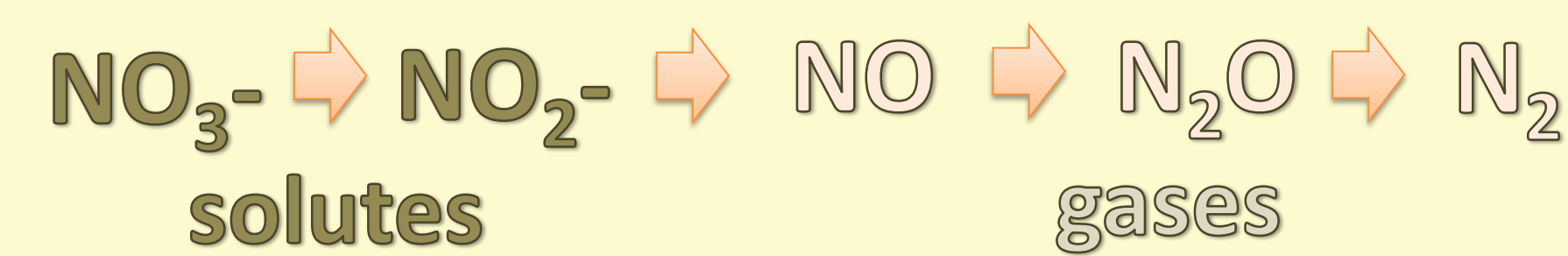


# Creating a bridge from microbiology to modeling: Improving our ability to understand nitrous oxide (N<sub>2</sub>O) dynamics on multiple scales and create better climate models for the future

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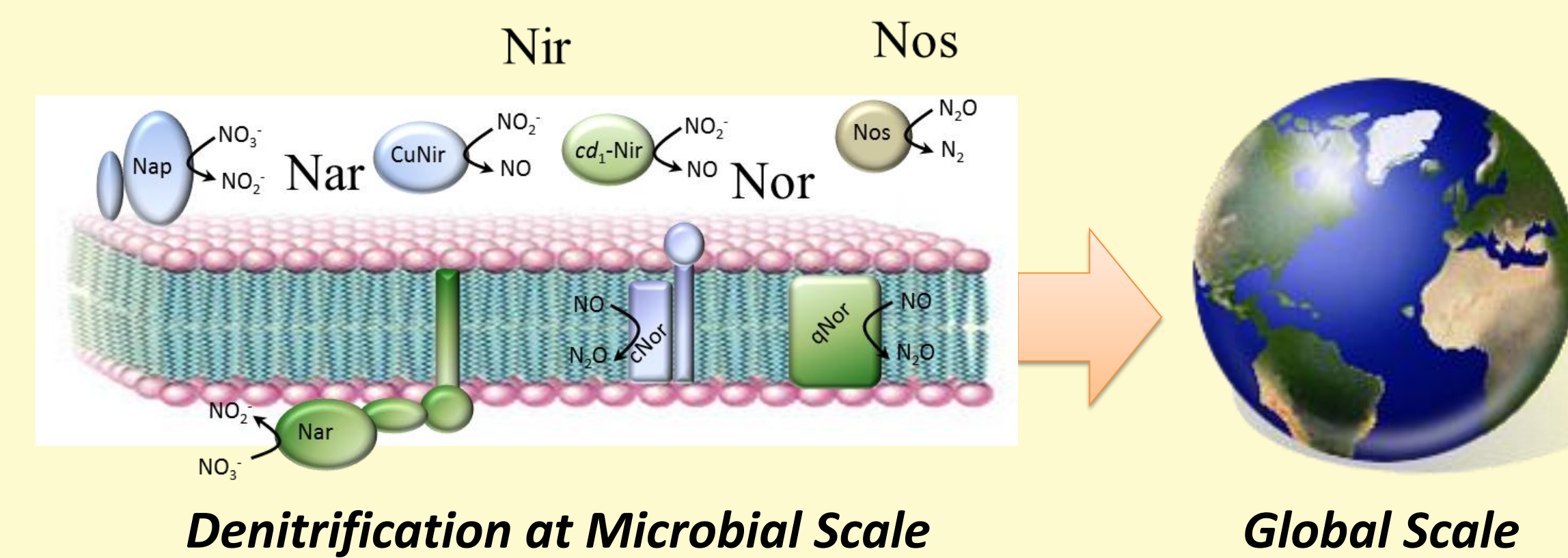
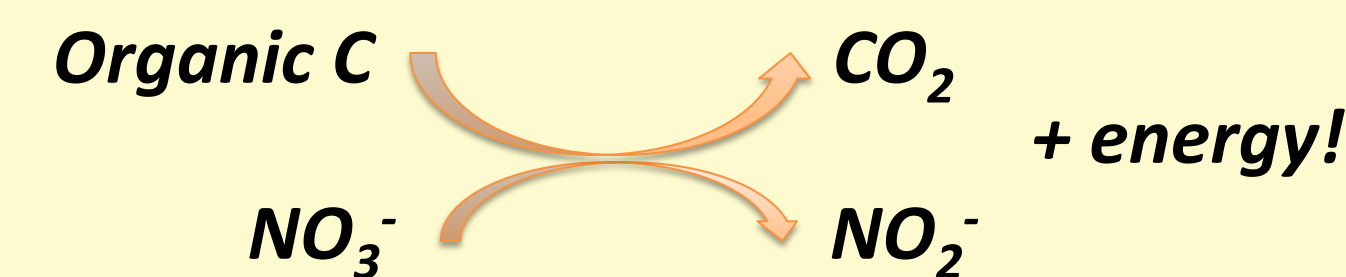
Cross-Scale Biogeochemistry and Climate IGERT and <sup>1</sup>Dept. of Biological & Environmental Engineering <sup>2</sup>Dept. of Microbiology <sup>3</sup>Dept. of Ecology & Evolutionary Biology, Cornell University, Ithaca NY

