Disentangling the driving factors of the natural fresh-salt groundwater distribution in deltas

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Context

Deltas are often densely populated areas where freshwater demand is high. Population growth and associated intensified water demands in these areas lead to increased groundwater pumping, thus increasingly burdening freshwater-bearing aquifers. Unfortunately for the freshwater users, large parts of deltaic groundwater systems are saline due to several factors, among which the past Holocene marine transgression is an important one. A lot of research has been done on the effects of individual parameters and driving processes behind the fresh-salt distribution of deltas, but which of these predominantly control the natural deltaic groundwater salinity remains unknown.

Methods

To find which inputs are dominant, we conducted a global sensitivity analysis on a 3D numerical model of a generic deltaic groundwater system with a deterministic geology. (Fig 1.) This model required 23 inputs and simulates the last 45,000 years. With the genericity of the deltaic groundwater system used, we aim to have results that are applicable to any large-scale delta groundwater system.

The sampling strategy for the sensitivity analysis is as follows: From a random starting point in the input hyperspace, we changed each input one at a time to create a trajectory (Morris' method, see Fig 4.). In total we created 10 of these trajectories, which means we ran 240 simulations.

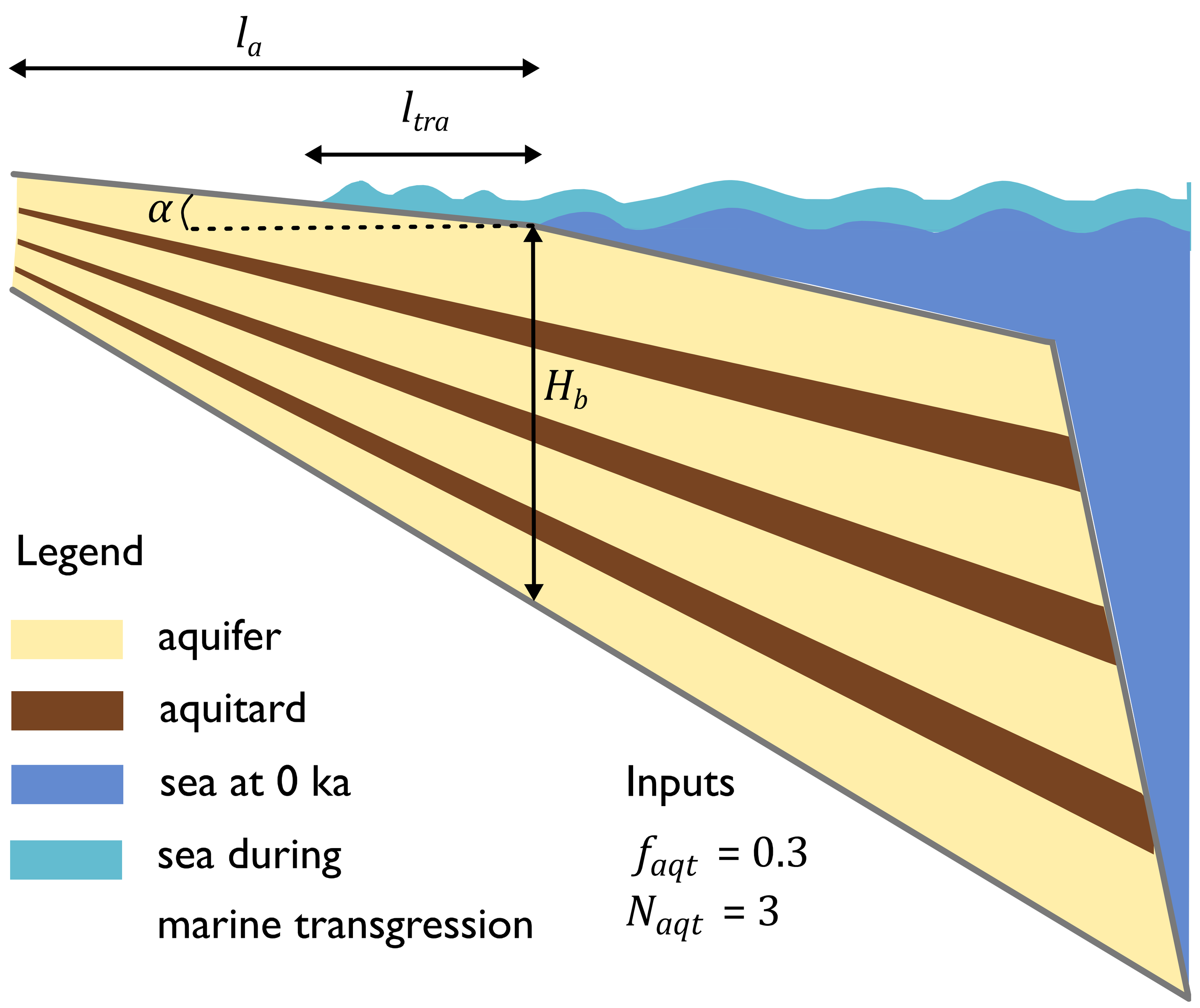

Figure 1: Sketch of our conceptual groundwater model showing the most important inputs in our global sensitivity analysis.

