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The effect of random and systematic measurement uncertainties on temporal and spatial upscaling of N_2O fluxes

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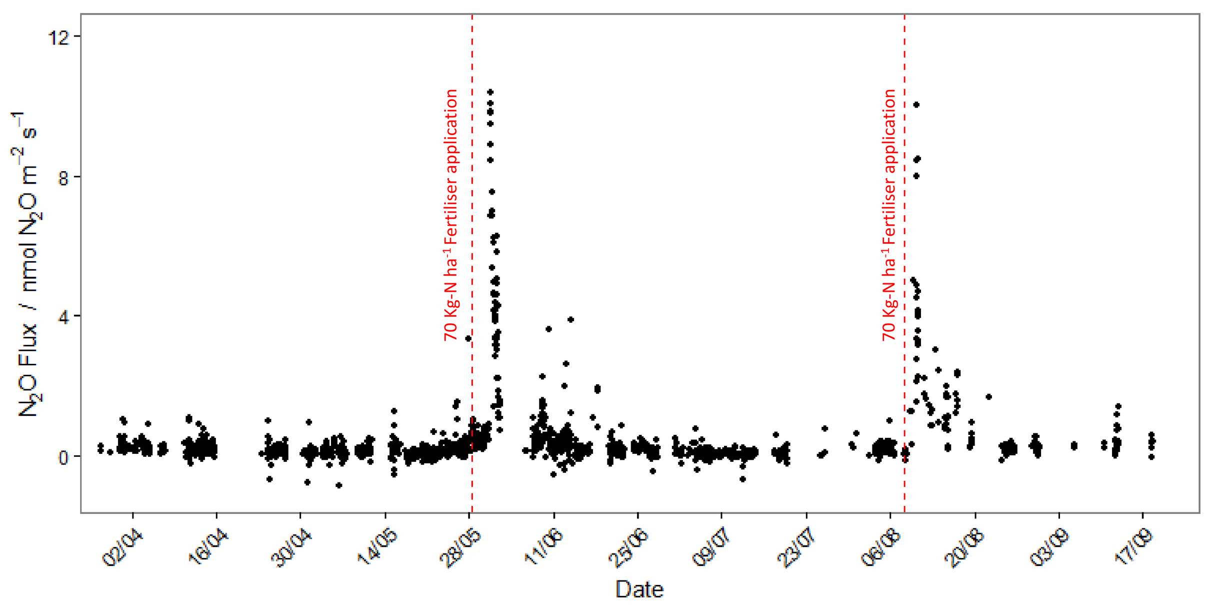
1. Temporal variability of N_2O

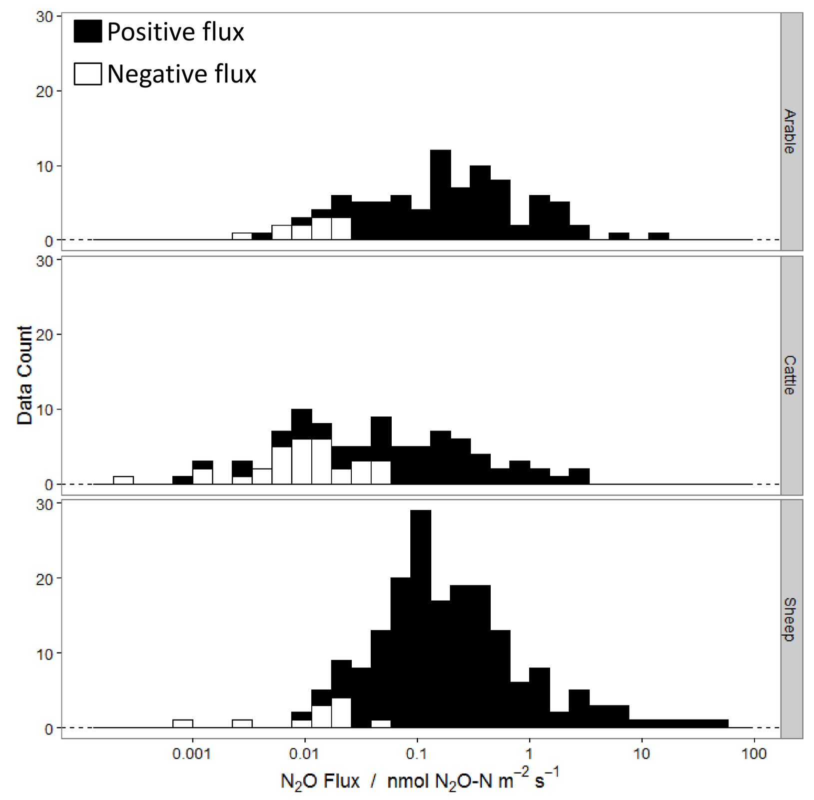
- **Fluxes of N_2O from agricultural soils exhibit a high degree of unpredictable temporal variability**
- This is especially true during periods after nitrogen fertiliser events, when fluxes are significantly higher for several weeks