## Scaling a microbial process to a global model



Denitrification, shown above, is a process that reduces nitrate (NO<sub>3</sub><sup>-</sup>) into several potential products including nitrous oxide (N<sub>2</sub>O), a gas with a global warming potential 310 times greater than CO<sub>2</sub>.<sup>1</sup>

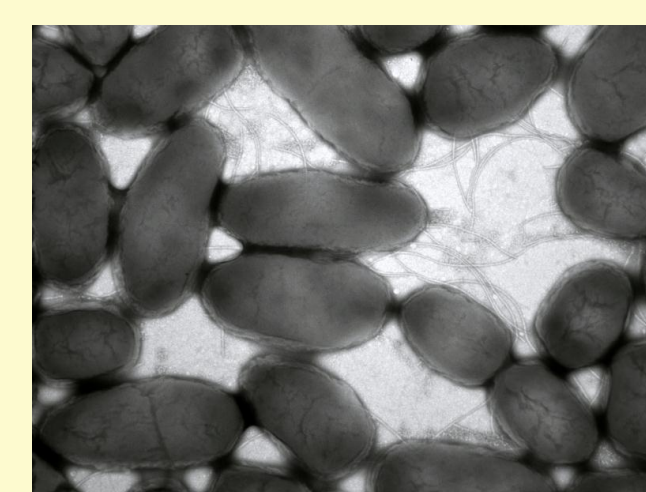
Denitrification is performed by microbes who gain energy from the process. Each part of the denitrification pathway is controlled by separate genes which have variable environmental controls. Thus, environmental conditions have potential to control the rates and products of denitrification, including N<sub>2</sub>O.



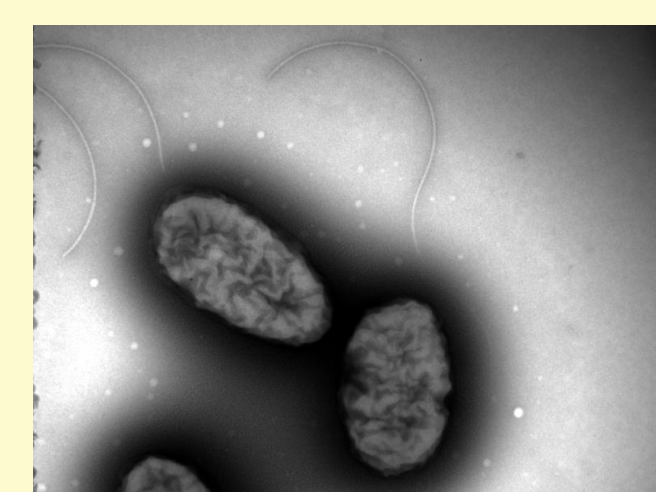
In order to ultimately improve estimates of N<sub>2</sub>O emissions in global climate models, we need a good understanding of what controls the production of N<sub>2</sub>O via microbial denitrification. To tackle this problem, we are conducting research to understand these controls at the microbial and landscape scales.

