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Upscaling nitrous oxide emissions from plot to region

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Extended Abstract

Policy-relevant nitrous oxide (N_2O) flux estimates are required at annual and regional scales, but the supporting measurements are mostly conducted at the small plot scale with infrequent measurements (at the most daily); and more recently by high temporal resolution field scale eddy covariance flux measurements. Soil N_2O fluxes in all ecosystems, croplands, grasslands, forests, wetlands, are highly variable in space and time. This variability is caused by the heterogeneity of the physical, chemical and biological soil properties at the soil microsite scale level, and often leads to lognormal distributions of both N_2O fluxes and their drivers (i.e soil moisture, soil mineral N content). Upscaling to the region and year therefore can be highly uncertain. The aim of this extended abstract is to outline how to reduce the uncertainty of N_2O flux calculations through statistical approaches (Bayesian methods), improved measurements using drones, and validation of IPCC emission inventories with atmospheric concentration measurements.

Nitrous oxide flux measurements at the plot and field scale

Most of our understanding of nitrous oxide (N_2O) processes and flux rates are based on manually operated static chamber measurements, where small (< 1m^2) chambers are placed onto the soil surface for short periods (~ 1 hr), to increase N_2O concentrations to measureable levels [1]. Measurements are labour intensive, only cover a very small area of the field, and at low frequency (daily to seasonal). It is easy to miss peaks, triggered by i.e. nitrogen fertiliser application or a rain event after a prolonged dry period [2], thus leading to large uncertainties in quantifying annual, field scale or regional N_2O fluxes. Automatically opening and closing chambers can overcome the temporal issues to some extent, but not the spatial issues. In contrast eddy covariance systems provide instantaneous high frequency (>10 Hz) measurements integrating over large areas (~0.01-1 km^2). Fluxes are calculated from atmospheric N_2O concentration measurements and the vertical components of wind speed, provided the surface is homogeneous (flat terrain without obstacles, i.e. hedges, huts). They are ideal for monitoring long-term temporal trends of N_2O fluxes at the field scale [3]. And fortunately the number of eddy covariance measurements across Europe and beyond is rising due to the development of more affordable, user-friendly high precision instruments. In spite of large differences between chamber and eddy covariance measurements, several inter-comparison studies have shown reasonable agreement of both measurement approaches [4,5]. The ideal strategy would be to routinely combine eddy covariance (high temporal resolution) and occasional chamber measurements (spatial variability), as advocated by the Integrated Carbon Observation System (ICOS) [3].

Improved gapfilling and uncertainty estimates for chamber and eddy covariance measurements

In spite of the high measurement frequency, eddy covariance, also can have substantial data gaps, due to constrains of meteorological conditions (i.e. wind direction, wind speed). Therefore not only chamber data, but also eddy covariance data require gap fillings. The most simplistic, but also the most uncertain method to gap fill would be to use the arithmetic mean flux, or the trapezoidal method (the average between adjacent measurement points). These commonly used methods are problematic, as the heterogeneous nature of the fluxes and many of their drivers too (i.e. NH_4, NO_3, soil moisture) are log normally distributed. Therefore, outliers will have large influence on the average flux and provide highly uncertain estimates [5].

Alternative approaches are to use Bayesian statistics or Generalised Additive Mixed Model (GAM) approaches [5, 6, 7]. Typical input data for the gap-filling models would be measurements of environmental data that influence N_2O fluxes, such as soil and meteorological data. The Bayesian statistical approach works well for data sets with large data gaps (i.e. chambers), and calculates robust constrains on the uncertainty compared to the standard approach [Table 1].

Upscale N_2O hotspots to the field scale using UAV's

Intensively managed grasslands require large N fertilisation rates to sustain high density livestock grazing. The sheep/cattle will return some of the nitrogen, consumed as grass, to the soil as dung and urine. Urine patches are highly visible in such grasslands, and identifiable by their dark green colour. Maire [8] has developed an interesting approach to derive the contribution of N_2O emissions from urine patches at the field scale by combining chamber flux measurements, over urine affected and clean grass areas, with airborne spectral measurements using an unmanned airborne vehicles (UAV) fitted with two cameras. Spectral image tools were used to calculate the contribution of urine patches to the entire field. In this particular study urine patches contributed 12% of the field area, but 47% of the total field N_2O emissions. Thus UAV's can play an important role in providing improved N_2O emission estimates from grazed fields.

