

The manuscript titled “Barometric Pumping as a Driver of Subsurface CO₂ Emissions: A Comparative Study of Vadose Zone vs. Ground Water Wells” aims to determine the effect of the Well type (dry or wet) on the gas exchange mechanisms for CO₂ via high-resolution experiments. The study team has conducted extended in situ monitoring at selected depths in two wells. Studies have shown that dry-well CO₂ emissions depend on barometric pumping, and wet-well CO₂ emissions are seasonally dependent on diffusion and thermally induced convection. The study shows novelty, careful experimental design, and clear presentation of results and understanding. I only have a limited number of comments. The manuscript can be accepted for publication after the authors address the following comments.

We thank the reviewer for the positive feedback and constructive comments, which we believe will help us significantly improve the manuscript. Detailed answers are provided below in blue font. The main revisions we propose in response to the three reviewers’ comments include the following:

- (1) A new quantitative analysis was added to include the contribution of diffusion.
- (2) New analyses were added with further discussion indicating why wind-induced convection and thermal-induced convection were less significant.
- (3) Eq. 1 was corrected. Units and calculations were double-checked and corrected as detailed below.
- (4) A new paragraph discussing potential sources of CO₂.

Abstract: The abstract is well written and provides a good qualitative explanation. However, a quantitative index between dry- and wet-well gas transport mechanisms is required.

Within the wet well, as detailed in the discussion section, we cannot calculate an advective component. Therefore, we propose to add the following sentence to the abstract:

“The two-cycles-per-day advective transport was quantified in the dry well with an average air velocity of 0.246 m/min (during outflow events), whereas no comparable periodic advective signal was detected in the wet well”

Methods:

Line 131: How do the authors validate the barometric pumping impacts at ~47 m depth of a 0.2m narrow pipe? Further, how does this study relate to wells of larger diameter, for example, ~2 m wide wet wells of similar depths?

The barometric pumping impact is detailed in section 2.5 (using the FFT analysis) and in the results (i.e., Fig. 6).

Regarding larger diameters, this was investigated in previous studies, including those from our group. The most detailed discussion, as far as we know, is given in Neeper (2003) and Levintal et al. (2018), in which it is stated that the air velocity due to barometric pumping is inversely correlated with the well radius (i.e., Eq. 5 in Levintal al., 2018). In any case, we note that for wet wells in which the water table is above the perforated section, barometric pumping is always suppressed. This is because the groundwater table in the wet well acted as an impermeable boundary to barometric pumping (L. 29-30).

Line 157: T and RH should be spelled out at first

Done.

Line 180: What is the basis for the assumption of “assuming advective transport, where CO₂ moves as part of bulk mass...”?

The assumption that CO₂ moves with the bulk air, so that the travel time between the two sensor nodes reflects air velocity, rests on several independent lines of evidence in our data:

- (1) O₂ mirrors CO₂. During outflow, CO₂ rises while O₂ falls simultaneously at both nodes (Fig. 2b-c). This is what displacement of one air mass by another produces. Diffusion of CO₂ alone would not cause a corresponding O₂ change on this timescale.
- (2) Diffusion is far too slow to explain the observed timing. The diffusive time scale between the two dry-well nodes is in the order of months, however we see that the observed lag between the bottom and top CO₂ responses is on the order of an hour, i.e., about 0.25 m/min.

The correlated movement of CO₂ and O₂ is presented and discussed throughout the results and discussion (e.g., section 3.1); therefore, we feel it is reasonable to leave L.180 as is.

Line 186: What is the source of ~420 ppm atmospheric concentration?

420 ppm is an arbitrary value we used for the atmospheric boundary, rather than something we measured throughout the year. In this study, we don't need a few ppm accuracy because the lower boundary in the well reaches up to 40,000 ppm, as shown in the results, which is why we think it is a reasonable choice. We clarified in the text that this value is assumed, not measured.

