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MODELLING NITROUS OXIDE EMISSIONS FROM ORGANIC SOILS IN EUROPE USING A STATISTICAL BASED, FUZZY LOGIC APPROACH

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SUMMARY

Greenhouse gas emissions of peat land ecosystems are relevant in the emission budget for Europe. Therefore the GHG-Europe project aims to improve the modelling capabilities for greenhouse gases, e.g. nitrous oxide, in all ecosystems including peatlands. The heterogeneous and event driven fluxes of nitrous oxide are challenging to model on European scale. Due to these challenges adequate techniques are needed to create a robust and simplified statistical model. Therefore we gathered flux measurement data for European sites and calibrated an empirical fuzzy logic model to estimate nitrous oxide emissions from organic soils in Europe.

KEY WORDS: Modelling, Fuzzy Logic, Nitrous Oxide, Organic Soil, GHG-Europe

INTRODUCION

The estimation of the greenhouse gas (GHG) budget for Europe is the ambitious aim of the GHG-Europe project (www.ghg-europe.eu). Therefore improvements in understanding and predicting the GHG fluxes of terrestrial ecosystems are developed in this project. That includes a differentiation between natural and anthropogenic induced emissions and the determination of spatial and temporal hot spots for emissions. One hot spot for GHG emissions are peatland ecosystems. In Europe about 5-6 percent of the surface area is covered by peatlands (Joosten and Clarke 2002). They occur primarily in temperate and boreal regions. The land use of peatland is various (cropland, grassland, peat cut, forestry or natural undrained mires). Drained organic soils can be a source of carbon dioxide (CO2), while waterlogged peat land primarily emit methane (CH4) due to anaerobic conditions, Drösler et al. (2008). In this study we regard another important trace gas, nitrous oxide (N2O). N2O is a major greenhouse gas that contributes remarkable to the global warming potential of the atmosphere (Houghton et al. 2001). Generally significant emissions of N2O occur in fen peatlands that are drained and are additionally enhanced by fertiliser application. Bog peatlands have limited emissions due to low nutrient content (Byrne et al. 2004). N2O is basically produced by nitrification and denitrification processes in soil. The main controlling factors for these processes are oxygen content, carbon content, nitrate and ammonium concentrations. These control parameters are affected by several physical, chemical and biological properties of the ecosystem (Firestone and Davidson 1989). This interactive system is complex and observations of N2O fluxes shows that the emissions are heterogeneous and in addition potentially event driven, e. g. by fertilisation or precipitation. A modelling approach by Klemedtsson et al. (2005) uses successfully the C/N ratio as driving parameter to describe the N2O emissions for boreal forests on peat land. The IPCC Guidelines for national GHG inventories actually considers emissions from organic soils via assignment of emission factors (EF) for different land use, management, climate zone and peatland type (IPCC 2006). In this study we model N2O emissions of organic soils according to environmental (e. g. soil and climate conditions) and management factors (e. g. fertilisation and drainage) by using an empirical, data driven fuzzy logic approach. The model structure has to be robust and simple enough to be available for regionalisation purpose on European scale. First results shows the development of a model which handles the main controlling factors and is capable to reproduce potential nonlinear behaviour of these factors.

MATERIALS AND METHODS

Database

The basis of this study is a data collection for GHG measurements on European peat land sites. The data is gathered from publications, measurement projects and other synthesis studies. In this study we used only annual fluxes for model calibration. Therefore we have collected approximately 300 annual measurement campaigns for the period between 1992 and 2010. We have gathered the main controlling factors for N2O and in addition environmental parameters for climate and soil as well as meta data for measurement methods and site conditions. The collected sites are spread over the temperate and boreal climate zone with focus on central Europe and Scandinavia. The collected data can be differentiated into six land use forms based on historical and actual type of use (cropland, grassland, mire, forest, degraded, restored). First statistical analysis shows evidence for significant difference in N2O emission and groundwater table between these land use forms (Fig. 1). Arable sites on organic soils feature higher N2O emissions and lower water table than sites that are related to a constant high water table like mires or rewetted areas. In addition the N2O emissions are varying significantly between different peatland types (Fig. 2). The bog peatlands feature higher C/N ratios and lower soil pH values than fen peatlands due to lower nutrient content and acid conditions. This apparently leads to low emissions of N2O for bog peatlands, while our database suggests, that fen peatlands induce higher emissions and a greater variability.

