Response to RC2 from Rachel Housego

This manuscript applies a linear regression deconvolution to remove ocean-driven water fluctuations from groundwater heads observed at different three different locations and depths across the barrier island. After removing the ocean-driven forcing the residual groundwater fluctuations are used to understand recharge and pumping responses on the island. Overall, I think the paper is well-written, the figures are easy to interpret and it was interesting to see how well the timing of the fluctuations in the corrected time series did coincide with the pumping schedule. I think some of the methods and conclusions would benefit from adding some additional context about what is unique about applying these functions in a coastal setting to further differentiate it from other papers manuscripts that have applied similar techniques. With some additional clarification I think this manuscript will make a nice contribution to HESS. See specific comments below.

Thank you for your time reviewing the manuscript as well as the constructive and helpful comments provided. In the 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.

A lot of work (although not yet applied in coastal settings) has been done using transfer function noise models, which is also a convolution-based method for groundwater time series analysis but presumes a fixed shape of the response function. I think it would be worth citing some of this work and noting the difference in the methods.

Collenteur, R. A., Bakker, M., Caljé, R., Klop, S. A., & Schaars, F. (2019). Pastas: open source software for the analysis of groundwater time series. Groundwater, 57(6), 877-885.

We will add an explanation of the difference between the regression deconvolution method and transfer function noise (TFN) modeling and include appropriate references. This will point out that regression deconvolution does not rely on the a-priori assumption of the response function (e.g., Gamma distribution), but rather estimates the response function directly from the data, i.e., the shape is not predefined by a chosen response function model, which is of advantage for gaining process understanding.

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.

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 will include an explanation including a recommendation to include wave-setup data when analyzing groundwater-level time series close to the shoreline.

How does the ORF behave in the frequency domain? Is it consistent with what is known about how ocean driven water table fluctuations propagate through the subsurface, e.g. longer wave periods propagate faster and attenuate less?

We note that ORFs are not comparable with frequency analysis. With the given memory of the ORF (48 h, 150 h, and 250 h), the ORFs are too short for a reliable frequency domain analysis, like Fast Fourier Transform, as strong spectral leakage is expected. Figure B2 in the manuscript shows that different time lags are required to remove different tidal constituents successfully. E.g., the diurnal constituent O1 is removed less successfully than the semi-diurnal M2 (amplitude ratio of O1 is larger than that of M2 at all memories). This is related to the differing propagation properties of the tidal constituents, where O1 is less attenuated than M2. Since this non-linearity is introduced within the aquifer, it cannot be fully removed from the groundwater-level time series using regression deconvolution. As mentioned further below (in response to the comment on Lines 235-245), we will add this information in the discussion of the results.

Also in response to a comment of RC1 regarding Figure 5, we will add an additional Figure showing the amplitudes in the frequency domain of the corrected time series. This shows that all major tidal constituents but S1 and the shallow water constituent M4 are successfully removed from the groundwater-level time series.

How sensitive are the ORF parameters to the storm? There is only one in the data set, if it is removed how different is the maximum time lag at each well? I think it may be possible that the maximum time lag is heavily influenced by the intensity and duration of the surges in the data set and if a more extreme event was measured that parameter may be different.

We agree that the presence of storm events is relevant, and we will include more information about this in the revised manuscript. Please refer to our response to referee comment 1 (p. 4, comment “How reproducible are the response functions when calculated for different portions of the dataset?”). We will add a Figure and additional explanation pointing out the relevance of storm events for the shape of the ORF.

Would there be any benefit to applying the tidal constituents and the moving-averaged trend as separate drivers/would the residual be different if you took that approach?

This could be beneficial if one was only interested in the response to storm events for example. Then extracting a trend time series using a filter designed to remove ocean tides from time series could make sense. This trend time series could then be analyzed using regression deconvolution to obtain the response to storm events and other non-tidal sea-level influences. The residuals would look different if only a single sea-level influence (i.e., ocean tides or storm events) were removed because one of the drivers would remain in the signal. Separating the drivers could generally make sense depending on the question at hand. Since this technical note is concerned with removing the entire sea-level influence, this is beyond the scope of this manuscript.

