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Parameter estimation for an island aquifer considering tidal overheight (Norderney, Germany)

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Introduction

Parameter estimation for coastal groundwater flow models is time-consuming and computationally expensive due to the relevance of variable-density driven groundwater flow. Further, tidal influence can impact groundwater levels near the coast; in case of small islands, often throughout the entire freshwater lens. Besides short-term variability, ocean tides can cause the groundwater table to elevate above mean sea level (tidal overheight).

Objective

Parameter estimation for a barrier island groundwater flow model considering tidal overheight using a phase-averaged tidal boundary condition (PA-TBC) and compare it with a procedure using mean sea level (MSL-BC).

Study area and data

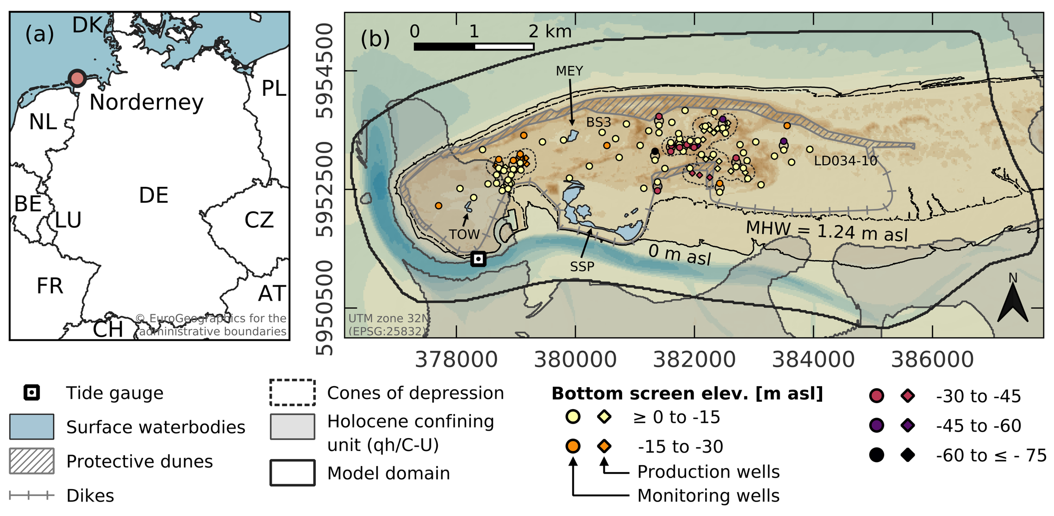

Fig. 1 Location of Norderney (a) in Germany and (b) location of the tide gauge "Norderney Riffgat", monitoring as well as production wells, surface waterbodies (TOW, MEY, and SSP) and major geological features. Furthermore, the area protected by dunes and dikes and is depicted [Data origin: 1,2].

- Barrier island with mostly fine-grained sands
- Locally present confining lenses
- Observed hydraulic heads of 80 monitoring and 23 production wells averaged from 2006 to 2015 and 14 vertical head differences at multi-well sites
- Prior knowledge on hydraulics previous studies on island and mainland [3,4]