Line 209: Explain 30-point rolling mean

The sensors logged at 1-minute intervals, so the 30-point rolling mean is a 30-minute moving average, where each smoothed value is the mean of 30 consecutive measurements. We applied it to the CO₂ series before calculating first-order derivatives, because differentiating raw data amplifies sensor noise and produces spurious zero-crossings that would corrupt the detection of valleys and peaks. The window is short relative to the dominant semi-diurnal cycle (~12 h), so it removes high-frequency noise without meaningfully distorting the timing or amplitude of the outflow and inflow events. A centered window introduces no time shift, and because the same window is applied to the top and bottom nodes, any offset would cancel when the lag between them is calculated. We propose to add the following sentence:

“We used this window because it is short relative to the dominant semi-diurnal cycle (~12 hr as discussed below), so it removes high-frequency noise without distorting the timing or amplitude of the outflow and inflow events.”

Line 295: The graph should be improved with a legend, and the vertical axes should be given in black text

This comment will be implemented in the revised text.

Conclusions: It is clear that the higher depth of the wet well is to reach the groundwater table. However, I am wondering if ~42 m depth has a relatively low impact of the BP relative to the 22

m depth of the dry well. At the same time, if the wet well has the same shallow depth, will there be increased impact from the BP?. Therefore, how will the authors take this depth difference into account?

A wet well is defined as one in which all the perforations are below the water table (as we state in the introduction). In this case, it means that BP cannot be developed because the groundwater table is considered an impermeable boundary to BP-driven air transport (You et al., 2010) (L. 364-367).

If the water table is below the wet well's perforation (for example, after groundwater declines), then most likely BP will be developed. The magnitude of BP is depth-dependent with a dump lag effect, and therefore will most likely be lower than at a depth of 22 m. An analytical model discussing this effect is given in Neeper 2003, which is cited in our manuscript.

Further, the conclusions are well written based on the observations from the experiments. I am wondering how these understandings could be used in application. Therefore, an implications section would improve the paper.

We propose adding a “Potential implications” section to the discussion. In this section, we include the previous paragraph of the environmental aspect and add new implications:

“The contrast between dry and wet wells has practical consequences for emission accounting, monitoring, and well management. First, from an environmental perspective, the dry well exhibits higher CO₂ emissions than the wet well, primarily due to the dominance of advective transport driven by BP, compared to the more diffusion-dominated transport (with a seasonal TIC addition) in the wet well. Although the CO₂ fluxes measured in this study were relatively low (Fig. 5) and thus associated with minimal environmental impact, these findings may not be representative of all well systems. In shallow wells that are directly open to the atmosphere and strongly influenced by P_{atm} fluctuations, CO₂ emissions may be substantially higher and could contribute meaningfully to atmospheric GHG concentrations. Moreover, site-specific factors such as soil type, higher GHG concentrations in groundwater or the unsaturated zone, climatic conditions, and wellhead geometry (e.g., diameter) are likely to modulate the magnitude of gas emissions, potentially leading to greater environmental impacts in other settings.

Second, measurement design matters: in the dry well, the CO₂ profile depends on the phase of the P_{atm} cycle (Fig. 6), so short or single-time sampling can be biased by orders of magnitude, and flux campaigns should be continuous or span full pressure cycles, while wet wells require seasonal sampling because summer and winter profiles differ strongly (Fig. 7). Third, for managed aquifer recharge, our observations suggest that keeping the water table above the perforation suppresses BP, and that recharge with CO₂-poor rainwater lowers CO_{2(aq)} and well CO₂ concentrations in winter. Whether wellhead sealing or venting could regulate gas exchange, and whether recharge timing could be used to limit CO₂ release, remain hypotheses for future testing. Finally, the results indicate which processes models should include BP for dry wells, and diffusion plus a TIC term for wet wells. Well gas time series can also serve as a low-cost indicator of the unsaturated-zone response to P_{atm} and temperature, the position of the water table relative to the perforation, and the effect of recharge on CO_{2(aq)}.”