## Lab & Field Research at the Microbial Scale

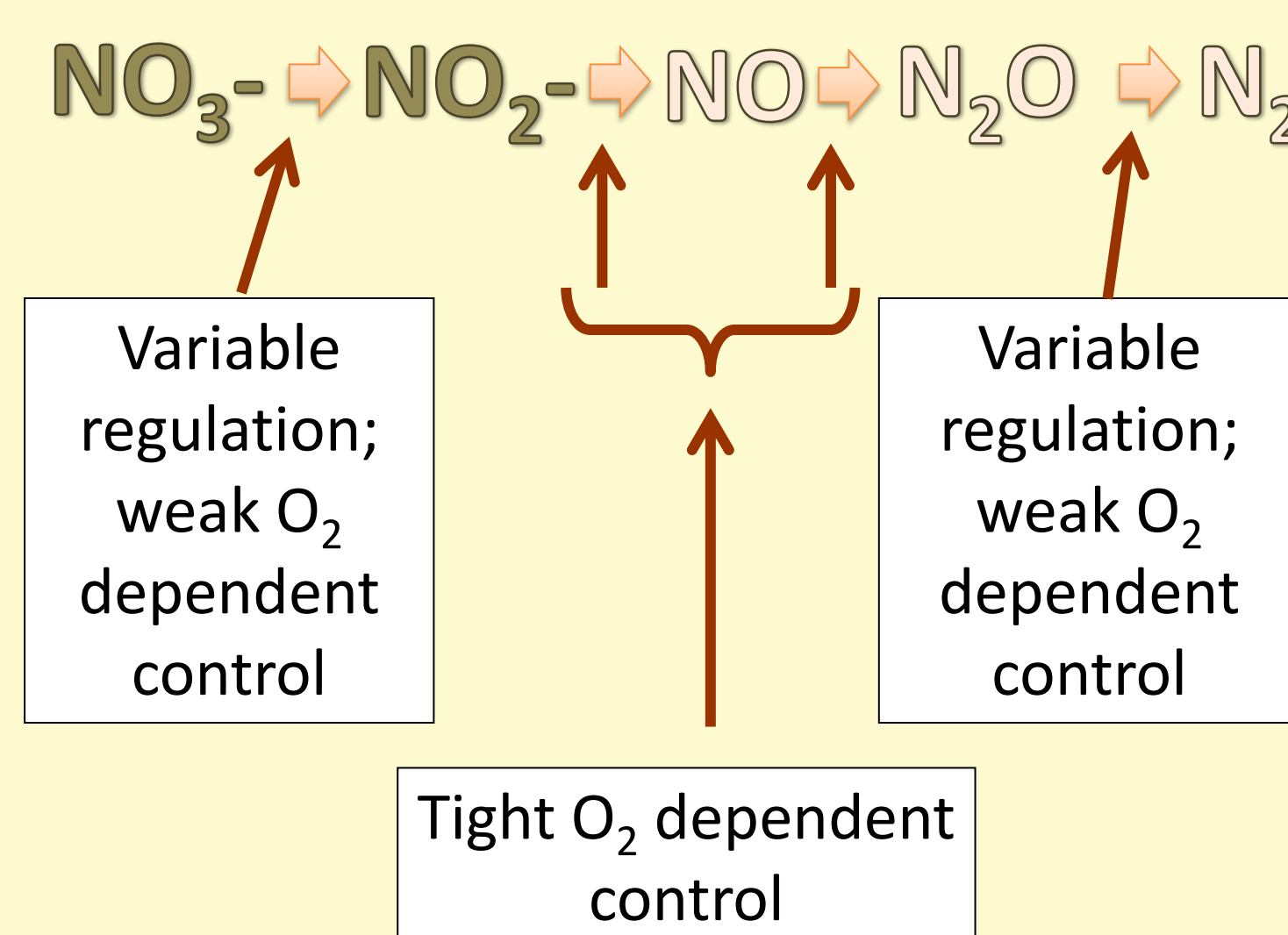
Researcher: Armanda Roco



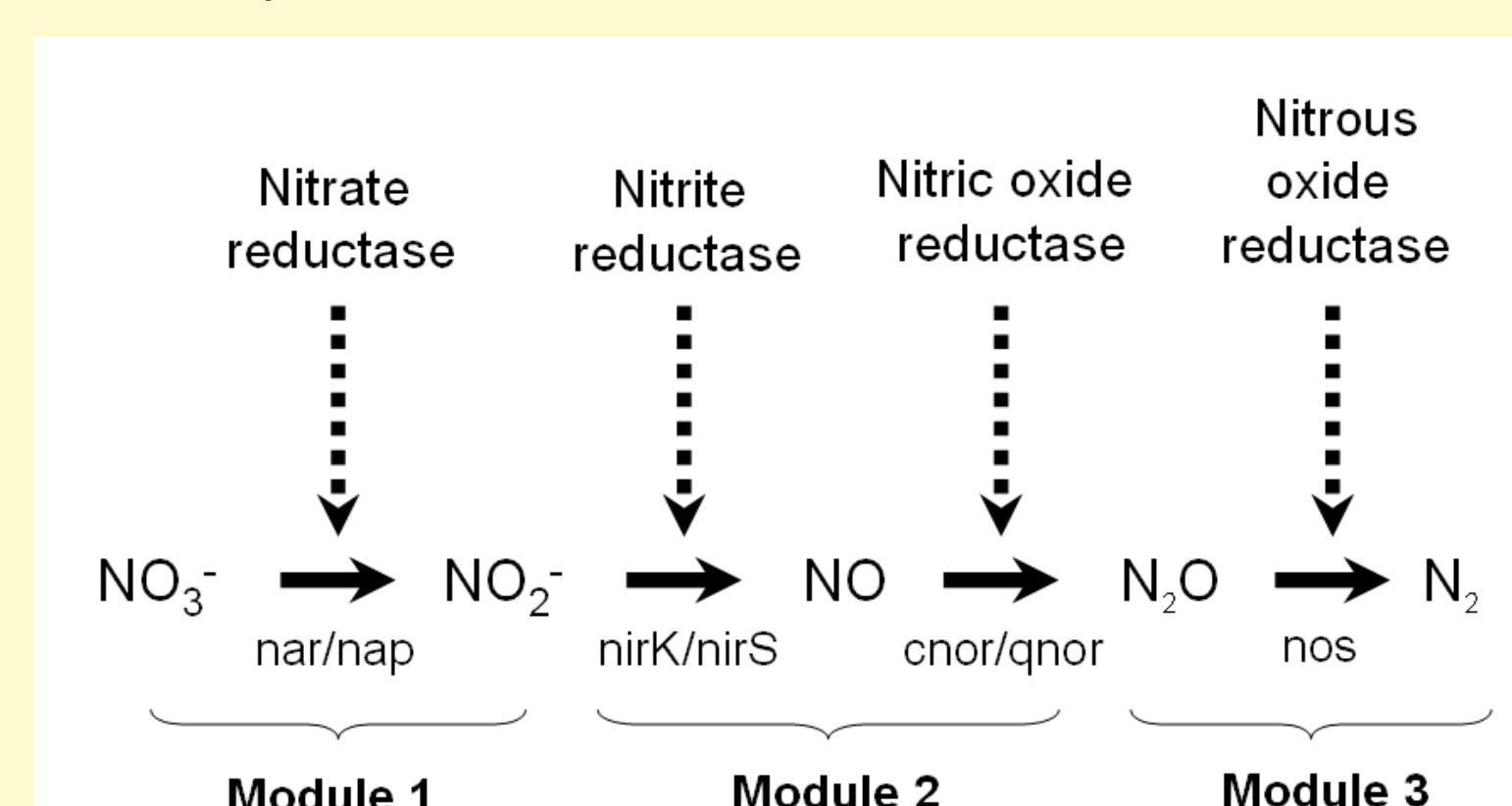
I have isolated bacteria from a number of different ecosystems and have seen that that denitrification is more dynamic than expected and a wider diversity of microorganisms play prominent roles.



