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Preface: Towards a full greenhouse gas balance of the biosphere

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Ecosystem greenhouse gas (GHG) emissions (CO_2, CH_4, and N_2O) represent a major driver of global environmental change (IPCC, 2014). While there exists an emerging understanding on the net exchange of CO_2 across terrestrial and aquatic ecosystems due in part to the existence of large measurement and modeling networks (Baldocchi et al., 2001; Friend et al., 2007; Raymond et al., 2013; Tranvik et al., 2009), similar information on the biosphere–atmosphere exchange of non-CO_2 greenhouse gases (i.e., CH_4 and N_2O) is sparsely available in comparison. To date, a strong focus has been given to so-called high-emission ecosystems, such as wetlands, rivers and lakes, rice cultivations and ruminants for CH_4 (Nisbet et al., 2014) and agricultural ecosystems for N_2O emissions (Butterbach-Bahl et al., 2013; Sutton et al., 2007). Even though CO_2, CH_4, and N_2O emissions have been increasing during the last century, a combined quantification of the exchange of these three major greenhouse gases from a wide range of terrestrial and aquatic ecosystems is still missing. Therefore, approaches to develop full greenhouse gas monitoring networks, as currently undertaken in larger environmental research infrastructures such as ICOS (Integrated Carbon Observation System) and NEON (National Ecological Observation Network), are highly valuable.

The recently finished COST Action ES0804 – Advancing the integrated monitoring of trace gas exchange Between Biosphere and Atmosphere (ABBA) – evaluated the current state of greenhouse gas flux monitoring stations in Europe as a first step and initiated multi-flux monitoring sites in a second stage. In a third step, an initiative on scaling data collected at the site level to larger scales was undertaken. The fourth goal of the project was to train future researchers on experimental flux measurements as well as to introduce the next generation of researchers to modeling approaches. Under the auspices of Working Group 2 of ABBA, which focused on multi-flux monitoring sites, a full day session during the European Geosciences Union (EGU) General Assembly was organized in both 2012 and 2013 to exchange knowledge and discuss advantages and limitations of ecosystem-scale CH_4 and N_2O exchange observations. The session further focused on bridging the terrestrial and the aquatic research communities, who often act independently despite having similar research questions. In a synthesis sub-session, researchers discussed how to bring the knowledge gained at plot or ecosystem level to larger regional and continental scales via modeling approaches. Both sessions resulted in this Special Issue with which we aim to answer the following three questions:

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1. What is the magnitude of N_2O and CH_4 emissions in different ecosystems and what are the respective driving forces?

2. What are the difficulties in measuring and modeling their exchange rates and how do these rates relate to ecosystem C and N turnover?

3. How do non-CO_2 greenhouse gases (CH_4 and N_2O) contribute to the total global warming potential of terrestrial and aquatic ecosystems?

The manuscripts included in this Special Issue investigate GHG emissions from a variety of aquatic and terrestrial ecosystems, ranging from freshwater rivers (Maeck et al., 2014) and lakes (Sturm et al., 2014) to grasslands (Hörtnagl and Wohlfahrt, 2014, Imer et al., 2013, Merbold et al., 2013), crops (Savage et al., 2014), forest ecosystems (Peichl et al., 2014; Wang et al., 2013), and peatlands (Tupek et al., 2015). The climate zones covered ranged from the boreal region (Hanis et al., 2013) via the temperate zone (Imer et al., 2013) to the tropics (Jamali et al., 2013; Werner et al., 2014). Multi-site studies, which comprised approximately half of the Special Issue contributions, compared different ecosystem types (Luo et al., 2013), investigated effects of gradients in elevation (Teh et al., 2014) and soil moisture (Tupek et al., 2015), ecosystem management (Imer et al., 2013, Schrier-Uijl et al., 2014), and forest age (Peichl et al., 2014). Hiller et al. (2014) scaled up anthropogenic and natural CH_4 emissions to the country scale, and Tian et al. (2013) and Kim and Kirschbaum (2014) conducted global analyses. Around one third of the papers covered all three major greenhouse gases (CO_2, CH_4 and N_2O), while most studies discussed at least two of them. The first major result of these papers is that the contribution of the CH_4 and N_2O exchange to the total GHG budget varied considerably, from small and intermediate (Merbold et al., 2013; Peichl et al., 2014) to up to 50 % (Hörtnagl and Wohlfahrt, 2014). Thus, this Special Issue drives the existing knowledge base substantially towards a more comprehensive quantification of the total ecosystem greenhouse gas balance.

A mix of experimental methods was employed amongst the contributed studies. Traditionally, chambers were the method of choice for flux measurements, and were also employed in many of the contributing manuscripts (Imer et al., 2013; Podgrajsek et al., 2014). Chamber measurements, however, are now increasingly complemented with or replaced by eddy-covariance flux measurements (Podgrajsek et al., 2014; Wang et al., 2013), which are facilitated by the technical advance of fast-response gas analyzers (Peltola et al., 2014; Savage et al., 2014). Challenges in measuring reliable fluxes with the various methods were discussed, in particular regarding CH_4 and N_2O and the spatiotemporal heterogeneity of their exchange (Maeck et al., 2014; Podgrajsek et al., 2014; Savage et al., 2014; Werner et al., 2014). A great example of this is the role of CH_4 ebullition from aquatic ecosystems, which are not only difficult to accurately quantify but also tend to dominate total emissions from aquatic systems where ebullition is common (Maeck et al., 2014; Sturm et al., 2014). This highlights the second major insight from this Special Issue, the importance of hot spots and hot moments that need to be considered when designing chamber flux sampling schemes and interpreting eddy-covariance flux data (Hörtnagl and Wohlfahrt, 2014; Imer et al., 2013; Savage et al., 2014).

Finally, as the third major result the papers in this Special Issue show that N_2O fluxes tend to be explained poorly by micrometeorological and hydrological variables (Luo et al., 2013; Merbold et al., 2013), suggesting that substrate availability and/or microbial community dynamics may play important roles. In contrast, abiotic drivers, and in particular soil water content, exhibited considerably more skill in predicting the sign and magnitude of CH_4 exchange (Tupek et al., 2015; Wang et al., 2013).

Thereby, this Special Issue emphasizes the necessity of concerted collaboration between different disciplines and the research communities for developing more comprehensive approaches. Ultimately, continued exchanges similar to those demonstrated herein will lead to a better understanding of the feedbacks that biosphere–atmosphere greenhouse gas exchange exerts on climate.

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