Biogeosciences Discuss., 8, C6127–C6131, 2012
www.biogeosciences-discuss.net/8/C6127/2012/

Biogeosciences Discussions

Interactive comment on "Oxygen exchange and ice melt measured at the ice-water interface by eddy correlation" *by* M. H. Long et al.

M. H. Long et al.

mhl4a@virginia.edu

Received and published: 16 March 2012

Our response to the short comment by K. Attard and D. McGinnis: The commenter's remarks are in *italics* and our responses are in normal font.

We would like to applaud the authors for an interesting paper describing a novel application of the aquatic eddy correlation technique. Having read the Discussion Paper we are left with a few questions/recommendations that we are hoping the authors would kindly address. These are the following:

1. On page 11263 (lines 4-8) the authors infer 'well-mixed conditions' under the ice from a -5/3 fit to the inertial subrange of the spectra for Vz. We would like to point out that whilst the -5/3 fit does suggest well-developed turbulence, it is not necessarily indicative

of well-mixed conditions below the ice. Brand et al. (2008) found, for example, that even though turbulence was within the inertial subrange at low current velocities, this was not sufficient to transport O2 through the stratified top of the BBL. Being such a crucial assumption, we feel that this statement should be at the least complemented by a hypothetical model of mixing height vs current velocity as in Brand et al. 2008, Fig. 8.

We have removed the statement on the -5/3 slope being indicative of well-mixed conditions, and now only state that the -5/3 slope is indicative of well-developed turbulence. We believe that the vertical transport of O2 is inherent in our data because we only use periods where the cumulative flux consistently exhibits clear linear trends as shown in Fig. 4. We maintain that such cumulative fluxes, when seen consistently across numerous 0.25 h measuring periods, are good proxies for ice-water exchange. This is an underlying assumption in eddy correlation flux extractions as discussed in detail by Hume et al. 2011. In that light, we do not see a need for a hypothetical stability calculation as presented in Brand et al. (2008).

2. The footprint calculation (page 11264, line 27 onwards) as demonstrated by Berg et al. (2007) assumes law-of-the-wall (LOW). We feel that this assumption deserves some more attention in order to be justified, since this paper deals with a system that exhibits both low flow velocities as well as stratification. For example, Lorke et al (2003; Fig. 3) show that LOW does not always hold true during periods of low current velocity. Assuming LOW during periods where LOW is not valid may compromise the values obtained for u, zo, dissipation and subsequently the footprint calculation. As a rough estimate, the timescale of establishing a well-mixed boundary layer can be estimated as* $t = L^2/(2Kz)$ *where L is the thickness of the boundary layer and Kz is the vertical diffusivity. The authors could also double-check that the LOW assumption by calculating the dissipation using the inertial dissipation method and then comparing the dissipation values obtained using both methods.*

The text has been clarified by stating that the footprint size is only a first order calculation and we furthermore emphasize that it only serves as an illustration of the large area that is integrated in eddy correlation measurements. Please also note that we do not use the footprint in any calculations of O2 exchange or its controls. For these reasons we feel that this secondary analysis using the inertial dissipation method would be beyond the scope of this manuscript. Furthermore, the inertial dissipation method relies on many assumptions which may also lead to a bias in the estimation of dissipation (e.g. Bluteau et al., 2011). Please also see our comment to referee F. Meysman on the very stable conditions that prevailed during the time period for which we estimated the footprint.

The commenter's advice to estimate the timescale for establishing a well-mixed boundary layer gives a scale of 0.34 h based on values of L of 44 cm and Kz of 0.80 cm2 s-1, where the prior is taken to be 2 times the measuring height and the latter arises from the our footprint calculation. This small timescale of 0.34 h should be seen on the basis of our 20 consecutive 0.25 h measuring periods, equivalent to 5 h of data, and also the several hour long period of relatively stable flow conditions prior to when the actual footprint calculation was initiated.

