Soil-biogenic NOx Emissions General Review

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Soils are an important source of reactive nitrogen (NOx) due to the microbial production of nitric oxide (NO) in the nitrification and (chemo-)denitrification process and the subsequent chemical transformation of the emitted NO. Nitrification, denitrification and chemodenitrification depend on biogeochemical and physical properties of the soil, e.g., microbial species, soil texture, soil water, pH, redox-potential and nutrient status [e.g., *Conrad*, 1996]. Soil emission fluxes are also tightly linked to land use management through the impact of the application of natural and synthetic fertilizers, tillage, irrigation, compaction, planting and harvesting [e.g., *Frolking et al.,* 1998]. The actual flux of NOx into the atmosphere over vegetation depends on the interactions between turbulent transport, chemistry and the subsequent uptake of the reaction products within the canopy [e.g., *Ganzeveld et al.*, 2002].

Soil NO emissions control NO_x budgets in remote and rural areas, while the fossil fuel source of 20-25 TgN yr^{-1} [e.g., *Delmas et al.,* 1997; and references therein] dominates the NO_x budget in industrialized areas. Estimates of the soil NO sources range between 9.7 TgN yr^{-1} *Potter et al.* [1996] and 21 TgN yr-1 *Davidson and Kingerlee* [1997] whereas estimates, that include the role of canopy deposition, are about 50% smaller [*Yienger and Levy*, 1995, *Ganzeveld et al.*, 2002]. The inventory by *Yienger and Levy* [1995], which is available to the modeling community through the GEIA site, is based on an empirical model that accounts for different biomes, pulsing, which is the enhancement of the emissions through rainfall, and the effect of the canopy uptake. Their NO soil emission flux of 11 TgN yr^{-1} (below canopy, and consequently their atmospheric source estimate is 5.5 TgN yr^{-1}) is slightly larger compared to estimate of 9.7 TgN yr^{-1} by *Potter et al.* [1996], who used an ecosystem modeling approach (CASA) by integrating remote sensing, climate, vegetation and soil datasets. Monthly mean global distributions at a 1 degree grid resolution of the NO emission fluxes (and other gases) simulated with the CASA model can be downloaded from the NASA Ames ftp server: http://geo.arc.nasa.gov/sge/casa/data.html.

The inventory by *Davidson and Kingerlee* [1997] is a purely measurement based source inventory, based on major global biomes, with an estimated total global soil NO emission of 21 TgN yr-1, with major contributions from temperate and tropical cultivated land, chaparral/thorn forest and tropical savannah/woodland. The model-based estimates of the soil NO emission flux by *Yienger and Levy* [1995] and *Potter et al.* [1996], and the measurement-based estimates by *Davidson* [1991] and *Davidson and Kingerlee* [1997], disagree by a factor of 2 overall. This discrepancy suggests that the role of some important soil emission control factors such as fertilization and pulsing might not be realistically represented in the models [*Hutchinson et al.,* 1997]. An essential difference between the model- and measurement based inventories is that the model based inventories can provide a temporally resolved soil-biogenic NO_x flux. This depends on to what extent the role of parameters that control the temporal variability, e.g., soil moisture, temperature and fertilizer application, has been included in the model and, in addition, what the temporal resolution of these input parameters is.

Another useful database that provides a global agricultural NO (and N2O and NH3) emission inventory at a 0.5 degree spatial resolution [*FAO/IFA*, 2001; *Bouwman et al.,* 2002] is accessible at: http://arch.rivm.nl/ieweb/ieweb/index.html. This dataset is based on statistical analyses of 846 N2O and 99 emission measurements in agricultural fields used to describe the role of the major drivers that control the emissions.

Sensitivity to future climate, land cover and land use changes.

As mentioned before, the processes that are mainly controlling the production of soil NO are influenced by soil environmental conditions such as soil– temperature, moisture, fertility, vegetation cover, fire and land use management. For example, a 10 °C rise in soil temperature produces a 2-5 fold increase in NO emission rates [*Williams and Fehsenfeld*, 1991; *Valente and Thornton*, 1993]. Short-term changes in soil moisture after a rainfall event can influence soil behaviour such that production of NO can revert to NO consumption [*Davidson*, 1991] or it can result in large pulse of NO [*Davidson*, 1992; *Meixner et al.,* 1999]. One of the specific land-use practices, biomass burning, results in a temporary reduction in the plant and microbial sink of soil inorganic nitrogen and thereby favouring the conditions for NO production [e.g., *Verchot et al*., 1999]. These examples of the sensitivity of soil-biogenic NOx fluxes to the specific control factors, and the fact that the actual emission flux is determined by a complex interplay between all the production and destruction processes, complicates a prediction of the impact of climate change and land cover and land use changes on the emissions. A straightforward extrapolation of these sensitivities, like the temperature induced emission increase, is not expected to result in a realistic prediction of the changes in the global soil-biogenic NOx emissions due to climate change. For example, there might be a short-term increase in the soil NO emissions due to a temperature change but the question arises if this temperature effect would last on the long-term due to a faster depletion of the substrates that are involved in the microbiological processes.