Methods

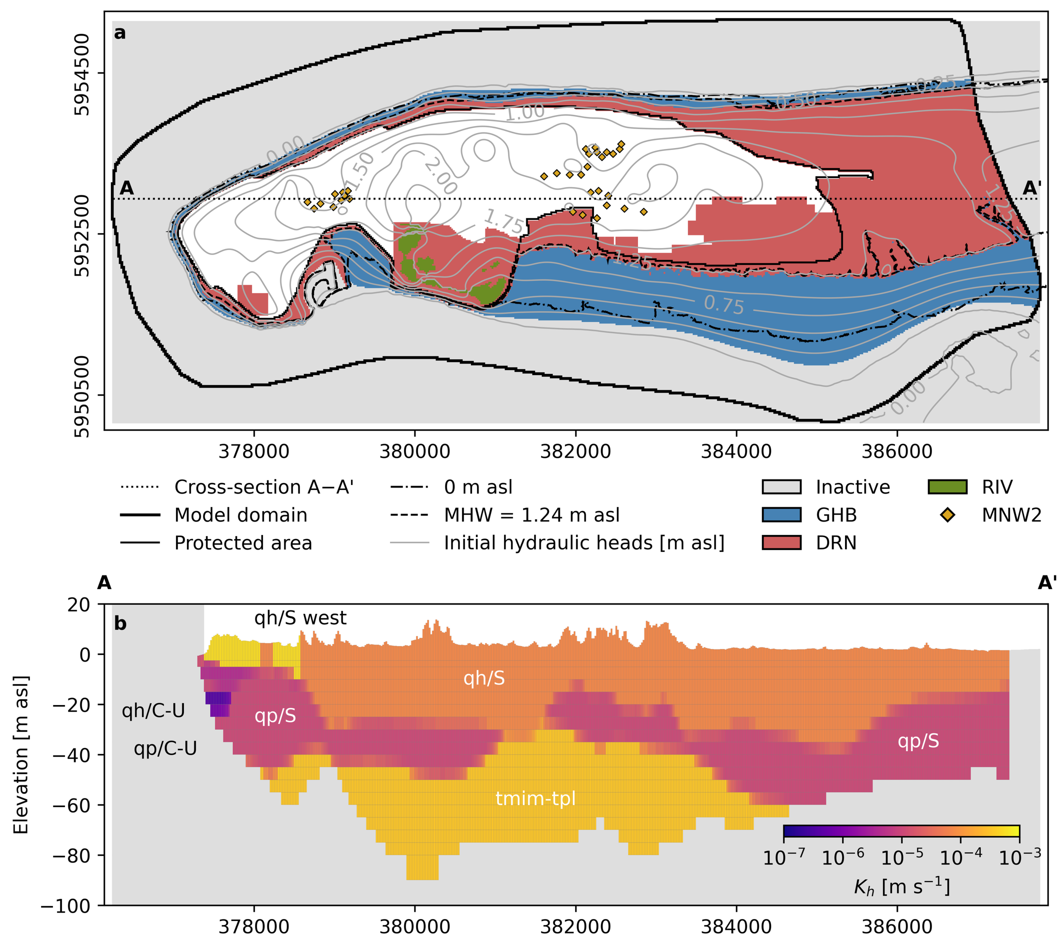

Fig. 2 (a) Map of the model domain with initial heads and applied boundary conditions (GHB, General Head Boundary; DRN, Drainage Boundary; RIV, River Boundary; MNW2, Multi-Node Well). (b) Example cross-section through the model domain depicting the Ghyben-Herzberg based no-flow boundary at the a-priori assumed fresh-/saltwater interface and the spatial distribution of the estimated horizontal hydraulic conductivity.

- Estimation of 16 parameters with PEST++ GLM using Tikhonov regularization and uncertainty estimation based on Monte Carlo sample preconditioned by FOSM posterior parameter covariance matrix
- Observation weights defined following [5]
- MODFLOW-2005 steady-state model
- Initial heads interpolated from observed data
- Ghyben-Herzberg estimated no-flow boundary to replicate freshwater-lens body
- Hydrogeological units defined based on structural model of the island [2]
- Spatially-distributed and time-averaged groundwater recharge and abstraction [6]
- PA-TBC using mean high water [7] and MSL-BC using mean tide level
- Validation with transient model simulated from 2005 on for 2016 to 2019 with monthly recharge and abstraction signals

