Updated access link to Zenodo repository during peer-review:
https://zenodo.org/records/10868409?token=eyJhbGciOiJIUzUxMiIsImlhdCI6MTcwNjYyNzAyMiwiZXhwIjoxNzM1NjAzMTk5fQ.eyJpZCI6IjIwYjE3YTU1LWExNTktNDc3NS04NDQwLTdlYmM1NTljMTNjNyIsImRhdGEiOnt9LCJyYW5kb20iOiIzMGU2ZTBlZTc1Y2JlMzRhOGIzYTkwYjk2NDg2NjM3OCJ9.Cr9YcHfeJ1kOV3cF8Nb5ameI97Kvnf3YKNVW3Q56qR8wI25tKcZrubEBEYysB7pVFKXGNfNuGOUNIM0dp4r0wA

We thank both reviewers for their time reviewing the revised version of this manuscript as well as for the constructive and helpful comments provided. Following you find our responses to your comments, which are color coded with blue for neutral, green for agreement, orange for partial agreement, and red for disagreement. Line numbers refer to the revised version of the manuscript unless stated otherwise.

Response to report of referee #1, Jonathan Kennel

Lines 135-139: Previously I commented on this, but I still think it still needs clarification. The current text states this is an offset effect, but I think it is a scaling effect. When comparing sea level and freshwater I would use the same units (i.e. convert sea level to an equivalent freshwater or vice-versa). For example a change of 1 m sea level will be equivalent to a change 1.027 m of freshwater based on its density. This is the driving force for the impulse response and I don't think taking first differences has any effect on this. This directly scales the Ocean Response Function by ~ 2.7% and if you don't adjust for this your maximum ORF will be increased by this amount compared to the freshwater-freshwater comparison. Unless you want to define the Ocean Response Function in terms of salt water to freshwater (which is probably not the way to go) I think this should be changed. Consider the analogy to barometric pressure – you always want the units to be the same for the barometric response function or barometric efficiency calculation. This would affect the figures as well but the overall story of the paper remains the same.

Thank you for pointing this out again. In our revisions, we argued with the measured heads when we should have considered the head differences. We revised the paragraph from Lines 135 to 138 in submitted manuscript accordingly and put the additional explanations in a separate paragraph **(Lines 156-178)**:

> "**2.5 Considering density effects**
>
> The density difference between seawater and freshwater has to be considered when applying Eqs. (8), (9), and (14) with sea levels present in ΔX. Here, the ORF is defined based on hydraulic head measurements in freshwater. The propagation of external influences in the aquifer depends on the pressure of the external stressor rather than the elevations, which are used as a proxy (i.e. hydraulic heads). A change of hydraulic head in seawater yields a larger pressure change than the same change in freshwater would due to the density difference. Therefore, sea-level records need to be corrected for this higher density to correctly represent the pressure changes of the sea level at the shore with reference to fresh groundwater inland.
>
> Density correction of hydraulic heads is typically achieved by calculating freshwater heads
>
> $$h_f(t) = \frac{\rho}{\rho_f} h(t) - \frac{\rho - \rho_f}{\rho_f} z, \qquad (15)$$
>
> where h is the measured point water head, ρ_f is the freshwater density (1000 kg m^{-3}) and ρ is the density of the water at the screen elevation z of a monitoring well (Post et al., 2007). In case of sea-level observations, ρ is the seawater density and z is the elevation of the sea floor. When using first differences, the freshwater head difference between times t_i and t_{i-1} is
>
> $$\Delta h_f = h_f(t_i) - h_f(t_{i-1}) = \frac{\rho}{\rho_f}[h(t_i) - h(t_{i-1})] = \frac{\rho}{\rho_f} \Delta h \qquad (16)$$

so that sea-level differences in Eqs. (9) and (14) have to be defined as freshwater-equivalent differences

$$\Delta X_f^{\mathrm{SL}} = \frac{\rho}{\rho_f} \Delta X^{\mathrm{SL}} \quad (17)$$

which corrects differences from measured sea levels ΔX^{SL} by the density ratio ρ/ρ_f between salt- and freshwater.

Should the groundwater monitoring well be screened in a location of brackish water or saltwater, the density correction needs to be applied to the hydraulic head differences as well to obtain freshwater-equivalent hydraulic head differences

$$\Delta Y_f(t) = \frac{\rho(t)}{\rho_f} \Delta Y, \quad (18)$$

which allows to obtain comparable ORFs between monitoring sites. Especially at beach sites, the density ratio may be a function of time reflective of salinity changes around the screen of the monitoring well (Greskowiak and Massmann, 2021; Grünenbaum et al., 2023). Details on the estimation of groundwater density from electric conductivity measurements are provided by Post (2012)."