A promising approach to assess the impact of anticipated future climate and land use and land cover conditions on soil-biogenic NOx emissions is the use of process-based soil N emission models, like the CASA model [*Potter et al.*, 1996], CENTURY/DAYCENT [e.g., *Parton et al.,* 2001; *Kirkman et al.*, 2002] and DNDC [e.g, *Li et al.,* 2000]: http://www.dndc.sr.unh.edu. These models consider to some extent the short- and long-term variability in biogeochemical processes and emission fluxes as a function of the controlling environmental parameters like temperature, soil moisture and vegetation dynamics. These models provide a tool to assess the impact of climate change and land cover and land use changes on soil-biogenic NOx emissions through integrating the dependence of the emissions on all the controlling parameters involved on short- as well as long timescales. Moreover, the process models can be used to identify the key parameters that are mainly responsible for the changes in the soil-biogenic NOx emissions and that should be focus in such an assessment.

References

Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes, Modeling global annual N2O and

NO emissions from fertilized fields. *Global Biogeochemical Cycles*, 2002, (in press).

Conrad, R., Soil micoorganisms as controllers of atmospheric trace gases (H2, CH4, OCS, N2O and NO), *Micro-biological Reviews, 60,* 609-640, 1996.

Davidson, E. A., Fluxes of nitrous oxide and nitric oxide from terrestrial ecosystems. In: *Microbial production and consumption of greenhouse gases: methane, nitrogen oxides, and halomethanes*, Rogers, J. E., and W. B. Whitman (eds.), 219-235. Washington: American Society for Microbiology, 1991.

Davidson E.A., Pulses of nitric oxide and nitrous oxide flux following wetting of dry soil: an assessment of probable sources and importance relative to annual fluxes, *Ecological Bulletin, 42*, 149-155, 1992.

Davidson, E. A. and W. Kingerlee, A global inventory of nitric oxide emissions from soils, *Nutr. Cycling Agroecosys., 48,* 37-50, 1997.

Delmas, R., D. Serça and C. Jambert, Global inventory of NOx sources, *Nutr. Cycling Agroecosys., 48,* 51-60, 1997.

FAO/IFA (2001) Global Estimates of Gaseous Emissions of NH3, NO and N2O from agricultural land. Food and Agriciculture Organization of the United Nations (FAO) / International Fertilizer Industry Association (IFA), Rome, 106 pp. (available from http://www.fertilizer.org/ifa).

Frolking, S. E., A. R. Mosier, D. S. Ojima, C. Li, W. J. Parton, C. S. Potter, E. Priesack, R. Stenger, C. Haberbosch, P. Dörsch, H. Flessa, and K. A. Smith, Comparison of N2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models, *Nutr. Cycl. Agroecosyst., 52*, 77-105, 1998.

Ganzeveld, L., J. Lelieveld, F. J. Dentener, M. C. Krol, A. F. Bouwman, and G.-J. Roelofs, The influence of soil-biogenic NOx emissions on the global distribution of reactive trace gases: the role of canopy processes, *J. Geophys. Res.*, 107, 2002.

Hutchinson, G. L., M. F. Vigil, J. W. Doran, and A. Kessavalou, Coarse-scale soil-atmosphere NOx exchange modelling: status and limitations, *Nutr. Cycling Agroecosys., 48,* 25-35, 1997.

Kirkman, G. A., C. Ammann, E. A. Holland, D. A. Roberts, and F. X. Meixner, Soil NO emissions in Rondônia, Brazil, II: A regional up-scaling, *Ecological Applications*, submitted, 2002.

Li, C., J. Aber, F. Stange, K. Butterbach-Bahl, and H. Papen, A process-oriented model of N2O and NO emissions from forest soils: 1. Model development, *J. Geophys. Res.,* 105, 4369-4384, 2000.

Meixner, F. X., and W. Eugster, Effects of landscape patterns and topography on emissions and transport, in: *Integrating Hydrology, Ecosystem Dynamics, and Biogeochemistry in Complex Landscapes,* J. D. Tenhunen, and P. Kabat (eds.), Dahlem Workshop Report, 147-175, John Wiley & Sons Ltd., Chichester, 1999.

Parton W. J., E. Holland, S. Del Grosso, M. D. Hartman, R. Martin, R. Arvin, R. Mosier, D. S. Ojima, and D. S. Schimel, Generalized model for NOx and N2O emissions from soils, *J. Geophys. Res., 106*, 17,403-17,420, 2001.

Potter, C. S., P. A. Matson, P. M. Vitousek, and E. Davidson, Process modeling of controls on nitrogen trace gas emissions from soils worldwide, *J. Geophys. Res., 101,* 1361-1377, 1996.

Valente, R. J. and F. C. Thornton, Emissions of NO from soils at a rural site in Central Tennessee, *J. Geophys. Res., 98,* 16745-16753, 1993.

Verchot, L. V., E. A. Davidson, J. H. Cattanio, I. L. Ackerman, H. E. Erickson, and M. Keller, Land use change and biogeochemical controls of nitrogen oxide emissions from soils in eastern Amazonia, *Global Biogeochem. Cycles, 13,* 31-46, 1999.

Williams E. J., and F. C. Fehsenfeld, Measurement of soil nitrogen oxide emissions at three North American ecosystems, *J. Geophys. Res.*, 96, 1033-1042, 1991.

Yienger, J. J., and H. Levy, II, Global inventory of soil-biogenic NOx emissions, *J. Geophys. Res., 100*, 11,447-11,464, 1995.

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