- **Eddy covariance can be used to measure the temporal variability of N_2O fluxes at a wide scale (> 100 m^2), however this method does not capture the extent of the spatial variability of the fluxes present (above)**
- Gap filling between missing measurement points is limited due to the unpredictable temporal nature of N_2O fluxes
- The short peaks in N_2O fluxes (sometimes < 24 hours) are easily missed by intermittent measurement methods

2. Spatial variability of N_2O

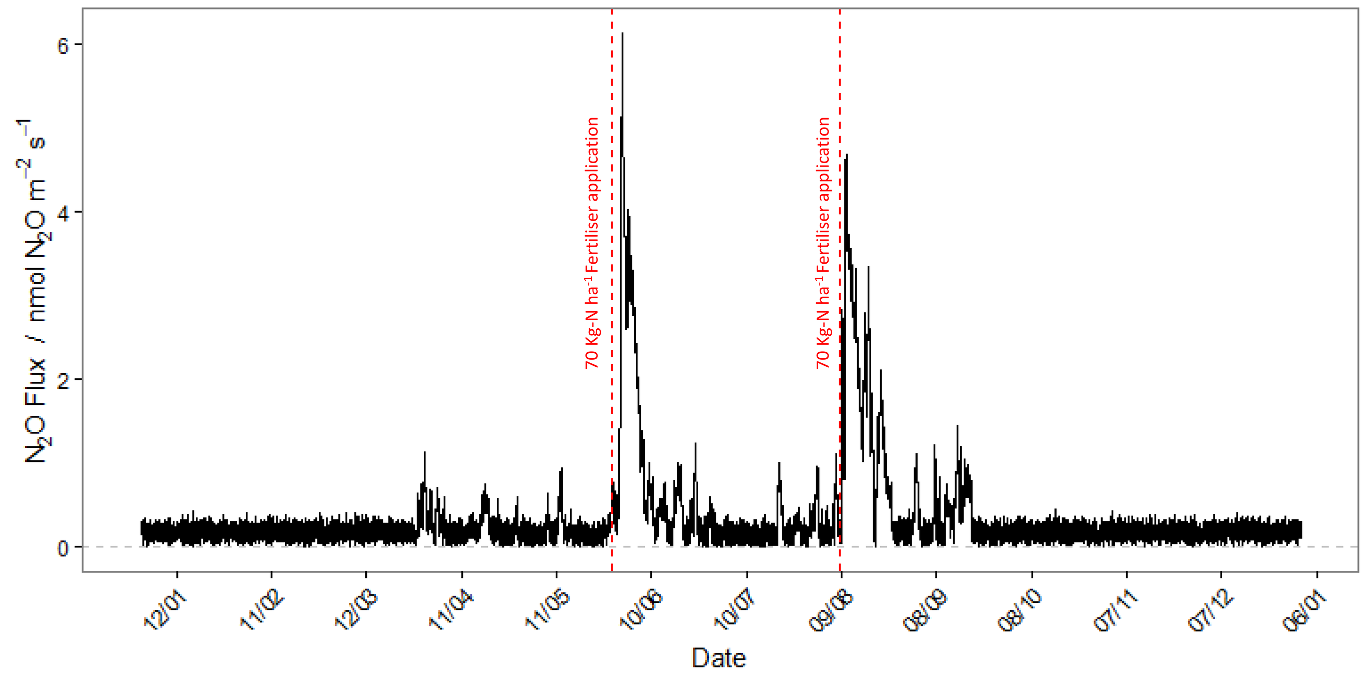
- **Fluxes of N_2O from agricultural soils exhibit a high degree of unpredictable spatial variability**
- **Flux chamber methods are able to observe some of the spatial variability in N_2O fluxes present at the field scale; however, accounting for temporal variability is limited and large gaps may remain between measurement dates**
- Often N_2O flux measurements made using chamber methods will vary by several orders of magnitude in areas less than 10 m^2
- **Any attempt to gap-fill between measurements is limited due to the large and unpredictable nature of the spatial variability**



