Greater contribution from agricultural sources to future reactive nitrogen deposition in the United States

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1. Background

- Greater contribution from agriculture sources to the environment reactive nitrogen (Nr) load is expected in the foreseen future.
  - to sustain food production for the growing population
  - warming effects favor the release of NH_3 from vegetation, soil surface, and farms
- Decrease in Nr deposition achieved by controls on mobile sources and power generation may be canceled out by increasing Nr release from agricultural sources.
- Atmospheric deposition is usually the dominant source of Nr in remote areas such as headwater lakes and sensitive streams within protected regions.
- The impact on soil and water quality can be evaluated by comparing with the nitrogen critical loads (CLs).
- Change in total Nr loads received by watersheds can be simulated by linking CMAQ with a water quality model.

2. Methods

- Model configuration
  - Emission:
    EPA 2011 air emissions modeling platform;
    FEST-CMAQ with NH3 bi-directional exchange model for fertilizer application NH_3 emissions
    Regression with animal population growth for livestock emissions
    Sectoral adjustment factors following RCP8.5+SSP5 for other sources
  - Meteorology: downscaled with WRF spectral nudging from the NASA GISS ModelE2
  - CTM: CMAQ v5.0.2
  - Water quality simulation: USGS SPARROW model
  - Time: 2010 for the present-day scenario; 2030 and 2050 for future scenarios
  - Domain: CONUS with a focus on the protected areas designated for biodiversity conservation

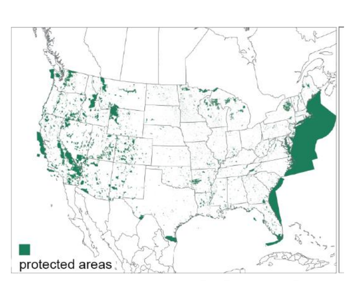

Figure 1. Modeling domain

Table 1. Description of emissions and meteorological data for simulation scenarios

Scenario description	Emission year		Year of meteorology
	Ag sources	Other sources	
Present-day	2010	2010	2010
Future baseline	2030/2050	2030/2050	2030/2050
Future counterfactual	2010	2030/2050	2030/2050

3. Results and Discussion

- **Nr deposition changes between the present-day and future scenarios**
  - In the future scenarios, the NH_3 emission increase from the agricultural sources will offset the decreasing trend of Nr deposition achieved by NO_x emission reductions from the mobile and power generation sectors, especially in areas with intensive fertilizer application or hosting concentrated animal feeding operations.
  - *The decreasing trend of the total Nr deposition becomes flat beyond 2030 when the decrease in oxidized-Nr deposition slows down and is offset by a steady increase in the reduced-Nr deposition*
  - Specially, most areas will switch from Nr-ox-dominated in 2010 to Nr-red-dominated in 2050

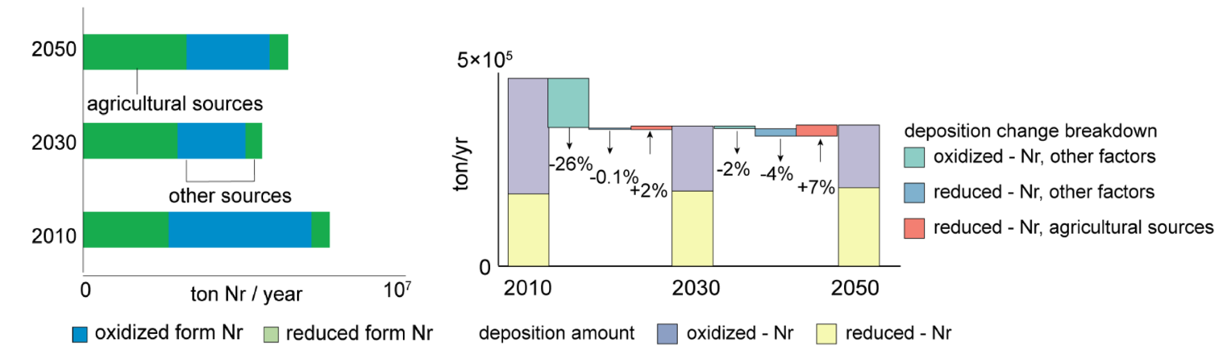

Figure 2. Nr emissions (left) and deposition (right) changes between the present-day (2010) and future (2030 and 2050) scenarios. The left figure shows the change in absolute amount of Nr emissions and the breakdown of oxidized and reduced forms of Nr from agricultural sources and other sources. The right figure shows the change in absolute amount of Nr deposition and the relative contribution from agricultural sources and other factors including emission changes in other sources and meteorological conditions.

- **Comparison between Nr deposition and multiple CL datasets**
  CL data source: the National Critical Loads Database (NCLD) for nitrogen and sulfur developed by the National Atmospheric Deposition Program [1].

  - **CL based on terrestrial ecosystems biodiversity**

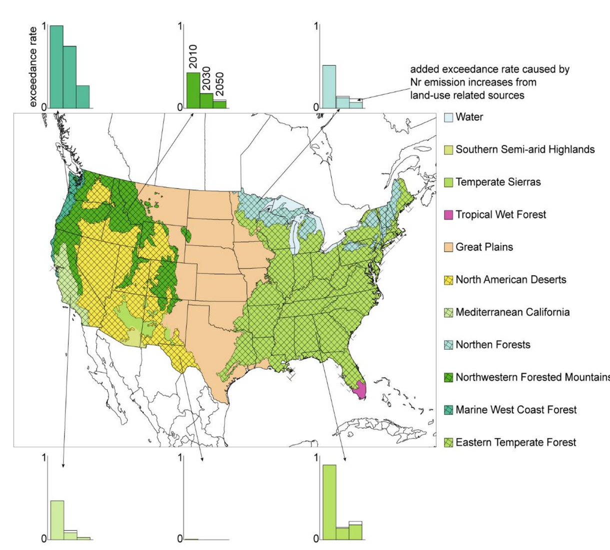

Figure 3. Changes in exceedance rate of Nr deposition on protected areas in difference ecoregions.

