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New parameterizations of air-sea CO_2 gas transfer velocity on wave breaking

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Ocean surface waves and wave breaking play a pivotal role in air-sea Carbon Dioxide (CO_2) gas exchange by producing abundant turbulence and bubbles. Contemporary gas transfer models are generally implemented with wind speed, rather than wave parameters, to quantify CO_2 transfer velocity (K_{CO2}). In our work, the direct relationship of K_{CO2} and waves is explored through the combination of laboratory experiment, field observational data and estimation of global ocean uptake of CO_2.

In laboratory, the waves and CO_2 transfer at water surface are forced for simultaneous measurements in a wind-wave flume. Three types of waves are exercised: mechanically generated monochromatic waves, pure wind waves with 10-meter wind speed ranging from 4.5 m/s to 15.5 m/s, and the coupling of monochromatic waves with superimposed wind force. The results show that K_{CO2} is well correlated with wave height and orbital velocity. In the connection of K_{CO2} with breakers, wave breaking probability (b_T) should also be considered. The wind speed is competent too in describing K_{CO2} but may be inadequate for varied wave ages. A non-dimensional formula (hereafter the RHM model) is proposed in which gas transfer velocity is expressed as a main function of wave Reynolds number ($R_{HM} = U_w H_s / \nu_w$, where U_w is wave orbital velocity, H_s is significant wave height, ν_w is viscosity of water) while wind is accounted as an enhancement factor ($1+\hat{U}$, where $\hat{U}$ is non-dimensional wind speed denoting the reverse of wave age). For wave breaking dominated gas exchange, second formula (hereafter the BT model) is developed by replacing components of R_{HM} with breaker's statistics and integrates an additional factor of $b_{T.}$

Utilizing campaign observations from open ocean, the RHM model can effectively reconcile the laboratory and field data sets. The BT model related with wave breaking, on the other hand, is adapted by including a complementary term of bubble-mediated gas transfer in which the bubble injection rate is parameterized with R_{HM}. The updated BT model also performs well for the data. The conventional wind-based models show similar features as in laboratory experiments: the wind speed successfully captures the variation of gas transfer for respective observation yet is insufficient to neutralize the gaps among data sets.

Our wave-based gas transfer models are applied for the estimation of net annual CO_2 fluxes of global ocean in the period of year 1985-2017. The results are in high agreement with previous studies. The wind-based gas transfer models might underestimate the CO_2 fluxes although the estimations still distribute within the range of uncertainty. Moreover, the models using wave

parameters are found advantageous over the wind-based models in reducing the uncertainties of gas fluxes.