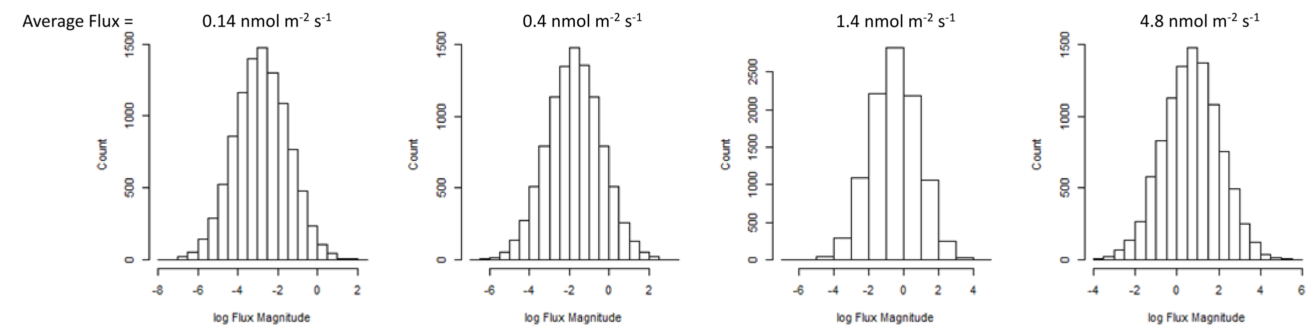
- A consistently observed phenomenon of N_2O fluxes at the field scale using traditional chamber methodology is the log-normal nature of the measurements (left)
- **This log-normal distribution of data is consistently observed during periods of low and high N_2O fluxes**
- Using arithmetic means to estimate fluxes leads to very high uncertainties in these circumstances

3. Simulating N_2O flux at the field scale

- **In this simulation of field scale fluxes we assume fluxes follow the temporal pattern of the double fertilisation observed by real Eddy Covariance measurements (Section 1).**
- **Using the log-normal spatial pattern of the chamber measurements (Section 2) we create a simulated field scale model of a typical grassland field**

