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IMPLEMENTATION OF DIFFERENT CANOPY REDUCTION MECHANISMS IN CMAQ

Jan A. Arndt*, Volker Matthias, Armin Aulinger, Johannes Bieser, Matthias Karl
Chemistry Transport Modelling, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany

1. INTRODUCTION

Nitrification and denitrification are microbial processes in soil that lead to the production of nitric oxide, NO, a gaseous reactive nitrogen compound. In various peer reviewed papers, soil has been identified as a major source of NO. The range of soil emissions that contribute to global NO and NO_2 varies between 4 and 21 Tg N (see Yienger and Levy (1995) and Davidson and Kingerlee (1997)), resepectively up to 15% (Hudman et al. (2012)) to total NOx emission.

Because NO is not persistent, the soil-emitted nitrogen oxide is quickly converted to nitrogen dioxide, NO2, in the lower layers of the atmosphere. Both substances, summarized as NOx, have a big influence on the lower troposphere ozone concentration and the production of the hydroxyl radical (Crutzen (1979)).

Nitrogen oxides and ozone (in low levels) are toxic and reactive air pollutants. They can form peroxides and lead to air pollution, in extreme cases smog (see Haagen-Smit (1952)) with consequential dangerous impact on human health. It is also involved in the formation of respirable aerosol particles. Furthermore nitrogen dioxide forms by dilution in water (e.g. in fogs or clouds) nitric acid, which contributes to acidification of rain that damages the natural ecosystem (Crutzen (1979)).

In the endeavor to understand the impact of nitrogen oxides originating from soil, the atmophere plays a key role in the exchange of gaseous nitrogen compounds between the different components of the earth system. For the simulation of atmospheric nitrogen dispersion, Helmholtz-Zentrum Geesthacht uses the Models-3 CMAQ chemistry transport model with the SMOKE for Europe Emission Model to simulate air quality in Europe and in North European coastal areas.

**Corresponding author:* Jan Alexander Arndt, Chemistry Transport Modelling, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany;
e-mail: jan.arndt@hzg.de

In CMAQ, the interaction between the pollutants and the vegetation is taken into account in the calculation of the dry deposition velocity in form of a stomatal resistance, as well as in a basic parameterization of canopy reduction for agricultural land types during the growing season. It is not cosidered, that different land types and vegetation types have different impact on the reduction of in-air concentration of nitrogen oxides due to stomatal loss.

There are two commonly used approaches: The YL95 approach (see Yienger and Levy (1995)) and the Wang approach (see Wang et al. (1998)). Both mechanisms only effect the primary biogenic emission of nitrogen oxide. They do not consider the primary emission of other nitrogen oxide sources which may also flow through the canopy and underly partly uptake by plants.

In this study, we created a third parameterization, which pays attention to the vegetation type, emission type and the ambient air concentration of nitrogen dioxide.

2. MODEL SETUP AND PARAMETERIZATIONS

2.1 Model Setup

For this study we used the Models-3 CMAQ chemistry transport model version 5.0.1 with Carbon-Bond 5 chemistry mechanism and aero6 aerosol module. The model domain covers the Northern part of central Europe on a 16x16 km² grid. We chose 2012 as reference year and made first runs for February and July in this study. For the emission modeling, we used the SMOKE for Europe Emission Model with Emission Inventories based on EMEP and EDGAR. Biogenic Emissions are created with the BEIS 3.12 model, based on the GLC2000 Land-Cover and the meteorological Input from COSMO-CLM 11x11 km² runs, preprocessed with LM-MCIP 4 PX Version.

2.2 Parameterization following Yienger and Levy (1995)

A canopy reduction factor (CRF) for primary biogenic NO soil emissions, based on Leaf Area Index (LAI) and Stomata Area Index (SAI).
The parameterization is initially made for annual total emission correction. We modified it by annual and daily profiles of LAI and SAI.

$$CRF = \frac{e^{-(ks \times SAI)} + e^{-(kc \times LAI)}}{2} \quad (1)$$

2.3 Parameterization following Wang et al. (1998)

This parameterization is based on Jacob and Bakwin's (1991) study about cycling of nitrogen oxides in tropical forest canopies. It describes a reduction factor (CRF) for primary biogenic NO soil emissions, based on Leaf Area Index, Stomatal Resistance, and Land-Use considering ventilation velocity (V_{vent}).

$$CRF = \frac{R_{Stomata,NO}}{R_{Stomata,NO} + V_{vent}(LAI, FF, LandUse)} \quad (2)$$

2.4 Own Parameterization

This parameterization is based on a removal of chemically transformed nitrogen dioxide by additional dry depositional loss (see Byun and Young (1999)) in the lowest model layer. It is controlled by the canopy portion of dry deposition rate ($R_{Stomata,NO2}$), calculated by the bulk stomatal resistance ($R_{Stomata}$) and the dissolved concentration of nitrogen dioxide in water of the stomatal openings of leaves ($c(NO_{2,\,aq})$) .

$$R_{Stomata,NO2} = f(R_{Stomata}, LAI, c(NO_{2,\,aq}) \quad (3)$$

$$C(NO_2)_{new} = C(NO_2)_{old} \times \frac{-1}{R_{Stomata,NO2}} \times \frac{\Delta t}{\Delta z} \quad (4)$$

3. RESULTS

We performed tests with all three parameterizations for the month February and July of 2012 with 10 days spin-up time each. We chose February, because it has a minimum LAI, and July because of a maximum LAI. While there is only a very small and nearly equal impact on the ambient air concentration of NOx in winter, all three canopy reduction parameterizations show a noticeable reduction of NOx air concentration in July 2012 (Figure 1).

