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U.S. nitrogen science plan focuses collaborative efforts

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U.S. Nitrogen Science Plan Focuses Collaborative Efforts

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Nitrogen is a major nutrient in terrestrial ecosystems and an important catalyst in tropospheric photochemistry. Over the last century, human activities have dramatically increased inputs of reactive nitrogen (N_r, the combination of oxidized, reduced, and organically bound nitrogen) to the Earth system (Figure 1). Nitrogen cycle perturbations have compromised air quality and human health, acidified ecosystems, and degraded and eutrophied lakes and coastal estuaries [*Vitousek et al.*, 1997a, 1997b; *Rabalais*, 2002; *Howarth et al.*, 2003; *Townsend et al.*, 2003; *Galloway et al.*, 2004].

Increased N_r affects global climate. Use of

Center for Atmospheric Research (NCAR) in Boulder, Colorado, in November 2003, involving 43 scientists from 31 universities or institutes. Terrestrial, atmospheric, and aquatic disciplines within the nitrogen cycling scientific community were all represented.

During the following year, the ideas explored in the workshop were developed into a November 2004 document titled "A U.S. Nitrogen Science Plan: Atmospheric-Terrestrial Exchange of Reactive Nitrogen." The science plan and a full list of workshop participants is available online at http://www.essl.ucar.edu/times/nsp/nsp.html.

The science plan outlines an interdisciplinary approach to the study of nitrogen-relevant

and regional nitrogen cycling.

Science Questions

The science plan identifies gaps in knowledge about nitrogen cycling that may be summarized as two science questions: How do human-induced perturbations to the global nitrogen cycle influence the speciation of nitrogen and carbon in the atmosphere and their fate in terrestrial ecosystems? What are the resulting Earth system feedbacks?

Biological processes important to atmospheric-terrestrial nitrogen cycling include emissions of reactive compounds, assimilation of N_r, and nitrogen impacts on ecosystem productivity. Emissions of nitrogen trace gases (N_2, N_2O, NO, and NH_3) vary both spatially and temporally, depending upon climate conditions and atmospheric composition. Emissions are also influenced by plant and microbial physiology, by complex terrain, and by pro-

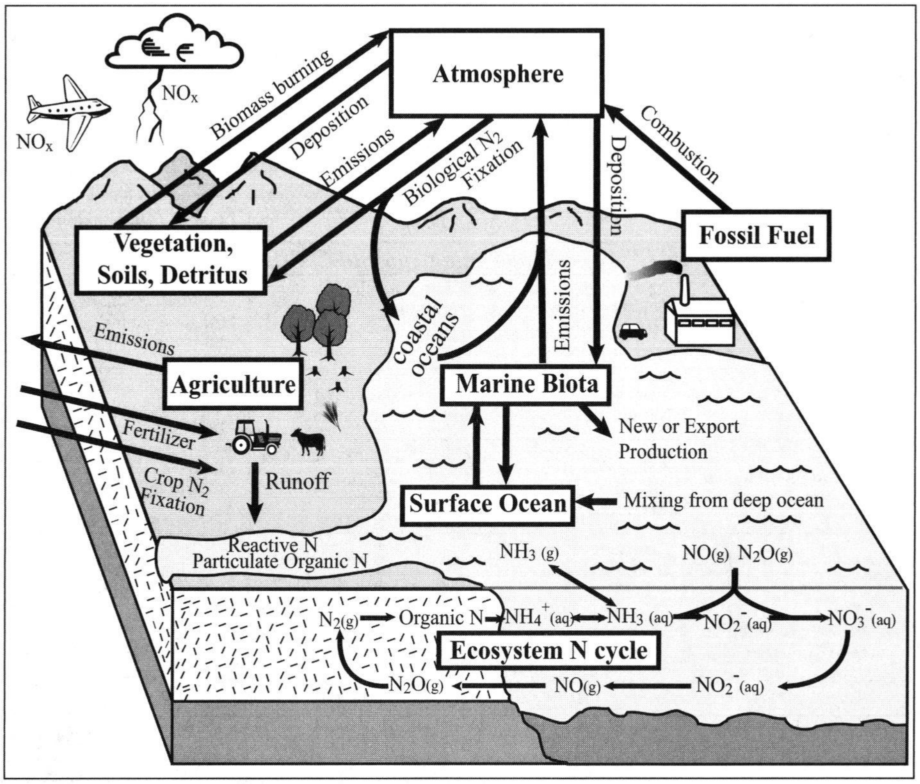

Fig. 2. Nitrogen cycling between reservoirs occurs at local, regional, and global scales. After Brasseur et al. *[1999].*

tions. The biosphere emits a wide variety of oxygenated and higher-molecular-weight reactive volatile organic compounds (VOCs) that react with N_r. Reaction products include multifunctional organic nitrates that react further, are incorporated into atmospheric organic aerosols, or undergo transport and deposition. Knowledge of the fate of atmospheric nitrogen depends on improvements in measurement capabilities.