The textbook definition of denitrification is that it is a tightly connected pathway whose activity is inversely correlated with oxygen levels<sup>2</sup>. My work has shown that the tight connectivity is not universal and O<sub>2</sub> regulation is variable throughout the pathway. I have also been able to isolate many denitrifiers who don't have the genes to perform all four steps of the pathway, so called 'incomplete denitrifiers'.



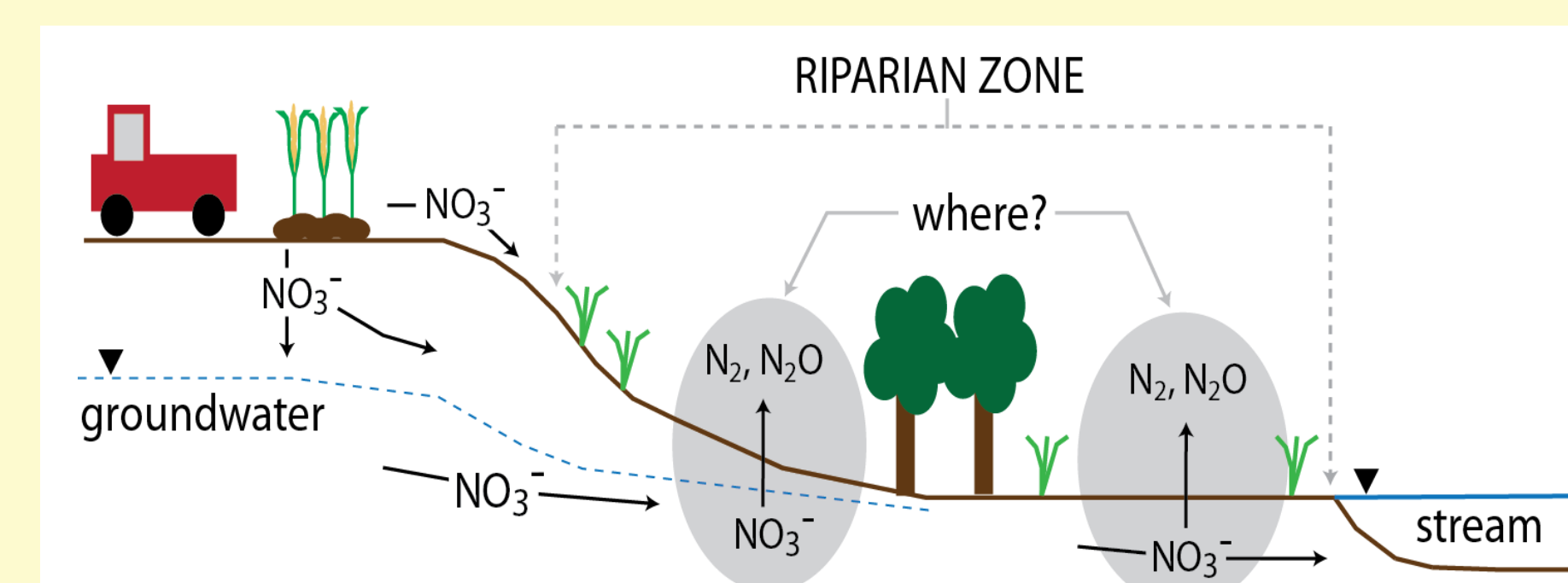
Taking into account these differences in gene regulation and the common occurrence of incomplete denitrifiers, it is unrealistic to model denitrification as a single, tightly linked pathway. We hypothesize that denitrification should be best modeled as a three module pathway, shown in the figure below. The idea of modularity may explain the distribution of denitrification genes in a community and may help us understand what is driving high N<sub>2</sub>O emissions in some ecosystems over others.



