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Biogeosciences Discussions

Interactive comment on "Gas exchange estimates in the Peruvian upwelling regime biased by multi-day near-surface stratification" *by* Tim Fischer et al.

Tim Fischer et al.

tfischer@geomar.de

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1 General Comments

Referee Comment:

The article by Fischer et al. is concerned with the impact of stratification on the air-sea gas exchange of N2O, which leads to gradients of disolved nitrous oxide which diminish as the surface is approached. This type of study has been carried out for CO2, but this is the first time that such a study has been conducted for N2O in an upwelling region, which are recognised as hotspots for N2O emission. It is important to better constrain

the air-sea exchange of N2O as it is thought that the ocean is a strong source of N2O. The authors provide reasonable and justifiable arguments for the effect of stratification on N2O gas exchange, and with some further effort the article could be published.

Answer:

Thank you very much for reviewing the manuscript and giving valuable advice. We now clarify the relation between existing research on CO2 exchange bias and our study, by complementing the Introduction after introducing the surface trapping (P4L2). In that context we also added a study by Miller et al. (2019), who conducted research in a similar way to our study, only for the Arctic ocean and CO2. Their paper was published after submission of our manuscript. The Introduction now reads from P4L3: 'For dissolved gases, vertical gradients in the top meters due to surface trapping had been predicted (McNeil and Merlivat, 1996), and later were indeed observed for oxygen and carbon dioxide (Soloviev et al., 2002; Calleja et al., 2013; Miller et al., 2019). Vertical concentration gradients due to surface trapping cause an additional bias in gas exchange estimates, independent of issues with solubility estimates which are caused by temperature gradients and which have particularly been studied to quantify CO2 exchange bias (e.g., Ward et al., 2004; Woolf et al, 2016). Concerning the surface trapping, the studies of Soloviev et al. (2002) and Calleja et al. (2013) showed that vertical concentration differences in oxygen and carbon dioxide exist across the top meters of several open ocean regions, however with little average effect on gas exchange estimates. Miller et al. (2019) found CO2 concentration gradients across the top meters of the Arctic ocean, and diagnosed substantial errors in CO2 exchange estimates if sampling below the surface layer. This may be rather a case of a very shallow seasonal mixed layer than a case of temporal surface trapping, but still underlines the practical importance of near-surface stratification and the DeltaC sampling issue. In coastal upwelling regions, there have been no reports on near-surface gas gradients so far. However, the conditions here for near-surface stratification and gradients should be more favorable than in the oligotrophic open ocean, ...'

2 Specific Comments

Referee Comment: P3L28: Add references to Sutherland et al. 2014 and Sutherland et al. 2016

Answer: Thank you for bringing these references to our attention. We add now references at the indicated place, now reading: 'Observations mainly from the open ocean revealed a diurnal cycle of near-surface temperature which is associated with the build-up of shallow stratification during daytime and its destruction during nighttime. This picture has become more and more detailed, as timeseries of high-resolution profiles in the undisturbed surface ocean have become available, from buoys (Prytherch et al., 2013; Wenegrat et al., 2015) and a free-rising profiler (Sutherland et al., 2014, 2016).' Sutherland et al. (2016) is now also added to P3L32 as a study with extensive observations.

Referee Comment: For figure 4, can you add a mean diurnal cycle of temperature. I would like to see the extent of the thermal stratification.

Answer: The observations of temperature at the thermosalinograph inlet during the cruise in December 2012 show a distinct diurnal cycle with an amplitude of 0.6 Kelvin at 3m depth. Unfortunately, there is no additional continuous record of temperature at other depths, which could have provided a more complete picture of the near-surface T profile in its dependence on external factors. We add a new panel to Fig.4 showing the mean diurnal T cycle at 3m depth.

Referee Comment: section 2.2.5: can you add a histogram of the wind speed data used

Answer: We add a histogram of rms averaged wind speed at N2O stations (averaged during 6h and in a radius of 5nm max.) as a new figure. The figure is now referred to in the text at P8L11, to illustrate that the encountered wind speed was in the low to medium range.

Referee Comment: section 2.2.7: I did not fully understand your model. Can you please elucidate with a schematic? I also did not understand why the model was constrained by the glider data only.

Answer: We add a schematic as a new figure, which incorporates on the one hand the terms we used in the text, and on the other hand the variables and flux equations we used for the model runs.

Fig.: The one-dimensional gas-transfer model to simulate the surface trapping mechanism. The interface of complete mixing inhibition shifts up and down according to the high-resolution timeseries of observed TLD without instantaneously affecting local N2O concentration. Vertical N2O transport is achieved by mixing within the two layers after the shifting interface has left a portion of clower-water in the top layer, or vice versa.

