Anonymous Referee #3

Significance and major comments

- The authors evaluate new observations of gas transfer velocity calculated using the dual tracer method in the Baltic Sea and compare their findings to previously established gas transfer velocity equations for the open ocean, coastal regions, and the Baltic Sea.
- Overall, the manuscript contributes meaningfully to the large body of work investigating air-sea gas transfer velocity. The manuscript clarity needs major improvement. The introduction does not adequately set up the background and knowledge gap that this study is investigating and the methods are not described in enough detail for reproducibility. There are several instances in the results and discussion where the text does not fully state the result. A few of instances are identified in specific comments below.

- We are grateful for your comments, and have revised the paper according to your comments.

- It is mentioned that EC fluxes were measured on this cruise but they do not seem to be reported here or used for comparison to the dual tracer results.

- The EC data are presented in Dong et al. (2026b). We have added a brief comparison using mean and standard deviation values in section 3.2 as follows.

  The measured $k(600)$ by $^3He/SF_6$ tracer technique was 10.8 ± 2.9 cm h^{-1} for the whole period (Fig. 1 and Table 3). The observed $k(600)$ was similar to offshore regions at the same wind speed. During the experiment, concurrent measurements of $k(600)$ was made using closed-path eddy covariance. $k(600)$ from closed-path eddy covariance was 11.0 ± 4.4 cm h^{-1} for the corresponding period, which is similar to $^3He/SF_6$ $k(600)$. A detailed explanation and comparison between eddy covariance and $^3He/SF_6$ $k(600)$ are presented in Dong et al. (2026b).

Comments

- Table 1 – recommend adding lines to separate columns (currently there are floating + that I assume belong in the equations for column 2). It also would be helpful to add a marker in column 1 to differentiate the method used by each of the studies (for example: *Ho et al. (2006), with key at the end of the table indicating that * means dual tracer experiment).

- We added lines as you suggested. We added a column to explain how they derived the parameterizations.

- Section 1.2 the introduction would benefit from including the role of inverse wave age, surfactants, and bubbles (and the role of salinity) on gas transfer velocity. The introduction does not adequately address why the Baltic Sea is a region of interest. The first sentence of the paragraph does not connect to the rest of it.

- Thank you for the comments. We deleted the first sentence of the paragraph. We added the section 1.3 and 1.4 to introduce biogeochemistry paper using *k* values in the Baltic Sea and to explain the role of fetch, surfactants, and bubble on *k*.

  section 1.3:

  1.3 Biogeochemical studies applying *k* in the Baltic Sea

  Observational and modeling studies conducted over the last decade in the Baltic Sea to examine biogeochemical cycles, where fluxes of CO_2 and O_2 need to be quantified, have utilized a variety of wind speed/*k* parameterizations (Table 2). However, *k* derived from different parameterizations can differ by more than a factor of 2. This difference in *k* means that the choice of an appropriate parameterization could significantly impact the conclusions of these biogeochemical studies.

  The central Baltic Sea is known to be a source of CO_2 based on biogeochemical measurements such as pH and total alkalinity for 15 years and parameterized *k* (Wesslander et al., 2010). Wesslander et al. (2011) reported a faster air-sea equilibration time of CO_2 in this region compared with open ocean, based on measured biogeochemical parameters and parameterized *k*. Schneider et al. (2014) conducted shipboard measurements of pCO_2 in three years and found that this area is a weak source of CO_2 to the atmosphere, but they also pointed out the difficulties in determining it because it is a reminder of large absorption in spring and summer and large emission in autumn and winter.

  Western Baltic Sea is also known to be a source of CO_2 to the atmosphere (Wesslander et al., 2010). Kuss et al. (2006) calculated air-sea CO_2 and O_2 fluxes using measured

pCO_2 and O_2. These two fluxes showed opposite seasonality, with mean values of 8.3 and 10.8 mmol m^{-2} d^{-1} by applying a parameterization of Wanninkhof (1992).

