

## **Integrated measurements and modeling of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O fluxes using soil microsite frequency distributions**

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Soil fluxes of greenhouse gases (GHGs) play a significant role as biotic feedbacks to climate change. Production and consumption of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) are affected by complex interactions of temperature, moisture, and substrate supply, which are further complicated by spatial heterogeneity of the soil matrix. Models of belowground processes of these GHGs should be internally consistent with respect to the biophysical processes of gaseous production, consumption, and transport within the soil, including the contrasting effects of oxygen (O<sub>2</sub>) as either substrate or inhibitor.

We installed automated chambers to simultaneously measure soil fluxes of CO<sub>2</sub> (using LiCor-IRGA), CH<sub>4</sub>, and N<sub>2</sub>O (using Aerodyne quantum cascade laser) along soil moisture gradients at the Howland Forest in Maine, USA. Measured fluxes of these GHGs were used to develop and validate a merged model. While originally intended for aerobic respiration, the core structure of the Dual Arrhenius and Michaelis-Menten (DAMM) model was modified by adding M-M and Arrhenius functions for each GHG production and consumption process, and then using the same diffusion functions for each GHG and for O<sub>2</sub>.

The area under a soil chamber was partitioned according to a log-normal probability distribution function, where only a small fraction of microsites had high available-C. The probability distribution of soil C leads to a simulated distribution of heterotrophic respiration, which translates to a distribution of O<sub>2</sub> consumption among microsites. Linking microsite consumption of O<sub>2</sub> with a diffusion model generates microsite concentrations of O<sub>2</sub>, which then determine the distribution of microsite production and consumption of CH<sub>4</sub> and N<sub>2</sub>O, and subsequently their microsite concentrations using the same diffusion function. At many moisture values, there are some microsites of production and some of consumption for each gas, and the resulting simulated microsite concentrations of CH<sub>4</sub> and N<sub>2</sub>O range from below ambient to above ambient atmospheric values. As soil moisture or temperature increase, the skewness of the microsite distributions of heterotrophic respiration and CH<sub>4</sub> concentrations shifts toward a larger fraction of high values, while the skewness of microsite distributions of O<sub>2</sub> and N<sub>2</sub>O concentrations shifts toward a larger fraction of low values. This approach of probability distribution functions for each gas simulates the importance of microsite hotspots of methanogenesis and N<sub>2</sub>O reduction at high moisture (and temperature). In addition, the model demonstrates that net consumption of atmospheric CH<sub>4</sub> and N<sub>2</sub>O can occur simultaneously within a chamber due to the distribution of soil microsite conditions, which is consistent with some episodes of measured fluxes.

Because soil CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub> fluxes are linked through substrate supply and O<sub>2</sub> effects, the multiple constraints of simultaneous measurements of all three GHGs proved to be effective when applied to our combined model. Simulating all three GHGs simultaneously in a parsimonious modeling framework provides confidence that the most important mechanisms are skillfully simulated using appropriate parameterization and good process representation.