Parameter estimation results

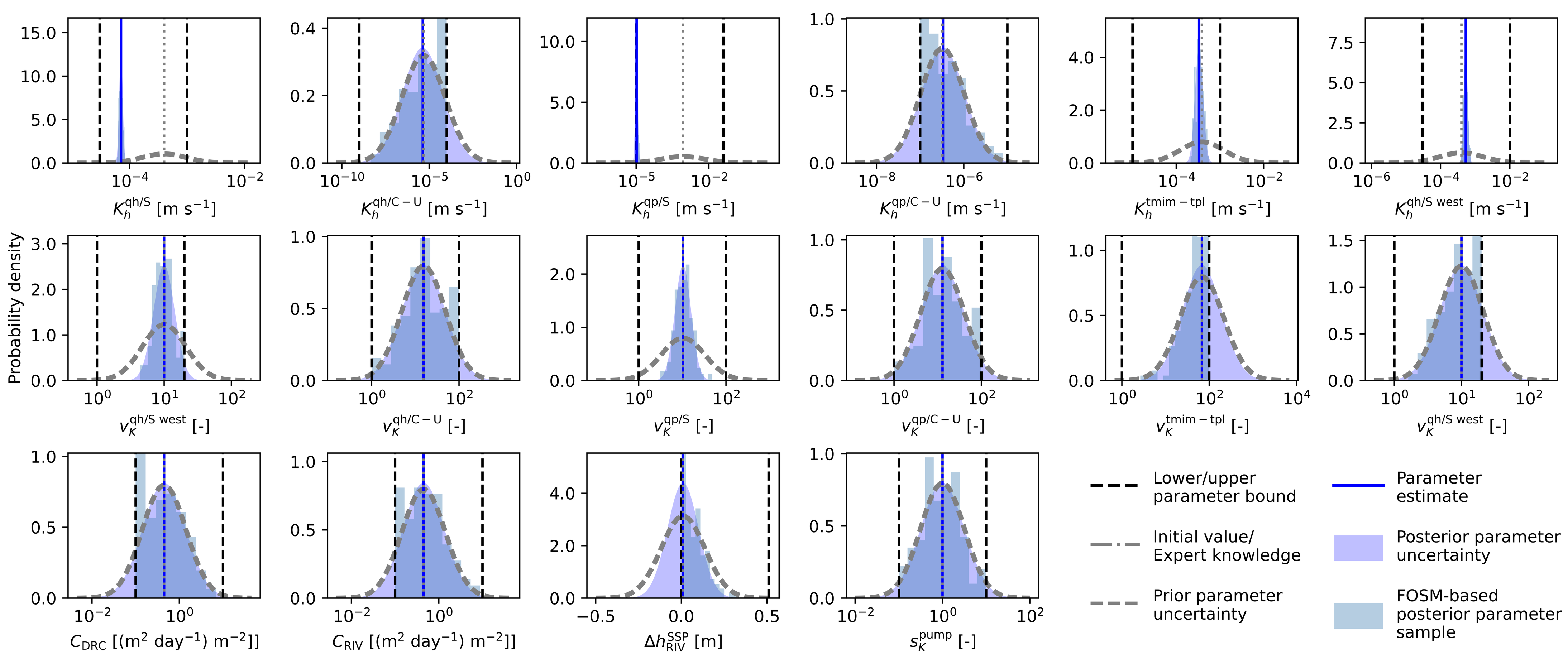

Fig. 3 Histograms of parameters being part of the estimation procedure. Depicted are prior and posterior parameter values and marginal distributions of parameter uncertainty as well as the Monte Carlo posterior parameter sample based on the FOSM-approximated parameter covariance matrix. Parameters are horizontal hydraulic conductivity (K_h) as well as the vertical ansiotropy factor ($v_K = K_h / K_v$) for different hydrogeological units (qh/S, Holocene sand; qh/C-U, Holocene clay to silt; qp/S, Pleistocene sand; qp/C-U, Pleistocene clay to silt; tmim-tpl, Pliocene to Middle Miocene deposits; qh/S west, Holocene sands in the area, where qh/C-U is present, cf. Fig. 1b), the conductance for drainage channels in the protected area (C_{DRC}) and for the surface waterbodies (C_{RIV}), water level adjustment height for the surface waterbodies (which are subtracted from the prior assumed waterlevel, Δh_{RIV}), and a scaling factor for the hydraulic conductivity of the well-skin sediment at production wells (s_K^{pump}).

- Mainly K_h was adapted during estimation
- Especially K_h for qh/S lower than expected due to locally present clay lenses not considered
- Heads are matched reasonably well considering structural uncertainties from pumping, ocean tides, and small-scale geological features
- Tendency of underestimating observed heads
- Vertical head differences only represented reasonably well for some multi-well sites

