Supporting document for diurnal soil nitrous oxide emission datasets

## Summary

The datasets were used for a study titled ‘Diurnal variability in soil nitrous oxide emissions is a widespread phenomenon’ to be published in Global Change Biology. The datasets contain four types of data, which were extracted from 46 published journal articles (see Table 1 and Reference) which performed diurnal N­2O flux measurements in their studies. csv files beginning with N2O\_ contain time of flux measurement, diurnal N2O flux (unit μg m-2 h-1) and normalised N­2O flux data within every 24 hours. csv files beginning with soil\_temp\_ contain time of soil temperature measurement and soil temperature data within every 24 hours. The numbers following the N2O\_ and soil\_temp\_ csv files correspond the datasets together (i.e. N2O\_001.csv and soil\_temp\_001.csv are measurement on the same day and from the same study, and should be analysed as such). dataset\_info.csv contains the data code, title of the literature and data of other non-diurnal parameters (e.g. pH, bulk density, soil texture, season of measurement, soil water-filled pore space, irrigation and grazing) extracted from the articles. diurnal\_pattern\_categorisation\_data.csv contains processed data, the data collection/generation method, nature and units of recorded values and details of data structure are described in the following sections.

## Data collection/generation method

A literature search was conducted on two major scientific literature databases – ‘Web of Science Core Collection’ and ‘ScienceDirect’, with the search terms list below. The 28th August 2019 was selected as the cut-off date, no literature searches were conducted after which.

* Title: (‘greenhouse gas’ OR ‘N2O’ OR ‘nitrous oxide’) AND (‘flux’ OR ‘fluxes’ OR ‘emission’ OR ‘emissions’)
* Abstract: ‘diurnal’ OR ‘diel’ OR ‘high frequency’ OR ‘automated’ OR ‘automatic’ OR ‘high temporal’ OR ‘highly temporal’
* Anywhere: ‘soil’ OR ‘soils’

A total of 314 journal articles (Web of Science: 215, ScienceDirect: 99) published between 1983 and 2019 were identified in the initial database search. Duplicate articles (n = 83) were subsequently removed, and a set of inclusion criteria to select studies eligible for data extraction. The inclusion criteria are listed as follows:

* N2O flux measurements were performed on cropland, grassland or forest soils;
* Five or more N2O flux measurements were taken in every 24-hour cycle;
* The first and last measurement points of each 24-hour cycle were within 00:00 – 03:59 and 20:00 – 23:59, respectively.

This resulted in a compilation of 46 journal articles eligible for data extraction and yielded 286 diurnal datasets of N­2O flux (listed in dataset\_info.csv). Of the 286 datasets, 160 contained soil temperature (5 – 10 cm) data, 157 contained soil pH data, 115 contained bulk density data, 175 contained soil texture data, 135 contained soil moisture data and 261 contained data of season of flux measurements. Information on N fertilisation and land use were provided in all articles. The data for these factors are recorded in dataset\_info.csv)

For each selected publication, N­2O flux and soil temperature (if provided) data were extracted from figures and converted into a numerical format using a data recovery tool – ‘Engauge Digitizer’ (Mitchell et al., 2020). N­2O flux and soil temperature in every 24-hour cycle were extracted and saved as one csv file.

The N­2O flux data files were later categorised into three diurnal patterns of N­2O emissions (daytime peaking, night-time peaking and non-diurnal), three sets of objective conditions were developed (listed below). Datasets that met all the conditions in a category were classified as such.

A threshold applies to all datasets for the categorisation of daytime peaking or night-time peaking pattern (condition 3) to ensure the majority of emission occurs in daytime/night-time. Since the hours between the first and last flux measurements in datasets were often less than 24 hours, we adjusted the 50% threshold for each dataset using the equation below the conditions. We then calculated the percentage of emission within three 12-hour periods (04:00 – 16:00 h, 06:00 – 18:00 h and 08:00 – 20:00 h). The percentages of emission were calculated by dividing the emission within those 12-hour periods with the total emission of the dataset. The emission of each 12-hour period were computed using a trapezoidal integration function (in R package ‘pracma’).

For the daytime peaking category, two subcategories were defined to identify morning peaking and afternoon peaking of N­2O flux. The categorisation conditions for each diurnal pattern are listed below:

* Daytime peaking:
  1. Both the highest and second highest N2Onorm occur between 04:30 – 19:30 h;
  2. The lowest N2Onorm occurs between 00:00 – 09:00 or 18:00 – 00:00 h;
  3. The percentage of emission calculated within 04:00 – 16:00 h or 08:00 – 20:00 h is greater than the adjusted threshold (Eq. (2));
     + If percentage of emission calculated within 04:00 – 16:00 h exceeds the threshold and the afternoon emission percentage, the dataset is considered as ‘morning peaking’;
     + If percentage of emission calculated within 08:00 – 20:00 h exceeds the threshold and the morning emission percentage, the dataset is considered as ‘afternoon peaking’.
* Night-time peaking:
  1. Both the lowest and the second lowest N2O­­norm occur between 04:30 – 19:30 h;
  2. The highest N2Onorm is between 00:00 – 09:00 h or 18:00 – 00:00 h;
  3. The percentage of emission calculated between 06:00 – 18:00 h is smaller than the calculated threshold.
* Non-diurnal:
  1. Dataset is neither daytime peaking nor night-time peaking.