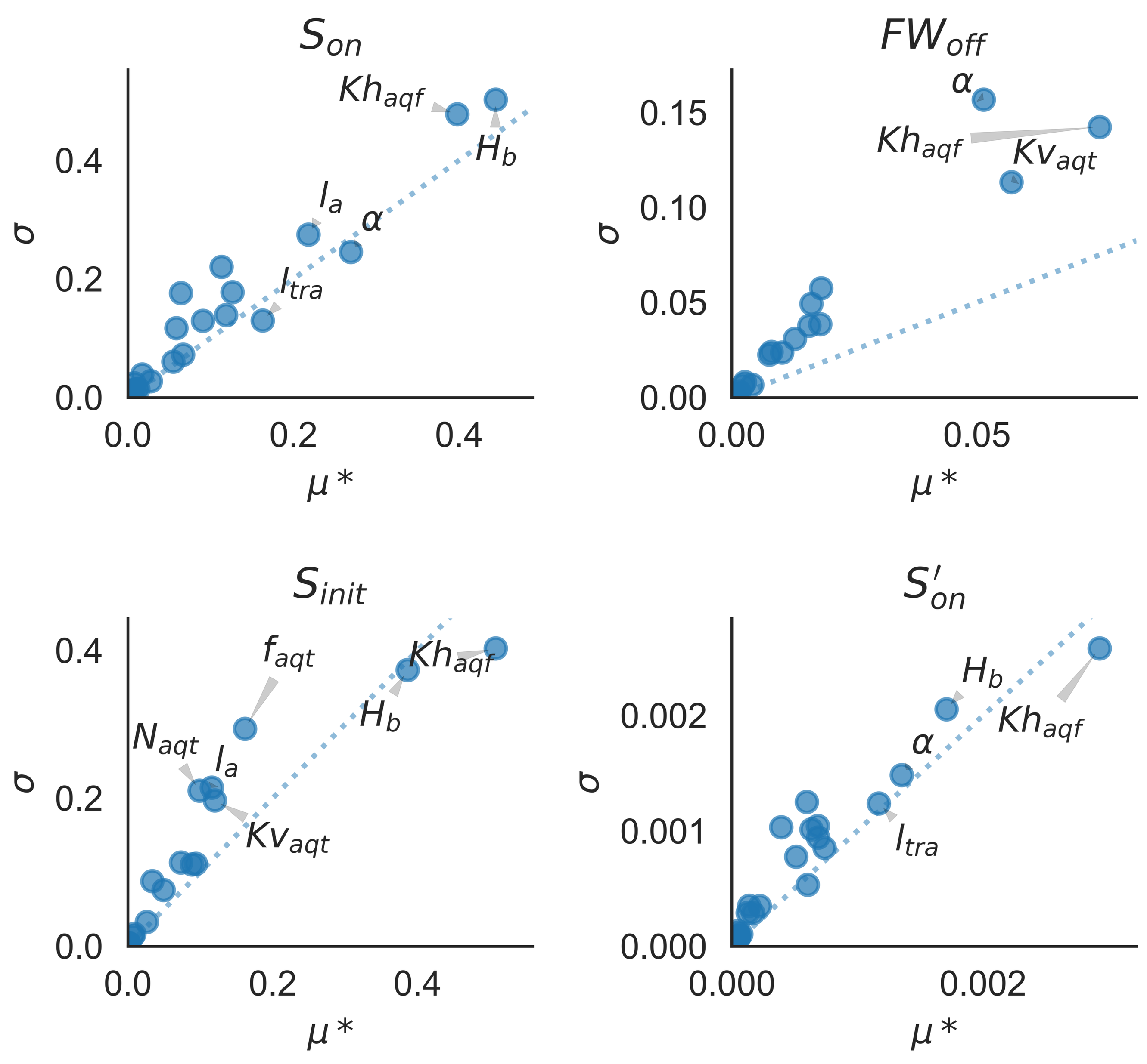

Figure 2: Scatterplot of the mean sensitivity of each input against its standard deviation for four different outputs. Each dot represents the effect of one input. The labeled inputs are deemed the most important.