Suggested modularity of denitrification based on differential environmental controls

## Field Research at the Landscape Scale

Researcher: Lauren McPhillips

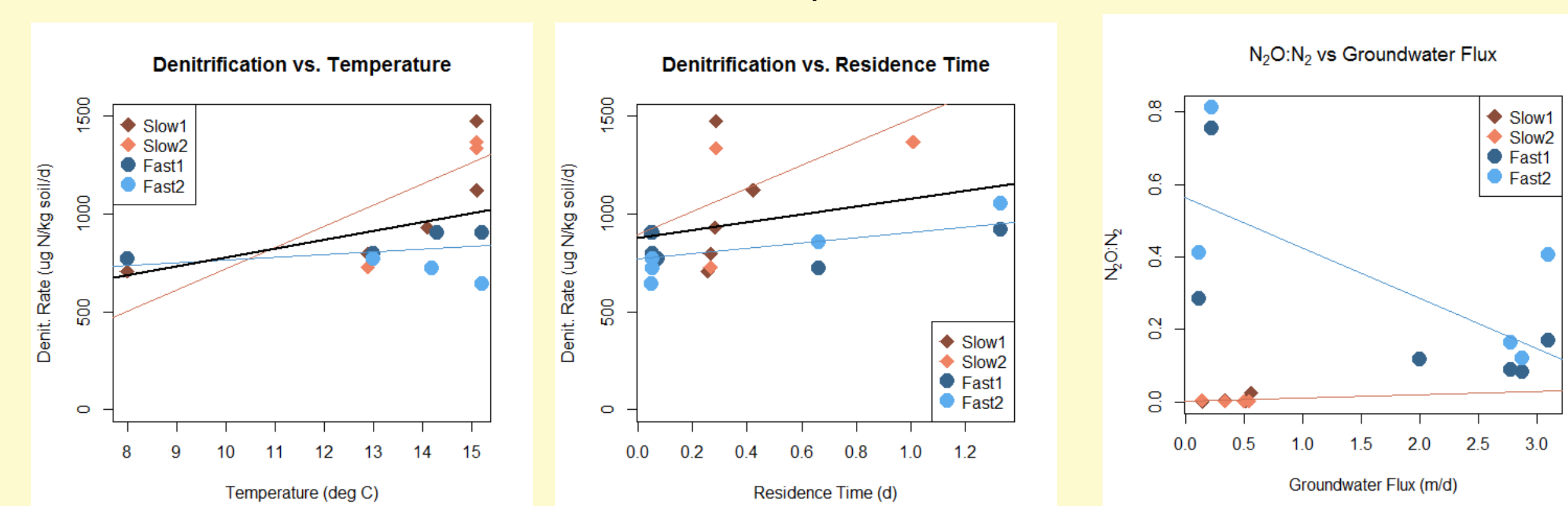


We studied denitrification at 2 sites in a stream riparian area, where relatively wet (and anoxic) conditions were expected to promote high denitrification rates.



To measure denitrification, we dosed groundwater with <sup>15</sup>NO<sub>3</sub><sup>-</sup> (photo at right) to be able to quantify both N<sub>2</sub>O and N<sub>2</sub>.<sup>3</sup> Along with these monthly measurements during summer and fall 2011, we quantified water and soil chemistry, temperature, and groundwater hydrology using a series of groundwater wells.

We combined our information on denitrification rates and production of N<sub>2</sub>O vs. N<sub>2</sub> along with the other measured environmental parameters to understand the controls on the observed denitrification patterns.



