



International Max Planck Research School on Earth System Modelling

The influence of plant nitrogen availability on
the global carbon cycle and N₂O emissions

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PhD Thesis prepared within the
International Max Planck Research School on
Earth System Modelling



Abstract

During the last two centuries, increasing atmospheric CO₂ concentration and climate change have altered the land carbon (C) cycling and the availability of nitrogen (N) for plants. Despite the cycling of C and N in the terrestrial ecosystems is tightly coupled, many modeling studies have ignored the interactions of land N cycle with the C cycle. In this thesis, their interactions are studied by incorporating a new and simple scheme for the terrestrial N cycling in the process-based land C cycle model JSBACH. The present study also investigates: Nitrous oxide (N₂O) emissions from natural soils under climate change and climate-N₂O feedback; N₂O emissions that arise from both land use change and fertilized agricultural soils; and the role of long-lived wood products for climate change mitigation.

To study the C-N cycle interaction, two main simulations are performed: carbon-only (C) and coupled carbon and nitrogen cycle (CN). The simulation results show that the coupling of C and N cycles leads to a lowering of the projected global land C uptake by 16% as compared to the C simulation during the 21st century in response to increasing atmospheric CO₂ concentration and climate change under the SRES A1B scenario. The results show that the inclusion of the land N cycle in the model leads to a significant reduction of positive climate-carbon cycle feedback by 21%. The development of Progressive Nitrogen Limitation (PNL) in forests and grasslands ecosystem is also analyzed. In forest ecosystems, the soil N availability decreases during the first half of the 21st century under increased CO₂ concentration and climate change. This results support the hypothesis “PNL” that soil mineral N availability decreases under elevated CO₂ as N is locked in long-lived woody biomass and soil organic matter. However, starting from roughly the second half of the 21st century, the PNL starts alleviating because of the relaxation of N scarcity due to global warming. In grasslands, the occurrence of PNL is much stronger than forests. Aside from this, to study the robustness of occurrence of PNL additional sensitivity experiments have been performed. Since doubling of N fixation is quite unrealistic, these experiments show that the appearance of PNL for grasslands during the 21st century is a very robust simulation result, whereas occurrence of PNL in forests is much less robust.

N₂O is produced in soils as a byproduct during nitrification and denitrification. This is a greenhouse gas and contributes significantly to global climate change. Simulations are performed to investigate N₂O emissions from natural soils under climate change and climate-N₂O feedback. The simulation results show that emissions from natural soils contribute 8.0 Tg N yr⁻¹ to the global N₂O budget by the end of the 21st century. By including all N₂O emission sources (e.g., soil, ocean, fossil fuel, fertilizer, etc.) it is found that rise in atmospheric N₂O concentration is consistent with observations over the period 1860-2005 (a rise from 276 to 320 ppb). Under the A1B scenario, the atmospheric N₂O concentration increases up to 469 ppb by the end of the 21st century. Globally, a radiative forcing from N₂O emissions is about 0.6 Wm⁻², which equates to a projected increase in temperature by 0.46⁰C by the end of the 21st century. According to this study, it is inferred that the climate-N₂O feedback is negligible because the value of feedback factor is very small (ca. 0.0003).

The results described in the previous paragraph were without agriculture. Human-induced land cover change (e.g., deforestation) and use of synthetic N fertilizers have released N₂O into the atmosphere. The simulated global N₂O emissions due to land use change are 0.75 Tg N yr⁻¹ for the 1990s; this contributes about 5% of the global N₂O budget. N₂O emissions from fertilized agricultural soils are 4.9 Tg N yr⁻¹ for the 2050s; a significant amount, namely 60% of these emissions is a direct consequence of the application of synthetic N fertilizers. In addition, the results show that agricultural N₂O emissions are highest in Asia, followed by North America, and Europe, that is, 46, 18, and 14%, respectively.

Wood products from forests are important in the context of climate change mitigation by curbing the land use emissions. The simulation results show that globally, long-lived wood products store 7.2 Pg C. The carbon sink from wood products lowers the land use carbon emissions by 6% over the period 1860-2000. As compared to fossil fuel emissions, this carbon sink has only a minor role to play in helping to mitigate the effects of climate change.