What concerns are there for overfitting and aliasing with this approach?

Regarding overfitting, the concerns would be the same as for linear regression analysis. Thus, the number of parameters (here, time-lagged input time series) should be (substantially) less than the number of data points. In the case of regression deconvolution, “too much” parameters would result in a lot of corresponding regression coefficients fluctuating around zero. This can introduce spurious fluctuations to the corrected time series.

Regarding aliasing, the sampling frequency should be such, that all relevant ocean tide constituents can be captured in the observed time series. Since the memory (maximum time lag) depends on the tidal frequencies and storm events present, sampling intervals exceeding a threshold may lead to misleading ORF shapes and imprecise time lag information in general. Due to the strong attenuation of high frequency tidal constituents (i.e., shallow water tidal constituents), the sampling interval of 1 h used in this study should suffice to avoid such issues. Besides, with the respective Nyquist frequency at 12 cpd in this case, the most relevant shallow water tidal constituents would also not cause an aliasing issue in this case. We will add a sentence about this to the manuscript.

Would the generated ORF function have the ability to forecast future groundwater levels based on ocean water level time series? Under what environmental conditions would this not work as well?

This is beyond the scope of this technical note but would be worthwhile investigating in a future contribution. If all relevant sea-level stressors (here: ocean tides and storm events) are present in the time series the ORF is derived from and this time series is long enough to cover the variability of these stressors, it should generally be possible to forecast groundwater levels. As other forecasting methods that rely on training data and statistical models, environmental conditions not present in the training data could pose a challenge to the forecast. Thus, should general characteristics of tides and storm events change in the future, forecasts calculated based on regression deconvolution would probably not be reliable.

Line 235-245 I think this is presented as being too generally applicable to all coastal environments however some field studies have shown non-linear responses to ocean forcing, developing skewness and asymmetry in the water table fluctuations that I do not think this method would be able to remove.

E.g. Raubenheimer, B., Guza, R. T., & Elgar, S. (1999). Tidal water table fluctuations in a sandy ocean beach. Water Resources Research, 35(8), 2313-2320.

In addition to the discussion of the linearity assumption as outlined in our response to the moderate concern comment of RC1, we will also mention the changing shape of the propagating ocean tide signal in the aquifer as a result of the different attenuation and phase shift properties of tidal constituents at different frequencies and due to the generation of higher harmonic tidal constituents in the aquifer sediment (Bye and Narayan, 2009). This potentially also adds to the noise present in the corrected time series, that cannot be explained from other sources. This will be mentioned as well in a revised version.

We would reformulate the paragraphs of the conclusions referenced in this comment as follows:

> "Our findings expand the range of applications for regression deconvolution by enabling the characterization and mitigation of external perturbations impacting groundwater levels. These perturbations encompass barometric pressure, Earth tide, river stage fluctuations, and now, oceanic influences. Our methodology is well-suited for analyzing data obtained from groundwater monitoring in oceanic and coastal aquifers. This capability is instrumental in enhancing our understanding and sustainable management of these critical water systems. Future research endeavors should prioritize a systematic exploration of how hydraulic processes (e.g., modulation of tidal signals within aquifer sediments) and properties (e.g., hydraulic diffusivity) in coastal aquifers affect Oceanic Response Functions. Additionally, estimating response functions linked to groundwater extraction becomes an important area for investigation once suitable data becomes available."

References

Bye, J. A. T., & Narayan, K. A. (2009). Groundwater response to the tide in wetlands: Observations from the Gillman Marshes, South Australia. Estuarine, Coastal and Shelf Science, 84(2), 219–226. https://doi.org/10.1016/j.ecss.2009.06.025

Nielsen, P. (1990). Tidal dynamics of the water table in beaches. Water Resources Research, 26(9), 2127–2134. https://doi.org/10.1029/WR026i009p02127

Nielsen, P. (1999). Groundwater Dynamics and Salinity in Coastal Barriers. Journal of Coastal Research, 15(3), 732–740.