Results

- The aquifer hydraulic conductivity ($K_{h,aqf}$) and the system thickness (H_b) predominantly control the outputs (Fig. 2).
- The onshore salt mass (S_{on}) is additionally controlled by the hydraulic gradient (α), length of the onshore (l_a), and extent of the Holocene marine transgression (l_{tra}).
- The initial salt mass still present (S_{init}) is to a lesser degree controlled by the resistance exerted by the aquitards ($K_{v,aqt}, f_{aqt}, N_{aqt}$).
- The hydraulic gradient (α) and the vertical hydraulic conductivity of the aquitards ($K_{v,aqt}$) control the size of the offshore fresh water volume (FW_{off}).

Discussion

The natural fresh-salt groundwater distribution in deltaic areas is often shaped over long timescales, depending on the factors named in the results. The effect of the Holocene transgression should not be underestimated, since a large input distribution was provided for $K_{h,aqf}$ (Fig 3.).

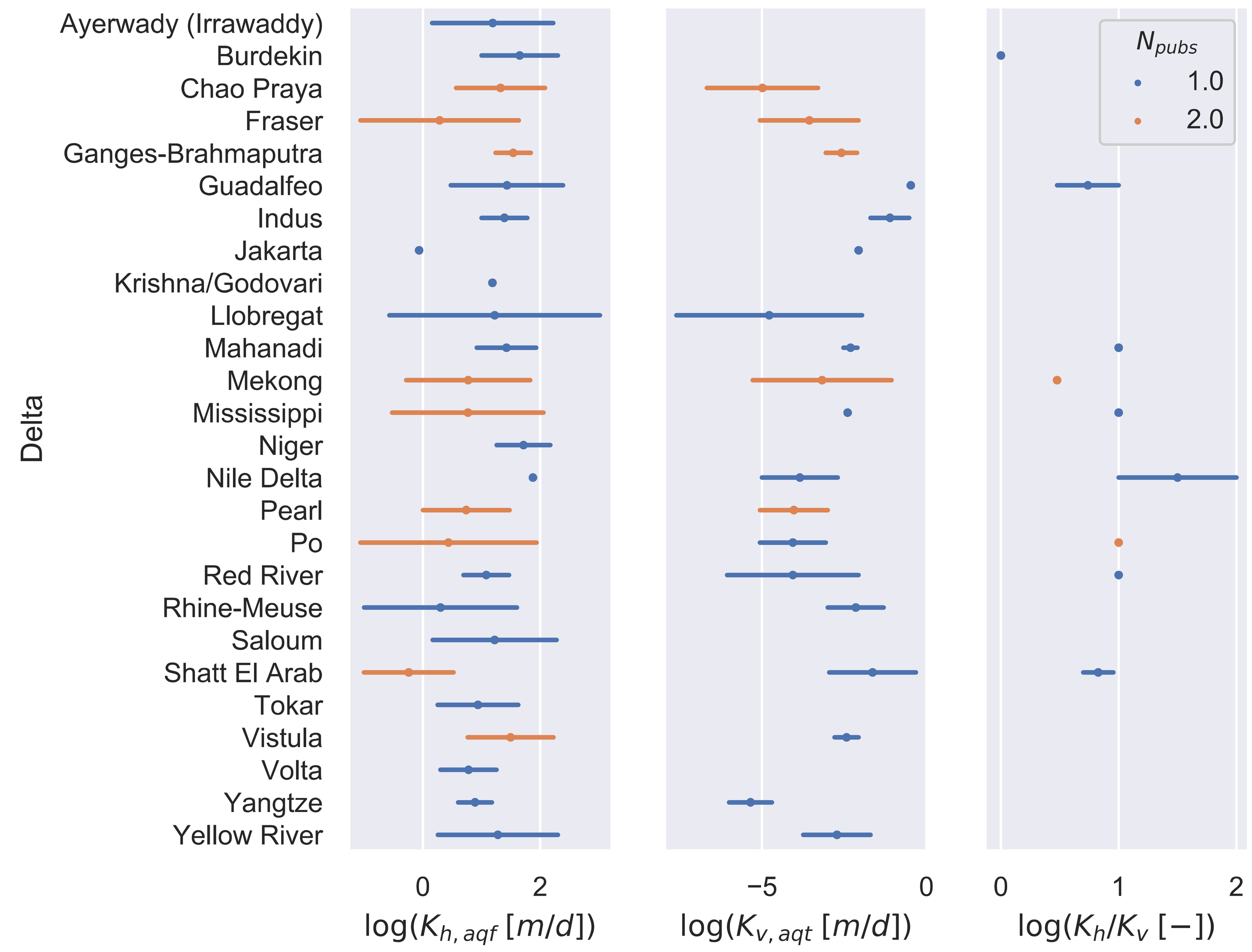

Figure 3: Range of a few selected inputs for different deltas as found in the literature.

