Climate Strategy Impact on Nitrogen Deposition in the USA

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INTRODUCTION

Nitrogen (N) leakage to the environment in the United States costs an estimated $210 billion per year, equivalent to 1-3% of the national GDP, in part due to atmospheric N pollution. For example, excess N deteriorates ecosystems via eutrophication in water bodies, causing fish kills and additional expense in water treatment (Sobota et al., 2015). To describe the nutrient threshold an ecosystem is able to withstand before its functionality is impaired, the Department of Agriculture developed critical loadings for ecoregions and vegetation types across the U.S. (Pardo et al., 2015). In present conditions, N deposition alone may cause sensitive ecosystems across the United States to exceed these values (Lee et al., 2015). Although the primary contributor to N deposition in the past has been in oxidized forms (NOx), ammonia (NH_3) is expected to be the predominant form in the future as air quality regulations reduce NOx emissions (Ellis et al., 2013).

Measures to mitigate climate change can complicate N projections because many are expected to provide air quality co-benefits through NOx reductions. However, strategies that substitute biofuels for conventional petroleum fuels could lead to an increase in NH_3 emissions from fertilizer application. Therefore, when evaluating climate mitigation strategies, it is imperative that we understand their effects on the N cycle to avoid economic, public health and ecological consequences.

PROJECTING EMISSIONS

We use a combination of several models to analyze the change in N emissions and deposition resulting from a set of scenarios to mitigate climate change. The Global Change Assessment Model (GCAM; Kim et al, 2006; http://wiki.umd.edu/gcam/) spatially allocates NOx and NH_3 emission projections to irregular polygons that represent global agro-ecological zones (example provided in Figure 1b). Here, we apply GCAM 4.2 to identify technological pathways for achieving increasingly stringent U.S. carbon dioxide (CO_2) economy-wide emission reduction targets. The targets analyzed include 30%, 40%, 50%, 60%, 70%, and 80% decreases in CO_2

emissions, linearly implemented from 2015 to 2050. We evaluate the sector-level change in emissions, including those from agriculture, livestock and biomass burning.

ESTIMATING DEPOSITION

While GCAM estimates emission trajectories for various CO_2 reduction targets, it does not describe pollutant fate and transport. Here we use the GEOS-Chem global chemical transport model (GCTM) to evaluate the transformation and ultimate deposition of nitrogen through space and time. In particular, we leverage the computational efficiency of version 35j of this model's adjoint tool (Henze and Seinfeld, 2006) to calculate the change in deposition resulting from a change in emissions. This "sensitivity" ($\partial D/\partial E$) is multiplied by the change in emissions from the GCAM reference case to a given policy scenario, which results in the change in deposition at a given site and time attributable to that policy. The sites investigated were Class I Areas which are federally protected from a change in visibility under the Regional Haze Regulations. The sensitivity of deposition to emissions were developed using 2010 monthly simulations of the dry deposition of all N species to emissions of NOx, NH_3, ammonium and inorganic nitrates.

GCAM TO GEOS-CHEM

This study is unique because it pairs sensitivity results with emission projections from GCAM. This required spatial and temporal re-gridding of the emission projections to match that of GEOS-Chem. GCAM aggregates emission projections by region (33) and agro-ecological zone (AEZ, 18) over 321 agro-economic regions. These comprise relatively coarse, irregular polygons that span landmasses across the globe. In comparison, the GEOS-Chem grid covers the world with 2° by 2.5° cells. Anthropogenic emissions of ammonia in the United States in 2010 generated by GEOS-Chem is applied to develop the emission density in space and time. Figure 1 provides an example of GCAM agricultural emissions before and after re-gridding.

Equation 1. The proportion of domestic emissions attributable to a given GEOS-Chem grid cell were used to spatially and temporally distribute emissions projected by GCAM.

$$E_{xy,m,t,s} = \frac{E_{xy,m}}{\Sigma_{xy,m} E_{xy,m}} \times E_{r,A,t,s}$$

Where:
$E_{xy,m,t,s}$ = GCAM emissions distributed on a latitude/longitude grid (*x*, *y*), per month (*m*) over the projection years (*t*) for a particular scenario (*s*)
$E_{xy,m}$ = GEOS-Chem emissions of a given grid cell (in latitude and longitude, *xy*) and month (*m*)
$E_{r,A,t,s}$ = GCAM emissions distributed by region and AEZ (*r*,*A*) over time (*t*) for a scenario (*s*)

Equation 2. Once the GCAM emissions are re-gridded, they are multiplied by the adjoint sensitivities to determine the change in nitrogen deposition attributable to climate policy.

