GLIMPSE

An Approach for Determining Optimal Control Strategies for Energy System Emissions of Ozone Precursor Gases

Shannon L. Capps, Rob W. Pinder, Dan Loughlin, Sergey Napelenok, Jesse O. Bash, Matthew D. Turner, Daven K. Henze, Peter B. Percell, Shunliu Zhao, Matthew G. Russell, Amir Hakami

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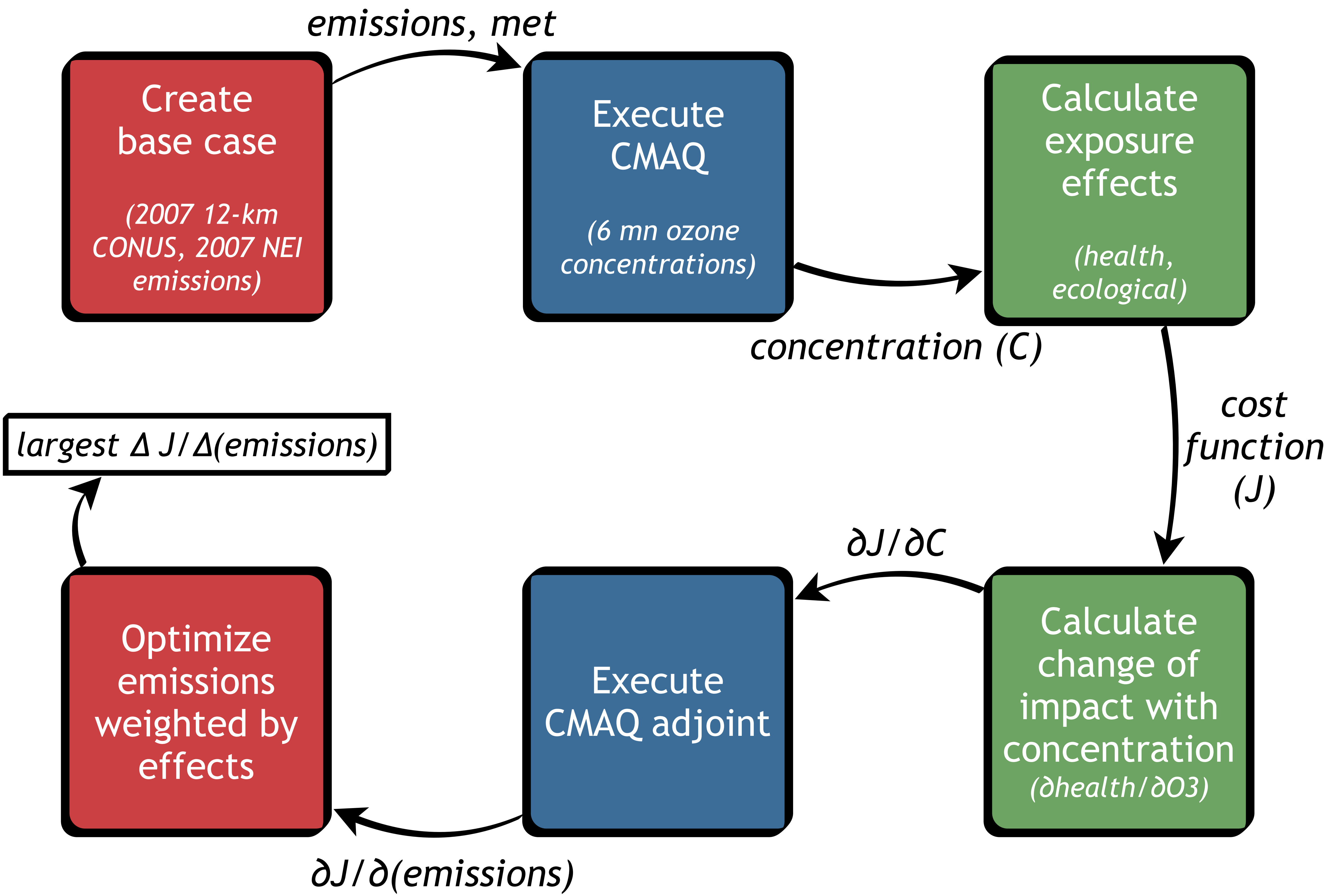
EPA

With grateful acknowledgement of funding from EPA through ORISE.

Objective

Optimize *ozone benefits* to human health & ecosystems of potential *energy systems emissions reductions* which could achieve regulatory endpoints through *efficient sensitivity analysis*.

Method


emissions, met
Create base case
(2007 12-km CONUS, 2007 NEI emissions)
Execute CMAQ
(6 mn ozone concentrations)
Calculate exposure effects
(health, ecological)
concentration (C)
cost function (J)
largest Δ J/Δ(emissions)
∂J/∂C
Optimize emissions weighted by effects
Execute CMAQ adjoint
Calculate change of impact with concentration
(∂health/∂O3)
∂J/∂(emissions)

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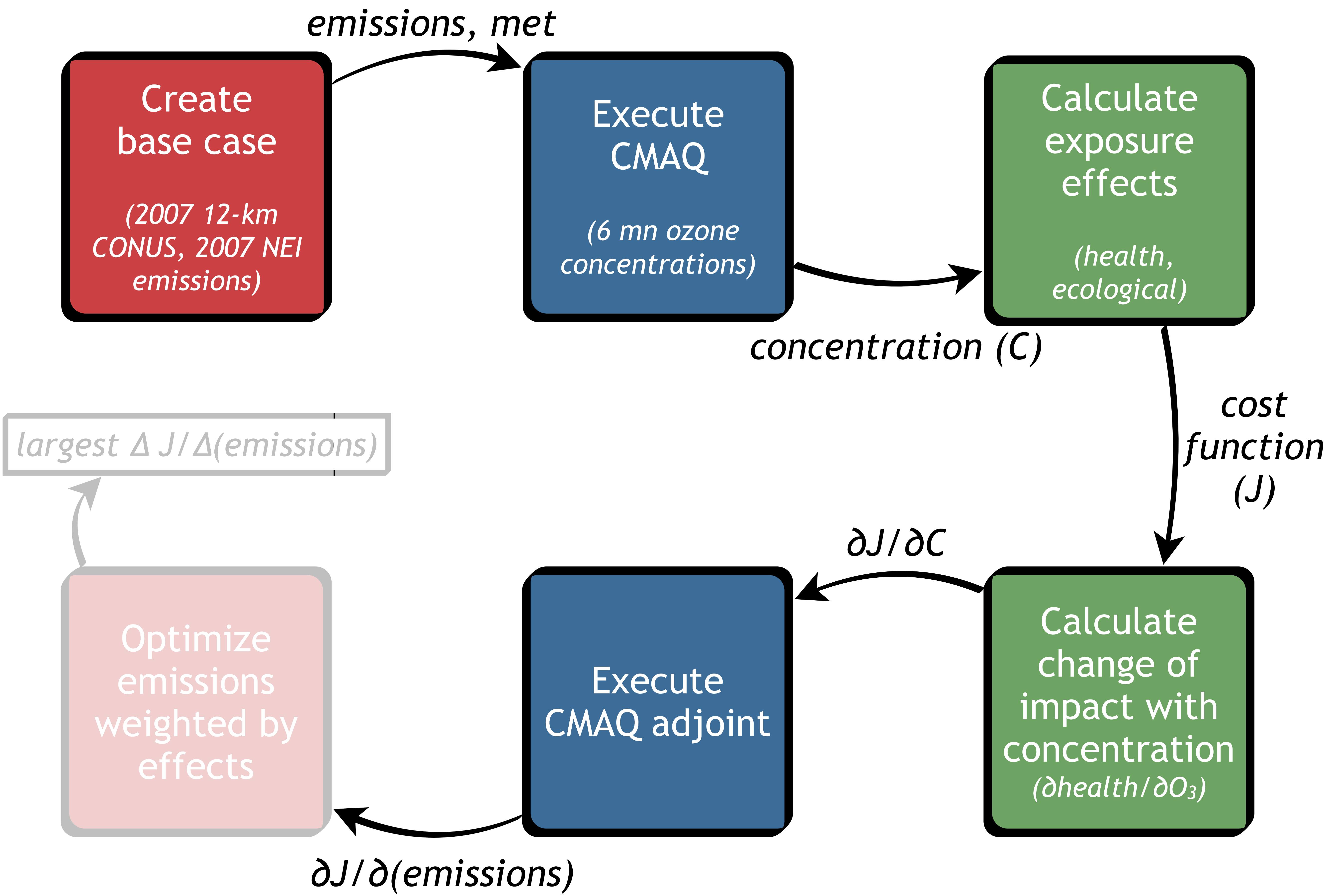

