OECD CRP Fellowship Summary Report:
Identifying drivers of N_2O emissions in a changing climate

Fellow: Dr. Eliza Harris
Host: Prof. Peter Rayner

Fellowship Details

- *Fellow name*: Eliza Jean Harris
- *Subject title*: Identifying drivers of N_2O emissions in a changing climate
- *Theme number*: 1 - Managing Natural Capital for the Future
- *Home institute*: Department of Ecology, University of Innsbruck
- *Host institute*: Department of Earth Sciences, University of Melbourne
- *Fellowship dates*: 16.12.19 to 14.05.20 (fellowship ended on 31.03.20 due to Covid19 situation)
- I consent to this report being posted on the Cooperative Research Programme's website

1 What were the objectives of the research project? Why is the research project important?

Nitrous oxide (N_2O) is a strong greenhouse gas and the most important stratospheric ozone-depleting substance emitted in the 21st century [9, 7, 6]. Anthropogenic emissions of N_2O result primarily from N addition to soils for agricultural fertilisation. Recent results have shown an acceleration in N_2O growth rate over the past decade; this acceleration is not due to rapidly increasing fertiliser use, but rather changes in N_2O emission processes [11], potentially due to the impact of climate change on emission pathways. The balance between contrasting N_2O emission pathways (oxic nitrification and anoxic denitrification) influences N_2O emission strength, and also relates to total reactive nitrogen loss, leaching, and fertilizer nitrogen (N) use efficiency, which control the environmental impacts of fertilizer N. However, modelling of N loss and N_2O emission processes at the global scale is currently limited, thus both past and future climate change feedbacks are difficult to constrain, complicating efforts to develop targeted mitigation policies.

This project aimed to develop a bottom-up model to understand the factors affecting N_2O emission processes globally, including climate change and anthropogenic activity, in order to identify hotspot regions with large fluxes and/or large predicted growth in fluxes. These regions represent potential targets for efficient mitigation of N_2O emissions. A specific goal of this project was to examine the impact of increasing drought and precipitation change, resulting from climate change, through examination of new experimental data in a global model framework.

2 Were the objectives of the fellowship achieved?

Significant progress towards the objectives of the fellowship has been made. Global data needed for model development has been collected, including an extension to the existing dataset of soil nitrogen isotopic composition for natural ecosystems ($\delta^{15}N_{soil}$) [3], that includes data collected from collaborators working in previously under-represented regions (Africa and Australia). A gridded global estimate of $\delta^{15}N_{soil}$ was calculated based on the $\delta^{15}N_{soil}$ database and global gridded datasets of mean annual temperature [8], aridity index [12], soil bulk density [2], soil carbon content [4] and soil pH [10]. These parameters provided a much better fit to $\delta^{15}N_{soil}$ data than previous parameterisations [1, 2] using only mean annual temperature and precipitation (Figure 1). Additionally, new data was added to the previous dataset of NO, N_2O and N_2 emissions presented in Bai et al. [2] to improve parameterisation of N-gas production based on soil moisture (Figure 2). A new parameterisation of nitrification and denitrification was also developed. These parameterisations were based on sigmoid curves fitted using Python's `scipy curve.fit` function .

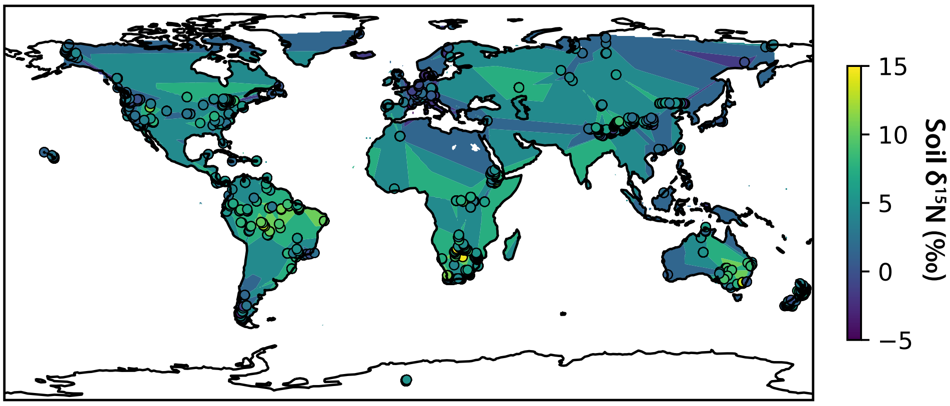

Figure 1: Global gradient in $\delta^{15}N_{nat_soils}$ based on parameterisation of measured $\delta^{15}N_{nat_soils}$ (shown with black outlines) using global gridded datasets of mean annual temperature, aridity index, soil bulk density, soil carbon content and soil pH.