- An empirical CL for lichen, which is a sensitive bioindicator of Nr level in terrestrial ecosystems
- A significant decrease in the exceedance rate of Nr deposition to protected areas between 2010 and 2050; emission changes from agricultural sources will lead to minor increases in the exceedance rates
- *Although the current evaluation shows that most areas will have Nr deposition level below the CLs for biodiversity in 2050, the improvements might be overstated because NH_3 deposition, the major driving species for future Nr deposition trend, has not been included in historic CL determinations.*

  - **sulfur-nitrogen-combined CL based on freshwater acidity and forest soil acidity**

- CLs derived from steady-state mass balance models for fresh water and forest soil
- CLs were grouped into each CMAQ grid and the 10th percentile is used as an indicator
- The prevalence of deposition exceedance has already been limited to those most sensitive regions in 2010
- The transition toward a low exceedance rates will mainly occur in the Northeastern U.S. where the most stringent controls are expected for emissions of SO_2 and NO_x
- Among the areas in exceedance in 2050, 22% can be attributed to emission increases from agricultural sources leading to exceeding the forest soil acidity CL.
- *For areas with intense agriculture production, the required deposition reduction can be up to 30 times that of the sulfur deposition, showing the importance of decreasing Nr species, especially the Nr-red from agricultural sources.*

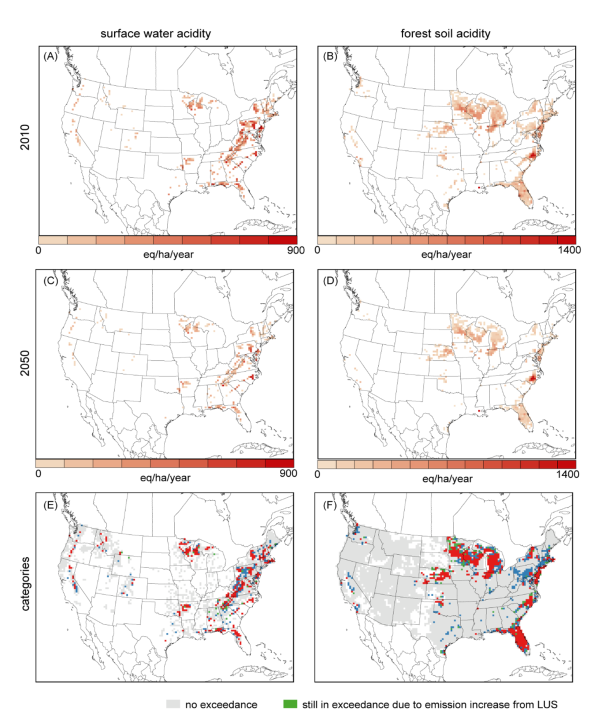

Figure 4. Exceedance of sulfur-nitrogen-combined (S+N) deposition for surface water acidity and forest soil acidity.

- **Impact of Nr atmospheric deposition on total Nr load received by watersheds**
- Future changes in total Nr loading of 61117 watersheds nationwide due to atmospheric deposition change caused by agricultural emission changes.
- Atmospheric deposition is the major source of Nr and key for regulation in remote areas with an absence of other significant anthropogenic contributors.
- .23% of the watersheds in the Great Plains region have atmospheric deposition as the major contributor
- Protected areas where atmospheric deposition control is crucial: the Glacier National Park in Montana, lakes within the Indian Peaks wilderness area in Colorado, and Superior National Forest in Minnesota

SPARROW simulations:
- Future baseline scenario in 2050
- Future counterfactual scenario in 2050 (atmospheric deposition level at 2010)

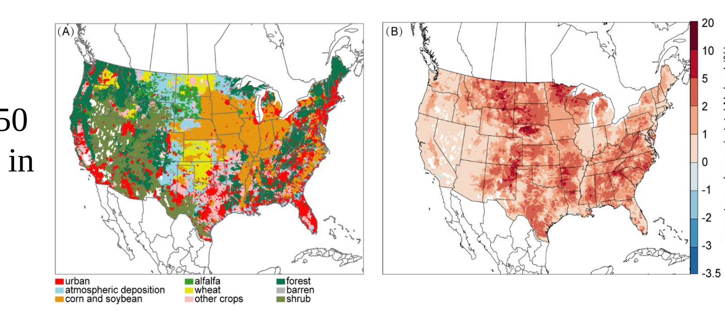

Figure 4. (A) Major source of total Nr loading by watershed. (B) Percentage changes in total Nr loading by watershed across the CONUS due to the changes in agricultural emissions between 2010 and 2050.

4. Conclusions

- NO_x emission reductions coupled with NH_3 emission increases will lead to a transition from an Nr-ox-dominated deposition pattern in 2010 to a Nr-red-dominated pattern in 2050
- Higher Nr burden in near-source regions (agricultural intense zones)
- Mitigating Nr deposition caused by increased agricultural emissions is the key to lower the deposition to sustain ecosystem health in protected areas in the future
- Analysis emphasizes the impact of rising temperatures in the future with continuous dependence on fossil fuels, but still has reductions in NO_x due to controls.

Acknowledgements
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Reference

Lynch, J. A., J. Phelan, L. H. Pardo, T. C. McDonnell, and C. M. Clark (2017), Detailed Documentation of the National Critical Load Database (NCLD) for U.S. Critical Loads of Sulfur and Nitrogen, version 3.0Rep., Champaign, IL.