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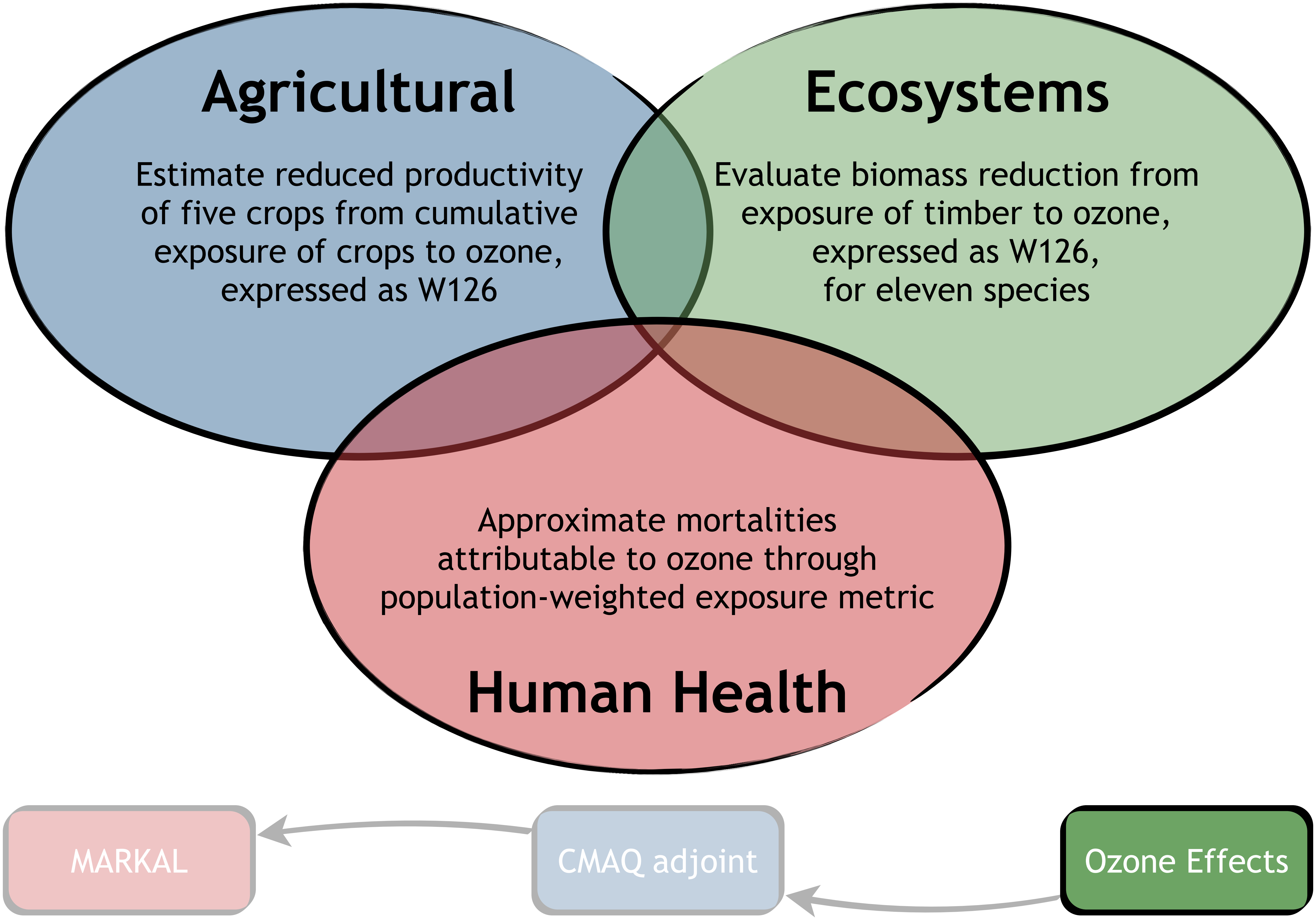
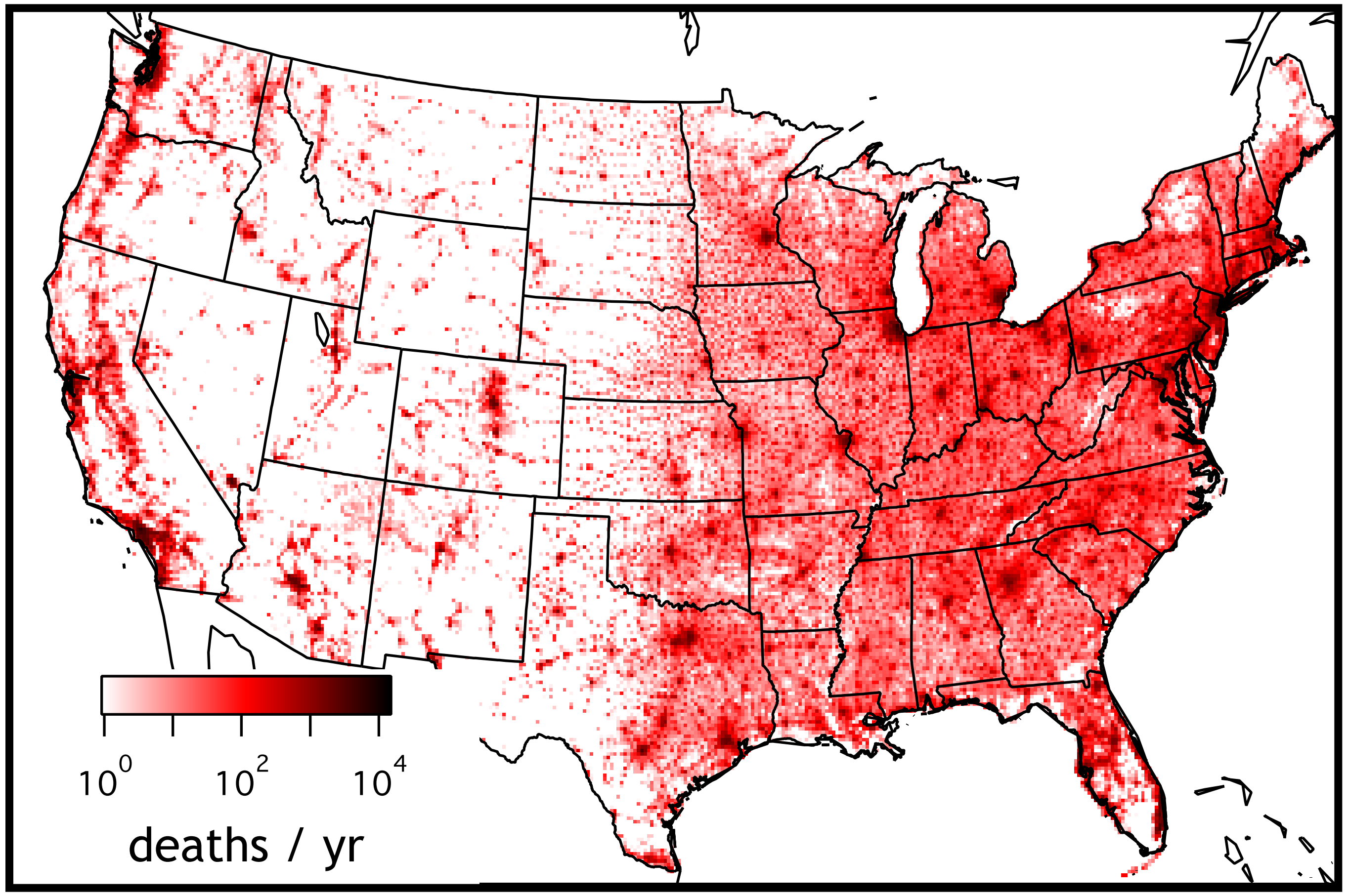
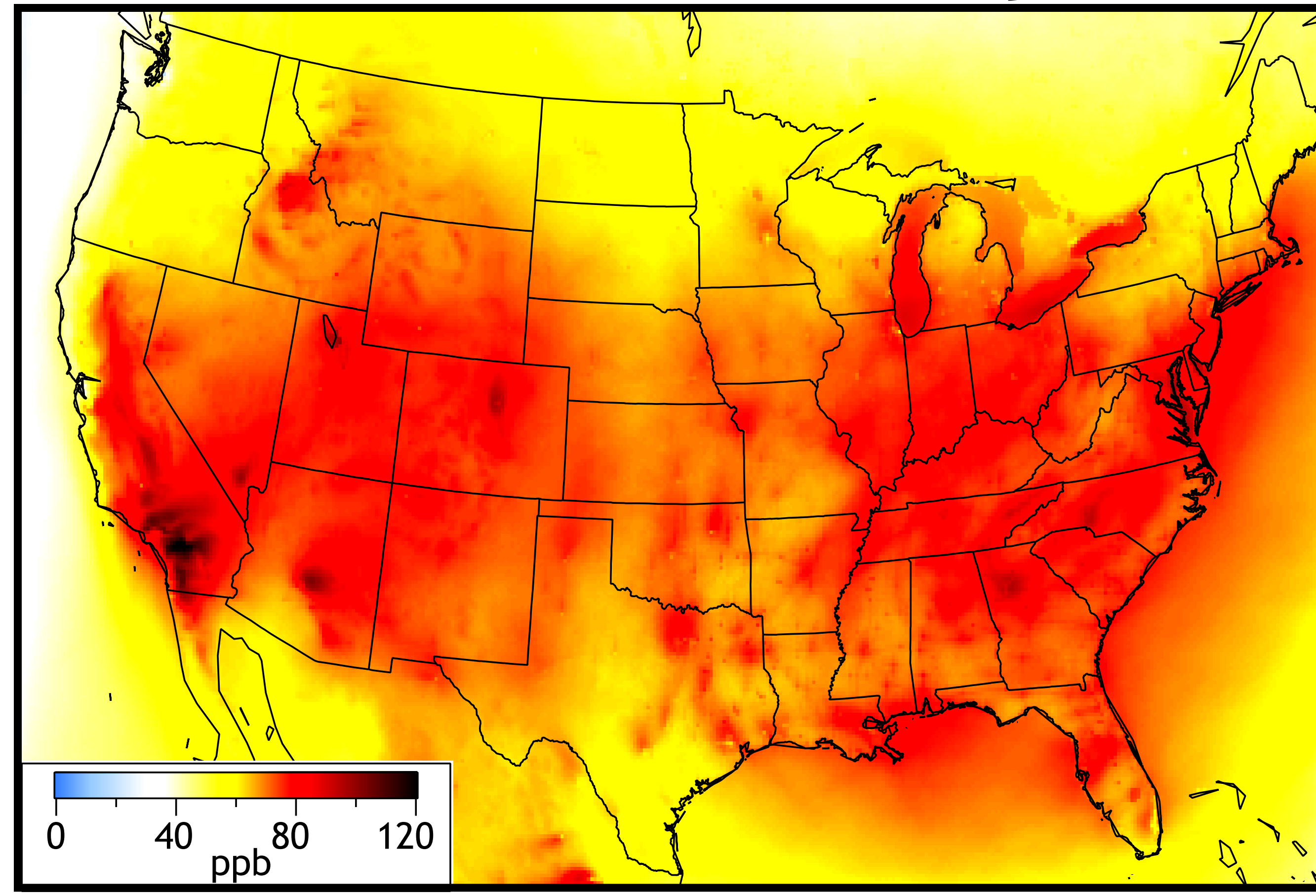
Quantifying Ozone Disbenefits