$$\Delta D_{i,t,s} \approx \Sigma_{\mathrm{xy}} \Delta E_{xy,m,t,s} \times \frac{\partial D_i}{\partial \mathrm{E}_{\mathrm{xy,m}}}$$

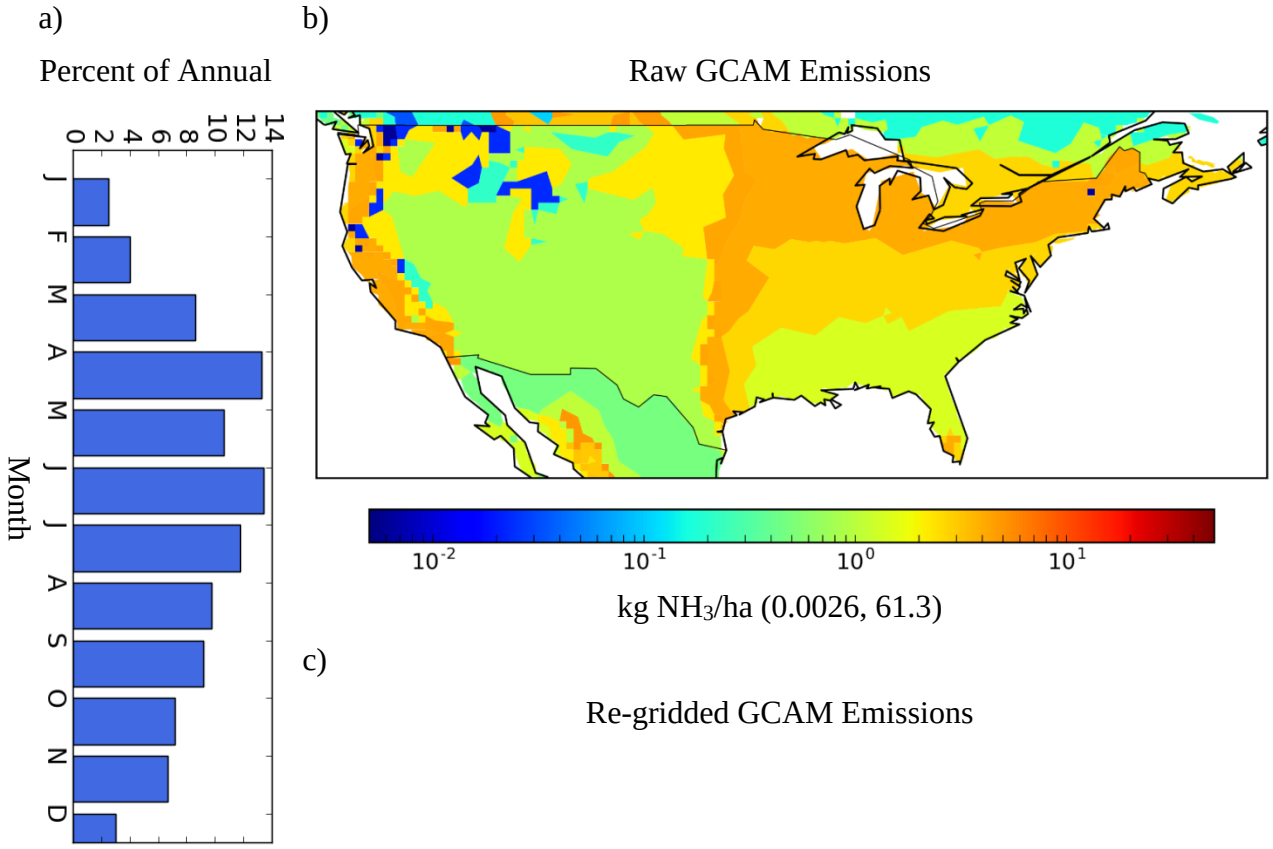
Where:

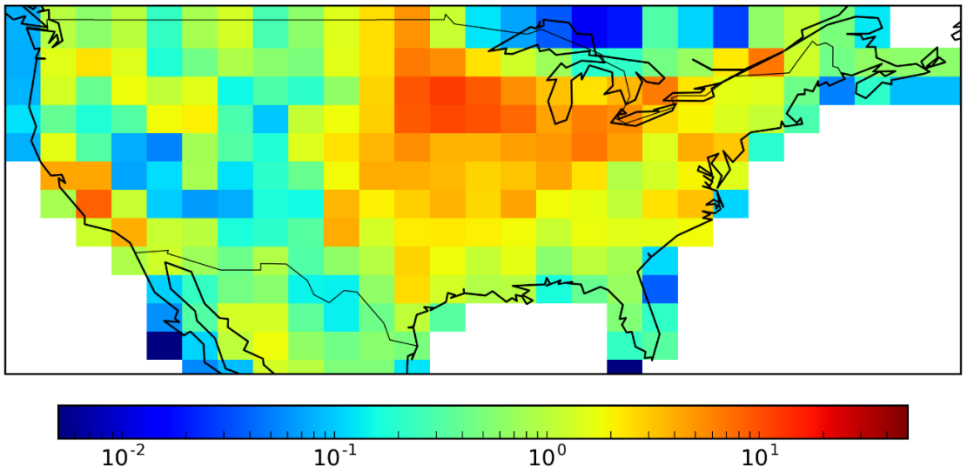
$\Delta D_{i,t,s}$ = Change in deposition of reactive N (D) for a given Class I Area (i), projection year (t) and scenario (s)

$\frac{\partial D_i}{\partial E_{xy,m}}$ = Sensitivity of N deposition at a site (i) to NH_3 emissions by location (xy) and month (m)

Here, we assume that the spatial distribution of emissions will change negligibly by 2100. Using spatially distributed future emissions (e.g. the IPCC's Representative Concentration Pathways) to re-calculate the sensitivities could improve this. It is also assumed that the relationship between a change in emissions and deposition is linear, which has been shown to produce a reasonable approximation using the GEOS-Chem adjoint (Lee et al, 2015).

Figure 1. GCAM re-gridding using GEOS-Chem spatial and temporal weighting factors. a) represents the monthly distribution of emissions in the United States, while b) illustrates the mapping of agricultural emissions in agro-ecological zones in GCAM and c) presents these emissions after the GEOS-Chem spatial weighting has been applied.

