Technical challenges of using high precision atmospheric O\textsubscript{2} measurements as a tracer for determining carbon fluxes in terrestrial ecosystems

Penelope A. Pickers\textsuperscript{1}, Emanuel Blei\textsuperscript{1}, Andrew C. Manning\textsuperscript{2}, Yuan Yan\textsuperscript{3}, Alex J. Etchells\textsuperscript{1}, Nick Griffin\textsuperscript{1}, Alexander Knohl\textsuperscript{3,3}

\textsuperscript{1}Centre for Ocean and Atmospheric Sciences, School of Environmental Sciences, University of East Anglia, Norwich, UK.
\textsuperscript{2}University of Goettingen, Bioclimatologie, Büsgenweg 2, 37077 Göttingen, Germany.
\textsuperscript{3}University of Goettingen, Centre of Biodiversity and Sustainable Land Use (CBL), 37073 Göttingen, Germany.

Introduction and project aims

Atmospheric oxygen (O\textsubscript{2}) measurements are a very useful tool for studying carbon cycle processes at the global scale, and have previously been used, for example, to separate the land and ocean sinks for carbon dioxide (CO\textsubscript{2}) (see Keeling and Manning, 2014). Until now, the potential of O\textsubscript{2} measurements at the ecosystem level has not been exploited, largely owing to the significant technical challenges faced in measuring atmospheric O\textsubscript{2} to an accuracy and precision of a few ppm or less against a background mole fraction of 21%.

Here, we introduce the ERC grant OXYFLUX: “Oxygen flux measurements as a new tracer for the carbon and nitrogen cycles in terrestrial ecosystems”. OXYFLUX aims to develop high precision O\textsubscript{2} flux measurements as a new ecosystem-scale tool for understanding carbon and nitrogen cycle processes in the terrestrial biosphere.

Methods and experimental design

- In OXYFLUX we will develop a fully automated system to make high precision O\textsubscript{2} and CO\textsubscript{2} flux measurements from tree branches, stems and soils (See Figure 1).
- The system can be roughly divided into three parts: chambers, gas delivery/plumbing and gas analysis.

Technical challenges:
- High variability between soil, stem and branch fluxes. Branch fluxes also vary significantly with temperature, incoming radiation and season.
- Chamber background air concentrations also vary over time, which need to be accounted for.
- O\textsubscript{2} and CO\textsubscript{2} concentrations have to be kept within a relatively narrow calibration range. All O\textsubscript{2} and CO\textsubscript{2} measurements will require rigorously calibration using a protocol similar to that employed in Keeling et al. (1998).
- The analysers operate at relatively small fixed flowrates, but fast gas delivery has to be achieved over long distances.
- Chamber materials need to be transparent, inert and impermeable to O\textsubscript{2}.
- Gas delivery to the analysers and switching has to minimise fractionation of O\textsubscript{2} with respect to N\textsubscript{2}.

Figure 1. Schematic of chamber and instrument setup for initial experiment

- Chamber measurements of the O\textsubscript{2}/CO\textsubscript{2} ratio will be later integrated into the multi-layer canopy model CANVEG (Baldocchi, 1997).
- The chamber-level O\textsubscript{2}/CO\textsubscript{2} ratios will be represented as functions of environmental variables within CANVEG to enable the prediction of O\textsubscript{2}/CO\textsubscript{2} ratios from meteorological data.
- The CANVEG model will also be used to produce fluxes for different ecosystem components (branch/leaf, stem and soil), which will be optimized using our chamber measurements.
- CANVEG will enable our chamber measurements to be scaled to the ecosystem level for comparison with our eddy covariance O\textsubscript{2} measurements.

Figure 2. Left: CO\textsubscript{2} and O\textsubscript{2} low flow measurement system (‘Calvin’). Right: O\textsubscript{2}, CO\textsubscript{2} and H\textsubscript{2}O Aerodyne fast response analyser (‘Hobbes’).
- O\textsubscript{2} and CO\textsubscript{2} fluxes will be measured using an ‘Oxzilla’ lead fuel cell O\textsubscript{2} analyser (Sable Systems International Inc.) in series with a Li-820 CO\textsubscript{2} analyser (LI-COR Biosciences), see ‘Calvin’ in Figs. 1 and 2.
- Air from the soil, stem and branch chambers will be sampled via a high flow rate (0.9 L min\textsuperscript{-1}) for CO\textsubscript{2} and H\textsubscript{2}O using an Li-840A analyser (LI-COR Biosciences), see ‘IRGA’ in Fig. 1. A specially designed ‘dip-tube tee’, which does not cause significant O\textsubscript{2}/N\textsubscript{2} fractionation will be used to sub-sample air, which is delivered to Calvin at 100 mL min\textsuperscript{-1}.
- A prototype laser-based O\textsubscript{2}, CO\textsubscript{2} and H\textsubscript{2}O instrument from Aerodyne Inc. (see ‘Hobbes’ in Fig. 2), which can operate with a high flow rate (6 L min\textsuperscript{-1}) and measuring frequency (up to 10 Hz), will be used to make O\textsubscript{2} and CO\textsubscript{2} eddy covariance measurements above the canopy.

Figure 3. O\textsubscript{2} artefacts produced by typical chamber instrumentation

We have found that instrumentation typically used to make CO\textsubscript{2} chamber measurements can be unsuitable for O\textsubscript{2} chamber measurements, owing to the plastic tubing and ‘tee’ junctions found within them. For example, we tested some instrumentation from LI-COR Biosciences (Fig. 3) and found large O\textsubscript{2} artefacts (an acceptable bias ≤ 2 per meg).

Modelling

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