To address these issues, the science plan recommends focused laboratory, field, and model studies, and multipronged studies covering a range of spatial and temporal scales. Gas phase and heterogeneous reaction studies should be performed under realistic conditions to determine reaction mechanisms for oxygenated and higher-molecular-weight biogenic VOCs and to identify oxidation products. New algorithms for emission and uptake should be developed using enclosure measurement systems. Aircraft flux measurements are necessary to evaluate extrapolations of emissions to regional scales in coupled atmosphere-biosphere models, and to characterize emission responses to land use and climate changes.

The science plan recommends linking observations of nitrogen cycling with other biogeochemical cycles, especially carbon. Tower-based measurements of simultaneous vertical nitrogen and carbon fluxes are needed in representative ecosystems. Ongoing field programs can be augmented to obtain comprehensive suites of observations, including surface fluxes and concentration gradients of key reactants, intermediates, and products.

Interactions

Key questions regarding aquatic interactions of nitrogen are: What are the hydrological, biological, and geochemical controls on landscape sinks of nitrogen, including groundwater and denitrification, and how do externally imposed changes affect water and nutrient cycles and their interactions with the carbon cycle? The science plan recommends continuation of existing long-term measurements of streamflow, water quality, atmospheric, and meteorological data, and implementation of international data-sharing protocols. Coordinated event-based sampling should be expanded to include rain events of varying duration and intensity, and carbon and nitrogen measurements should be extended to include organic and inorganic species. The observations must complement the development and testing of models that integrate atmospheric, terrestrial, and hydrologic processes.

Key questions regarding atmospheric interactions with belowground ecosystem nitrogen cycling are: How are plant and microbial communities influenced by natural environmental factors and nitrogen deposition, and what happens when several controlling factors change simultaneously? The most pressing research need is to generate baseline data on plant and microbial community composition, and on spatial and temporal variability in nitrogen cycling processes. The science plan recommends quantification of plant, microbial, and fungal community composition in relatively clean systems, in areas with increased nitrogen deposition and throughput, and at existing carbon study sites.

The cycles of nitrogen, carbon, and other key nutrients are inextricably linked. Their interactions are likely to provoke key nonlinearities in the evolving Earth system. It is therefore essential that the scientific efforts already devoted to the carbon and water cycles are complemented by the comprehensive and integrated study of the nitrogen cycle.

Request for Community Input

The recommendations presented in the U.S. Nitrogen Science Plan are intended to help focus collaborative efforts. The target audience encompasses the scientific community: researchers, funding agencies, and large-scale programs such as the U.S. National Science Foundation's National Ecological Observatory Network (NEON). The science plan writers welcome updates as the science community's needs and understanding evolve. Input for the next version may be sent to Elizabeth Holland (eholland@ucar.edu) and should be received by 5 September 2005.

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Table 1. Summary of Ongoing and Recently Completed Efforts Related to the Nitrogen Cycle

