Disentangling aquifer dynamics in coastal groundwater systems using high-resolution time series

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Introduction

Sea-level influences on groundwater levels can largely overprint other signals, like groundwater recharge (Fig. 1). Regression deconvolution has been successfully used to remove Earth tide (ET), barometric pressure (BP) and river-stage influences from groundwater (GW) time series [1,2,3].

Our objective was to demonstrate that regression deconvolution can successfully correct groundwater-level measurements from sea-level (SL) influences in an unconfined coastal aquifer.

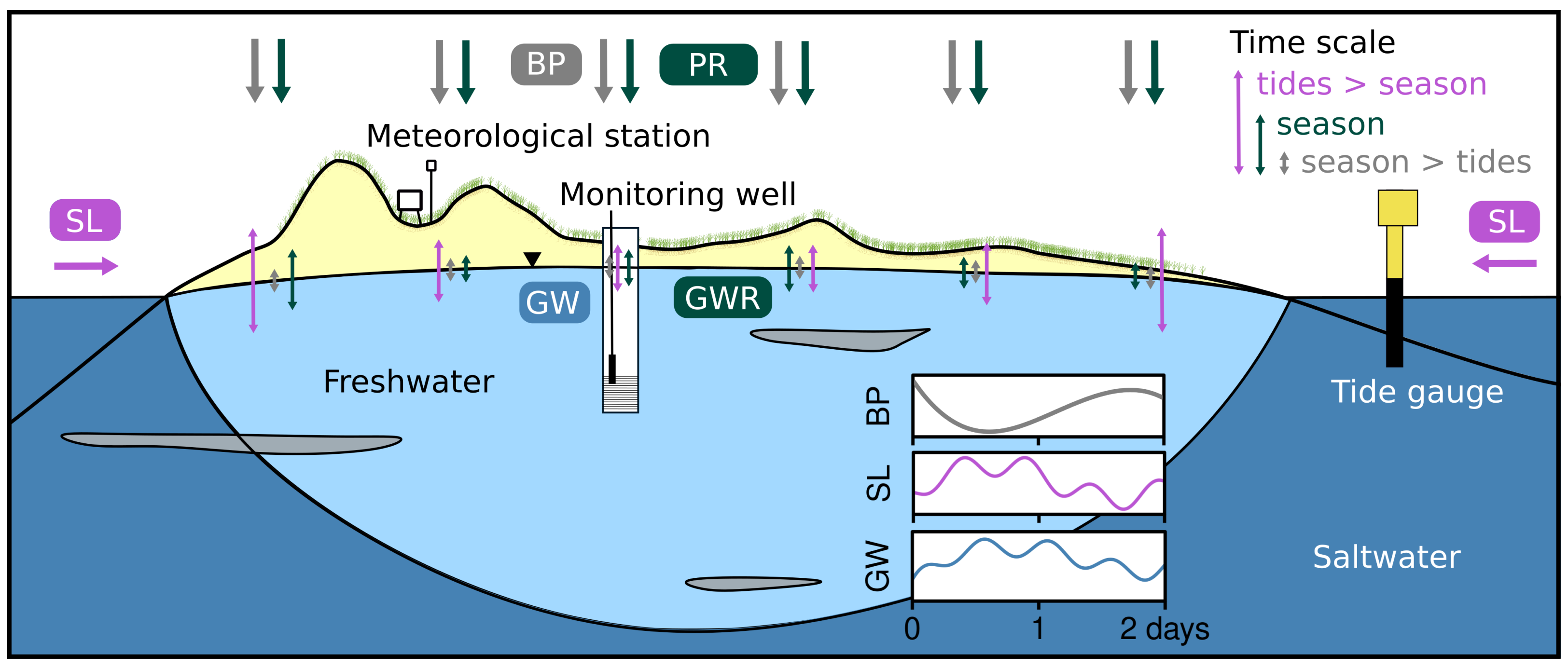

Fig. 1 Conceptual model of groundwater-level fluctuations (GW) on a coastal island with barometric-pressure (BP), sea-level (SL), and groundwater-recharge (GWR) forcing. The latter results from precipitation (PR) on oceanic islands. Note that the amplitude of groundwater fluctuations is larger for tidal influences near the shoreline than seasonal influences, but smaller toward the center of the island.