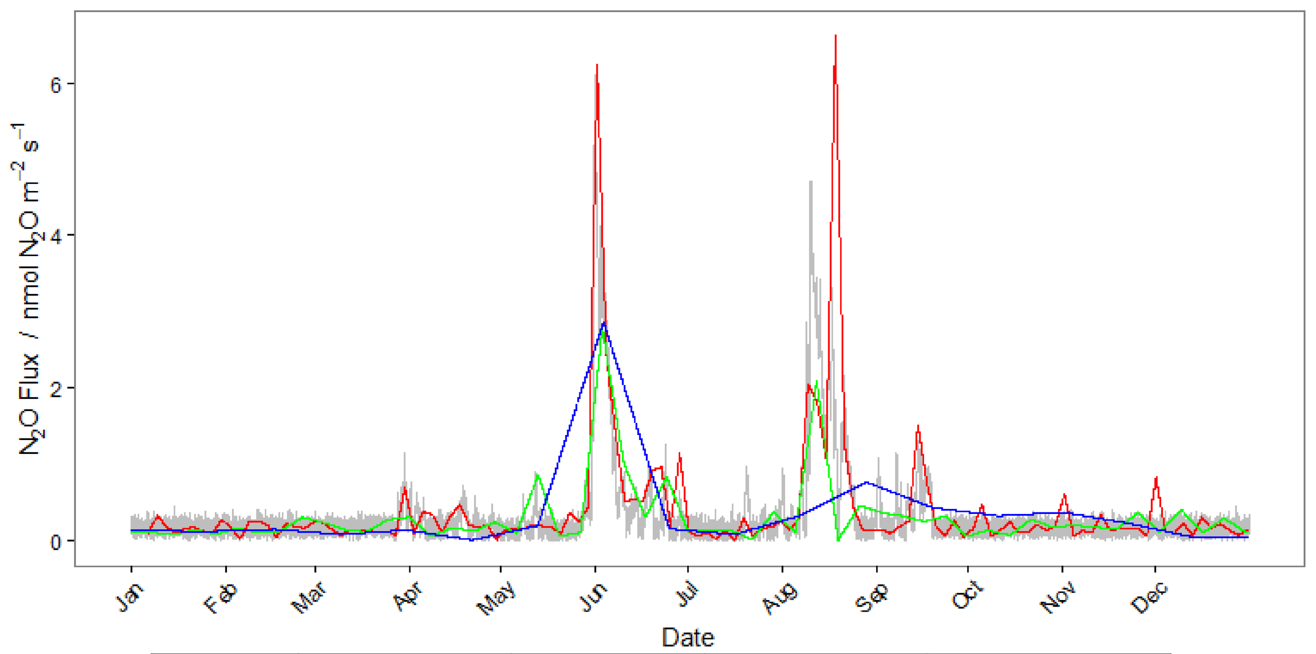


- Every 30 mins for the year long data set we simulate a log-normal distribution of 10,000 potential chamber measurements (examples below) with an average flux based on the simulated flux (above)



4. Simulating chamber measurements

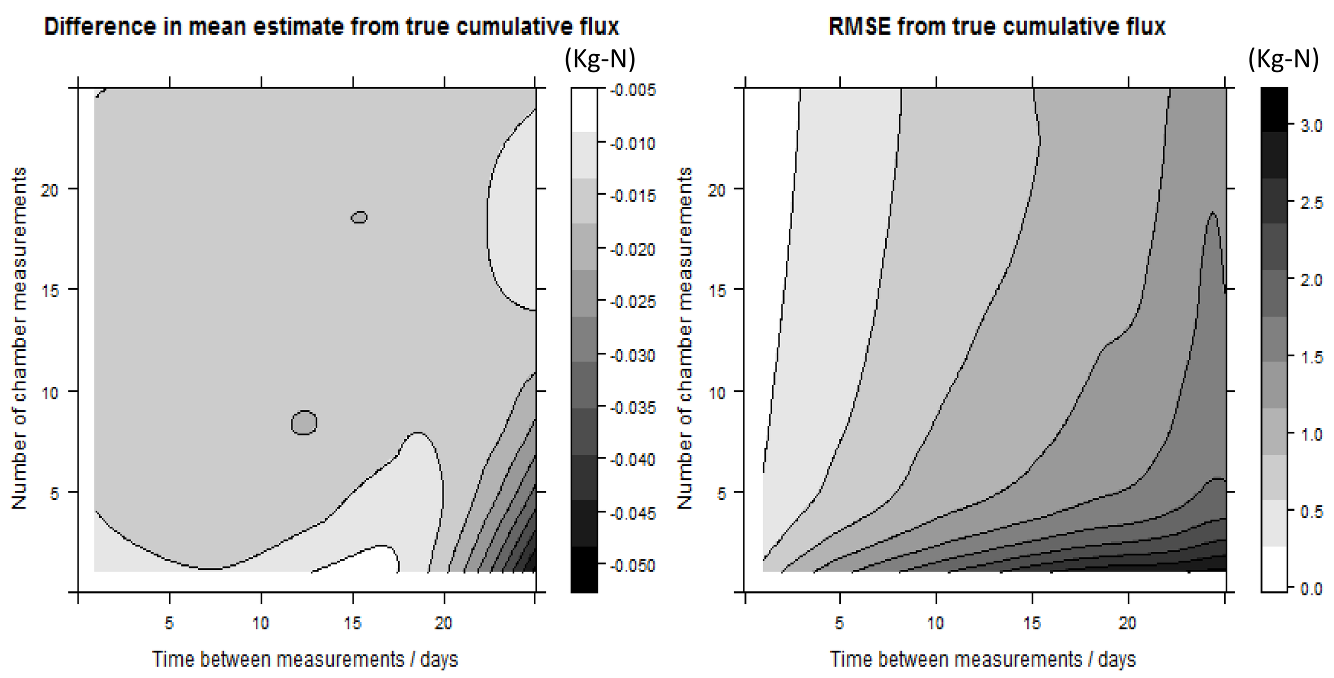
- **To asses how well we would estimate cumulative N_2O fluxes from our simulated field using a typical a chamber measurement scheme, we sample from the simulated data**
- The number of chambers and the regularity that they are measured from can be assessed by randomly sampling from our simulated data as if it were a real field
- **Example (below) shows how results from individual sampling schemes may compare with the true flux (grey) in the simulation (True flux = 3.02 Kg-N)**
- The results of the measurements are random in nature. Sometimes estimates are close to reality and sometimes they are very far off. This variability represents the uncertainty introduced in the cumulative flux estimates caused by the measurement methodology and sampling scheme