Program	*Details, Dates*	*Focus*	*Web Links*
Atmospheric Sciences:			
U.S. NAS[1] Commission on Geosciences, Environment and Resources	Report, 1998	Atmospheric science research needs, including N cycle studies.	http://www.nap.edu/books/0309064155/html
Nitrogen Cycle, International Efforts:			
ICSU[2] SCOPE[3] Project on Nitrogen Transport and Transformations	1994–2002; 13 workshops; 250 scientists from >20 countries	Synthesis of existing knowledge of human-caused changes in regional-scale N fluxes.	http://gaim.unh.edu/Structure/Future/fasttrack/nitrogen.htm
First International Nitrogen Conference	1998; Netherlands	Effects of increased N cycling: European focus.	http://www.esa.org/n2001/conference.html#firstconference
N2001: 2nd International Nitrogen Conference	2001; 400 scientists from 30 countries	Optimizing N management in food and energy production and environmental protection.	http://www.esa.org/n2001/index.html
International Nitrogen Initiative: SCOPE[3]/IGBP[4]	Established 2003; 5 regional centers	Human impacts on N cycle: health and ecosystem effects.	http://initrogen.org
N2004: 3rd International Nitrogen Conference	2004; Nanjing, China	Impacts of population growth and economic development on N cycle.	http://www.issas.ac.cn/n2004/
Nitrogen Cycle, U.S. Efforts:			
NSTC[5] Committee on Environment and Natural Resources	Report, 1999	Sources of N to the Gulf of Mexico and resulting hypoxia.	http://www.nos.noaa.gov/products/pubs_hypox.html
NAS[1] Committee on Causes and Management of Coastal Eutrophication	Report, 2000	Eutrophication of coastal waters, the causes and consequences.	http://www.nap.edu/books/0309069483/ html/
NOAA[6] National Centers for Coastal Ocean Science	Science Plan, 2003	Nutrient pollution in U.S. coastal waters.	http://www.nccos.noaa.gov/documents/nutrientpollution.pdf
Related Biogeochemical Cycles:			
Water Cycle Study Group, USGCRP[7]	Science Plan, 2001	H_2O, C, and N cycles at terrestrial-aquatic and plant-atmosphere interfaces.	http://www.usgcrp.gov/usgcrp/Library/watercycle/wcsgreport2001/default.htm
Carbon and Climate Working Group, USGCRP[7]	Science Plan, 1999	Regional CO_2 cycle and carbon management.	http://www.carboncyclescience.gov/PDF/sciplan/ccsp.pdf
North American Carbon Program, USGCRP[7]	Science Plan, 2001	CO_2, CH_4, and CO cycling: North America and oceans.	http://www.isse.ucar.edu/nacp/
U.S. Climate Change Science Program	Strategic Plan, 2003	U.S. research on climate and global change.	http://www.climatescience.gov/Library/stratplan2003

[1] NAS: National Academy of Sciences; [2] ICSU: International Council for Science; [3] SCOPE: Scientific Committee on Problems of the Environment; [4] IGBP: International Geosphere-Biosphere Programme; [5]NSTC: National Science and Technology Council; [6]NOAA: National Oceanic and Atmospheric Administration; [7] USGCRP: U.S. Global Change Research Program

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For more information or a printed version of the science plan, contact E. Holland; E-mail: eholland@ucar.edu. The science plan may be downloaded at http://www.essl.ucar.edu/times/nsp/NSciPlan_Nov2004.pdf.

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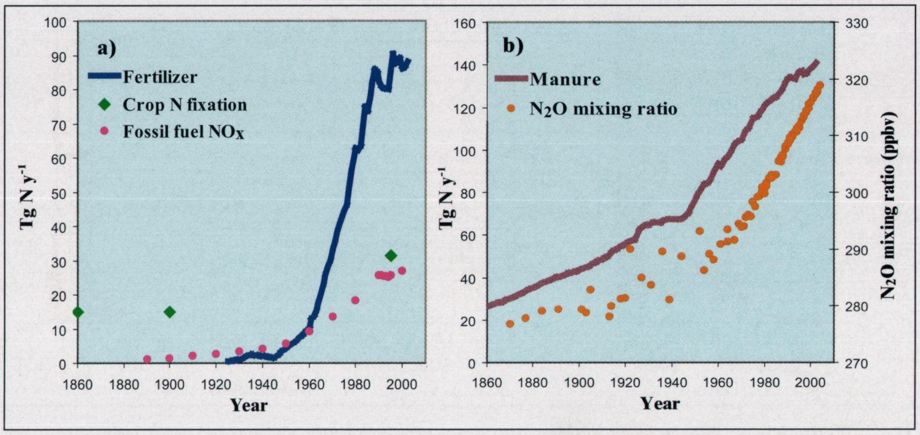

Fig. 1. (a) Changes in fluxes of reactive, or biologically available, N. (b) The simultaneous increase in atmospheric N_2O concentrations, and increased manure production as a result of reactive N generation in Figure 1a. The Haber-Bosch process for the creation of fertilizer from N_2 was invented in 1913. For data sources, see http://www-eosdis.ornl.gov/.