SCIENTIFIC REPORT

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Host: Rui Salgado, Professor at University of Évora
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BACKGROUND

Lakes cover $4.2 \cdot 10^6$ km^2, representing an area of more than 3% of Earth continental surface (Downing et al., 2006), and they have an important contribution in the energy and trace gas exchange between the atmosphere and Earth's surface (e.g. Nordbo et al., 2011; Mammarella et al., 2015; Erkkilä et al., 2017). For example, the energy exchange affects the regional weather and climate (Balsamo et al., 2012).

Interests towards lake–atmosphere exchange of CO_2 have recently increased as the lakes have noticed to have significant contribution to the global CO_2 budget (Raymond et al., 2013). The global estimates are, however, very uncertain and they are based on few studies only (Raymond et al., 2013; Mammarella et al., 2015). Therefore, more studies at different locations would be of great interest.

The gas exchange can be measured using several methods. Recently, the eddy covariance has become the standard to measure the biosphere–atmosphere exchange, i.e. flux, at the ecosystem scale. It is a direct method to determine turbulent transport, continuous measurements are easy to obtain and its error sources are generally well understood (e.g. Baldocchi, 2014; Mammarella et al., 2016). Conversely, chamber measurements represent only a small footprint and those measurements require more manual maintenance.

However, the CO_2 flux from lakes is usually quite small compared with other ecosystems, such as forests, especially when the lakes are covered with snow. Thus, flux corrections can even change the sign of the flux (e.g. Ham and Heilman, 2003). This concerns especially open-path instruments, such as LI-COR 7500 or Campbell IRGASON. Therefore, a validation of the instruments and methods is important.

In this project, our aim has been to do a flux inter-comparison between a closed-path LI-COR 7200 and the open-path Campbell IRGASON, and try to conclude how well small CO_2 fluxes can be measured above an ice covered lake. The measurements were already conducted at boreal lake Vanajavesi (61.133935°N ; 24.259119°E), Finland, between winter and spring 2016. The campaign was done together with University of Évora.

I visited at the University of Èvora, Portugal, between June 12 and June 17. The visit was hosted by Professor Rui Salgado and Dr. Miguel Pontes. During the trip, our aim was to go through our data from the comparison campaign, and plan forthcoming papers.

METHODS

The fluxes were conducted using the eddy covariance (EC) method. The flux, F, is, by definition,

$$F = \frac{1}{N} \sum_{i=1}^{i=N} w'(i - f\lambda) X'(i), \tag{1}$$

where w' and X' represent turbulent fluctuations of vertical wind and a scalar of interest, respectively. λ is a lag time caused by, for example, sampling tubes, and f is the sampling frequency. The EC measurements must be done with high frequency ($10 - 20$ Hz). The averaging period $\overline{(\quad)}$ is typically 30 min, i.e. $N = 18000 - 36000$ depending on the measurement frequency. (see e.g. Aubinet et al., 2012)

The infrared gas analyzers, such as LI7200 and IRGASON, report a concentration of CO_2 or H_2O as the molar density (ρ_x, [mol m^{-3}]) which is a function of the infrared attenuation in an air column. Thus, the density fluctuations – caused mainly by temperature and H_2O – affect the measured molar densities and thereby bias the measured flux $\overline{\rho_x' w'}$ (Webb et al., 1980). For closed-path instruments, the effect is partly canceled by sampling tubes, and rest of the effect can be corrected online using fast response temperature, pressure and H_2O measurements (e.g. Ibrom et al., 2007). However, for open-path instruments, this must be done afterwards using a WBL-correction (Webb et al., 1980). The WBL corrected flux, F_{wbl}, is

$$F_{\text{wbl}} = \overline{\rho_x' w'} + \left(\frac{M_a}{M_w} \frac{\overline{\rho}_x}{\overline{\rho}_a} \right) \overline{\rho_w' w'} + \left(1 + \frac{M_a}{M_w} \frac{\overline{\rho}_w}{\overline{\rho}_a} \right) \frac{\overline{\rho}_x}{\overline{T}} \overline{T' w'}, \tag{2}$$

where M_a and M_w are the molar masses of (dry) air and H_2O, respectively. T, ρ_a and ρ_w represent the ambient temperature, the molar density of dry air and the molar density of water vapour, respectively. (Webb et al., 1980)

As seen from Eq. (2), the WBL correction can change the sign of the measured flux, $\overline{\rho_x' w'}$. Therefore, especially open-path measurements are potentially biased if the correction terms are large compared with the actual flux. This might happen due to uncertain WBL corrections or if the current knowledge of the density corrections was not exact (e.g. Burba et al., 2008). Of course, flux measurements are also affected by high frequency losses etc. However, these other correction terms affect only the magnitude of the flux and they are therefore less important from the point of the inter-comparison (see e.g. Aubinet et al., 2012; Mammarella et al., 2016).

WORK CARRIED OUT AND MAIN RESULTS

During the visit, we were discussing about the results of the inter-comparison made above the snow covered lake Vanajavesi. The fluxes were calculated using the EC method (Eq. 1) and obtaining all the necessary corrections.

