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Interactive comment

Interactive comment on "Simulating future salinity dynamics in a coastal marshland under different climate scenarios" *by* Julius Eberhard et al.

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We thank Anonymous Referee #2 for reviewing our manuscript. We believe that the comments and suggestions identified important issues and clearly help to improve the paper, which we are very grateful about. In the following, we would like to respond point by point to the referee comments (RC), typeset in italic type, to the best of our abilities. Responses are marked as author comments (AC) and typeset in roman type.

RC1: *A detailed introduction of marshland salinization is missing, as the authors only generally discussed the seawater intrusion and salinization. Why marshland salinization is important to study? What are the science questions and difficulties in* *modeling marshland salinization?*

AC1: We see now that the second paragraph in the introduction is not very well structured. Though the different possible processes leading to salinization are all mentioned, we see that it can be confusing and not clear which processes are most important in our study area and why we decided to model these processes with SWAP. We will attempt to rewrite these parts of the manuscript in order to clarify the following points: "Marshlands are important for agricultural use and are prone to salinization effects of salt water intrusion from deeper aquifers, especially under the conditions of climate change (de Louw et al., 2010; 2011; 2013; Oude Essink et al., 2010; Herbert et al., 2015). That is because of the inhomogeneous geological setup which consists of Holocene peats, clays, and sand structures in varying thicknesses. Apart from salt import from deeper layers, the salt concentration in a soil increases through evaporation and plant transpiration, whereas it decreases through precipitation and subsequent infiltration (de Louw et al., 2013). So it is important to understand how these types of soils react to changing meteorological conditions with a potential increase in dryness and higher temperatures."

RC2: *More parameter information is required, for example, how is the heterogeneity of marshland being solved in the 1D SWAP model?*

AC2: Thank you for the suggestion. The horizontal marshland heterogeneity is not resolved in our model. In this model we calibrated the salt transport for a possible profile in the Freepsumer Meer. Of course there are some spatial heterogeneities in the soil profiles in the area, such as minor differences in the surface altitude or the depth of the confining layers. These heterogeneities might also have some impact on the current salinity of the soil water. In this study, however, the aim was to simulate future changes due to climate change. We do not expect that the long-term trend in salinity due to climate change would differ significantly across the area. Therefore we think that the modeled profile can be seen as representative.

RC3: *How is the groundwater level simulated in the model, as SWAP only solves the flow in the soil?*

AC3: We agree that this point needs clarification in the manuscript. The simulated groundwater level is, after its initialization, determined by the given boundary conditions. That is, we specified pressure heads in the deep aquifer, implying a Dirichlet-type bottom boundary condition for the modeled soil water column. The lateral boundary condition was given by prescribed water levels in the nearby drain ditches and the geometry and hydraulic properties (lateral boundary parameters in Table 1 of the manuscript) of the drained field in which the modeled site is located. Additional fluxes from or toward the top of the soil column are subject to the meteorological conditions. We will add the missing information in the manuscript.

RC4: *Did you simulate the horizontal water flux?*

AC4: The horizontal water flux was not explicitly simulated. The horizontal fluxes implicitly included in the model are the surface runoff and the drainage flux from or toward the soil column. The latter results from the lateral boundary conditions as specified in AC3.

RC5: *In general, I'm not convinced by the modeling capability of 1D SWAP model to accurately simulate salinization in the marshland. It's not clear how salinization is simulated in the model. Usually, seawater intrusion in the aquifer is simulated by a coupled variable-density flow and solute transport processes, or equivalent freshwater head calculated by the salinity and the depth of aquifer. Did you consider this? Anyway, I didn't find how salinization is simulated in this paper.*

AC5: Thank you for the suggestions. We would like to clarify the hydrological situation of the model site and why in our view the model is a suitable choice. Our study site, the Freepsumer Meer, consists of numerous rather small fields (cf. Figure 1b of the manuscript), which are separated by drain ditches. Thus, any horizontal groundwater fluxes are largely dominated by the surface drainage. Direct lateral intrusion of salt water to the unconfined aquifer is not an issue here. As a result, the main mechanism causing the observed salinization must be the upward seepage through the aquitard, the existence of which we infer from the geological setting (Figure 1c). Therefore, the water and salt balance are determined by the one-dimensional bottom flux through the aquitard, the lateral drainage, and the climate conditions at the top. All of these components are considered in our model. Moreover, the SWAP model is designed specifically for the simulation of such field-scale processes and was originally applied in similar landscapes (e.g. Kroes et al., 2000). We will make this point clearer in the manuscript.