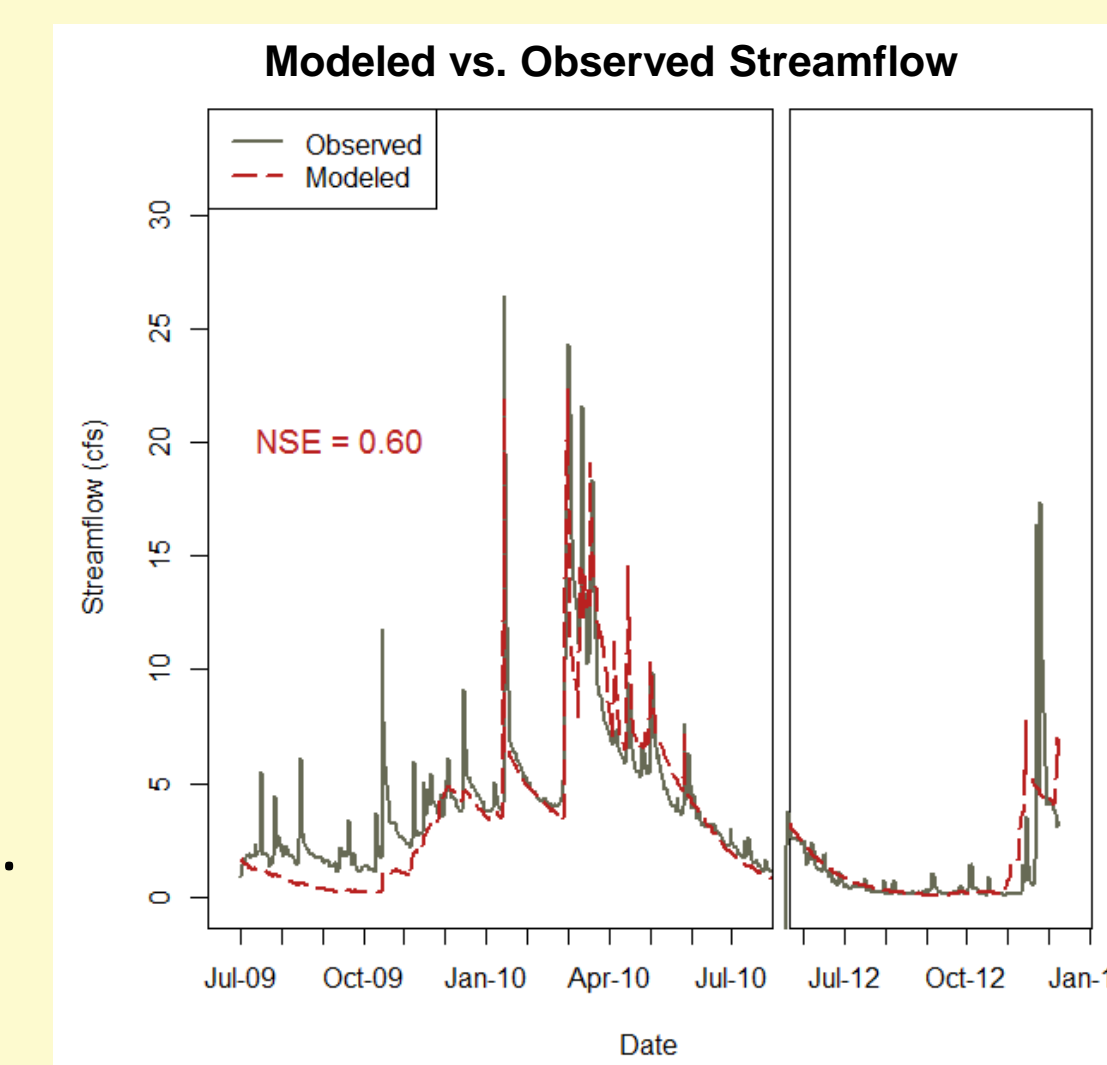
The results highlighted positive feedbacks between denitrification and temperature. Residence time (calculated from groundwater fluxes) also showed a positive correlation - so while moisture is important to have anoxic conditions for parts of the denitrification pathway, very fast groundwater movement can actually reduce denitrification. Groundwater fluxes were found to reduce N<sub>2</sub>O production at one site, though the other site had very low N<sub>2</sub>O production in general.

## Modeling at the Landscape Scale

Researcher: Janet Barclay

We take denitrification measurements at the landscape scale and use them to model denitrification across the landscape. The basis of our model is a semi-distributed hydrologic model, coupled with a denitrification model.

The hydrologic model tracks daily soil water in 10 wetness classes, to predict soil moisture in each wetness class and the daily stream discharge (right). Soil moisture serves as a proxy for soil O<sub>2</sub> dynamics.

