PERSISTENCE OF NITROGEN LIMITATION OVER TERRESTRIAL CARBON UPTAKE

G. Churkina, M. Vetter, and K. Trusilova

Max-Planck Institute for Biogeochemistry, Hans-Knöllstr, 10, 07749 Jena, Germany
churkina@bgc-jena.mpg.de

ABSTRACT

Because vegetation growth in the Northern Hemisphere is typically nitrogen-limited, increased nitrogen deposition could have attenuating effect on rising atmospheric CO_2 by stimulating the accumulation of biomass. Given the high carbon to nitrogen ratios and long lifetimes of carbon in wood, a most significant effect of nitrogen fertilization is expected in forests. Forest inventories indicate that the carbon content of northern forests have increased concurrently with increased nitrogen deposition since the 1950s [*Spiecker et al.*, 1996]. In addition, variations in atmospheric CO_2 indicate a globally significant carbon sink in northern mid-latitude forest regions [*Schimel et al.*, 2001]. It is unclear however, whether elevated nitrogen deposition or other factors are the primary cause of carbon sequestration in northern forests. We argue that the elevated nitrogen deposition is unlikely to enhance vegetation carbon sink significantly because of its differentiating effect on the carbon sequestration capacity of uneven aged forests and climatic limitations on carbon sequestration in the Northern Hemisphere. We estimate the potential of forests with lifted nitrogen limitation to decelerate CO_2 concentrations rise in the atmosphere and therefore to mitigate climate warming. We also outline areas of the Northern Hemisphere which are most sensitive to increased nitrogen deposition.

METHODS

To determine the effect of increased nitrogen deposition on carbon sequestration in Northern Hemisphere we investigated changes in modeled carbon fluxes from 1948 to 2002 under different environmental change scenarios. Carbon fluxes were simulated using a well established biogeochemical process model BIOME-BGC [*Thornton*, 1998; *Running and Hunt*, 1993], which simulates carbon, nitrogen and water cycles. The global model performance (forest growth) was analyzed by *Churkina and Running* [2000]. The model performance (carbon and water fluxes) was also favorably compared with measurements over networks of sites in Europe [*Churkina et al.*, 2003] and in North America [*Thornton et al.*, 2002]. The climate drivers were obtained from NCEP Reanalysis database. The distributions of nitrogen deposition for both industrial and preindustiral scenarios were from MOGUNTIA model results [*Dentener and Crutzen*, 1994]. To outline forest areas most sensitive to enhanced nitrogen deposition, we assumed continuous forest coverage of the Northern Hemisphere with deciduous broadlead and evergreen needleaf forests as well as constant preindustrial (0.0001 kg N $m^{-2}yr^{-1}$) and industrial nitrogen depositions (0.0016 kg N $m^{-2}yr^{-1}$) homogeneously distributed over the study area. The nitrogen deposition constants for these scenarios were assigned according to *Holland et al.* [2005; 1999].

RESULTS

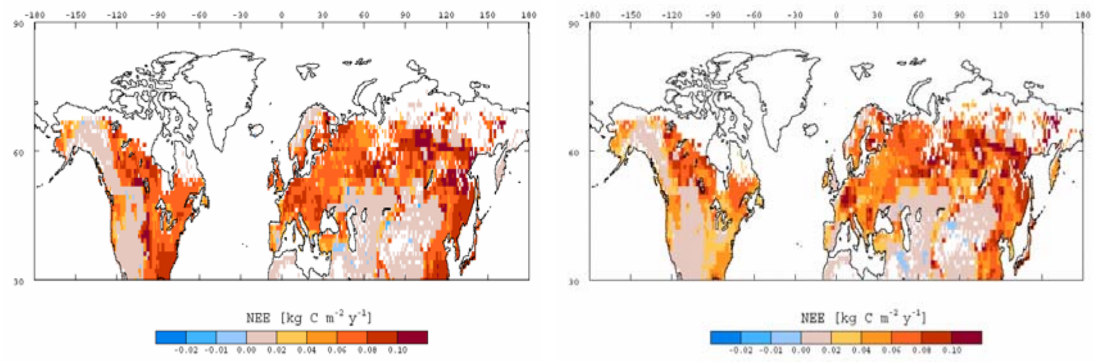
We estimated the potential of forests in the Northern Hemisphere with lifted nitrogen levels to decelerate CO_2 concentrations rise in the atmosphere and therefore to mitigate climate warming. Our model predicts that increased nitrogen deposition combined with CO_2 fertilization caused 8.1 Pg of carbon to accumulate in forests between 1948 and 2002. The accumulated carbon was distributed between evergreen needleaf (3.9 Pg), deciduous broadleaf (4.0 Pg), and deciduous needleaf (0.21 Pg) forests.