## Nature and units of recorded values

Continuous time series graphs were first divided into individual datasets per 24-hour cycle (i.e. 00:00 – 23:59) with N­2O flux data standardised to μg N2O-N m-2 h‑1. Hour and minute were also converted to decimal units (0.00 – 23.99 h). Where data were presented as 24-hours graphs of average or standardised N­2O flux (i.e. deviations from daily mean N­2O flux) over their measurement periods (e.g. 10 days), data from each graph was extracted as one dataset.

Magnitude differences between datasets were eliminated by normalising N­2O flux in every 24 hours. Normalised N2O flux data (N2Onorm) were bound between 0.0 and 1.0 using the following equation:

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where N2Onorm,t is the normalised N2O flux at one point in time (t), N2Ot is the N2O flux at t, N2Omin is the minimum N2O flux in a dataset, and N2O­max is the maximum N2O flux in a dataset.

## Details of data structure

Each dataset (csv file) titled N­2O\_xxx (where xxx is the reference number of the dataset listed in dataset\_info.csv) contains the time of measurement (hour), soil N­2O flux in μg N­2O-N m-2 h-1 (N2O\_flux) and normalised N­2O flux (norm\_flux, unitless) within a 24-hour cycle; whereas datasets with titles beginning with soil\_temp\_xxx contain the time of measurement (x) and soil temperature at 5-10 cm depth in Celsius (Curve1). Dataset\_info.csv contains the title of the literature and data of other non-diurnal parameters (e.g. pH, bulk density, soil texture, season of measurement, soil water-filled pore space, irrigation and grazing) corresponding to each dataset.

diurnal\_pattern\_categorisation\_data.csv contains processed data from the second part of the data generation methods, which include the time of maximum and second maximum N­2O flux (max\_hour and sec\_max\_hour), the time of minimum and second minimum N­2O flux (min\_hour, sec\_min\_hour), cumulative N­2O flux and percentage at 04:00 – 16:00 h (cum\_early, cum\_early\_percent), 08:00 – 20:00 h (cum\_late, cum\_late\_percent) and 06:00 – 18:00 h (cum\_mid, cum\_mid\_percent), and the cumulative N­2O flux between first and last flux measurement (cum\_all) and the adjusted threshold value for each dataset. first\_condition\_D, second\_condition\_D and third\_condition\_D refer to whether the dataset meets the first, second and third condition for daytime peaking category (Y = yes, N = no, E = yes and morning peaking (early) and L = yes and afternoon peaking (late)), whereas first\_condition\_N, second\_condition\_N and third\_condition\_N refer to the meeting of the conditions for night-time peaking category. daytime\_peaking and nighttime\_peaking refer to whether the dataset is categorised as daytime peaking (Y in daytime\_peaking, N in nighttime\_peaking), night-time peaking (N in daytime\_peaking, Y in nighttime\_peaking), or non-diurnal (N in both daytime\_peaking and nighttime\_peaking).

Table 1 References and titles of the 46 published journal articles (see Reference section for full reference details)