Estimating Premature Mortality



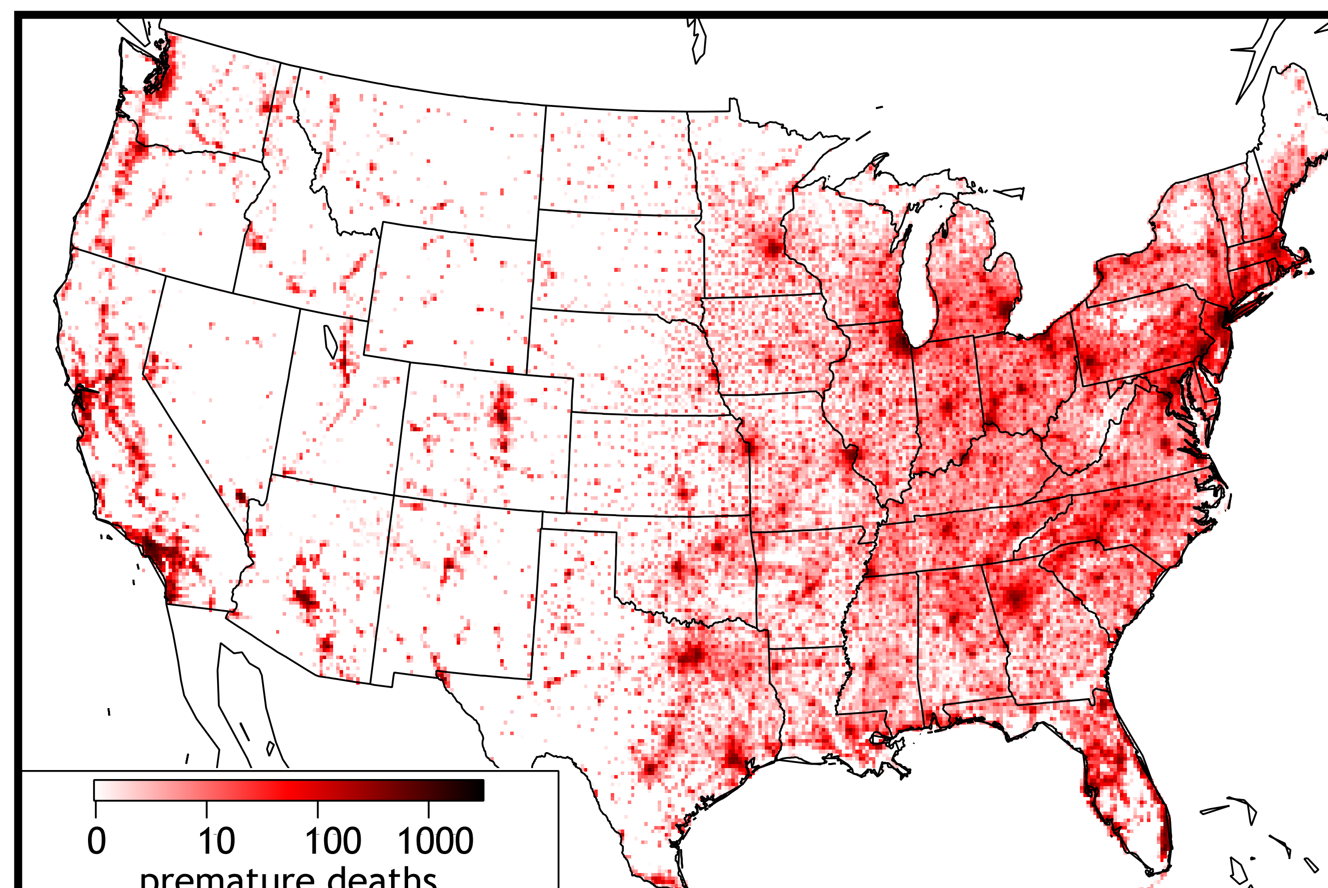
Baseline mortality of exposed population, ≥30 yo