The air-sea CO_2 exchange of the whole Baltic Sea is investigated either by interpolating measured pCO_2 (e.g., Laruelle et al., 2014) or by applying numerical models (e.g., Thomas and Schneider, 1999; Gustaffson et al., 2014; Gustaffson et al., 2015). Laruelle et al. (2014) found that most of the marginal seas, including the Baltic Sea, are weak source of CO_2. Gustaffson et al. (2014) used a physical-biogeochemical model to simulate the carbon cycle in the Baltic Sea; they calculated the mean air-sea CO_2 flux to be 0.98 ± 0.89 mmol m^{-2} d^{-1} by using Wanninkhof et al. (2009). Gustaffson et al. (2015) used the same model as Gustaffson et al. (2014), and tested the sensitivity of the air-sea CO_2 flux calculations depending on different parameterizations. They reported the changes in long-term net flux by 1.5% increase in Wanninkhof (1992) and 4.7% decrease in Liss and Merlivat (1986) compared with Wanninkhof et al. (2009). They also suggested that the effect of fetch limitation and surfactant activity might need to be considered for parameterizing *k*, which should vary in space and time.

section 1.4:

1.4 The effect of surfactants, fetch, and salinity on *k*

In addition to wind, several factors could affect *k*. The sensitivity of air-sea gas exchange to the presence of surface organic films is well documented (e.g., Asher, 2019). Concentrations of these surfactants are particularly elevated in productive coastal regions, where soluble surfactants are released by phytoplankton (Frew et al., 1990). Schmidt and Schneider (2011) used water from the Baltic Sea for laboratory experiments and found a 55%-65 % decline in *k* compared with surfactant-free water. Pereira et al. (2016) collected water from coastal stations and identified a strong correlation between the ratio of *k* for seawater to *k* for clean water and surfactant activity.

Under fetch-limited conditions, *k* is known to be suppressed due to reduced turbulence. Dobashi and Ho (2023) measured *k* in a fetch-limited seagrass ecosystem and observed lower *k* than in other regions at the same wind speeds. Bigdeli et al. (2018) developed a parameterization that accounts for wave age. It is based on the relationship that *k* is a function of turbulence kinetic energy dissipation rate, ε, to the power of 0.25 ($k \sim \varepsilon^{0.25}$) and ε is a function of inverse wave age, Ω, which is defined by u_{10}/wave speed, to the power of -3.5 ($\varepsilon \sim \Omega^{-3.5}$). They showed that their model explained measured *k* in lakes and sea ice-covered regions where the fetch is limited.

The characteristics of bubbles are crucial for controlling *k*, especially for sparingly soluble gases such as CO_2 (e.g., Bell et al., 2017; Dong et al., 2026a). If the bubble is submerged for longer in the ocean, there is more time for air inside the bubble to exchange with the water. Salinity influences bubble coalescence (Firouzi et al., 2015), thereby affecting bubble size and, therefore, how long bubbles remain submerged. Firouzi et al. (2015) showed that increasing salt concentration decreases bubble size due to reduced bubble coalescence. This implies that the reduced salinity in brackish waters, such as the Baltic Sea, could result in *k* being different from the open ocean. The objectives of this study are to determine gas transfer velocities in the central Baltic Sea, assess the applicability of published parameterizations in this region, and examine factors that drive air-sea gas exchange in this inland sea ecosystem.

- Line 75: it would be helpful to the reader to note that CTD stations are referenced based on what Year day they were collected on.

- We are consistently using yearday throughout this paper. “yearday” first appeared in Line 68, so we did not modify anything.

- In Section 2.1 the authors state that the cruise was equipped to measure k using dual tracer and EC methods but do not report EC results.

- The EC data are published in Dong et al. (2026b). We added a comparison using mean and standard deviation, and cited the paper as described above.

- Line 100: adjustment of ship observed winds using ERA-5 needs to be explained in more detail. (for example: Does the ship U10 get adjusted to match the ERA-5? Is the correction only done when the wind is blowing from specific directions? How is the time mismatch accounted for between ERA5 and 1-min ship observations? Is the amount of flow distortion known for this ship? What percentage of observed winds were from the direction of minimum distortion?)

- Yes, ship u_{10} was adjusted to match the corrected ERA5. They are corrected based on the relative wind direction.
- No, the correction factor varies between 1 and 1.42 depending on relative wind direction. We added the reference specifying the figure as follows.

  The ship-derived u_{10} was then compared with the corrected ERA5 u_{10} at the same relative wind direction (see details in Appendix A3 and Fig. A9 in Dong et al. (2026b)) and calibrated subsequently.

- The ERA5 data extracted for the reference station location and corresponding period are first compared with the reference station wind measurements. A correction relationship was derived from this comparison and then applied to the ERA5 data extracted for the CenBASE cruise locations and times, hereafter referred to as the corrected ERA5 data. The ship wind speed and direction were averaged hourly to match the corrected hourly ERA5 wind data. Then, hourly ship u_{10} and hourly corrected ERA5 u_{10} were compared to obtain correction factors for the ship wind speed (Fig. A9 in Dong et al. (2026b)). We then adjusted the 1-min ship wind based on the correction factors. Their figure A9 is pasted below.