Outlook

The results of this study help prioritizing uncertainty analyses of similar systems, can support assumptions made to create parsimonious models, and might help the exploration of offshore fresh water groundwater volumes. They furthermore are a first step towards an estimation of the fresh-salt groundwater distribution for several major deltas worldwide.

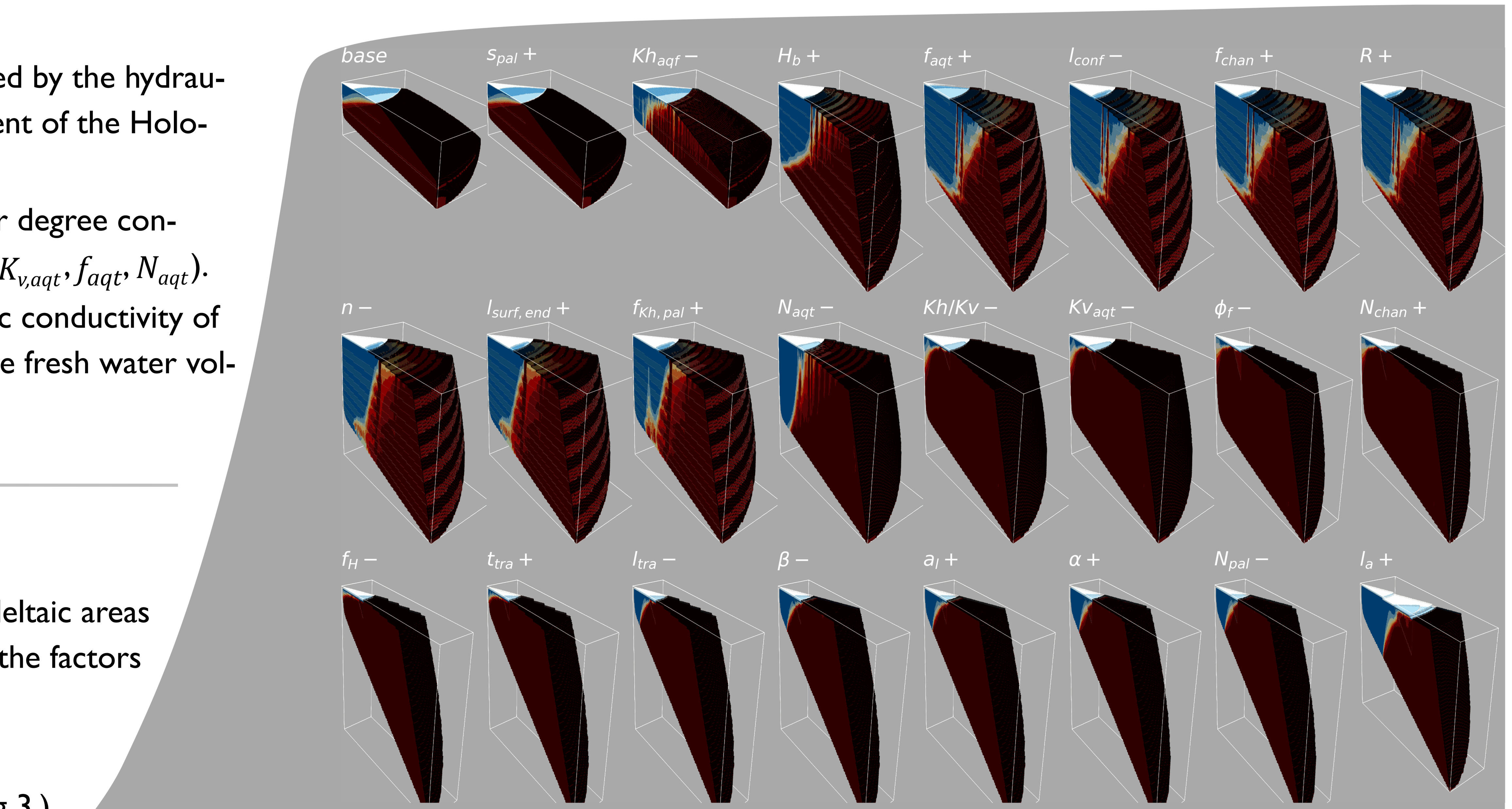

Figure 4 Fresh-salt distributions at 0 ka of one trajectory. Red colors indicate salt water, blue indicate fresh. The symbol indicates which input is altered and the sign in which direction.