Colour	No. of chambers	Time between measurements	Cumulative flux (Kg-N)	Difference from true simulated flux
red	20	3 days	3.57	+ 18.4 %
green	10	7 days	2.74	- 9.4 %
blue	5	21 days	3.30	+ 9.4 %

5. Simulating uncertainties in cumulative fluxes

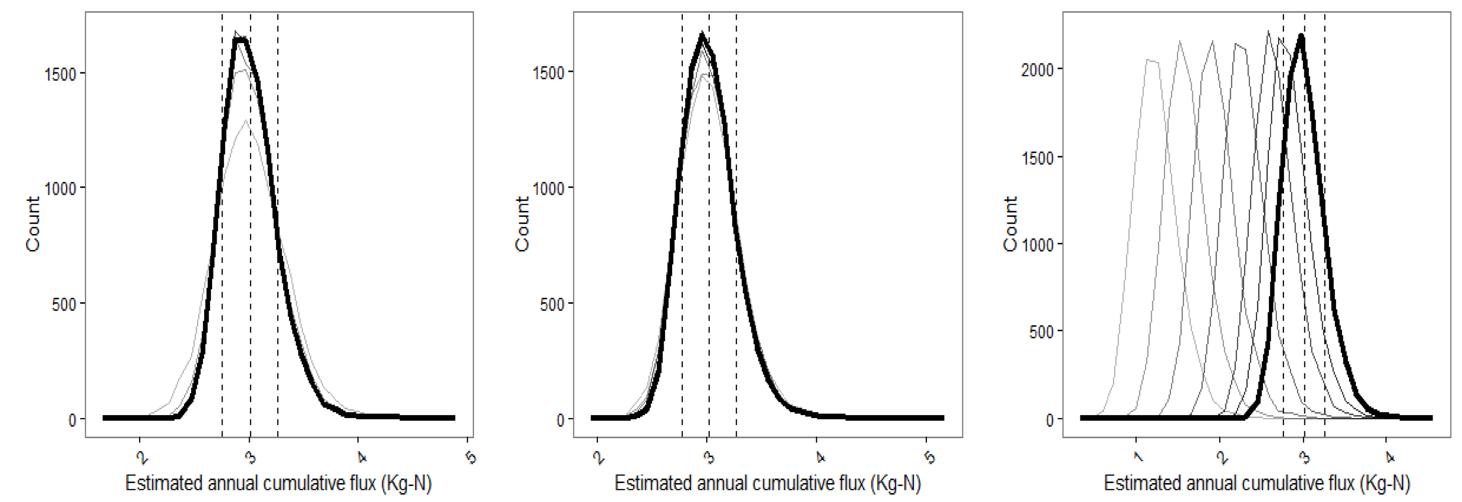
- **Using the Monte-Carlo method we can sample from the simulation repeatedly (n = 10,000) to asses the uncertainty in a particular chamber measurement scheme**
- Every repetition will provide a different cumulative flux estimate depending on where and when the chambers measurements are made, just as it would in a real experiment