2007 6-month mean of hourly maximum O_3

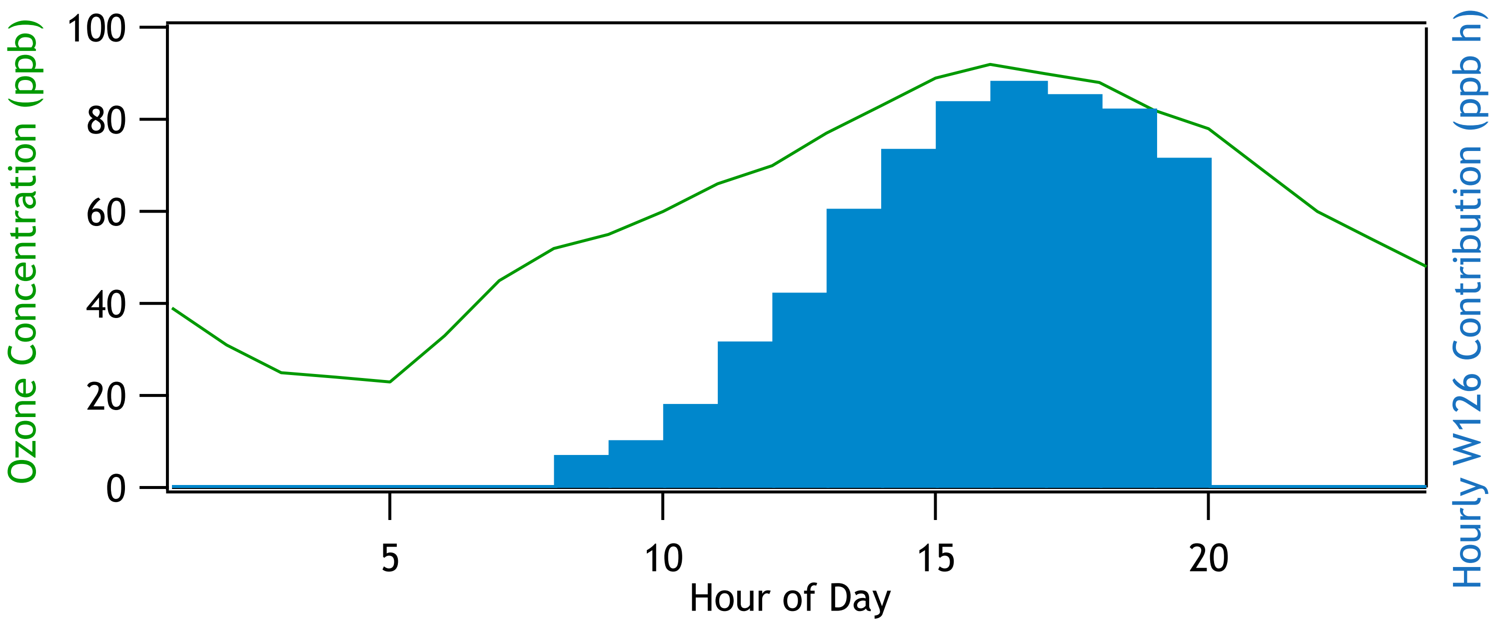
$$\Delta M = M_0 P(1 - e^{-\beta \Delta C})$$

where M_0 is the baseline mortality, P is the exposed population over 30 years old, β is 0.0427% per ppb O_3, and C is the 6-month mean of hourly maximum O_3.



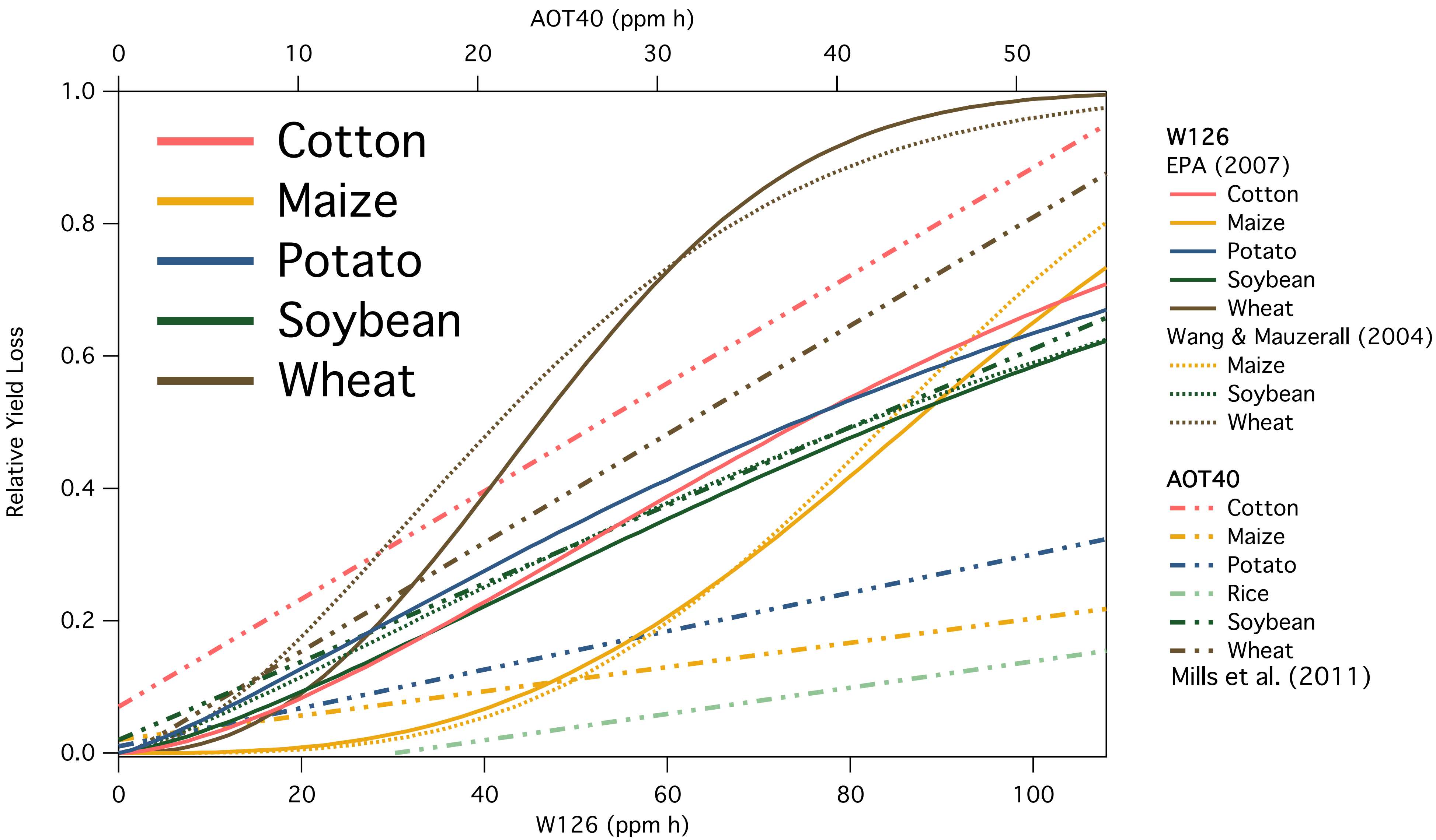
(BenMAP, Jerrett et al., 2009)