A soil model was developed to estimate nitrogen losses in the preindustrial era from $\delta^{15}N_{soil}$ on an 0.5 x 0.5 degree grid. The soil model was based on the work of Bai et al. [2] and extended to include Rayleigh fractionation processes, isotopic site preference, and nitrification and denitrification pathways. The soil model provided an estimate of N losses to leaching, NH_3 volatilization, and gas production of NO, N_2 and N_2O globally. N_2O production was additionally partitioned into nitrification and denitrification pathways, and N_2O isotopic composition was calculated.

N_2O emissions as a fraction of N input from the soil model were converted to absolute values for each grid cell using N inputs from deposition, fixation[1] and fertilisation [5] from the preindustrial era to the present day. The calculated terrestrial emissions were coupled to a two-box model of the atmosphere representing a well-mixed troposphere and a stratosphere [13] to simulate temporal trends of N_2O mixing ratio and isotopic composition. This allowed comparison between the model and measured data from background stations (Cape Grim, Australia and Jungfraujoch, Switzerland).

The coupled soil-atmosphere model and data were then assimilated using a Markov-Chain Monte Carlo (MCMC) approach to optimize representation of key parameters describing N_2O emissions and processes. The model-data assimilation stage is not yet complete, however initial results show a strongly improved

[1]From the CABLE model, provided by Ying-Ping Wang, CSIRO

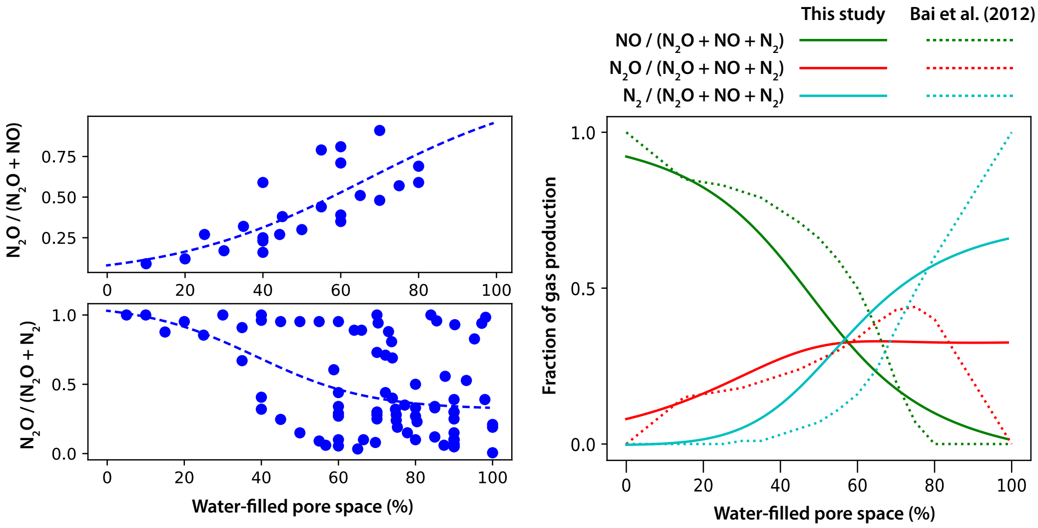

Figure 2: Left-hand panels show sigmoid fits to experimental measurements of $N_2O/(N_2O+NO)$ and $N_2O/(N_2O+N_2)$ as a function of soil moisture. Right-hand panels show the combined sigmoid fits used to calculate proportions of N_2O, N_2 and NO to total N gas production, as well as the empirical fits used previously [2].

representation of atmospheric data (Figure 3). Remaining steps for this project include the assimilation of global N_2O flux data, completion of statistical analysis of the data assimilation, and calculation of key output parameters such as the changing contribution of nitrification and denitrification pathways to N loss and N_2O emissions, as well as projection of future emissions using climate forecasts to estimate potential hotspots. The model will also be later extended to simulate multiple soil layers to facilitate use of N_2O depth profile measurements to constrain processes, and to simulate N_2O processes in climate extremes, particularly drought.

A major aim of the project was to foster networking and develop a research collaboration with Australian researchers, in particular the host Prof. Peter Rayner. The collaboration with Prof. Rayner was very successful, and I learnt a wide range of new skills, in particular working with gridded datasets, programming with Python, and Bayesian data assimilation. The collaboration with Prof. Rayner will be continued as the model development proceeds, and funding applications for future work are in progress. I also gave a seminar in the Soil and the Environment Research Group led by Prof. Deli Chen at the University of Melbourne, which resulted in many useful connections within the soil nitrogen research community. A connection to CSIRO in Aspendale, Melbourne, was also built upon, which was critical for N_2O data and measurements from the Cape Grim atmospheric research station (Drs. Paul Krummel and Zoë Loh), as well as guidance on model structure and N cycle inputs from the CABLE model (Dr. Ying-Ping Wang). Further networking opportunities resulted in obtaining new $\delta^{15}N_{soil}$ data from Australia (Dr. Naomi Wells, Southern Cross University; Dr. Mark Farrell, CSIRO Land and Water) and Africa (Dr. Matti Barthel, ETHZ; Dr. Marijn Bauters and Prof. Pascal Boeckx, Ghent University). Unfortunately, several planned seminars and meetings, including a contribution to the Earth System Science seminar at the University of Melbourne, had to be cancelled due to the Covid19 situation.