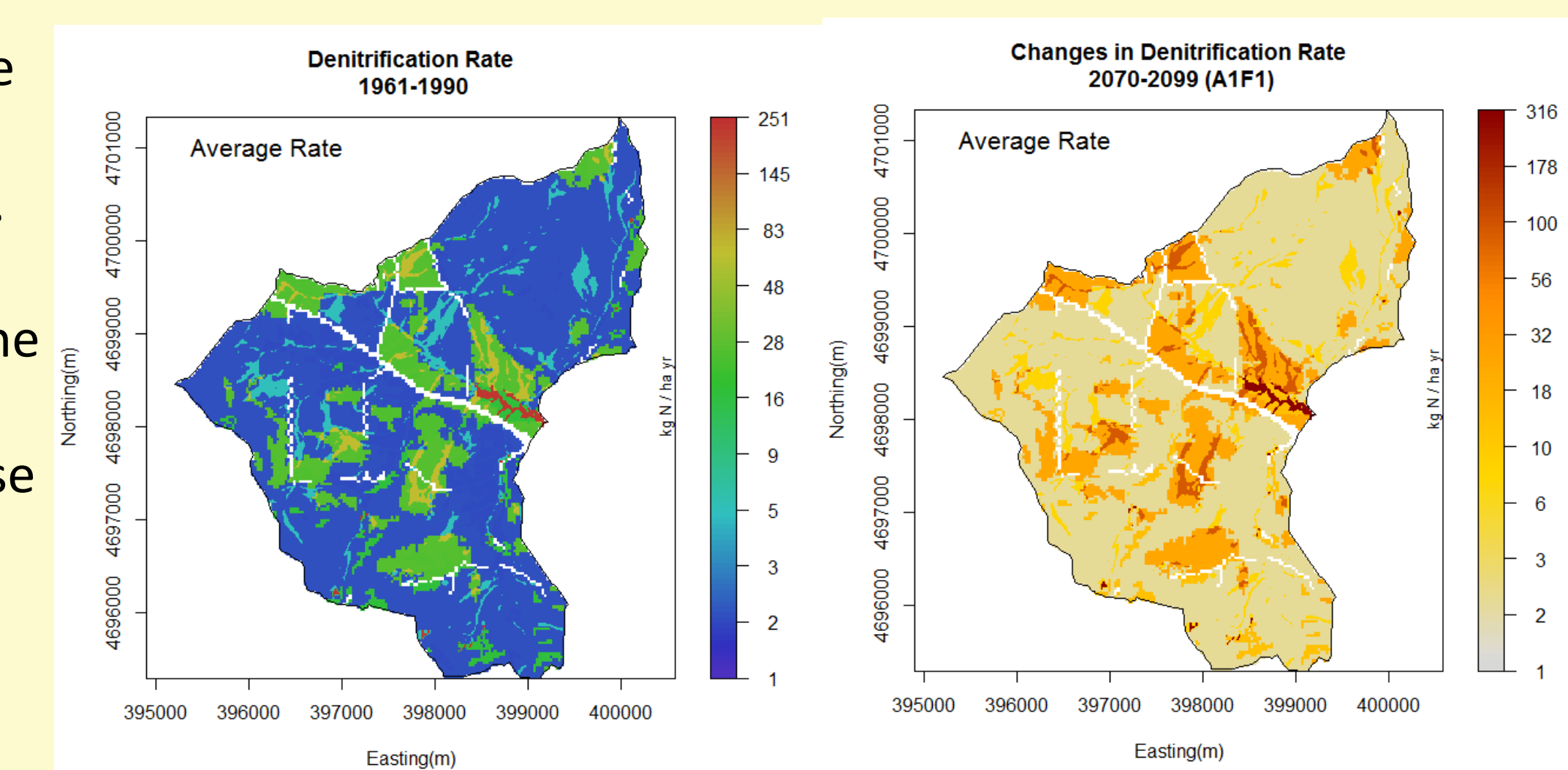
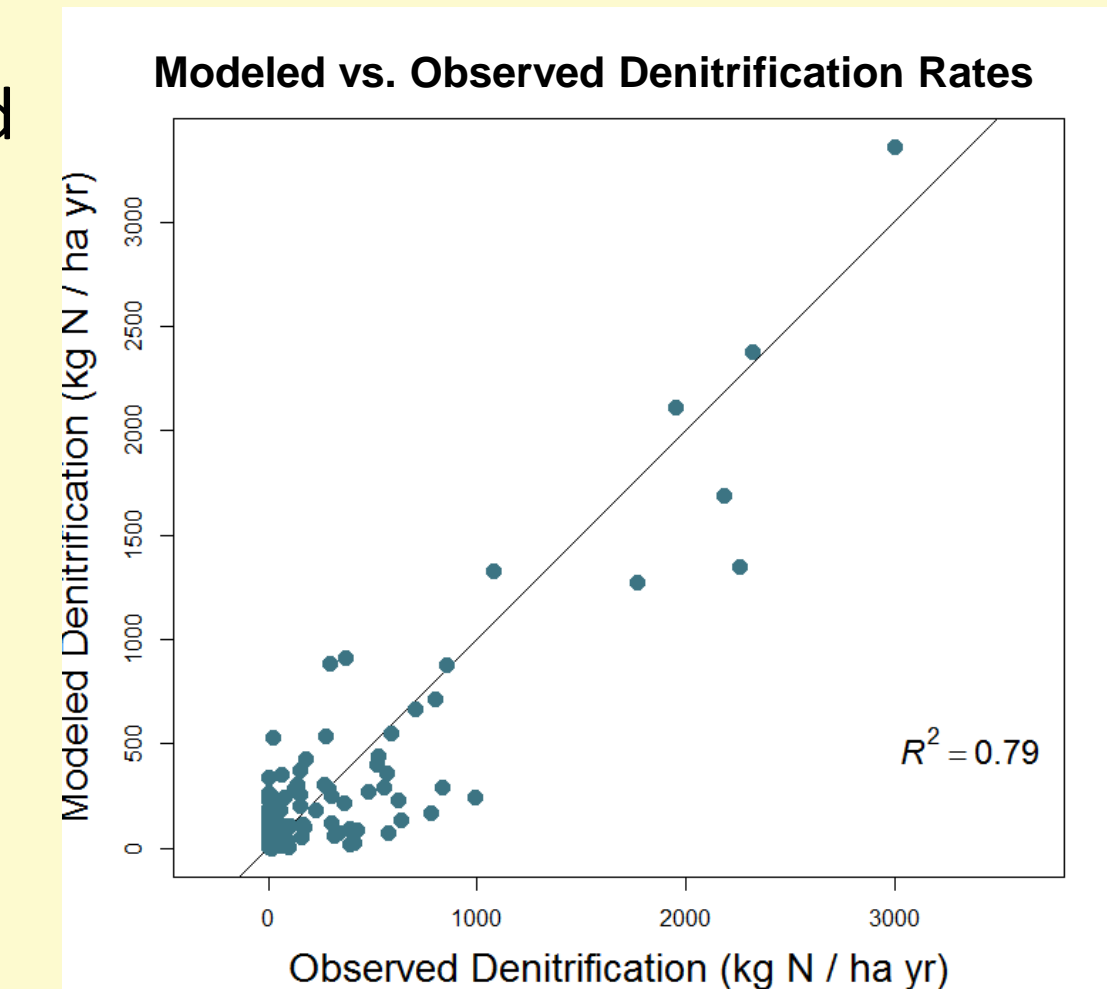


The denitrification model (below), predicts the denitrification rate (D<sub>a</sub>) as a function of a potential denitrification rate (D<sub>p</sub>), and five parameters related to NO<sub>3</sub><sup>-</sup> concentration (f<sub>N</sub>), Soil Saturation (f<sub>s</sub>), Soil Temperature (f<sub>T</sub>), Dissolved Organic Carbon (f<sub>DOC</sub>), and Soil Organic (f<sub>OM</sub>).