We also found that not all forests of the Northern Hemisphere are sensitive to increased nitrogen deposition. Climatic limitations and soil characteristics play here a significant role. Forests located in rather cold, wet climates and at higher elevations would benefit from the nitrogen fertilization the most. Forests growing in Western Europe, Siberia, North-east Asia, and Eastern United States (humid and rather cold climate due to high elevation) would benefit stronger and uptake more carbon in response to the enhanced nitrogen deposition than forests located in the central United States and Central Asia where climate is dry (Fig. 1). Other studies also confirm this pattern [*Vetter et al.*, 2005]. Experimental studies claimed that temperate forests are not particularly sensitive to nitrogen fertilization [*Nadelhoffer et al.*, 1999].

Our study suggests that during the last 55 years additional carbon uptake in the forests associated with increased nitrogen deposition was not as significant as previous studies demonstrated. Reforestation and change in nitrogen deposition patterns however may alter this additional carbon uptake.

Fig. 1. Areas of the Northern Hemisphere where carbon sequestration is sensitive to increased atmospheric nitrogen deposition. Forests are assumed to be in equilibrium with climate. The maps show average change in carbon sequestration in response to increased nitrogen deposition and CO_2 fertilization over the last 20 years. It is assumed that Northern Hemisphere is continuously covered with

a) Deciduous broadleaf forest b) Evergreen needleleaf forest



REFERENCES

Churkina, G., and Running, S.W. (2000) Investigating the balance between timber harvest and productivity of the global coniferous forests under global change. *Climatic Change*. **47**: 167-191.

Churkina, G., Tenhunen, J., Thornton, P.E., Elbers, J.A., Erhard, M., Falge, E., *et al* (2003) Analyzing the ecosystem carbon dynamics of four European coniferous forest using a biogeochemistry model. *ECOSYSTEMS*. **6**: 168-184.

Dentener, F.J., and Crutzen, P.J. (1994) Three dimensional model of the global ammonia cycle. *J. Atm. Chem*. **19**: 331-369.

Holland, E.A., Dentener, F.J., Braswell, B.H., and Sulzman, J.M. (1999) Contemporary and pre-industrial global reactive nitrogen budgets. *Biogeochemistry*. **46**: 7-43.

Holland, E.A., Braswell, B.H., Sulzmann, J., and Lamarque, J.-F. (2005) Nitrogen deposition onto the United States and Western Europe: Synthesis of observations and models. *Ecol.l Appl*. **15**: 38-57.

Nadelhoffer, K.L., Emmett, B.A., Gundersen, P., Kjønaas, O.J., Koopmans, C.J., Schleppi, P., *et al* (1999) Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. *Nature*. **398**: 145-148.

Running, S.W., and Hunt, E.R.J. (1993) Generalization of a forest ecosystem process model for other biomes, Biome-BGC, and an application for global-scale models. In *Scaling Physiological Processes: Leaf to Globe*. edited by Ehleringer, J.R., and Field, pp. 141-158, Academic Press, San Diego.

Schimel, D.S., House, J.I., Hibbard, K.A., Bousquet, P., Ciais, P., Peylin, P., *et al* (2001) Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. *Nature*. **414**: 169-172.

Spiecker, H., Mielikäinen, K., Köhl, M., and Skovsgaard, J.P. (1996) *Growth Trends in European Forests: Studies from 12 Countries*, Springer-Verlag, Berlin.

Thornton, P.E. (1998) *Regional Ecosystem Simulation: Combining Surface- and Satellite-Based Observations to Study Linkages between Terrestrial Energy and Mass Budgets*, University of Montana, Missoula.

Thornton, P.E., Law, B.E., Gholz, H.L., Clark, K.L., Falge, E., Ellsworth, D.E., *et al* (2002) Modeling and measuring the effects of disturbance history and climate on carbon and water budgets in evergreen needleleaf forests. *Agric. and For. Met*. **113**: 185-222.

Vetter, M., Wirth, C., Böttcher, H., Churkina, G., Schulze, E.D., Wutzler, T., and Weber, G. (2005) Partitioning direct and indirect human-induced effects on carbon sequestration of managed coniferous forests using model simulations and forest inventories. *Global Change Biology*. **11**: 810-827.