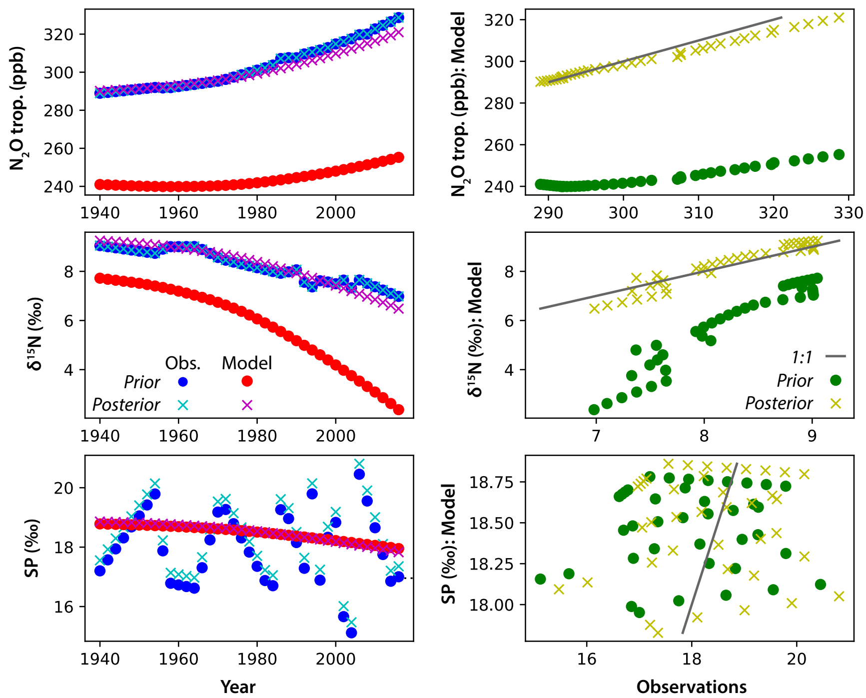

Figure 3: Observations and modelling of N_2O mixing ratio and isotopic composition in the troposphere using the couple soil-atmosphere model. An MCMC approach with 10 000 iterations was applied for model-data assimilation to optimize values for key parameters.

3 What were the major achievements of the fellowship?

The major achievements of this fellowship were:

1. Development and initial optimization of the coupled soil-atmosphere model of N loss processes
2. New skills I have obtained, in particular programming skills in Python and a familiarity with Bayesian data assimilation
3. A strong and ongoing collaboration between my work at the University of Innsbruck, and Prof. Rayner and other climate change and nitrogen cycle researchers in Australia

4 Will there be any follow-up work?

Model development and optimization will continue for several more months, following which a publication will be prepared. The publication is expected to be finalised and submitted by late 2020 (the OECD Co-operative Research Programme will be notified and acknowledged for their funding contribution). Funding application(s) for future collaborations - in particular extension of the model to simulate multiple soil layers and drought processes - will be submitted in 2020 for work beginning in late 2020 and 2021.

5 How might the results of your research project be important for helping develop regional, national or international agro-food, fisheries or forestry policies and, or practives, or be beneficial for society?

This work will greatly improve our understanding of N loss processes, as well as the global contributions of different N_2O emission pathways and thus the factors driving N_2O emissions from the preindustrial to today. This will allow emission hot spots to be identified, where emission reductions may be most efficient, in order to facilitate development of emission mitigations that can also foster sustainable agriculture and food production practices.

6 How was this research relevant to the objectives of the CRIP and the CRP research theme?

This research is relevant to the theme area ”Managing Natural Capital for the Future” as it relates to sustainable use of nitrogen by minimising losses as well as reducing greenhouse gas emissions. The focus on drivers and pathways is particularly relevant to identify hotspots and hot moments where mitigation of N loss and N_2O emissions can be most effective, thus contributing to the protection of functioning ecosystems for future generations.

7 Satisfaction with the fellowship

The fellowship was completely successful; I was able to gain many new skills and form lasting connections with many expert researchers, despite finishing early due to Covid19. I will be able to apply these skills to research questions at my home institute in Austria and open new research areas, as well continuing to work and collaborate with the new network I have developed in Australia.

8 Advertising the Co-operative Research Program

I found out about the OECD CRP fellowship program through a flyer in the break room at the University of Innsbruck. I have also seen the program advertised on the ISOGEOCHEM mailing list and heard about it from colleagues who have had conferences or travel funded through the program. Topical mailing lists are a good way to reach many interested researchers, as is dissemination through past fellows. I have recommended the program to other potential candidates.

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