Ecosystem Ozone Exposure Metric



$$W126_{90\ day} = \left[\sum_{i=1}^{90} \left(\frac{[O_3]}{1+\left(4403e^{-126[O_3]}\right)} \right) \right]_{i,8am\text{-}8pm}$$

$$RYL = 1 - \exp\left[-\left(\frac{W126}{A_i} \right)^{B_i} \right]$$



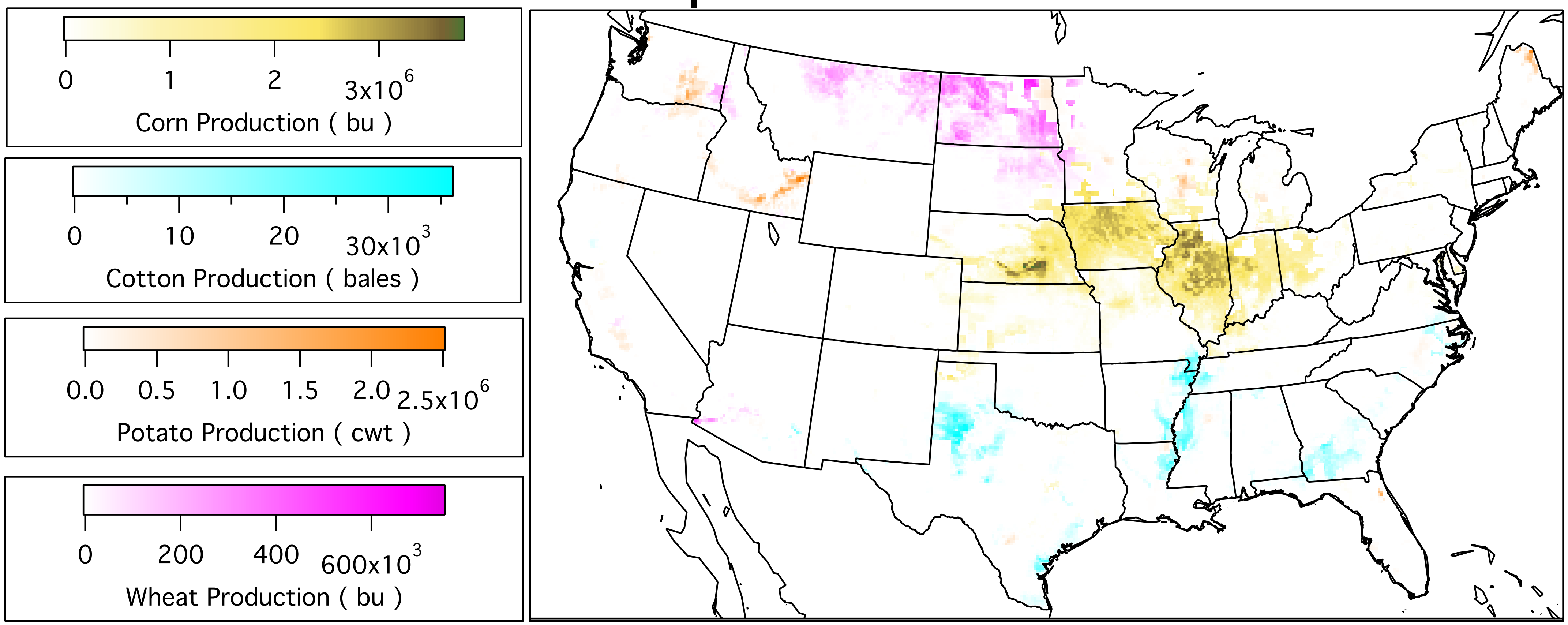
Relative yield loss (RYL) as a function of the W126 ozone exposure metric has been empirically determined for 5 crops and 11 tree species.

Multiplying RYL by the productivity determines the potential productivity loss (PPL) of each species.

Lehrer, A. et al.,EPA 452/R-07-002, 2007.

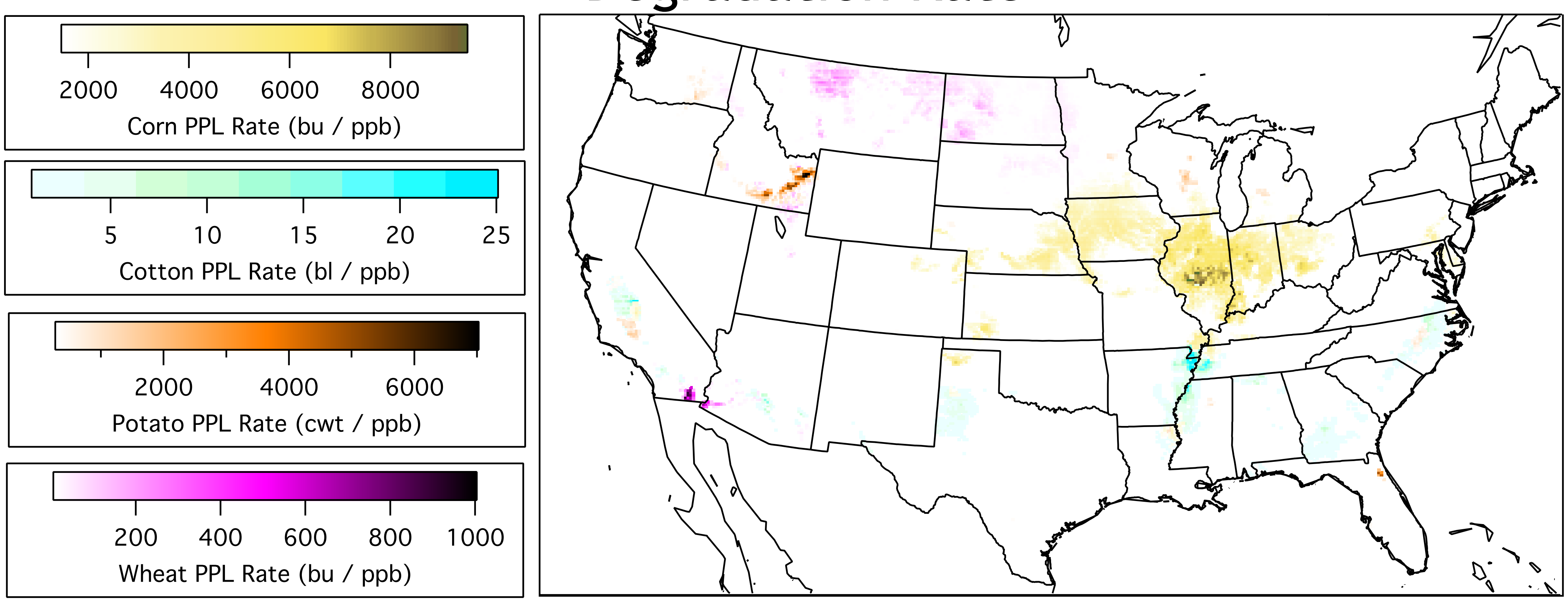
Crop Degradation by Ozone Exposure

Crop Production



USDA National Agricultural Statistics Survey (NASS) 2007 crop production distributed in accordance with the Biogenic Emissions Landuse Database (BELD) v.4