First results of the comparison are interesting, showing differences for CO_2 flux measurements between the instruments (Figs. 1 and 2). As the measured CO_2 fluxes were pretty small, the differences are probably caused at least partly by uncertainties of the WBL correction terms. For example, the difference is relatively large when the heat flux is peaking (Fig. 2). However, the results require still careful analysis because we found also significant differences between the anemometers (Fig. 2) which was unexpectable.

FUTURE COLLABORATION

We are planning to write at least two papers about the campaign. The first one focuses on the instrument comparison and the second on the physical and biological factors which affect the CO_2 exchange. We will also utilize data from the Alqueva station

CONFIRMATION BY THE HOST INSTITUTION OF THE SUCCESFUL EXECUTION OF THE STSM

The host institution, represented by Rui Salgado, confirms that the main goal of the STSM was achieved.

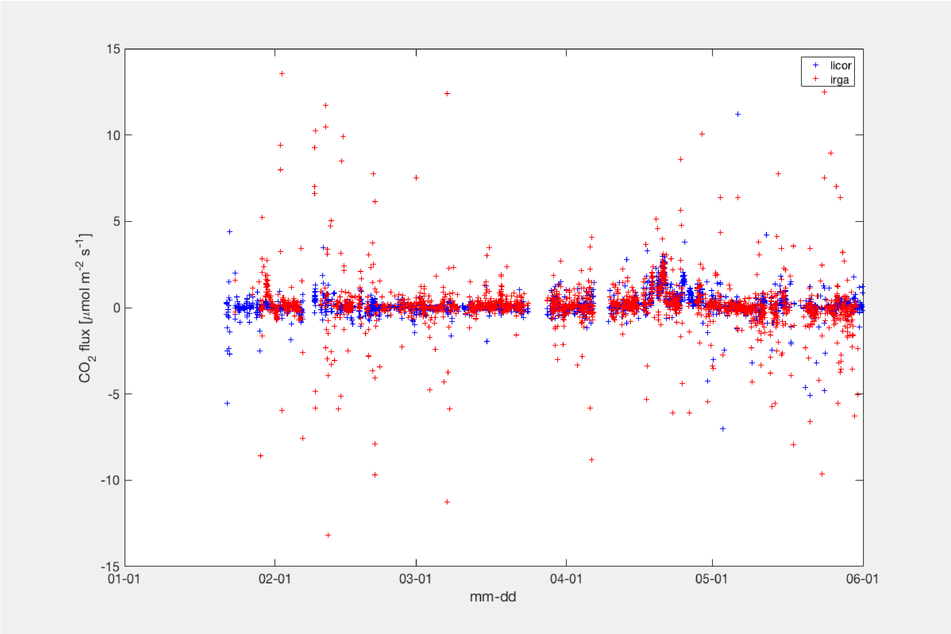

Figure 1: Time serie of CO_2 flux of both instruments at lake Vanajavesi during the campaign in 2016.

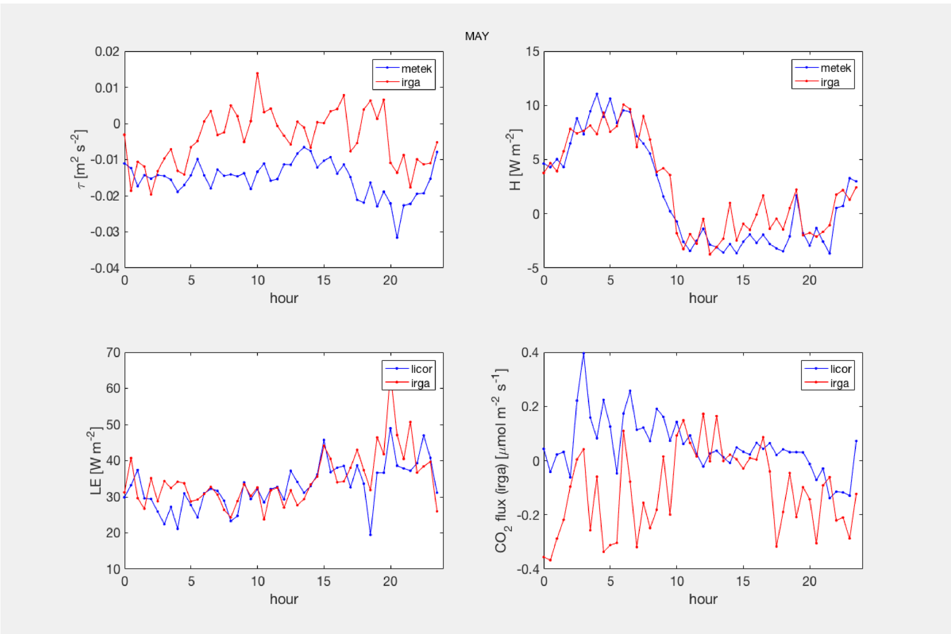

Figure 2: Diurnal cycles of momentum flux, sensible heat flux (Metek u-Sonic3 Scientific and IRGASON), latent heat flux and CO_2 flux (LI7200 and IRGASON) at lake Vanajavesi in May 2016.

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