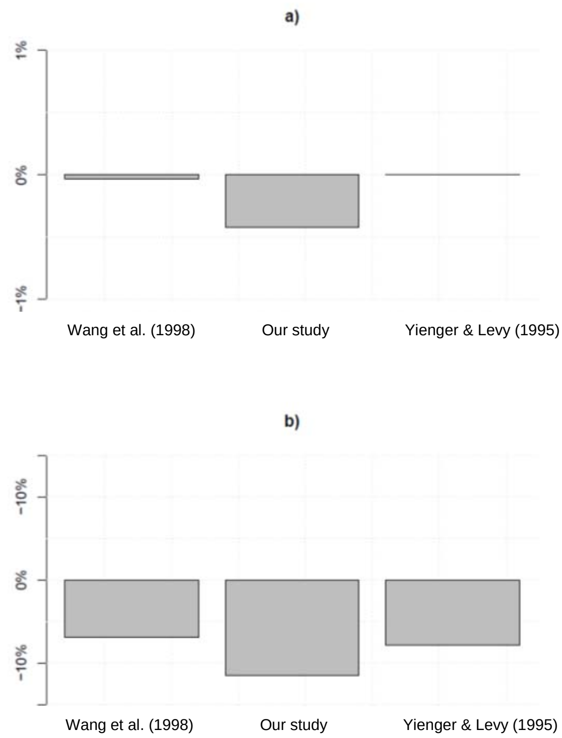

Fig. 1. Normalized Mean Bias in percent of the daily mean air concentration in the whole model domain. a) shows winter values, b) summer values.

The approaches following Wang et al. (1998) as well as Yienger and Levy (1995) have a comparable impact on total NOx in-air concentrations and only small differences in their regional distributions (Figure 2).
Our parameterization has a domain total reduction impact allmost twice as much of the other two paramterizations and has a clearly different regional distribution (Figure 2) compared to the other ones.

The different regional distribution originates from the consideration of actual NO_2 concentration in the calculation of our canopy reduction parameterization. It determines not only the effective soil NO emissions, but also all other NO emissions in the lowest model layer.

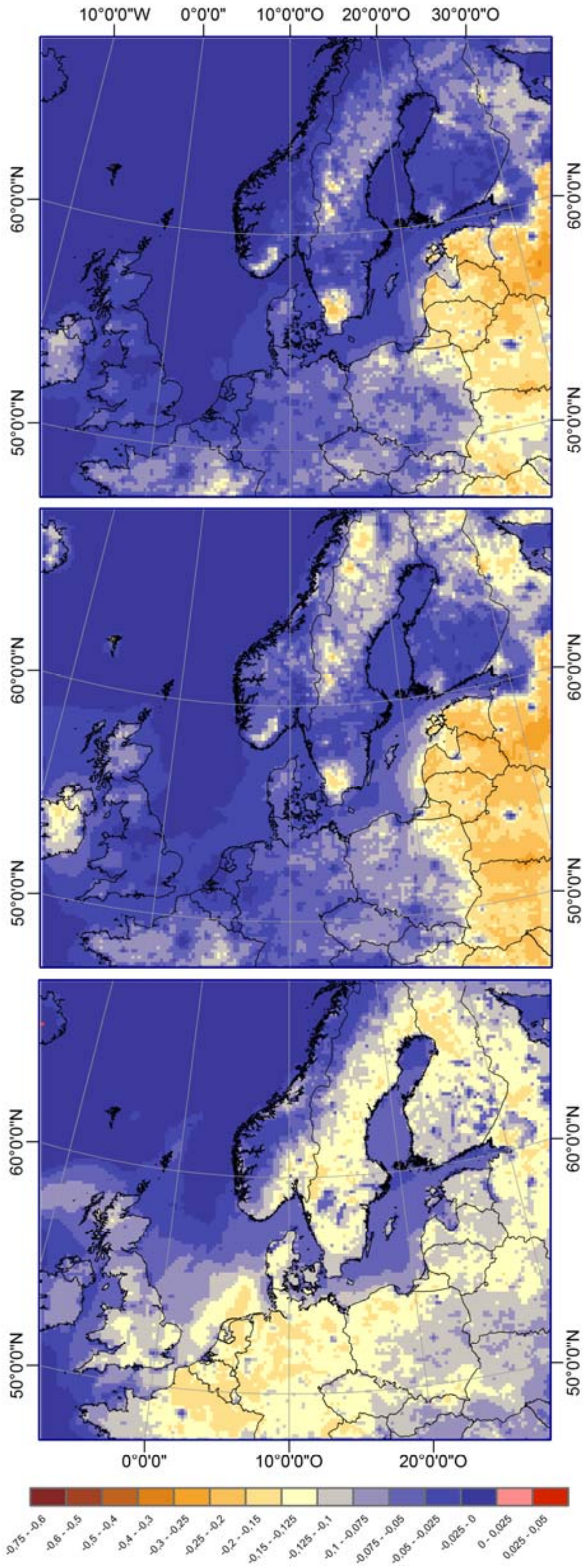

Fig. 2. NMBF for NOx in July
Top: Wang et al. (1998); Middle: Yienger and Levy (1995) ; Bottom: our parameterization.

4. CONCLUSIONS

Canopy reduction functions reduce the mean total air concentration of nitrogen oxides in Northern European regions by 7-23% in July 2012.

Common canopy reduction techniques reduce the primary biogenic emission of nitrogen oxide only. It has to be considered in further development of canopy reduction parameterizations that other emissions e.g. anthropogenic emissions from car exhaust or biogenic stimulated emissions by animal husbandry might also flow through the canopy of plants and are removed partly by stomatal uptake. The consideration of this fact in the model system leads to noticeable regional different reduction of nitrogen oxide concentration.

Further test for other months and other timespans, as well as other years, has to be done to confirm the first findings.

5. REFERENCES

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