Methods

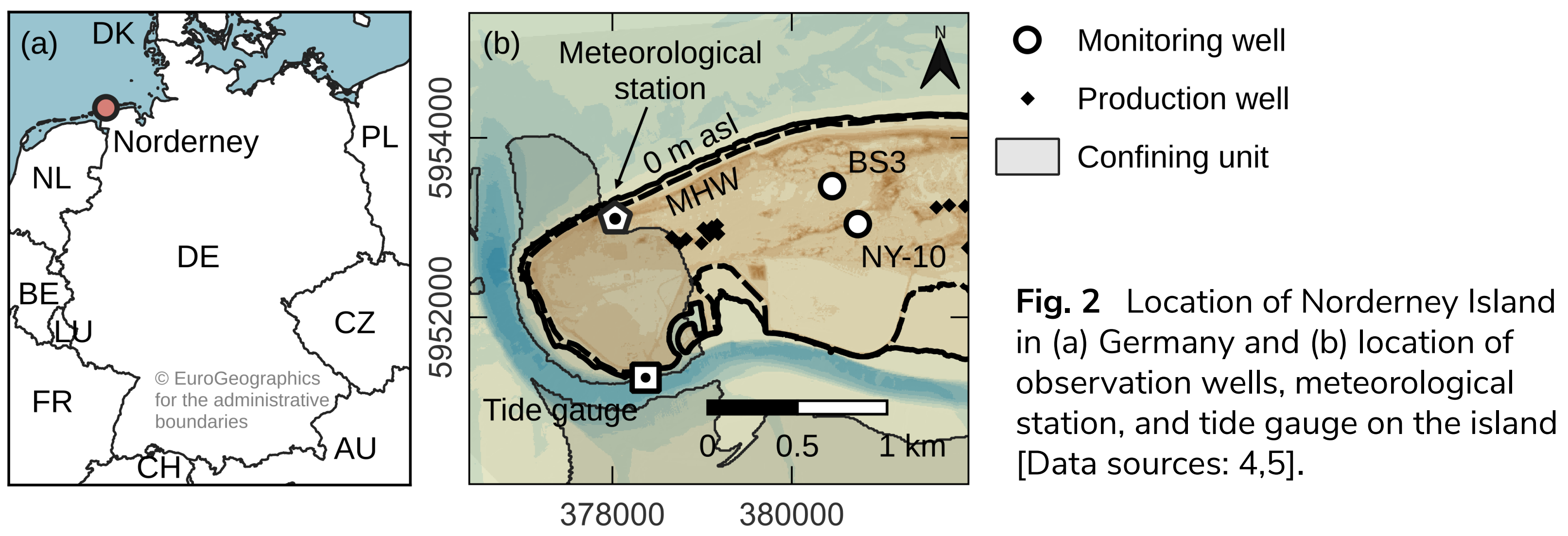

Fig. 2 Location of Norderney Island in (a) Germany and (b) location of observation wells, meteorological station, and tide gauge on the island [Data sources: 4,5].

Regression deconvolution

- Inversion of convolution

$$\Delta Y(t) = \sum_{p=1}^{P} \sum_{k=0}^{K^P} \beta^p(\tau_k)\, \Delta X^p(t-\tau_k)$$

of multiple drivers provides groundwater response to each of them [2]

- Oceanic Response Function

$$\mathrm{ORF}(\tau_k) = \sum_{k=0}^{K^{\mathrm{SL}}} \hat{\beta}^{\mathrm{SL}}(\tau_k)$$

describes characteristics of sea-level influence at site

Study area and data

- Barrier island Norderney with approx. 2 km north-south extent (Fig. 2)
- Fine-grained sand
- Time series: 1 year with 1 h increments
- Shallow screened wells

Variables

β	instantaneous coefficients
ΔY	groundwater levels first differences
ΔX	input processes (e.g., SL, BP) first differences
K	maximum number of time lags
P	total number of processes
t	time
τ	time lag