The model needs a high-resolution timeseries of undisturbed near-surface density profiles, in order to constrain it with a meaningful observational TLD-timeseries. Particularly the early morning hours are important, as destruction of the near-surface stratification can happen on short timescales having considerable effect on the N2O distribution. The glider data set we use is unique in that it consists of four timeseries of several weeks duration, showing undisturbed near-surface density profiles with multi-day stratification occurring. We are not aware of other suitable data sets in the Peruvian upwelling regime that would provide adequate TLD timeseries to use such a model to study the effects of multi-day near-surface stratification. We will augment the text of subsection 2.2.7, explaining the close interrelationship between the glider based TLD-timeseries and the 1-D model for studying the effects of multi-day near-surface stratification.

3 Technical Corrections

Referee Comment: P5 L2: define OMZ

Answer: The abbreviation 'OMZ' is now introduced in the Introduction P2L21 where the oxygen minimum zone of the tropical South Pacific is first mentioned explicitly.

Referee Comment: P5 L5: and will be called 'oxygen interface' in the following − > henceforth referred to as 'oxygen interface'

Answer: Changed to suggested wording

Referee Comment: P5 L6: express 0.5 nm in meters

Answer: Changed to 'at least 1km' instead of 'at least 0.5 nm'

Referee Comment: P5L7: ship-caused − > ship-induced

Answer: Changed to suggested wording

Referee Comment: P7L27: Fig 4 comes before fig 2

Answer: We removed the reference to Fig. 4 at this place, and rearranged the text to get the point clarified without a figure reference. It now reads from P7L25: 'However, horizontal temperature variability on short scales, vertical movements of the water column, and sensor noise add to temperature variance. The salinity required to convert the temperature gradient into stratification is taken from the thermosalinograph record, using the average salinity during the respective time bin, i.e. assuming a vertical salinity gradient of zero. After having calculated N2 at 3m depth for the entire cruise, we find an apparent lower limit of N2 > 10-5 s-2, which is probably caused by the temperature variance which is not due to the vertical temperature gradient.'

Referee Comment: P9L1: It is to be investigated − > Here we investigate

Answer: Changed to suggested wording

Referee Comment: P10L18: you cannot start a sentence with I.e.

Answer: Changed to 'So' instead of 'I.e.'.

4 References

Sutherland, G., L. Marié, G. Reverdin, K. J. Christensen, G. Bröstrom, and B. Ward, 2016. Enhanced turbulence associated with the diurnal jet in the ocean surface boundary layer. J. Phys. Oceanogr., 46:3051–3067.

Sutherland, G., G. Reverdin, L. Marié, and B. Ward, 2014. Mixed and mixing layer depths in the ocean surface boundary layer under conditions of diurnal stratification. Geophys. Res. Lett., 41:8469-8476

Added:

Miller L.A., Burgers, T.M., Burt, W.J., Granskog, M.A., and Papakyriakou, T.N. (2019): Air-sea CO2 flux estimates in stratified Arctic coastal waters: How wrong can we be?, Geophysical Research Letters, 46, doi:https://doi.org/10.1029/2018GL080099.

Ward, B., Wanninkhof, R., McGillis, W.R., Jessup, A.T., DeGrandpre, M.D., Hare, J.E., and Edson, J.B. (2004): Biases in the air-sea flux of CO2 resulting from ocean surface temperature gradients, Journal of Geophysical Research, 109, C08S08, doi:10.1029/2003JC001800.

Woolf, D.K., Land, P.E., Shutler, J.D., Goddijn-Murphy, L.M., and Donlon, C.J. (2016): On the calculation of air-sea fluxes of CO2 in the presence of temperature and salinity gradients, Journal of Geophysical Research Oceans, 121, 1229-1248, doi: 10.1002/2015JC011427.

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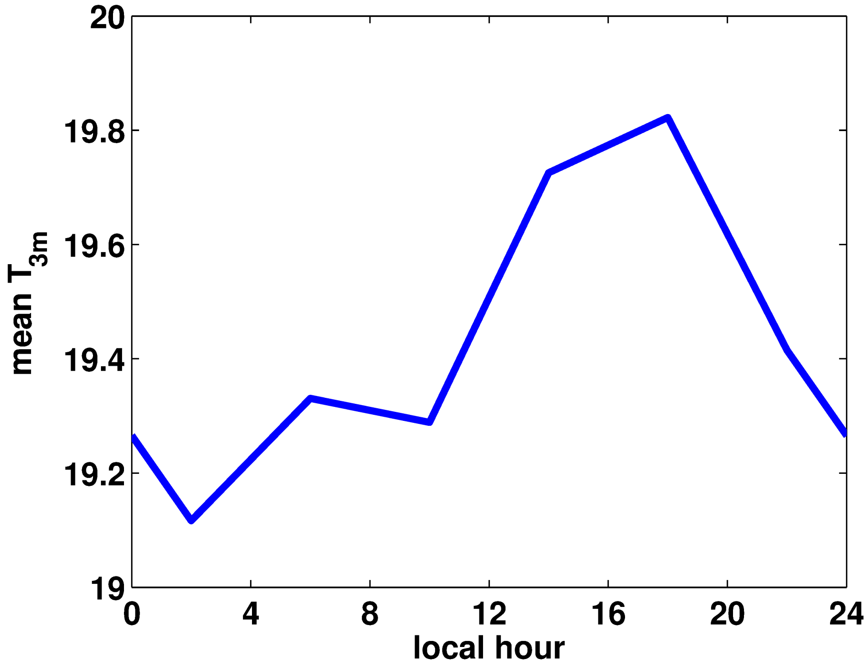