The paragraph about transfer function noise models in Lines 139 to 144 of the submitted manuscript was kept in Section 2.4, now found following Eq. (14) in **Lines 150-155.**

Site-specific information regarding the density correction was added in **Lines 224 to 225**:

"Sea-level differences as required for Eq. (14) were converted to freshwater-equivalent sea-level differences according to Eq. (17) with density ratio $\rho/\rho_f = 1.025$, assuming a saltwater density of 1025 kg m^{-3} at the study site."

Figures showing results regarding the regression deconvolution were adapted according to the conversion of sea-level differences to freshwater-equivalent sea-level differences (Figs. 3, 4, 5, 6, 7, 8, C2, D1, D2, and S1 to S9 in the supplement). Overall, the outcomes did not noticeably change when the density correction was applied. Differences in the results scale with the density ratio applied (1.025).

This required following adaptions to the text:

- **Line 291:** Changed ORF value for BS3 from 0.43 to 0.42
- **Line 319:** Changed ORF value for SN12/1 from 0.45 to 0.44

Line 181: "The spatial distance of ca. 1 and 2.5 km" This isn't clear to me.

We clarified to which specific monitoring well(s) the respective distance referred to **(Line 215-218)**:

"The spatial distance between the meteorological station and the groundwater monitoring wells is approximately 1 km in case of SN12/1 and approximately 2.5 km in case of BS3 and NY-10. At this distance, the barometric pressure observations are assumed to be representative for the groundwater monitoring locations as the barometric pressure typically varies at larger spatial scales (cf. Appendix A)."

Line 418: "conzeptualization" typo

Corrected, thanks!

Response to report of referee #2, Rachel Housego

I appreciate the author's efforts in revising their manuscript in response to reviewer comments and I look forward to seeing this in print at HESS. At this stage there is only one issue about the effect of wave set-up in the author's reply that needs to be resolved before this can be published. Due to the application of this paper specifically to coastal settings I think it is important that this is clarified in the final version of the manuscript. See full response below to the original discussion.

[Authors' note: following citation in referee report from previous round of revisions marked in italic and indented]

> *Neglecting wave set-up likely causes an issue in removing the oceanic effects on water levels, especially during surges. For more see the following papers and references therein. 565*
> *da Silva, P. G., Coco, G., Garnier, R., & Klein, A. H. (2020). On the prediction of runup, setup and swash on beaches. Earth-Science Reviews, 204, 103148.*
> *Stockdon, H. F., Holman, R. A., Howd, P. A., & Sallenger Jr, A. H. (2006). Empirical parameterization of setup, swash, and runup. Coastal engineering, 53(7), 573-588.*

> *We agree that waves may affect the oceanic response function. However, due to the high frequency of wave action, these effects would have very little to no effect on the data observed at the monitoring wells in this study. This is due to the low-pass filtering of the sediment which cancels the influence of high-frequency wave action over propagation distance. Wave setup can contribute significantly to groundwater table overheight also induced by tidal motion (Nielsen, 1990; 1999), but the oceanic response function focusses on the time-series dynamics rather than more persistent offsets such as is caused by wave-induced overheight. We included an explanation with a recommendation to include wave-setup data when analyzing groundwater-level time series close to the shoreline (Lines 237-242): "Besides ocean tides, waves can have a pronounced impact on near-shore groundwater-level dynamics (e.g., Nielsen, 1999; Housego et al., 2021). Due to the generally high-frequency of the wave dynamics at the shoreline (e.g., Stockdon et al., 2006; Hegge and Masselink, 1991) and the low-pass filter properties of the aquifer sediment (e.g., Rotzoll et al., 2008; Trefry and Bekele, 2004), waves can be assumed not to impact the groundwater-level dynamics at the monitoring wells in this study, which are several hundreds of meters from the shoreline (cf. Table 1). However, the influence of wave dynamics on groundwater levels may be relevant at beach sites or sites closer to the shoreline."*

I agree with the authors that the high frequency effects of wave action would not affect the inland groundwater levels. However, the net effect of wave set-up during storms is a long-term modification of the **mean water level at the shoreline due to conservation of momentum from wave breaking** which actually has a long effective wave period and would not be attenuated as described above and therefore could impact inland levels. **It is not a wave-by-wave process.** For example, if there were waves at 5 m offshore for a 2-day period during that entire two-day duration the water level at the shoreline would be elevated 1-1.25 m above the level predicted by using an offshore wave buoy to design the ocean time series. During calm conditions you can neglect this effect but during the storm responses this becomes important. The effect of set-up does attenuate inland and likely becomes less significant beyond 500 m inland where your sites are located. However, this is a methods paper specific to coastal settings so I think it is really important to present this accurately because this could be transferred to other coastal sites where wave setup would be important in terms of designing an accurate ORF, especially for time series where multiple surge events are being removed.