Constraining bottom up empirical inventories with atmospheric concentration measurements

Signatory countries of the Kyoto Protocol and subsequent agreements are required to calculate their annual greenhouse gas emissions. The IPCC has developed guidelines on how to calculate emissions from the different sectors (i.e. industry, agriculture), using a tiered system, increasing in complexity from a universal applicable multiplier (Tier 1 emission factors) to process based models (Tier 3) [9]. The uncertainty of this approach is naturally very large, due to the variability of N_2O emissions governed by external drivers (agronomy, meteorology, soil properties). This uncertainty can be constrained using independent measurement approaches of high frequency atmospheric concentration measurements from tall towers (>100m) [10] or global networks [11] together with atmospheric dispersion models and inversion systems [12, 13].

Figure 1 provides an example of work in progress, comparing atmospheric N_2O concentration measurements from the 'Ridgehill' tall tower (~90 m) in SW England, with a spatially (5 km^2) and temporally (monthly) disaggregated emission inventory, using data from the UK agricultural census (i.e. N mineral fertiliser rates, timing and frequency of application, manure, crop type) and IPCC Tier 1 emission factors. Overall the results from the various intercomparisons are promising. Future improvements of inverse modeling, a denser network of tall towers, could provide a powerful tool of long-term and high temporal resolution monitoring of changes in N_2O emissions (i.e. mitigation, climate change, landuse change) at regional, national and global scales [14].

Table 1. Uncertainty estimates of seasonal measurements of N_2O fluxes from arable fields and cattle grazed grasslands (n = number of measurements made across several fields). The fluxes calculated using the Arithmetic and Bayesian method were mostly similar. However, the confidence intervals were much reduced using the Bayesian method, and thereby constrains the plausible range of the average N_2O flux [6].

Source	Season	n	Arithmetic method average flux	95% C.I. lower/upper	Bayesian method average flux	95% C.I. lower/upper
Arable crop	Autumn	19	6	-25 / 36	3	0 / 6
	Winter	18	6	-7 / 19	7	4 / 13
	Spring	24	64	-75 / 203	65	41 / 101
	Summer	36	102	-326 / 530	81	51 / 128
Cattle grazing	Autumn	23	99	-757 / 954	11	4 / 21
	Winter	29	0	-4 / 4	0	-1 / 1
	Spring	29	57	-104 / 217	46	19 / 72
	Summer	11	14	0 / 28	14	10 / 19

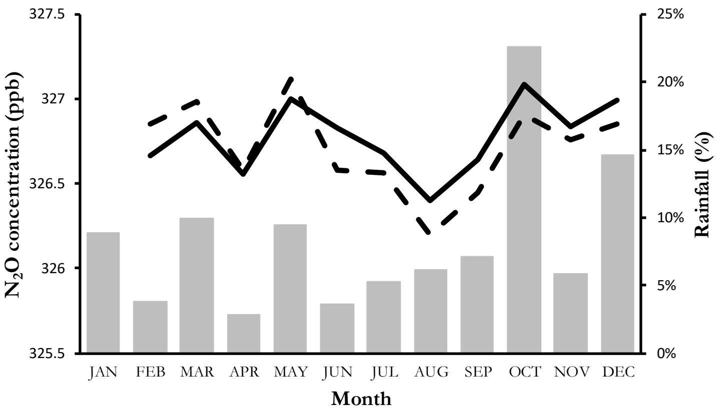

Figure 1. Comparison of tall tower N_2O atmospheric concentration measurements in SW England with the temporally disaggregated national emission inventory for the year 2013. The bars are the monthly rainfall for this region, the dotted line modelled data from the tall tower measurements, and the solid line the IPCC Tier 1 inventory data. Both methods observed the larger N_2O concentrations in Mar, May and October, as a result of higher rainfall and N fertiliser applications (March and May) and manure spreading, residue incorporation (October (Carnell E.J. American Geophysical Union, Fall Meeting 2016, abstract #B11E-0511).

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OECD disclaimer

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