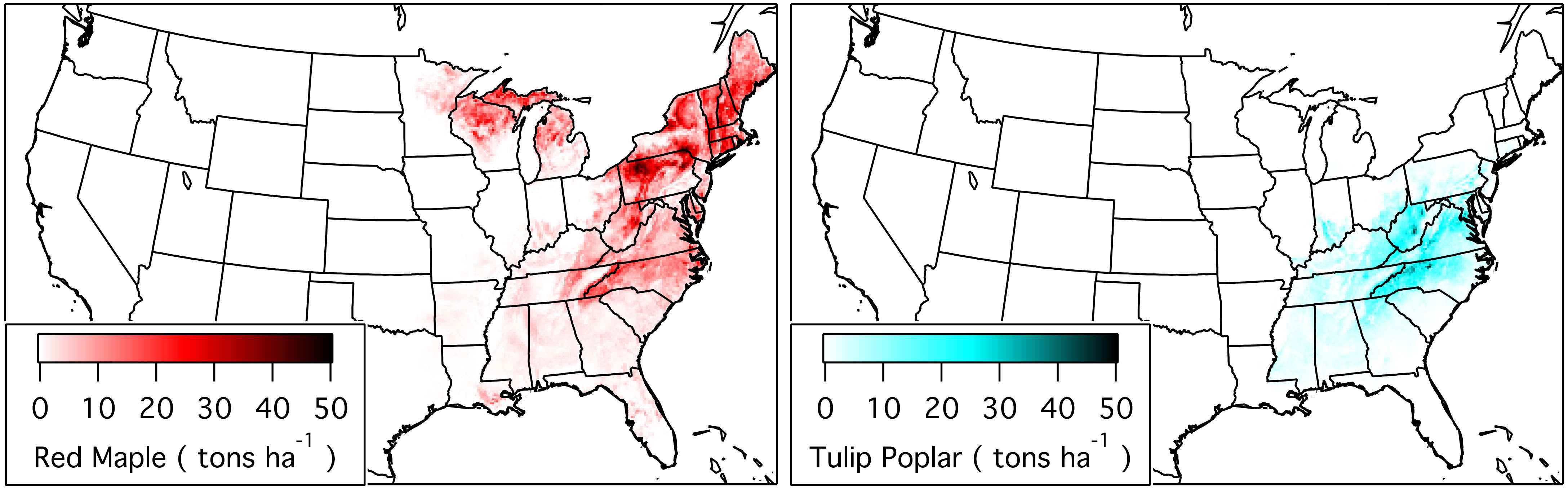
Degradation Rate



Time-averaged degradation rate over the 3-month growing period.

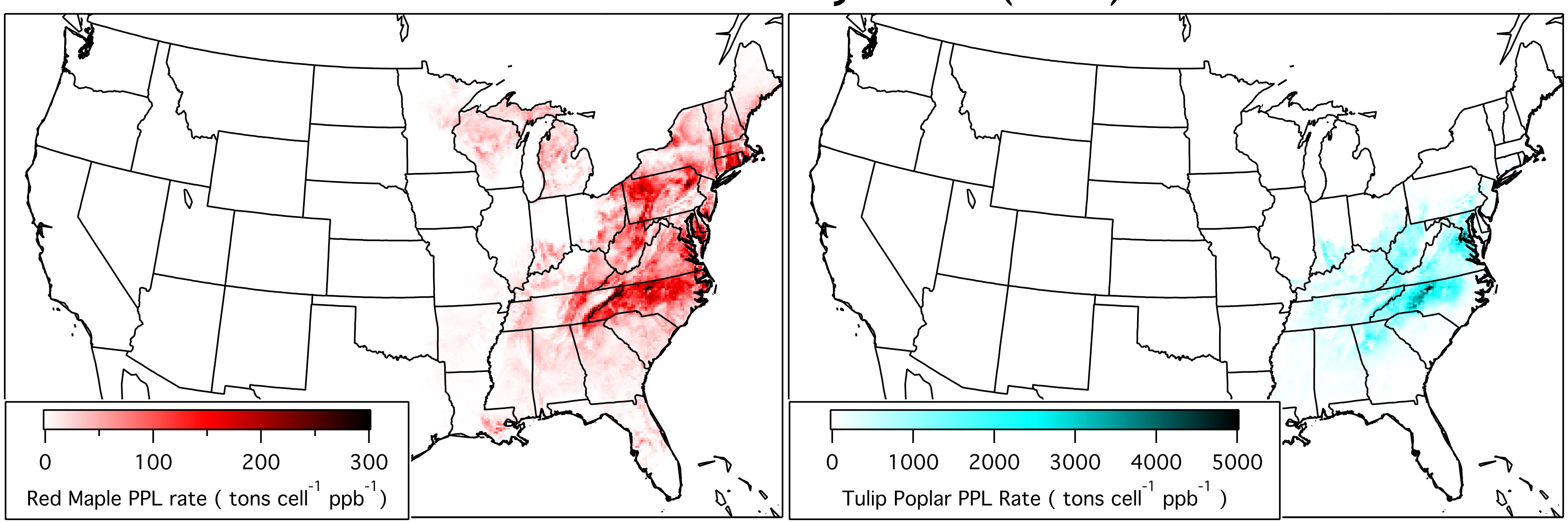
Timber PPL by Ozone Exposure

Tree Biomass Distribution



USDA Forest Inventory Analysis tree biomass distributed in accordance with the National Land Cover Database; MODIS-derived image composites and percent tree cover; and other geographic and climatological parameters.