Agreed, the influence of wave setup should be given consideration in the conceptual and methodological sections of the manuscript. Therefore, we added and reformulated parts of Section 2.1 to give the wave influence more prominence in the conceptualization of the method **(Lines 52-62)**:

> "Sea-level variation is dominated by diurnal and semi-diurnal periodicities, along with aperiodic behavior resulting from storm events (Boon, 2011). Further, waves breaking at the shore impact groundwater-level dynamics (e.g., Nielsen 1999, Housego et al., 2021). Wave dynamics generally occur at high-frequencies at the shoreline (e.g., Stockdon et al., 2006; Hegge and Masselink, 1991) while the continuous wave breaking at the shore results in a more persistent, lower-frequency wave setup (Stockdon et al., 2006; Gomes da Silva, 2020). Wave setup is generally larger during storm events (Senechal et al., 2011) and thus adds to the magnitude of the storm-event related, aperiodic rises in sea level.
>
> The influence of fluctuating sea levels and waves diminishes with distance from the shoreline, with tidal and high-frequency wave variation attenuating more rapidly than variation from season, wave setup or extreme events, such as floods or droughts (Ferris, 1952; Li et al., 2004; Nielsen, 1990; Li et al. 1997; Carwright et al., 2006; Rotzoll and El-Kadi, 2008). Precipitation recharges groundwater by vertical percolation through the overlying unsaturated zone or by direct recharge from surface-water bodies that fill during storm events."

These paragraphs also replace Lines 237 to 242 in the submitted manuscript in large parts. This paragraph was reformulated accordingly **(Lines 274-279)**:

> "Wave setup was not considered as a separate process since the additional considerations required for an empirical formula to estimate wave setup from offshore measures (Gomes da Silva et al. 2020) were beyond the methodological objective of this technical note. The influence of wave setup on groundwater levels may however be present in the corrected time series when the wave setup present at calm conditions increases during storm events for example (i.e. wave setup is not constant over the studied time frame; cf. Section 2.1). Here, this could be the case during the storm event in January 2019 or the time frame of pronounced sea-level variations in March 2019 for example (Fig. 3)."

In **Line 257** we added: "and wave setup."

In Section 2.4. we added in **Lines 146-149:**

> "A wave response function and groundwater levels with wave setup removed can be obtained equivalently, e.g. to account for additional storm-event related wave setup at the shore. Alternatively, wave setup can be incorporated into the sea-level time series to obtain an ORF representing both processes. Note that wave setup is generally estimated from offshore wave measures by means of empirical formulas (c.f., Gomes da Silva et al., 2020)."

Further changes and technical corrections

Lines 29 to 35: Reformulated due to additional literature: "Convolution by means of transfer function noise modeling has been applied by Bakker and Schaars (2019) to model hydraulic heads of a coastal aquifer based on time series from sea level, recharge, and groundwater withdrawal. An estimation of a response function from sea-level data itself and removal of sea-level influences from dynamic groundwater levels in coastal settings, like done with regression deconvolution, has not been performed (to the authors' knowledge). Especially in coastal settings periodic and aperiodic influences often obscure important groundwater processes, such as recharge, which is difficult to estimate or directly measure, and pumping."

Line 66: Replaced "ocean tide signal" with "sea-level signal".

Lines 140 to 141: Replaced "$\Delta x = \{\Delta\mathrm{SL}, \Delta\mathrm{BP}\}$" with "processes $p = \{\mathrm{SL}, \mathrm{BP}\}$ in Eq. (9).". The previous notation was from a previous notation of the processes that was changed before submission of the manuscript.

Line 187: Replaced "Norderney" with "Norderney's".

Line 271: Changed "temporally variability" to "temporal variability".

Line 303: Added "in the supplement" to figure references referencing to the supplement.

Line 332: Replaced "collected" with "available" for consistency with caption of Fig. 7.

Line 441: Added "in the supplement" to figure references referencing to the supplement.

Lines 463 to 464: Added "Further, we thank the two reviewers for their constructive comments which helped to significantly improve the paper."

Figure 2: Changed "meteorologic station" to "meteorological station" in caption.

Figure 5: Added "in the supplement" to figure references referencing to the supplement.

Table 1:

- Put "a" before DEM in footnotes (b) and (c)
- replaced "closest" with "nearest" in footnote (d)
- Corrected "top of screen [m asl]" for BS3 from -4.68 to -4.98
- Corrected "Distance to MHW [m]" for NY-10 from 978 to 979

References: Journal names were changed to Journal name abbreviations where not used beforehand.

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