Fig. 1. Panel complementing Fig.4: Mean diurnal cycle of temperature at 3m depth

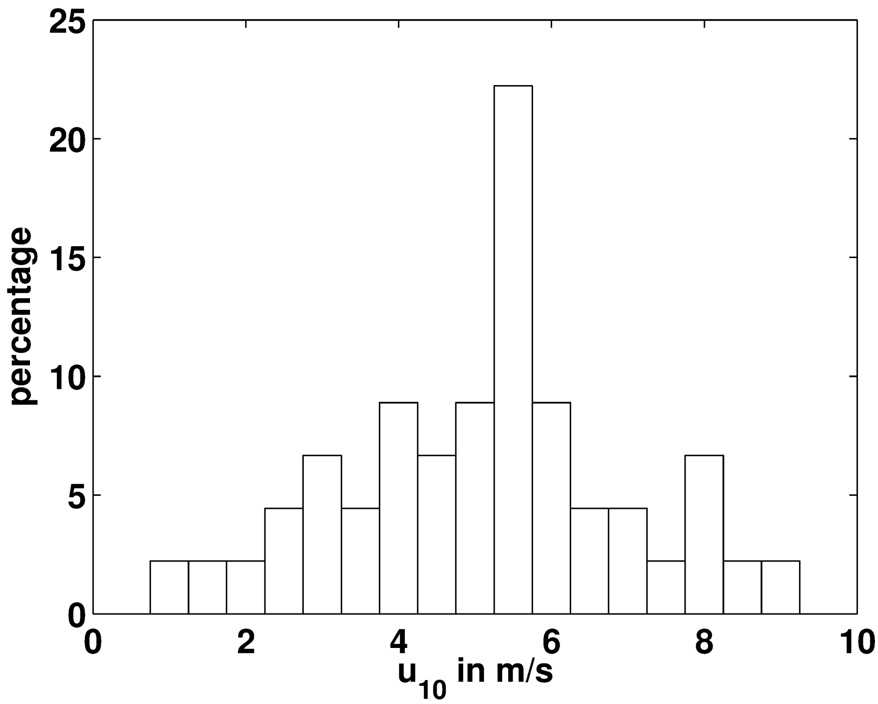

Fig. 2. Histogram of wind speed at the N2O stations

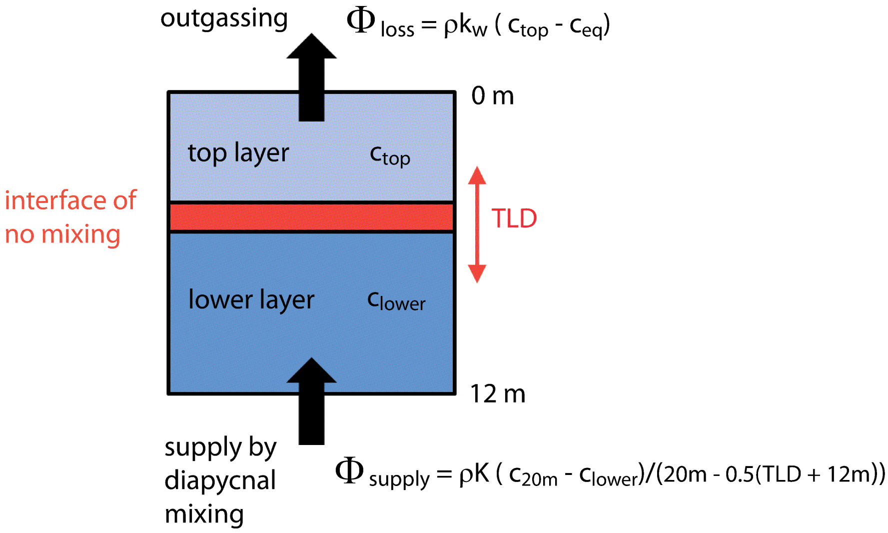

Fig. 3. The one-dimensional gas-transfer model to simulate the surface trapping mechanism.