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| **References** | **Titles** |
| (Akiyama et al., 2000) | N2O and NO emissions from soils after the application of different chemical fertilizers |
| (Akiyama & Tsuruta, 2002) | Effect of chemical fertilizer form on N2O, NO and NO2 fluxes from Andisol field |
| (Akiyama & Tsuruta, 2003a) | Effect of organic matter application on N2O, NO, and NO2 fluxes from an Andisol field |
| (Akiyama & Tsuruta, 2003b) | Nitrous oxide, nitric oxide, and nitrogen dioxide fluxes from soils after manure and urea application |
| (Alves et al., 2012) | Selection of the most suitable sampling time for static chambers for the estimation of daily mean N2O flux from soils |
| (Ball et al., 1999) | Field N2O, CO2 and CH4 fluxes in relation to tillage, compaction and soil quality in Scotland |
| (Brumme & Beese, 1992) | Effects of liming and nitrogen-fertilization on emissions of CO2 and N2O from a temperate forest |
| (Brummer et al., 2017) | Gas chromatography vs. quantum cascade laser-based N2O flux measurements using a novel chamber design |
| (Christensen, 1983) | Nitrous oxide emission from a soil under permanent grass: Seasonal and diurnal fluctuations as influenced by manuring and fertilization |
| (Das et al., 2012) | Influence of photosynthetically active radiation on diurnal N2O emissions under ruminant urine patches |
| (Denmead et al., 2010) | Emissions of methane and nitrous oxide from Australian sugarcane soils |
| (Du et al., 2006) | Diurnal, seasonal, and inter-annual variations of N2O fluxes from native semi-arid grassland soils of inner Mongolia |
| (Flessa et al., 2002) | Greenhouse estimates of CO2 and N2O emissions following surface application of grass mulch: importance of indigenous microflora of mulch |
| (Hosono et al., 2006) | Measurements of N2O and NO emissions during tomato cultivation using a flow-through chamber system in a glasshouse |
| (Huang et al., 2014) | Nitrous oxide emissions from a commercial cornfield (Zea mays) measured using the eddy covariance technique |
| (Keane et al., 2018) | Greenhouse gas emissions from the energy crop oilseed rape (Brassica napus); the role of photosynthetically active radiation in diurnal N2O flux variation |
| (Kostyanovsky et al., 2019) | Emissions of N2O and CO2 Following Short-Term Water and N Fertilization Events in Wheat-Based Cropping Systems |
| (Laville et al., 1997) | Temporal integration of soil N2O fluxes: validation of IPNOA station automatic chamber prototype |
| (Laville et al., 2011) | Field comparison of nitrous oxide emission measurements using micrometeorological and chamber methods |
| (Laville et al., 2017) | Effect of management, climate and soil conditions on N2O and NO emissions from an arable crop rotation using high temporal resolution measurements |
| (Liu et al., 2010) | Three-year measurements of nitrous oxide emissions from cotton and wheat–maize rotational cropping systems |
| (Liu et al., 2014) | Nitrous oxide and nitric oxide emissions from an irrigated cotton field in Northern China |
| (Loftfield & Brumme, 1992) | Automated monitoring of nitrous oxide and carbon dioxide flux from forest soils |
| (Lognoul et al., 2019) | N2O flux short-term response to temperature and topsoil disturbance in a fertilized crop: An eddy covariance campaign |
| (Machado et al., 2019) | Diurnal variation and sampling frequency effects on nitrous oxide emissions following nitrogen fertilization and spring-thaw events |
| (Maljanen et al., 2002) | Short-term variation in fluxes of carbon dioxide, nitrous oxide and methane in cultivated and forested organic boreal soils |
| (Peng et al., 2019) | N2O emission from a temperate forest soil during the freeze-thaw period: a mesocosm study |
| (Reeves & Wang, 2015) | Optimum sampling time and frequency for measuring N2O emissions from a rain-fed cereal cropping system |
| (Reeves et al., 2016) | Quantifying nitrous oxide emissions from sugarcane cropping systems: Optimum sampling time and frequency |
| (Savage et al., 2014) | High temporal frequency measurements of greenhouse gas emissions from soils |
| (Scheer et al., 2008) | Nitrous oxide emissions from fertilized irrigated cotton (Gossypium hirsutum L.) in the Aral Sea Basin, Uzbekistan: Influence of nitrogen applications and irrigation practices |
| (Scheer et al., 2012) | Nitrous oxide emissions from irrigated wheat in Australia: impact of irrigation management |
| (Scheer et al., 2013) | Soil N2O and CO2 emissions from cotton in Australia under varying irrigation management |
| (Scheer et al., 2014) | Impact of nitrification inhibitor (DMPP) on soil nitrous oxide emissions from an intensive broccoli production system in sub-tropical Australia |
| (Shurpali et al., 2016) | Neglecting diurnal variations leads to uncertainties in terrestrial nitrous oxide emissions |
| (Simek et al., 2010) | Diurnal fluxes of CO2 and N2O from cattle-impacted soil and implications for emission estimates |
| (Skiba et al., 1996) | Measurement of field scale N2O emission fluxes from a wheat crop using micrometeorological techniques |
| (Smith et al., 1995) | The Measurement of Nitrous-Oxide Emissions from Soil by Using Chambers |
| (Smith et al., 1998) | Effects of temperature, water content and nitrogen fertilisation on emissions of nitrous oxide by soils |
| (van der Weerden et al., 2013) | Using near-continuous measurements of N2O emission from urine-affected soil to guide manual gas sampling regimes |
| (Wang et al., 2005) | Effects of environmental factors on N2O emission from and CH4 uptake by the typical grasslands in the Inner Mongolia |
| (Williams et al., 1999) | Temporal variations in nitrous oxide fluxes from urine-affected grassland |
| (Yang et al., 2018) | Diurnal variations and gap effects of soil CO2, N2O and CH4 fluxes in a typical tropical montane rainforest in Hainan Island, China |
| (Yao et al., 2009) | Comparison of manual and automated chambers for field measurements of N2O, CH4, CO2 fluxes from cultivated land |
| (Yeboah et al., 2018) | Short-term effects of biochar amendment on greenhouse gas emissions from rainfed agricultural soils of the semi-arid loess plateau region |
| (Zona et al., 2013) | N2O fluxes of a bio-energy poplar plantation during a two years rotation period |

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