- **The results show that although the measurement schemes are overall only very slightly biased towards lower fluxes (left) that the uncertainty in the cumulative fluxes increases rapidly as measurement regularity in time and space decreases (right)**
- Temporal uncertainties appear to be far more significant than spatial contributions in this particular simulation, due to the relatively short-lived fertiliser induced N_2O peaks
- **This simulation suggests that in order to keep the RMSE in annual cumulative flux estimates below 10 %, that a minimum of 5 chambers every day, or 25 chambers every three days must be measured from random locations in our field (95% confidence interval ≈ 2 x RMSE)**

6. The effect of measurement uncertainty

- **The instrumental detection limit of the method (left), random uncertainty in regression analysis (middle) and bias in regression analysis (right) can all be assessed for the simulated chamber measurements**



Instrumental uncertainty at 0.02, 0.04, 0.08, 0.16 and 0.32 nmol m^2 s^{-1}

Random regression uncertainty at 2, 4, 8, 12 and 16 and 20 %

Systematic underestimate at 2, 4, 8, 12 and 16 and 20 %

- As instrumental and random regression uncertainty increase, the RMSE of the simulated results also slightly increases, but the mean does not change. This suggests that although these uncertainties do contribute to the overall uncertainty in cumulative flux estimates, that they are ultimately unbiased in nature
- **The question of linearity in regression analysis in chambers is still contested. Several papers predict that commonly used chambers underestimate fluxes by up to 20 %** (Chadwick et al., 2014; Cowan et al., 2014; Kroon et al., 2008; Levy et al., 2011; Parkin et al., 1990; Pedersen et al., 2010)
- If chambers do underestimate flux by 20 % the simulation predicts that cumulative fluxes (and therefore most global emission factors) measured using chamber methodology (such as that shown in Section 4) may underestimate N_2O flux by up to 60 %. This is due to the log-normal nature of the spatial variability at the field scale

References:

Chadwick, D. R., Cardenas, L., Misselbrook, T. H., Smith, K. A., Rees, R. M., Watson, C. J., McGeough, K. L., Williams, J. R., Cloy, J. M., Thorman, R. E. and Dhanoa, M. S.: Optimizing chamber methods for measuring nitrous oxide emissions from plot-based agricultural experiments: N_2O chamber methodology, Eur. J. Soil Sci., 65(2), 295–307, doi:10.1111/ejss.12117, 2014.
Cowan, N. J., Famulari, D., Levy, P. E., Anderson, M., Bell, M. J., Rees, R. M., Reay, D. S. and Skiba, U. M.: An improved method for measuring soil N_2O fluxes using a quantum cascade laser with a dynamic chamber, Eur. J. Soil Sci., 65(5), 643–652, doi:10.1111/ejss.12168, 2014.
Kroon, P. S., Hensen, A., Bulk, W. C. M., Jongejan, P. A. C. and Vermeulen, A. T.: The importance of reducing the systematic error due to non-linearity in N_2O flux measurements by static chambers, Nutr. Cycl. Agroecosystems, 82(2), 175–186, doi:10.1007/s10705-008-9179-x, 2008.
Levy, P. E., Gray, A., Leeson, S. R., Gaiawyn, J., Kelly, M. P. C., Cooper, M. D. A., Dinsmore, K. J., Jones, S. K. and Sheppard, L. J.: Quantification of uncertainty in trace gas fluxes measured by the static chamber method, Eur. J. Soil Sci., 62(6), 811–821, doi:10.1111/j.1365-2389.2011.01403.x, 2011.
Parkin, T., Chester, S. and Robinson, J.: Calculating confidence intervals for the mean of a lognormally distributed variable, Soil Sci. Soc. Am. J., 54(2), 321–326, 1990.
Pedersen, A. R., Petersen, S. O. and Schelde, K.: A comprehensive approach to soil-atmosphere trace-gas flux estimation with static chambers, Eur. J. Soil Sci., 61(6), 888–902, doi:10.1111/j.1365-2389.2010.01291.x, 2010.

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