Fuzzy Interference System

The presented modelling tool is based on a fuzzy logic approach. It is able to calibrate triangular fuzzy sets to independent parameters by a simulated annealing technique and adapt responses for a dependent variable, e. g. nitrous oxide emissions from organic soils. Bardossy et al. (2003) describe in their study about simulating nitrogen dynamics for agricultural land, fuzzy based modelling as fast, transparent and parameter parsimonious alternative to other approaches. Furthermore it allows regionalisation, estimations at a higher generalised level and enables consideration of expert knowledge. We use a forward selection algorithm for automatic parameter-sensitivity-analysis to determine the best fitted parameter combinations. Further we build up model ensembles (MODE) for specified parameter combinations by using the empirical bootstrapping method. The model structure and methods are described in details by Dechow and Freibauer (2011). In addition to model calibration, we implement a k-fold cross-validation technique to evaluate the model results (cf. Kohavi 1995). The whole modelling tool set is implemented in a GIS environment. We are using the open source Geographic Resources Analysis Support System (GRASS) GIS, Neteler and Mitasova (2008). The advantage is the direct processing of georeferenced, spatio-temporal data for model input and output, e. g. for regionalisation.

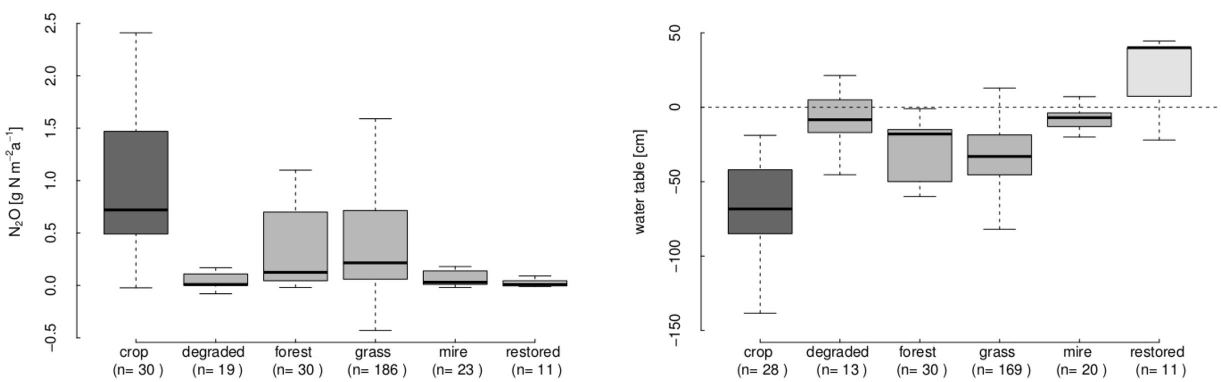

Figure 1: Boxplot of nitrous oxide emission (left) and annual mean groundwater table (right) for different land use categories (crop, degraded, forest, grass, mire and rewetted) on organic soils in Europe.

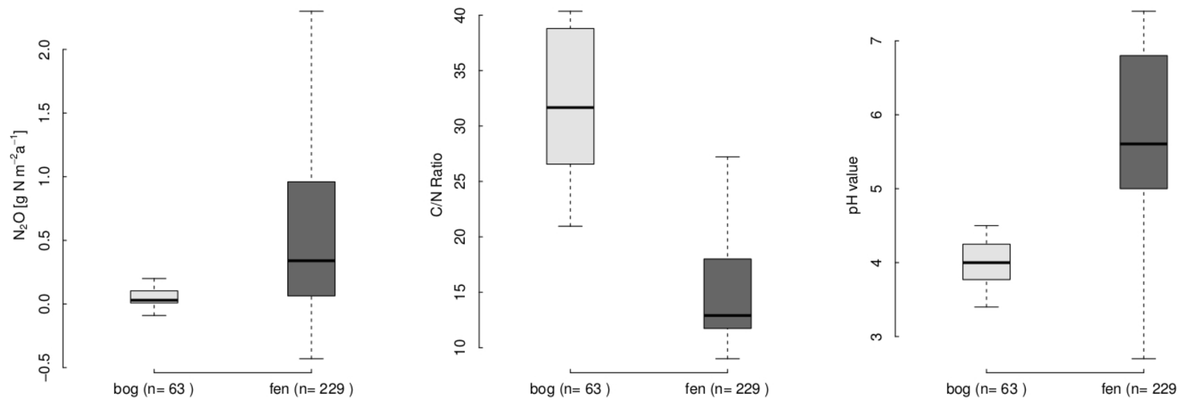

Figure 2: Boxplot of nitrous oxide emissions (left), C/N ratio (middle) and soil pH value (right) for different peatland types (bogs and fens) in Europe.