$$D_a = D_p f_N f_s f_T f_{DOC} f_{OM}$$

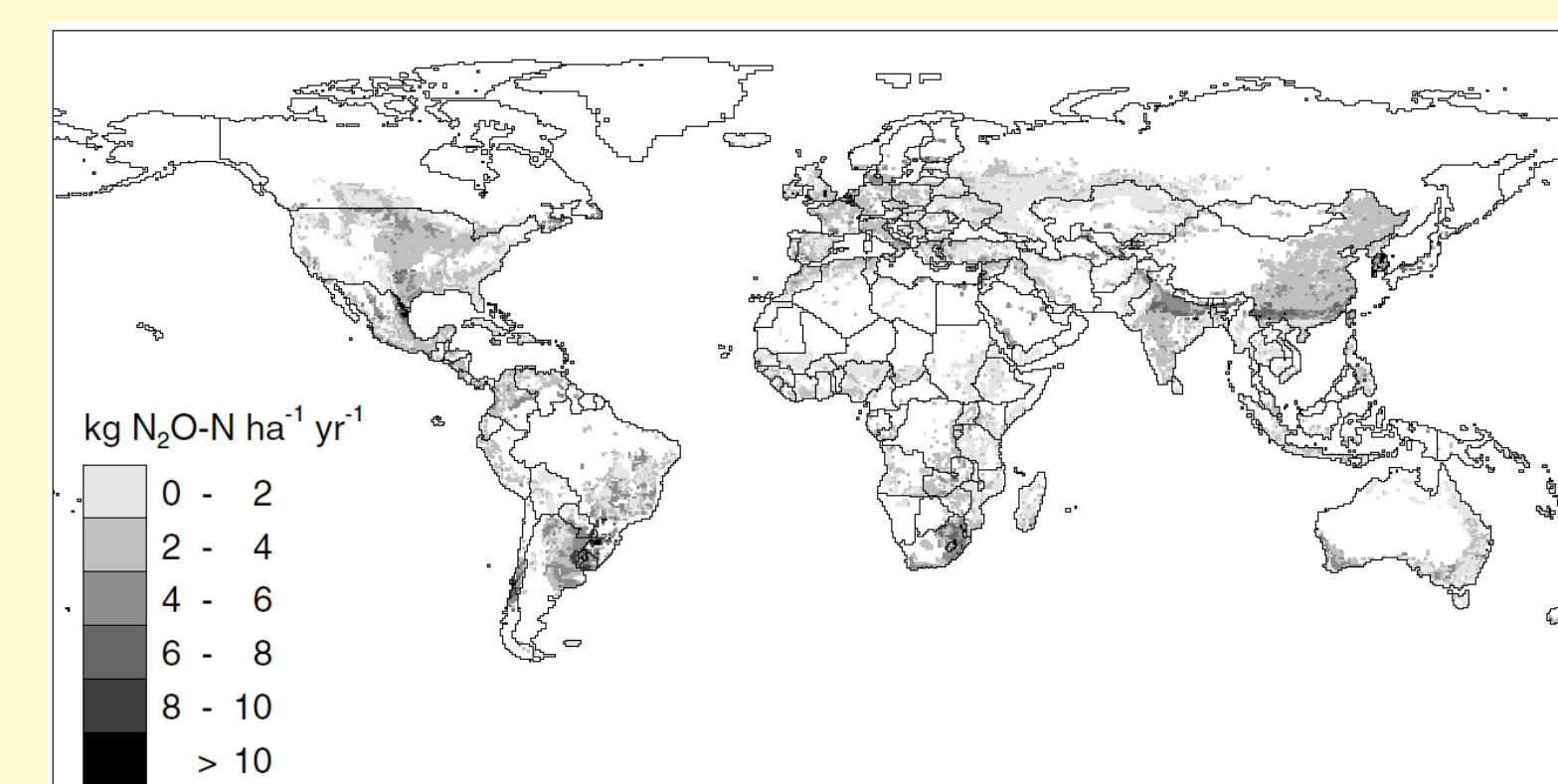
We used measurements of riparian denitrification to parameterize a simple multiplicative denitrification model.

One application of this model is to understand climate change feedbacks (e.g. temp., precip. increases) with denitrification in the landscape (right). We also hope to use it to inform larger-scale models of denitrification and eventually N<sub>2</sub>O.



## Next Steps

- Continue to create more direct synergies between these research scales (a major goal of our IGERT program)
  - Collaboration between Armanda (microbial scale) and Lauren (landscape scale) will investigate the microbial controls on the variable N<sub>2</sub>O dynamics at Lauren's riparian denitrification research sites
  - Use Armanda and Lauren's work to parse out specific denitrification products (N<sub>2</sub> vs. N<sub>2</sub>O) and better incorporate O<sub>2</sub> dynamics and modularity within Janet's denitrification landscape model
- Expand research on the landscape scale to cover a wider variety of land use areas, soil types, etc.
- Collaborate with researchers at the global scale to achieve our goal of bringing understanding of small-scale controls on denitrification and specifically N<sub>2</sub>O emissions into improvements of global climate models



Results from an existing model of global N<sub>2</sub>O emissions<sup>4</sup>

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