Results

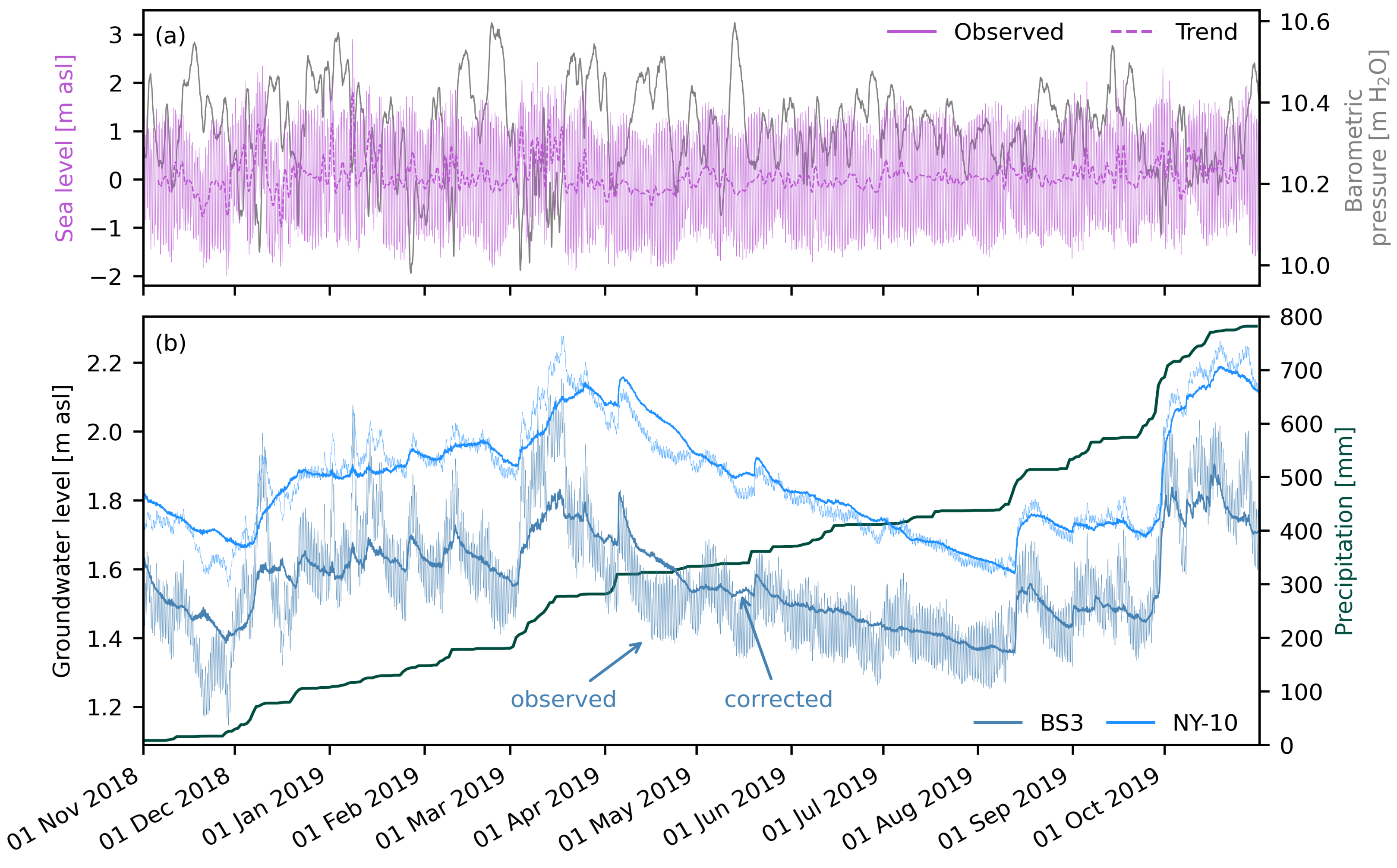

Fig. 3 Time series of (a) sea levels and barometric pressure, as well as (b) observed and corrected groundwater levels at monitoring wells BS3 and NY-10 (Fig. 2b) with maximum time lags of 150 and 250 h, respectively.