Potential Productivity Loss (PPL) Rate

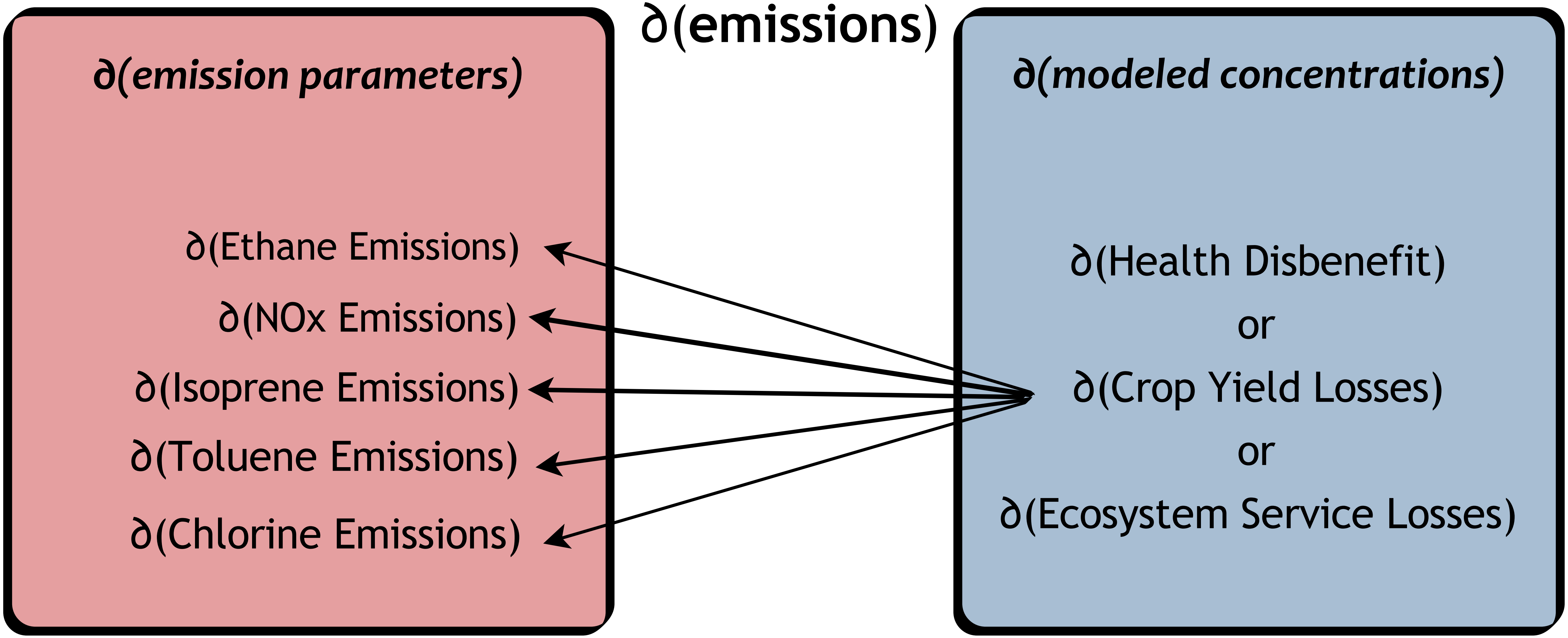


Time-averaged degradation rate over the 3-month growing period.

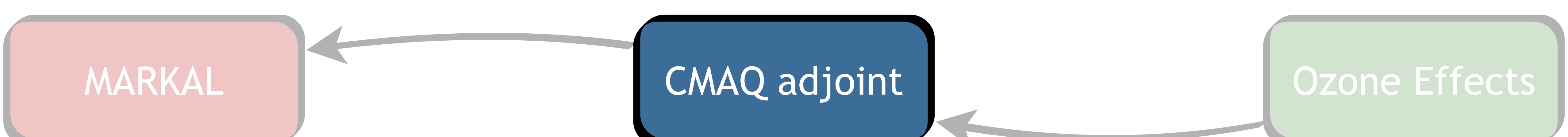
Blackard et al., 2008, Remote Sensing of the Environment

Connecting Ozone Effects to Emissions with CMAQ adjoint

$$\frac{\partial(O_3\ \text{effect})}{\partial(\text{emissions})}$$

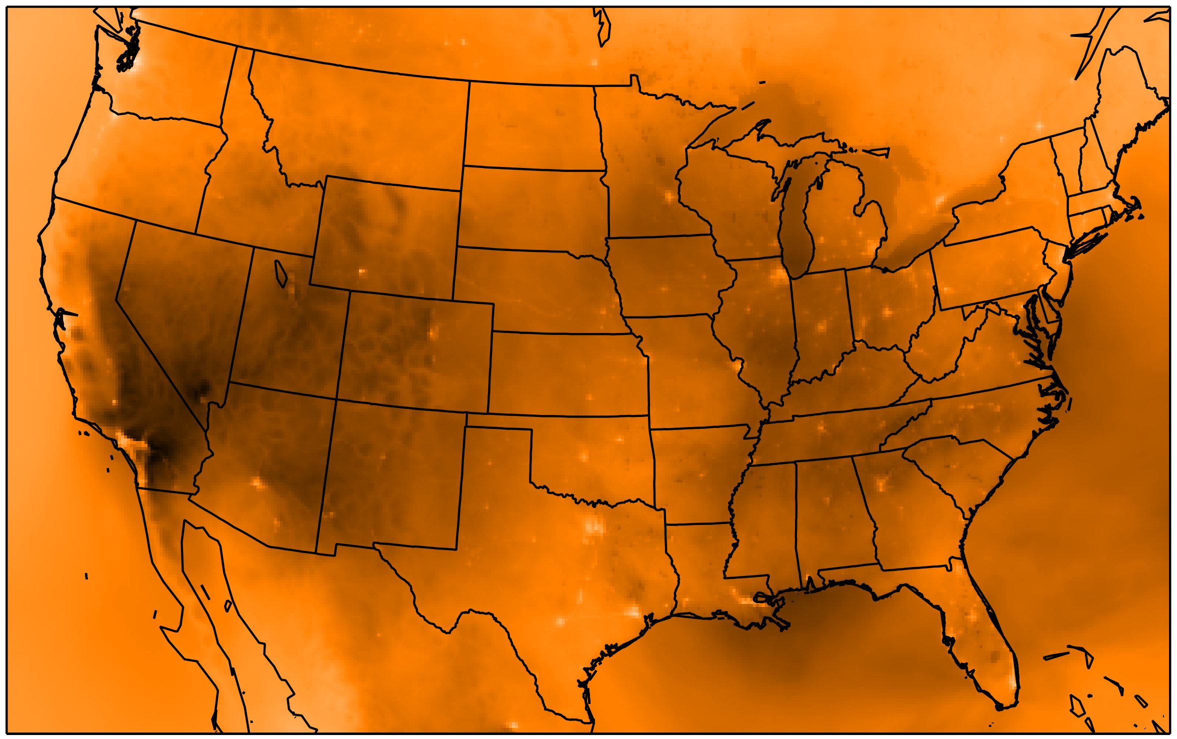


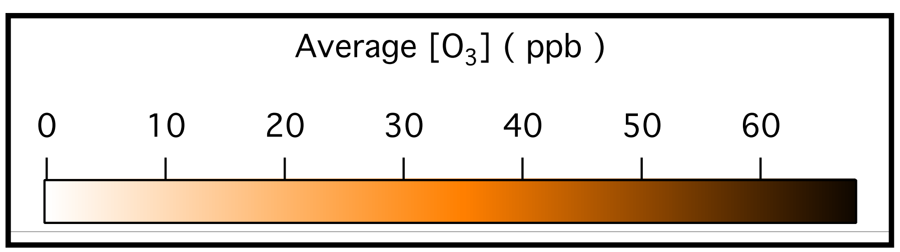
$$\partial\vec{x}=(F')^{T}(x,\partial y)$$