3. Looking at Figure 3, it is apparent to us that there is a mis-match between the periods defined as the inertial subrange of Vz and O2 and the turbulent transport of O2 as indicated by the cumulative cospectra. The inertial subrange for Vz (Fig. 3A) is defined for frequencies between around 0.06Hz to 0.7Hz. For O2 (Fig. 3B) this is defined between around 0.04Hz to 0.3Hz, however the cumulative cospectra (Fig. 3C) suggests that the contributing eddy range is between approximately 0.015Hz to 0.1Hz – a shift to the lower frequency range by a factor of $\sim$10. Looking at the cumulative co-spectrum you rightly note that eddies with a frequency of $<$0.1Hz contribute to most of the turbulence-driven O2 flux. However, this seems to be inconsistent with the turbulence range defined for Vz, especially since the cumulative co-spectrum suggests that around 80% of the turbulent O2 flux is driven by eddies with frequencies lower than the defined Vz inertial subrange.

Please note that the y-axis in Fig. 3C is linear while a log-scale is used in Fig. 3A and 3B. This may make differences appear larger than they actually are. We attribute the discrepancy at the lower frequency end of the spectra (0.06 vs 0.04 Hz) to uncertainties rooted in the few data points located here, which is also reflected in the visible variation between the binned data (open circles). The discrepancy at the higher frequency end of the spectra (0.7 vs 0.3) is expected for the following reason: At a Schmidt number (the ratio between viscous diffusion vs. molecular diffusion) $>>$ 1, the size scale responsible for smearing out O2 gradients is smaller than the Kolmogorov scale at which velocity gradients are smeared out. The Schmidt number for sea water at 0 C$^{\circ}$ is $\sim$1700. Because smaller size scales translate to higher frequencies, the O2 spectrum should continue further up toward higher frequencies than the velocity spectrum as it indeed does here (Fig. 3A and 3B). Batchelor (1959) showed that this part of the O2 spectrum should have a slope of -1 rather than -5/3, and in our case this -1 slope is evident around 0.3 Hz after which it continues up to around 1 Hz. However, we stress that the spectra at higher frequencies, probably around 1 Hz and above, should be interpreted cautiously. For example, there is an upper frequency limit to where the ADV, with its $\sim$1 cm3 measuring volume, can resolve the velocity spectrum. The O2 electrode measures at a point and does not have this spatial limitation, but is instead limited by a response time of $\sim$0.2 s which at best allows frequencies up to $\sim$5 Hz to be resolved.

According to the cospectrum (Fig. 3C), flux contribution falls in the 0.015 - 0.15 Hz range. We do not see this as being inconsistent with the velocity spectrum (Fig. 3A). It just means that some of the flux contributing eddies – equivalent to roughly half of the flux – have frequencies below the inertial subrange. This result is not uncommon. In fact, two recent papers by Lorrai et al. 2010 (Fig. 9) and Brand et al. 2008 (Fig. 4) on aquatic eddy correlation measurements present spectra with the exact same characteristics.

References:

Batchelor, G. K. Small scale variation of convected quantities like temperature in turbulent fluid. Part I: General discussion and the case of small conductivity. Journal of Fluid Mechanics, 5: 113 – 133, 1959.

Brand, A., D.F. McGinnis, B. Wehrli, and A. Wuest. Intermittent oxygen flux from the interior into the bottom boundary of lakes as observed by eddy correlation. Limnol. Oceanogr. 53: 1997-2006, 2008.

Bluteau, C.E., N.L. Jones, and G.N. Ivey. Estimating turbulent kinetic energy dissipation using the inertial subrange method in environmental flows. Limnol. Oceanogr. Meth. 9: 302-321, 2011.

Hume, A.C., P. Berg, and K.J. McGlathery. Dissolved oxygen fluxes and ecosystem metabolism in an eelgrass (Zostera marina) meadow measured with the eddy correlation technique. Limnol. Oceanogr. 56: 86-96, 2011.

Lorrai, C., D.F. McGinnis, P. Berg, and A. Brand. Application of oxygen eddy correlation in aquatic systems. J. Atmos. Oceanic Technol. 27: 1533-1546, 2010.

Interactive comment on Biogeosciences Discuss., 8, 11255, 2011.