RESULTS

Our first modelling objective is the simulation of annual N2O fluxes on European scale. On this high generalization level we use annual mean values for available driving parameters (pH, water table, carbon and nitrogen content, nitrogen fertilization, C/N ratio and annual and seasonal mean temperatures and precipitation). Statistical analysis of the database shows significant differences for N2O emissions between land use categories and peatland types (Fig. 1 and Fig. 2). But we are not able to distinguish between different land use types because of insufficient data. Hence we split up our data only by peatland type and using logscaled data for input prior to development of separate fuzzy models for each peatland type.

Fens

The input data for fen peatlands includes 130 annual data sets with different land use. The parameter-sensitivity-analysis offer best fitted model calibration for water table in combination with pH-value and N-input (Fig. 3 left). The coefficients of determination for the calibrated MODE results compared to the measured data are within the range of $R^2 = 0.36 - 0.68$ with a mean of $R^2 = 0.54$. In contrast to the calibration, the fit of a ten fold cross-validation is inferior with $R^2 = 0.34$ (Fig. 3 right).

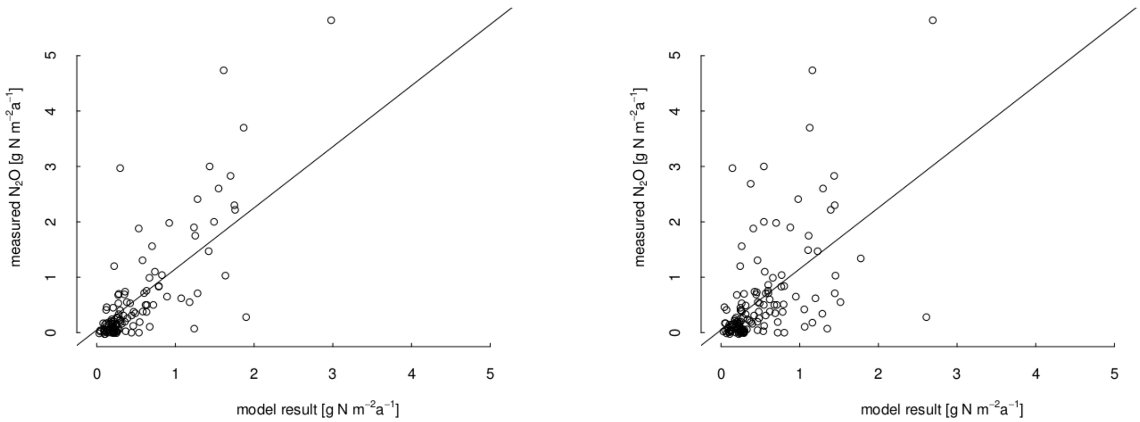

Figure 3: Average model fit of model ensembles for fen peatlands; exemplary calibration data set (left), validation data set (right).

Bogs

The database for bog peatlands feature a high amount of missing values for controling parameters. These missing values were replaced by default mean values of the parameter to be able to apply the model with an appropriate amount of input data. The best model performance can be derived by the parameter combination of water table, C/N ratio and annual precipitation. The MODE results are able to reproduce the measurement data with R^2 in a range of 0.2 – 0.91 and mean R^2 of 0.51. The results of the subsequent ten fold cross-validation are inferior with R^2 = 0.12.

