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Interactive comment on "Air-sea gas exchange at hurricane wind speeds" *by* Kerstin E. Krall and Bernd Jähne

Byron Blomquist (Referee)

byron.blomquist@colorado.edu

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This study presents results from an extensive series of air-water gas transfer experiments in laboratory wind-wave tanks with fresh water and seawater, utilizing several gases covering a wide solubility range. The focus is on high wind speed conditions. The principle merit of gas transfer studies in a wind-wave tank is the ability to precisely determine gas flux by measuring the loss of dissolved gas in the liquid phase over time. The use of gases with widely differing solubility is another strength of this study, permitting an assessment of the interfacial and bubble-mediated gas transfer mechanisms.

The manuscript is very well written and generally clear. Some points requiring more explanation will be mentioned below. There are very few problems with usage, spelling or punctuation so I will confine these remarks to the experimental results and analysis.

The experimental set up and methodology are clearly described. However, I would like to see a bit more detail on the assumptions involved in deriving an open ocean-equivalent 10m wind speed and u* from wind speed measurements in the wind tunnel (p.12). This is important for judging the comparison to field measurements.

I don't fully understand how the parameters defined on p.16 (ks600, kc600 and kr) were obtained from the measurements. Was kc600 determined using only data for SF6 and CF4 (and only SF6 in seawater), as mentioned on p.18 and are these results shown in Fig.7b? Were these then applied as fixed values in a two-parameter fit to data for all gases to obtain ks600 and kr in Fig. 7a,c?

There's potential confusion with the notation for kc600, defined on P.16 as a constant (maximum) value for bubble transfer at a given u*, because kc is also the second term in Eq.10 which could be measured under conditions where Sc=600, but would not be the same as kc600 defined on p.16 since it depends on gas solubility. I suggest using a different notation for the fit parameter representing the maximum limiting value of kc. Perhaps results for kc can also be shown on a plot similar to Fig.2, where the 'kc600' parameter is indicated as the value of kc at the low solubility limit, where the curve is flat?

I'm surprised the authors do not present a detailed comparison with results from Rhee et al. 2007, which is a similar wind-wave tank gas transfer study and should be more directly comparable to this work than the field studies.

The absence of detectable bubble transfer below u*w=5.8 m/s for all gases is certainly unexpected, and to me a sign that something is very wrong here. For example, from the information presented in Fig.2 (Mischler, 2014) we expect kc for CO2 (alpha=0.78 @ 20°C) and kc for DMS (alpha=12 @ 20°C) to differ by more than a factor of 10. The absence of any difference in transfer rate at moderately high wind speeds among gases covering a broad solubility range is an indication that something is wrong in the determination of kc, or that the experimental design is unable to simulate mechanisms of gas transfer at these wind speeds at sea. This result is certainly contradicted by field evidence from several studies showing a generally linear increase in k for DMS at wind speeds of 10-20 m/s and a roughly quadratic increase for a less soluble gas like CO2 over the same interval.

I don't see obvious errors in the theoretical model developed by the authors, which is generally similar to prior treatments in the literature. I suspect the unique conditions in the wind-wave tank at high wind speeds are not comparable to the open ocean. Even an 'infinite fetch' design cannot simulate the wave spectrum in open ocean conditions, except perhaps under light winds, and thus cannot simulate large breaking wave crests and deep bubble plume penetration. I therefore wonder if the absence of bubble-mediated transfer at moderate wind speeds and the observed abrupt jump in the slope of gas transfer at wind speeds above 30 m/s are merely characteristics inherent to the wind-wave tank experimental design?

I assume high wind interfacial conditions in the tank to correspond to a 'young' sea state, with very high surface stress and widespread coverage with small, choppy breaking waves. This condition is not common at sea except in a situation of very short fetch or a very rapid increase in wind speed, and in any case does not persist long before large breaking waves develop. It's therefore difficult to understand how these results apply to typical 'hurricane wind speed' conditions at sea. The authors should present a detailed analysis of these differences to provide some context for comparisons with field studies.

DMS is the high-solubility gas in this study (MA was omitted) and should represent interfacial transfer with minimal bubble-mediated contribution. The comparison to data from field studies in Fig.9 looks fairly good to me, despite the fact that there is little or no overlap in the wind speeds. Thus results for the first term in Eq.10, ks, seem roughly consistent with open ocean observations. Instances of suppressed DMS transfer noted

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Discussion paper

in a few field studies are the exception and suggest we don't yet understand all the factors controlling gas transfer. The effects of surfactants are an obvious factor that probably suppresses gas transfer, with some support from lab studies, but this has not been carefully examined under field conditions except at low wind speeds. Zavarsky et al. 2018 discuss the possible suppression of transfer by flow separation and angular differences in wind and wave direction.

With respect to the comparison with results in B2017 (Fig.10 and p.23), I can make a few clarifications. The B2017 cruise focused on high wind conditions with relatively few flux measurements at U10< 8 m/s, and these are generally under non-ideal conditions when the ship was moving at maximum cruise speed to reposition between storm events. So, we expect additional uncertainty or bias in the low wind speed results. Trends shown by the bin averages in Fig.10 are therefore misleading, and in any case the error bars for kdms and kco2 overlap at low wind speeds, so it's not meaningful to say results for the two gases differ by a factor of 3 at U10=3.4 m/s.

Nevertheless, at moderate wind speeds of 10-16 m/s sampled under ideal conditions, kco2 from B2017 shows quite a bit of scatter and a high bias compared to other studies, with lower transfer rates observed in 'young' sea states and enhanced transfer in fully developed conditions or in 'old' seas when wind speed is declining but waves are still quite large. These effects are less pronounced for DMS. See Fig.6 in B2017. This implies sea state is a significant factor in the transfer of low solubility gases, and these subtleties are obscured by bin averaging. The comparison between kdms and kco2 likely depends on the specific sea state conditions, and the bubble transfer contribution to low solubility gases in a very 'young' sea state may be significantly reduced, which could be consistent with the kc result in this report.

I think this is a carefully conducted study and well written report which explores the mechanisms of gas transfer in a wind-wave tank, but I struggle to understand the significance of these results with respect to conditions in the open ocean, especially at 'hurricane wind speeds'. I don't agree with the conclusion in Sec.4.6 that rough correspondence between the wave-tank and open ocean data in Fig.11 shows the lab results are capturing the essential mechanisms, since the mechanistic details in each case could be significantly different (the physical details certainly are) and the rough agreement coincidental. As someone with a keen interest in this topic but limited experience with of wind-wave tank experiments I'd like to see a more thorough examination of these issues.

Rhee, T. S., P. D. Nightingale, D. K. Woolf, G. Caulliez, P. Bowyer, and M. O. Andreae (2007), Influence of energetic wind and waves on gas transfer in a large wind–wave tunnel facility, J. Geophys. Res., 112, C05027, doi:10.1029/2005JC003358.

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