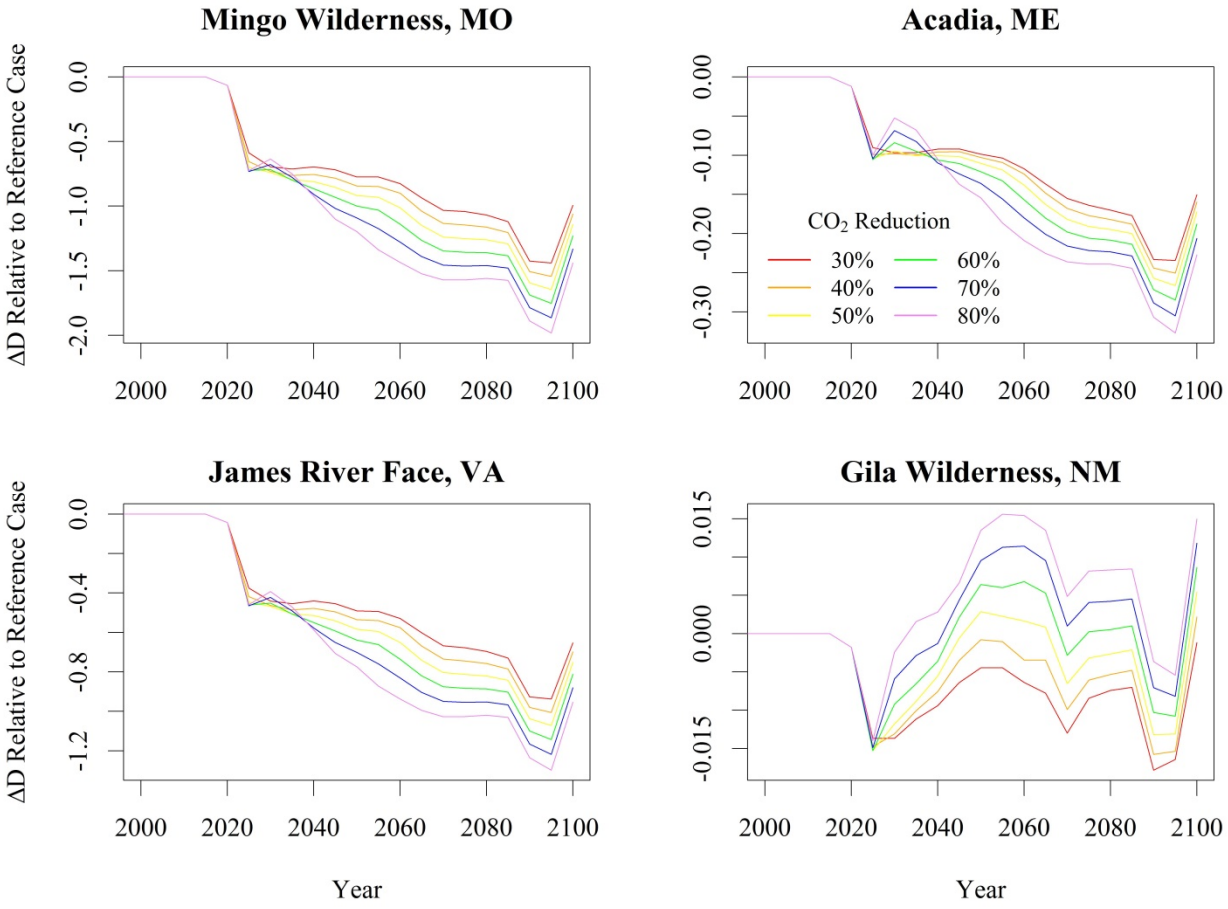




RESULTS BY U.S. CO_2 REDUCTION TARGET

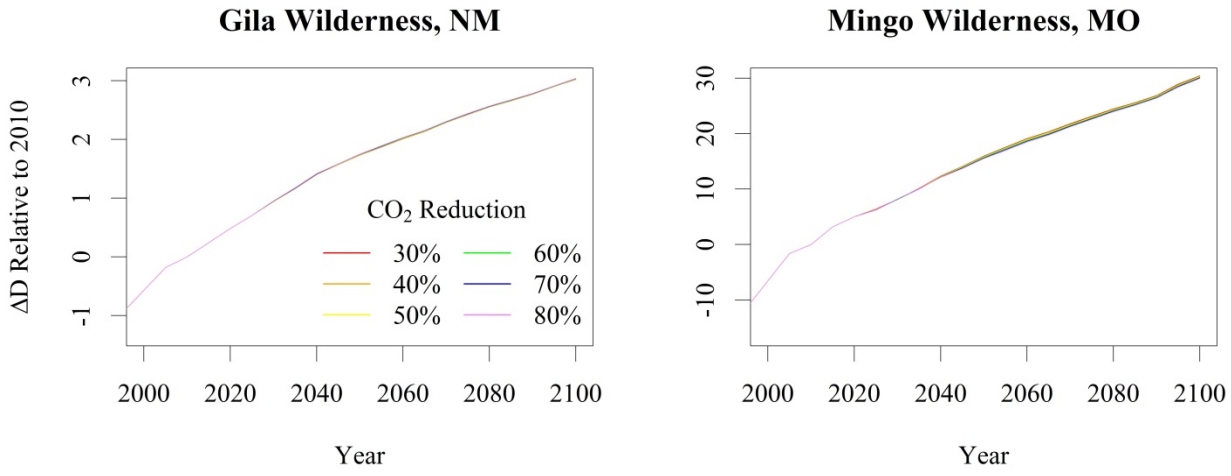
Figure 2 shows that by 2100, climate action leads to a decrease in N deposition relative to the reference case at the sites studied, except for a small increase in the Gila Wilderness in New Mexico. The most aggressive climate policy may cause a short-term increase in deposition relative to similar but less aggressive strategies. However, by 2100 the most aggressive action on climate change generally leads to the largest reduction in nitrogen deposition.

Figure 2. Change in N deposition (kg N/ha/yr) from NH_3 emissions relative to the reference case for strategies targeting U.S. CO_2 reductions.



Regardless of the CO_2 reduction target, all sites examined experience a dramatic increase in nitrogen deposition from NH_3 emissions by 2100, as seen in comparison with 2010 levels in Figure 3. In the Gila Wilderness, a nutrient loading as low as 4 kg N/ha/yr will impair lichens. Annual N deposition at this site in 2010 is 3.9 kg N/ha/yr, and the critical load is exceeded by 2025. Near the hub of domestic agriculture, pine forests in Mingo, MO have a critical load of 15 and present annual deposition of 25 kg N/ha/yr, which will double by 2100. This indicates that N deposition alone (in addition to runoff, etc.), may cause impairment in both ecosystems in the near term.

Figure 3. Change in N deposition (kg N/ha/yr) from NH_3 emissions relative to 2010.



Here, the biomass and refined liquids sectors were responsible for the increase in ammonia emissions, but this research could expand to explore alternative technological pathways. These results suggest that the future ecosystem and public health impacts of N deposition from NH_3 are critical to consider regardless of the stringency of climate change mitigation efforts.

Disclaimer: The views expressed in this abstract are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

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