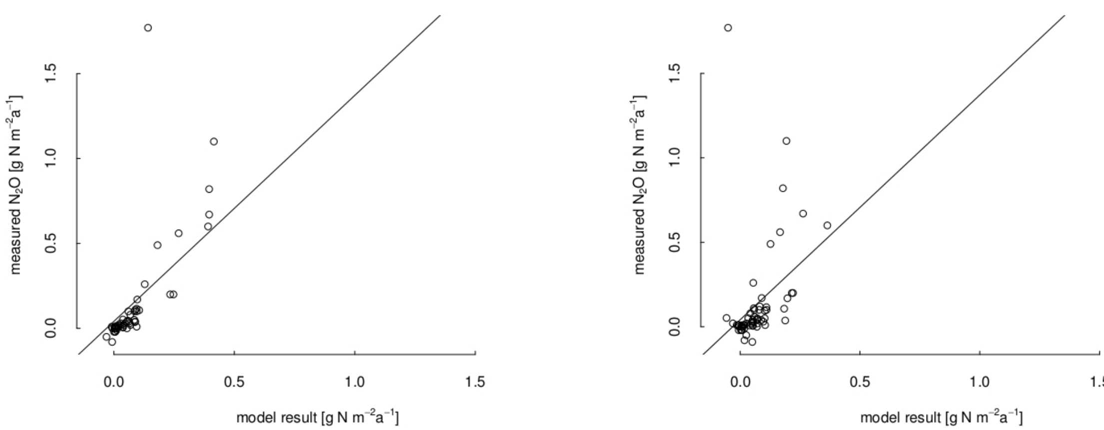

Figure 4: Average model fit of model ensembles for bog peatlands; exemplary calibration data set (left), validation data set (right).

DISCUSSION

The introduced modelling tool set has been successfully applied to N2O emission for organic soils in Europe. Basically the model predict high emissions of N2O due to low water table, low pH-value and high fertilisation rate on fen peatlands. While significant emissions on bog peatlands are related to low water table and C/N Ratio in combination to high precipitation rates. The separation of bog and fen peatlands leads to good model accuracy for calibration. The model is able to reproduce measured emission data but still has limited capabilities in predicting emissions from validation sites, as shown in the results of the cross-validation. In addition high emissions are underestimated in both models. A possible reason is that an explanatory parameter, which has significant effect on emissions, is missing. The different land use categories are not explicitly incorporated as separate models. However Fig. 1 shows, that the integrated water table could explain the differences of N2O emissions within the land use categories. The next demanding objective is the application of the model to estimate the N2O emissions from peatlands site in Europe.

REFERENCES

Bardossy, A., Haberlandt, U. & Krysanova, V. (2003). Automatic fuzzy-rule assessment and its application to the modelling of nitrogen leaching for large regions. Soft Computing - A Fusion of Foundations, Methodologies and Applications 7, 370-385.

Byrne, K. A. et al. (2004). EU peatlands: Current carbon stocks and trace gas fluxes. Carbo-Europe-GHG Concerted Action–Synthesis of the European Greenhouse Gas Budget. Report 4.

Dechow, R. & Freibauer, A. (2011). Assessment of German nitrous oxide emissions using empirical modelling approaches. Nutrient Cycling in Agroecosystems 91, 235-254.

Drösler, M., Freibauer, A., Christensen, T.R. & Friborg, T. (2008). Observations and Status of Peatland Greenhouse Gas Emissions in Europe. The Continental-Scale Greenhouse Gas Balance of Europe 203, 243-261.

Eggleston, H. (2006) IPCC Guidelines for National Greenhouse Gas Inventories vol. 4. Agriculture, forestry and Other Land Use.

Firestone, M.K. & Davidson, E.A. (1989). Microbiological basis of NO and N2O production and consumption in soil. 47.

Houghton, J.T. & others. (2001). Climate change 2001: the scientific basis. 881, (Cambridge University Press Cambridge).

Joosten, H. & Clarke, D. (2002). Wise use of mires and peatlands.

Klemedtsson, L., Von Arnold, K., Weslien, P. & Gundersen, P. (2005). Soil CN ratio as a scalar parameter to predict nitrous oxide emissions. Global Change Biology 11, 1142-1147.

Kohavi, R. (1995). A study of cross-validation and bootstrap for accuracy estimation and model selection. International joint Conference on artificial intelligence 14, 1137–1145.

Montanarella, L., Jones, R.J.A. & Hiederer, R. (2006). The distribution of peatland in Europe. Mires and Peatland

Neteler, M. & Mitasova, H. (2008). Open Source GIS. A GRASS GIS Approach, Third Edition, USA.