Ocean Science Discussions

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Comment on os-2021-104

Anonymous Referee #1

Referee comment on "Ocean bubbles under high wind conditions – Part 2: Bubble size distributions and implications for models of bubble dynamics" by Helen Czerski et al., Ocean Sci. Discuss., https://doi.org/10.5194/os-2021-104-RC1, 2021

Ocean bubbles under high wind conditions. Part 2: Bubble size distributions and implications for models of bubble dynamics.

The paper presents results from the field campaign highwings reporting on the bubble measurements in the first 10meters below the sea surface using optical and acoustic techniques. The paper is important for the community as very few of such measurements exist. I have a set of recommendations or suggestions for the authors to improve the manuscript.

In particular, I strongly recommend to use the published data from highwings on gas transfer, waves and whitecap coverage and see the correlation with the bubble plume. The data are available online and have been used by various authors . The bubble plume measurements are by construction fragmentary since the full entrainment process is not captured but it is certainly a very valuable/important information. Combining this information together with the gas transfer velocity, the whitecap coverage and comparing with recent models and parameterization would shed light on the transport process of the bubbles and how the present data can be used to better constrain these models.

In the introduction, you state "If normalised by void fraction, these distributions collapse to a very narrow range, implying that the bubble population is relatively stable and the void fraction is determined by bubbles spreading out in space rather than changing their size over time." Back of the envelope calculations of bubble mediated gas exchange can tell you that the transfer of CO_2, O_2 is relatively slow compared to your observation time of the bubbles, so that bubbles will not change size significantly in the first few meters even if they are exchanging gas (very true for CO_2 which does not account for much of the volume). Bubbles will only change size if they are brought deeper in the flow by some turbulence process (Langmuir turbulence, etc). This is discussed in the earlier papers from Keeling 1993, Woolf and Thorpe and is implicit in Liang et al 2011, 2012 or Woolf' modeling. I would recommend looking at recent modeling work on that topic:

Leighton TG, Coles DG, Srokosz M, White PR, Woolf DK. 2018. Asymmetric transfer of CO2 across a broken sea surface. *Sci. Rep.* 8:8301

Liang J-H, McWilliams JC, Sullivan PP, Baschek B. 2011. Modeling bubbles and dissolved gases in the ocean. *J. Geophys. Res.* 116:C03015
Liang J-H, McWilliams JC, Sullivan PP, Baschek B. 2012. Large eddy simulation of the bubbly ocean: new insights on subsurface bubble distribution and bubble-mediated gas transfer. *J. Geophys. Res.* 117:C04002.

Towards the end of the intro, you state: "We suggest that as bubbles move to depths greater than 2 m, sudden collapse may be more significant as a bubble destruction mechanism than slow dissolution, especially in regions of high void fraction." Yes, this is discussed by modeling studies from Liang et al and Woolf et al. The Langmuir type entrainment process is necessary to bring small bubbles down where they can collapse due to hydrostatic pressure. However, the life of the larger bubbles in the top two meter is important for co2 transfer, they exchange gas during their lifetime without changing the bubble size, since the content of CO2 is small compared to the overall volume of the bubble. This is discussed or implied in the models by Keeling 1993 and then Deike and Melville 2018

I would recommend citing Bowyer PA. 2001. Video measurements of near-surface bubble spectra. *J. Geophys. Res. Oceans* 106(C7):14179– 90; which present of the few direct optical measurement of bubbles below the ocean surface.

I do not understand the statement: "Our results suggest that local gas supersaturation around the bubble plume may have a strong influence on bubble lifetime, but significantly, the deep plumes themselves cannot be responsible for this supersaturation"

The authors present data on bubble void fraction, distribution, etc. During the same campaign, the gas transfer velocity (or piston velocity) for CO2 and DMS has been measured and is reported in Brumer et al 2017 (GRL) (which is not cited), as well as whitecap coverage data. Could the authors present cross comparison of these quantities? Similarly, Deike et al 2017, and then Deike and Melville 2018 presented scaling for air entrainment by breaking wave and some of that has been used to predict gas exchange. While your data do not get the full air entrainment because you are missing the large bubbles close to the surface it would be interesting to see whether the proposed scaling in the literature in terms of dependency with wind and wave can work or not. Similarly, Brumer et al 2017 proposed a wave Reynolds number scaling for gas transfer and it would be interesting to see if your bubble data follow such scaling. Finally seeing the correlation between whitecap coverage data from Brumer et al 2017 and your bubble data would provide information on how much of the bubbles are being transported down to the depth where you are making the measurements. This could be very useful for future modeling on the role of small bubbles getting fully dissolved in the water column, which will contribute to exchange of less soluble gases such as O2, N2.

Brumer S, Zappa C, Blomquist B, Fairall C, Cifuentes-Lorenzen A, et al. 2017a. Wave-related Reynolds num- ber parameterizations of CO2 and DMS transfer velocities. *Geophys. Res. Lett.* 44(19):9865–75

Brumer SE, Zappa CJ, Brooks IM, Tamura H, Brown SM, et al. 2017b. Whitecap coverage dependence on wind and wave statistics as observed during SO GasEx and HiWinGS. *J. Phys. Oceanogr.* 47(9):2211–35

Deike L, Lenain L, Melville WK. 2017. Air entrainment by breaking waves. *Geophys. Res. Lett.* 44(8):3779– 87

Deike L, Melville WK. 2018. Gas transfer by breaking waves. *Geophys. Res. Lett.* 45(19):10–482

About figure 2: the shapes at 2m seem compatible with the modeling work from Liang et al; which starts from a Deane and Stokes like distribution - similar to other recent bubble gas transfer formulation. While a quantitative comparison is probably out of scope, this should be mentioned. It seems that the present measurements are compatible with the current assumptions from bubble models.

Similarly and about all figures on bubble size distributions. Can you plot your integrated volume from these distribution as a function of wind speed? void fraction? wave age? wave height? Whitecap coverage? Gas transfer velocity? This could be useful to compare with existing models from air entrainment based on breaking dynamics (assuming the air lost between entrainment and 2m down scale in a similar way which is not obvious at all). This would provide very useful information/constraints for modeling.