- Successful removal of sea-level influences; both tides and aperiodic events like storm floods (Fig. 3)
- Required time lags and maximum ORF values reflect the distance of the monitoring wells to the shoreline (Fig. 4)
- Response of corrected groundwater levels coincides with precipitation events (Fig. 3)
- Response of groundwater levels to barometric pressure was instantaneous

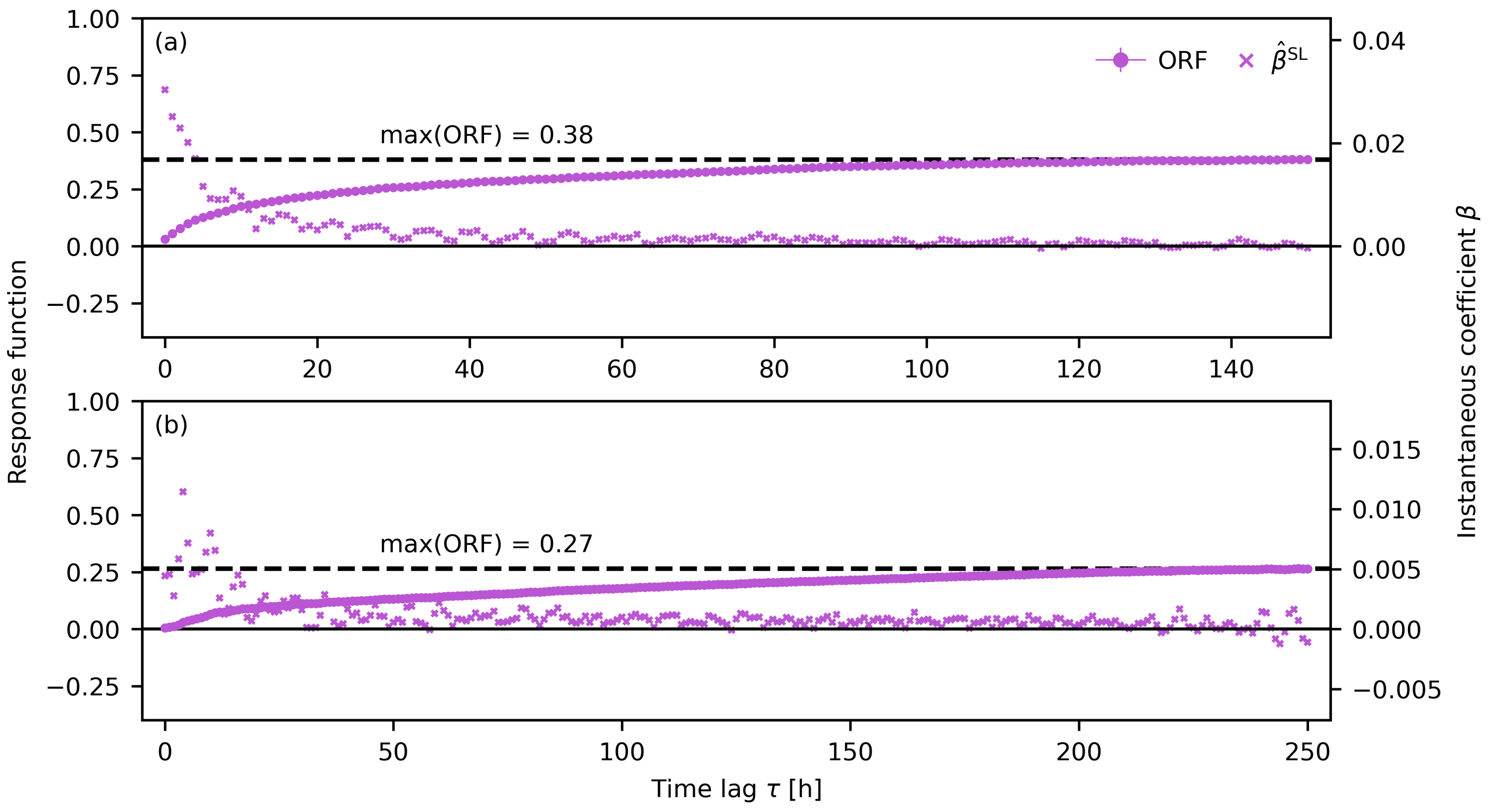

Fig. 4 Oceanic Response Function (ORF) for (a) BS3 and (b) NY-10 with corresponding instantaneous coefficients. Note the different maximum time lag for each well on the x-axis. Vertical errorbars indicate uncertainty of one standard error for the ORF.

Conclusion

Corrected groundwater levels show the previously masked response to precipitation. Similar to river-response functions [3], the required time lags for a successful regression deconvolution are generally larger than for Earth tides and barometric pressure. Can be applied to any other coastal groundwater setting around the world.

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