Freshwaters degas CO_2 to the atmosphere: why? how much? when? where?

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Rationale: Recent data have shown that rivers are not merely conduits of terrestrial carbon to the ocean but rather a significant component of that carbon is reprocessed within the river system such that the river is over-saturated with carbon dioxide and so will efflux gas to the atmosphere. For example streams and rivers in the US are supersaturated with carbon dioxide when compared with the atmosphere, emitting 97±32 Tg carbon each year[1]. Similarly most other freshwaters (lakes and reservoirs) are sources of atmospheric CO_2[2]. Knowledge of the intensity of this flux and what controls changes in this intensity is valuable information as it is required to inform models of the carbon cycle, used in forward projections of how a system may respond to changing environmental conditions, and to identify which components of the C cycle are the most sensitive to short-, medium- and long-term drivers.

Carbon dioxide efflux from a freshwater body depends on the degree of over-saturation within the freshwater (in turn controlled by production –biotic or abiotic- and consumption of CO_2) and environmental controls e.g. CO_2 efflux from deeper water in a lake may be restricted by the development of a thermocline; in a river CO_2 efflux and gas entrainment from the atmosphere may be controlled by flow turbulence and so may change systematically downstream as roughness and hydraulic conditions vary. These fluvial environmental controls, and so fluxes, change in space and time but neither form of variability has been documented to date.

There are only a few studies[e.g.1,3] that have sought to understand the controls of CO_2 efflux in a manner that is sufficiently systematic to allow upscaling of a system, and thus this is a research field open to significant advance. This doctoral training programme will combine fieldwork to measure CO_2 efflux and associated environmental controls, with analytical work, including stable isotope analysis[4], to characterize the source of the CO_2. The student will integrate this understanding in models currently more widely used in describing river and lake functioning and thus useful for upscaling. A good student may also explore how this understanding can be incorporate into Land Surface System parameters necessary for General Circulation Models to fully describe Earth system response under projected climate change.

Fig. 1. Students on the Dubh Lochan, a small freshwater lake adjacent to Loch Lomond where we have been measuring CO_2 efflux.

The research team have field interests in the Amazon basin, Greenland and Malayasia and the student is encouraged to design research questions that require fieldwork in these areas. However, intensive fieldwork will be initially focused on:

1) The Dubh Lochan (Fig. 1) and Loch Lomond. Loch Lomond is the UK's largest surface area lake and one of the sites used in UKLEON (the United Kingdom Lake Ecological Observatory Network), which links several lakes to consider environmental controls on aspects such as the carbon cycle, so the student will be part of this exciting research programme. Both these lakes are easily accessed from the University of Glasgow field station, the Scottish Centre for Ecology and the Natural Environment.

2) Whitelee windfarm catchment drainage systems. This is the largest on-shore windfarm in Europe and Waldron and colleagues have been working here for several years[5] and have a detailed understanding of the terrestrial-aquatic carbon cycle to support a research programmed on CO_2 efflux.

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References:
[1]Buttman D and Raymond PA (2011) Significant efflux of carbon dioxide from streams and rivers in the United States. *Nature Geoscience* DOI: 10.1038/NGEO1294
[2]Cole, J. J. et al. (2007) Plumbing the global carbon cycle: Integrating inland waters into the terrestrial carbon budget. *Ecosystems* 10, 171-184
[3]Alin, S. R. et al. Physical controls on carbon dioxide transfer velocity and flux in low-gradient river systems and implications for regional carbon budgets. *J. Geophys. Res*. 116 (2011).
[4] Waldron S., Scott E.M. and Soulsby C (2007) Stable isotope analysis reveals lower-order river dissolved inorganic carbon pools are highly dynamic. 41 (17): 6156-6162 *Environmental Science and Technology*, 10.1021/es0706089
[5.] Waldron S**.,** Flowers H., Arlaud C., Bryant C., and McFarlane S. (2009) The significance of organic carbon and nutrient export from peatland-dominated landscapes subject to disturbance. *Biogeosciences*, 6, 363-374

About you: We are seeking dynamic candidates, able to function across disciplines, but with a sound understanding of Earth system processes / limnology / environmental chemistry (particularly the terrestrial-aquatic C cycle), and a willingness to engage with fieldwork and analytical work modeling. Applicants should hold a minimum of a UK Honours Degree at 2:1 level or equivalent. This studentship requires significant fieldwork and thus a driving licence is preferred.
Your skill-development: In addition to the project specific skills that will leave you well-placed for a career as a research scientist, you will be expected to take part in the University of Glasgow's extensive programmed of transferable skill training development. This combination will ensure that the doctoral training you receive has balance between subject specific research skills and broader skills that employers seek, and that you are prepared for a diverse range of career options.

About us: The student will join the College of Science and Engineering Graduate School, a thriving post-graduate research community. The supervisory team is drawn from two different Schools from within the College.
Professor Susan Waldron of the School of Geographical and Earth Sciences leads the growing Carbon Landscape Research Group, which currently comprises three post-doctoral researchers and four PhD students, all researching aspects of the terrestrial-aquatic carbon cycle and active in knowledge exchange. Susan has more than 7 years experience of profiling [DIC] by spot sampling and characterisation of hydrological functioning; she also has applied continuous water quality monitors to her research for several years, both in rivers and lakes. Susan will provide supervision in field measurement of CO_2 efflux.
Professor Trevor Hoey of the School of Geographical and Earth Sciences specializes in fluid hydraulics and sediment transport, and has made extensive use of modelling and statistical techniques. He will provide supervision in field measurement of hydraulics and in data modelling and analysis.
Dr. Jason Newton manages the NERC Life Sciences Mass Spectrometry Facility at SUERC and has over twenty years experience of using stable isotope ratios to elucidate problems in a variety of subjects from bird migration to meteoritics. Jason will be supervising the stable isotope measurements.

Funding details: The first studentship is eligible for NERC funding and will pay the Research Council minimum stipend per year for a period of up to 3.5 years. Please note that due to restrictions on the funding, this studentship is for UK/EU applicants only and eligibility criteria apply.

How to apply: In the first instance please contact Prof. Susan Waldron to discuss your interest in these projects, providing a c.v. with relevant skills and experience: Susan.Waldron@glasgow.ac.uk. Susan will then advise on formal application as appropriate. This studentship will remain open until the funding is no longer available or an appropriate candidate is appointed.

To be considered for PhD studentships to be held in the School of Geographical and Earth Sciences (GES), suitably qualified candidates should apply via the website of the College of Science and Engineering (http://www.gla.ac.uk/colleges/scienceengineering/graduateschool/prospectivestudents/essentialinformation/). Closing dates for University and research council funded studentships will be in early in the new year, as stated on the GES studentships page: http://www.gla.ac.uk/schools/ges/research/postgraduate/.

Non- English speakers must meet the University's English language requirements. Candidates for NERC studentships should also meet the NERC's requirements for both academic qualifications and residential eligibility. For more information go to http://www.nerc.ac.uk/funding/application/studentships and please note that *non-UK European Union citizens will be awarded fees only by NERC.*

For informal enquiries about the research projects please contact the relevant supervisors. Information on the GES graduate school and the application process can be obtained from Mrs Jean McPartland, the assistant to head of the School (Jean.McPartland@glasgow.ac.uk).