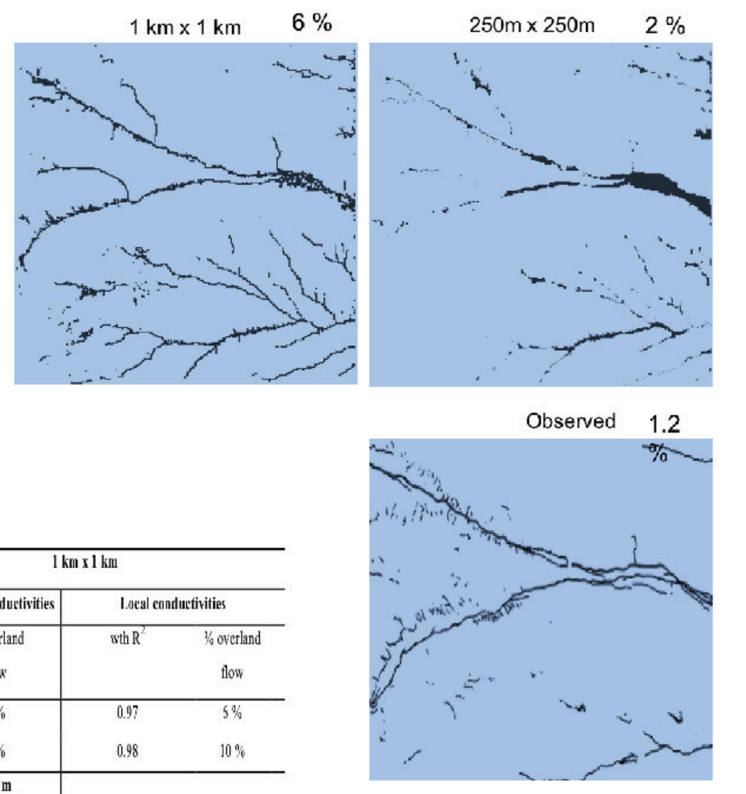


<< (a) simulated water table depths (wtd) at the two spatial resolutions using the updated global-scale conductivity values. (b) observed wtd (5) and (c) residuals, calculated as 'simulated - observed'.

Simulated open water cells (i.e. pressure ≤ 0) compared to observed openwater. Percentage of cells with open water is given. >>

- Groundwater heads are well captured by the model, so are open water locations.
- Residuals show an overestimation of water table depths. However, data on depth of the well is missing and open water is never sampled.
- The difference in horizontal resolution is less clear, likely because the absence of small drainage systems in combination with the coarse resolution of recharge input (see: III Case study).
- Best model peformance is obtained at hyper-resolution and detailed vertical discritization, using updated global-scale conductivity estimates. >>

	1 km x 1 km			
	Updated Global conductivities		Local conductivities	
	wth R²	% overland flow	wth R²	% overland flow
6 layers	0.98	4 %	0.97	5 %
12 layers	0.99	6 %	0.98	10 %
	250 m x 250 m			
12 layers	0.99	2 %		



Conclusions

- Model performace improved with higher spatial and vertical resolution, and including local information on aquifer spatial and vertical distribution and conductivities.
- The methods used in this study are relative simple and can easily be expanded to data-poor regions of the world.
- This study showed the importance of realistic aquifer parameterization at higher resolutions, and therewith the need for robust hydrogeological data at larger scales.

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