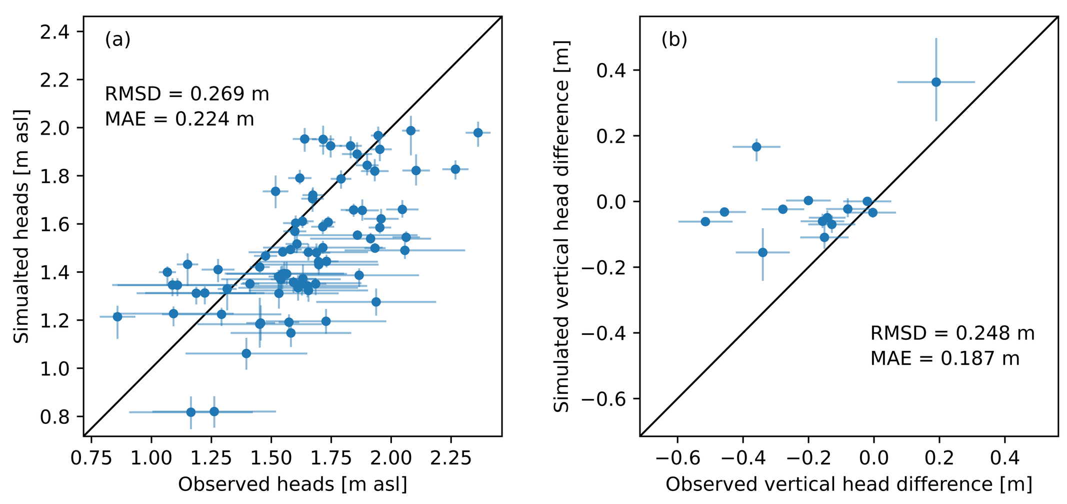

Fig. 4 Comparison of observed and simulated (a) hydraulic heads and (b) vertical head differences at mult-well sites. Horizontal bars show observation uncertainty, vertical bars uncertainty from parameter estimation based on the Monte Carlo parameter sample.

Validation

- Seasonal dynamics are represented in transient simulation of optimal parameter set
- Response times to storm events or recharge are not replicated equally well throughout the island → spatially variable geology
- Results with MSL-BC similar to PA-TBC
- Expert knowledge underestimates water levels

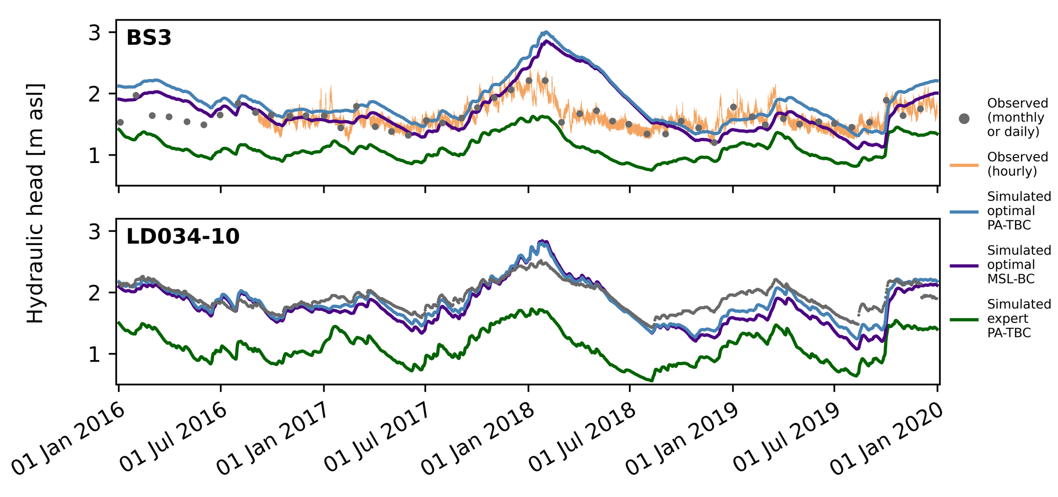

Fig. 5 Observed and simulated hydraulic heads of two example monitoring wells (cf. Fig. 1b for locations). Shown are simulation results of the validation time period for the optimal parameter set with the PA-TBC and the MSL-BC, respectively, as welll as for the expert-knowledge parameter set with the PA-TBC.

Conclusion

Reasonable transient simulation results for an island groundwater flow model can be obtained from parameter estimation using a fast-running, steady-state model that considers tidal overheight at the ocean boundary. High spatial variability of observed heads makes zone-based estimation of hydraulic parameters difficult.

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