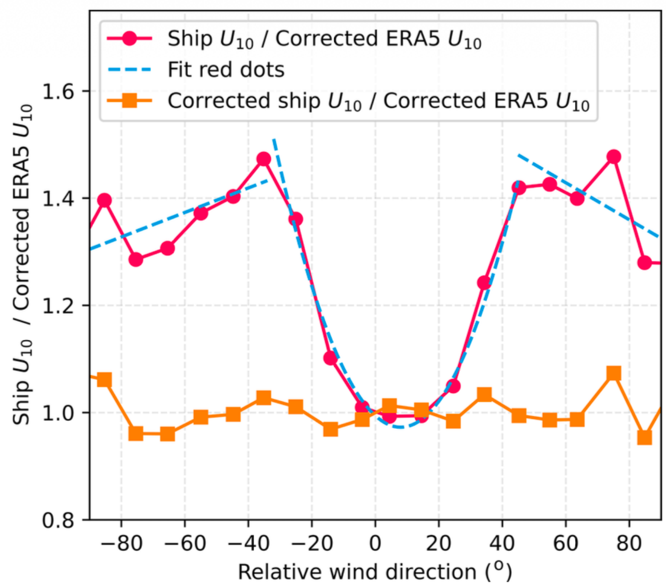

Figure A9. Ratio of ship wind speed to subsampled ERA5 wind speed before (red) and after correction (yellow) as a function of relative wind direction (RWD). ERA5 wind speeds were first calibrated against the Östergarnsholm station record (Fig. A8). The fitted relationships (blue) are: (1) $y = 0.00036(\mathrm{RWD} - 8)^2 + 0.97$ for −30 to 45°, (2) $y = 0.0023\mathrm{RWD} + 1.51$ for −90 to −30°, and (3) $y = -0.0035\mathrm{RWD} + 1.64$ for 45 to 90°.

- Yes, the amount of flow distortion was investigated by referencing the corrected ERA5, since ERA5 should not be affected by the flow distortion.
- The percentage of minimum distortion (ship u_{10}/corrected ERA5 u_{10} is between 1 and 1.1) was 15%. We added the information in the main text as follows.

  The minimum distortion percentage (correction ranging from 0% to 10%) was 15%.

- Line 105: Was flow distortion accounted for in the 3D sonic anemometer winds? What metrics were used to compare the measured vs calculated u* (please report the results in the main text).

- Yes, the flow distortion was taken into account for the 3D sonic anemometer as well. We added the sentence as follows.

  The effect of flow distortion was corrected as described above.

- Thank you for pointing it out. The measured u_* and calculated u_* at the corresponding time were compared to see if they were consistent. Since the information about the offset value was missing, we added it in Section 2.3. The measured u_* was ~10% higher compared with the calculated u_*.

  Since the calculated u_* was found to be generally consistent with the measured values (measured u_* was higher than calculated u_* with the mean offset=~10%), and the measured u_* data were not continuous, the calculated u_* was used.

- Line 119 seems out of place. This section described physical parameters that were measured in the field campaign and this sentence is a log of cruise activity- It might fit better in Line 60. It is not clear that ERA5 winds are used after YD 193 because the ship was out of the study site.

- We need the wind speed at which ^3He and SF_6 are present to investigate the relationship between wind speed and *k*. That is why we used ERA5 wind data after YD193 when the ship was out of the tracers (the ship wind was unavailable during this period). We modified the sentence as follows.

  Since air-sea gas exchanges of injected ^3He and SF_6 are affected by wind where these tracers exist, the corrected ERA5 wind speed data near these tracers were used after YD 193.

- Line 160 are the environmental conditions observed during the observational campaign representative of the mean conditions?

- We added section 4.1 to compare environmental condition with previous measurements as follows. We moved explanations about fetch length and surfactants from section 4.4 to section 4.1. We also moved explanations about salinity and bubble from section 4.3 to section 4.1.