RC6: *The subsection 2.4 calibration and 3.1 calibrations are confusing.*
AC6: We agree that the calibration needs some clarification. We propose to add the following description to subsection 2.4: "The parameter calibration was performed in three steps: (1) First, the parameters saturated hydraulic conductivity (k_s), dispersion length (L_{dis}), deep groundwater salinity, and vertical resistance were estimated with the aim to minimize the sum of squared deviations between the simulated and measured groundwater levels. For this purpose we used the PEST software package (Doherty, 2010) which uses a steepest decent searching optimization algorithm based on Gauss–Marquardt–Levenberg. (2) Second, the value of the deep groundwater salinity was varied, leaving all other parameters as estimated in the previous step. Here a visual comparison of measured and simulated salinity was used for the optimization. (3) After the previous steps were performed for each of the three PTFs, the sub-annual dynamics of each were compared (locations of local minima and maxima, ranges of sub-monthly fluctuations) and the PTF of Wösten et al. (1999) was chosen."

Additionally, subsection 3.1 will be expanded by a quantification of the calibrated model output: The sum of squared deviations between modeled and observed groundwater levels is 694.8 cm^2. The mean deviation per observation is 2.0 cm. The correlation coefficient of modeled and observed groundwater levels is 0.76.

RC7: *The results are not sufficiently discussed. For example, what's the initial condition did you use? And, it seems salinity is measured at soil layer/unconfined layer, and simply diluted by the rain water? Is salinity in the confined layer a boundary condition? How is it determined? How do bottom flux and drainage flue being calculated?*
AC7: We appreciate the suggestions and agree that some information in the discussion is missing. The simulation period of 2000–2099, which is considered in the results and discussion sections, was preceded by the spin-up period 1961–1999. At 1 January 1961, groundwater level was initialized with the first value of the observed groundwater levels in 2011 (-42 cm). The salt concentration profile was initialized with a constant value of 3 mg cm^{-3}. Both the groundwater level and the salinity undergo rapid changes and are considered independent from the chosen initial conditions after a few years. The salinity of the confined groundwater is given as a constant boundary condition in the model and was estimated in the model calibration. Table 2 in the manuscript provides the calibration range and the estimated value of 6.6 mg cm^{-3}. Bottom and lateral fluxes are calculated as provided in AC3.

RC8: *The parameters being perturbed in the scenario runs are not clear. I assume temperature and rainfall are obvious, but did you change the radiation?*
AC8: Thank you for the important question. We agree that the parameters modified in the climate scenarios were not sufficiently specified. The scenarios cover time series of radiation, minimum and maximum temperature, air humidity, wind speed, and rainfall.

RC9: *Does the potential sea level rise being considered? If sea level does not rise, how does wetter climate increase salinity?*
AC9: The issue of sea level rise has been approached on page 7, lines 1–5. It has

not been considered in the study due to two reasons. First, observations of the deep pressure head nearby the study site did not exhibit any significant trends in 1990–2014 despite an observed sea level rise in this period. Second, we regarded simulated deep pressure heads near the study site, produced by the hydrological model GSFLOW, driven by the climate scenarios I and II. The pressure head differences between simulations with assumed 0 cm, 80 cm, and 150 cm sea level rise within the 2000–2100 period were marginal (in the order of 10 cm at the end of the period) and the uncertainties involved in the model setup were considerable. We concluded that the effect of sea level rise is negligible for salinization in our case.

We agree that the change in salinity can not be seen as a direct result of only the winter precipitation, especially as an increase in precipitation would not be expected to result in an increase in salinity, as the reviewer correctly notes. We would like to change the text in order to reflect these results better: “In those scenarios where there is a positive trend in deep salinity, this seems to be the result of a combination of factors, such as increased ET and changed summer and winter precipitation. A higher ET might affect salinity in two ways: On the one hand, the salt concentration would increase in the remaining soil water when ET increases. On the other hand, the increase in pressure gradient when soils dry out in summer can cause a stronger bottom flux of saline water. In the case of, e. g., scenario IV with the strongest increase in salinity the ET has increased strongly and the summer precipitation decreased. The increase in winter precipitation was apparently not enough to flush the salt from the profiles. While in scenario VI the ET increase was highest, but both summer and winter precipitation increased in this scenario, thus limiting the increase in salinization.”

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Discussion paper

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