  Wind speed in this region varies between approximately 1 and 13 m s^{-1} over a similar period (Fig. 4 in Gutiérrez-Loza et al., 2022), so the wind speed during our experiment falls within this range. Salinity was also within a typical range, considering that salinity near the Gotland Sea has a range of about 6 and 7.5 (Fig. 3 in Wesslander et al., 2010). The air-water temperature difference (water minus air) is negative on average for the corresponding season (Fig. 4 in Gutiérrez-Loza et al., 2022), so the atmospheric conditions during this study were more unstable than the mean conditions.

  The distance from the land to the observation site ranged from approximately 70 to 340 km, implying that the fetch was limited relative to the open ocean and that *k* may have been reduced. Surfactant activity during CenBASE was higher than typical open ocean (up to 0.25 mg-eq L^{-1}; Fig. 5 in Mustaffa et al., 2020), potentially suppressing *k*. The depth is as deep as ~200 m, so the effect of the bottom-generated turbulence should be neglected. Salinity was constantly 7.3 throughout the measurement period. At this salinity, the number of bubble coalescence events is expected to be much higher than in the open ocean, where salinity is about 35 (Firouzi et al., 2015). The consequence is that in fresher water, bubbles will coalesce and rapidly rise to the surface, reducing both their contact time with the water and their surface area. This suggests that salinity during our observation period may have suppressed bubble-mediated gas exchange relative to the open ocean, even if the same number of bubbles were created by breaking waves. The bubble camera deployed at a wind speed of ~6 m s^{-1} did not detect bubbles, and whitecaps were not observed even at high wind speeds. This suggests the number of bubbles was small and that air-sea gas exchange via bubbles was not significant. Limited fetch may also have inhibited wave development, leading to a less developed wave field than in the open ocean and resulting in reduced breaking waves and bubble production. Indeed, Dong et al. (2026b) concluded that bubble-mediated air-sea gas exchange was not significant (~20% of total gas exchange) based on their analysis of closed-path eddy covariance data during CenBASE.

- Line 169 the measured k(660) is the same as observed k(660) – recommend using consistent terminology to avoid confusion.

- OK. We changed the sentence as follows.

  The observed *k*(600) was similar to offshore regions at the same wind speed.

- Line 179 I think it should be acknowledged that two of the Baltic Sea parameterizations were derived using EC methods, since you talk about these separately. Based on this analysis, it seems to me that EC methods consistently produce higher estimates of gas transfer compared to dual tracer methods.

- We added a column in Table 1 to introduce how each parameterization was derived. In the main text, we specified that the two parameterizations were from a "closed-path" eddy covariance technique.

- Line 186 can you expand on the analysis of the ratio of observed k(660) compared to Ho et al. (2006). How do the authors interpret the value of 0.65?

- The value of 0.65 is small compared with 1, but we see no obvious trend in Fig. 6 between *Ω* values of 0.6 and 1.8. We think that the relatively limited wind fetch, enhanced surfactants, and suppressed bubble-mediated gas exchange due to lower salinity might be reasons, as discussed in Section 4.3. We added the range of the ratio as follows.

  Between *Ω* of 0.6 and 1.8, the mean ratio was 0.9±0.2 (range=0.4–1.4, n=15), which is close to 1. The ~10% reduction might be explained by enhanced surfactants, relatively limited fetch, and suppressed bubble-mediated gas exchange compared with the open ocean.

- Line 215 this section made me wonder if the differences of u10 from observations compared to ERA5 reported in the methods section could partially contribute to the discrepancy between the dual tracer results and EC results.

- We do not think so. We have explained more clearly how we corrected the wind speed dataset in response to your comments above.
- Both the $^{3}He/SF_6$ data shown in this paper and eddy covariance data shown in Dong et al. (2026) and are interpreted using the same u_{10} with the same corrections, and their relationships between u_{10} and $k(600)$ were similar.

- The observations from this field campaign were collected in a seemingly narrow range of inverse wave age compared to the other Baltic GasEx observations. The authors do not acknowledge whether this is expected for the time of year of the field campaign or if it is the result of a distinctly different part of the Baltic Sea compared to the GasEx region.

- We think this is because CenBASE is unrestricted in all directions, while Baltic GasEx is close to land, where the fetch is very short in some directions. We added the following sentence in section 4.3.

  The inverse wave age varied widely in the nearshore Baltic compared with the central Baltic (Fig. 5), likely because the nearshore region has a greater variety of fetch lengths depending on wind direction than the central Baltic.

- Reference list missing Wanninkhof (2004)

- Thank you for pointing it out. We added it.

- Table 3 are there row labels missing?

- We do not think so.