Proof of Concept Scenario

Ozone Concentration





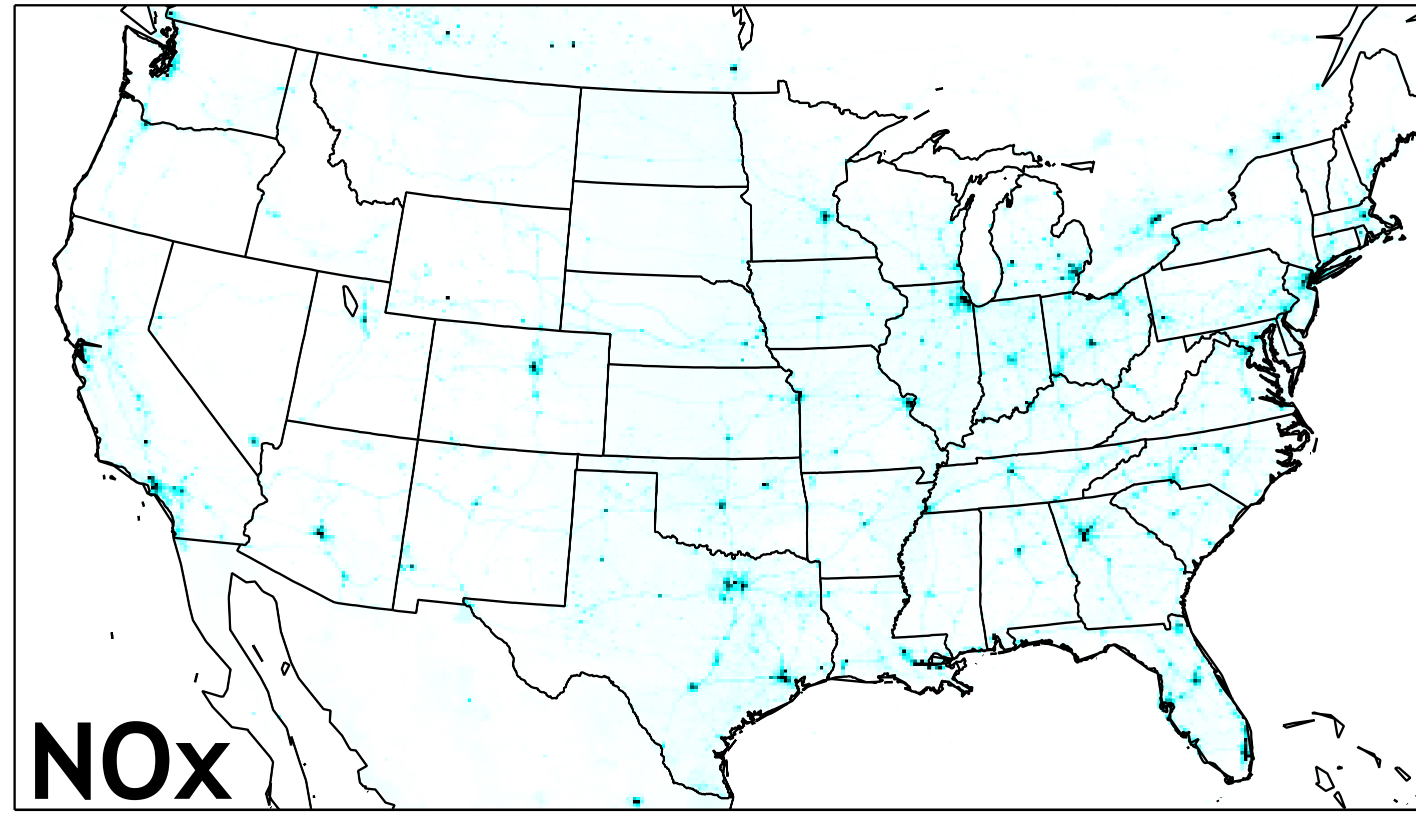
June 11-24, 2007

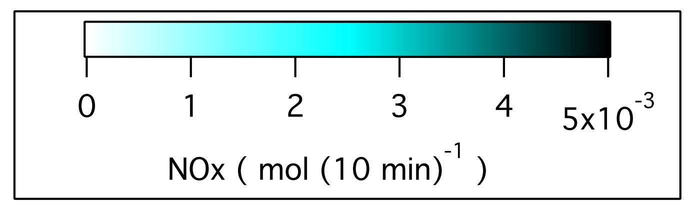
CMAQ 4.7.1 adjoint

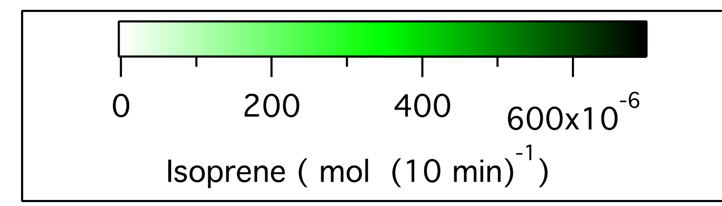
WRF meteorology

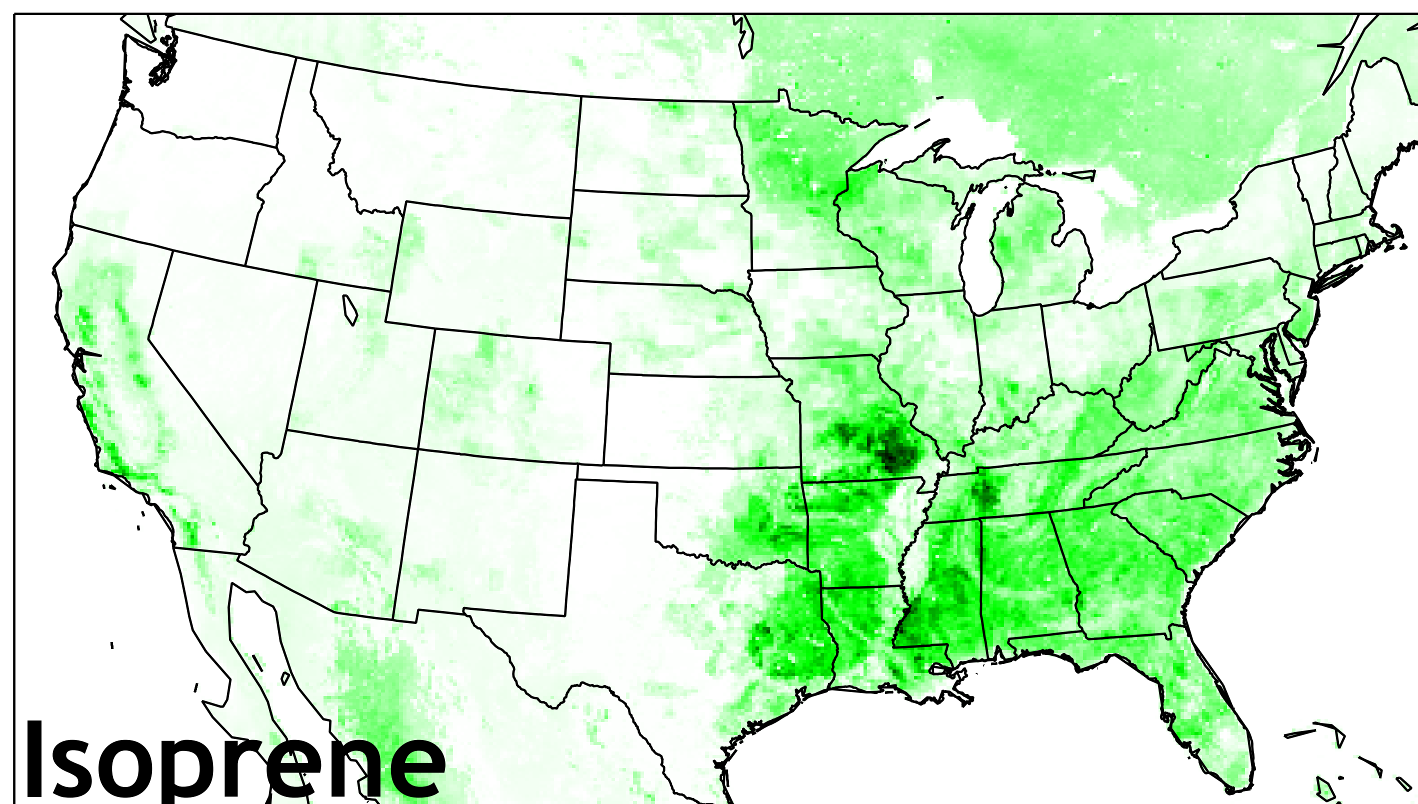
2007 National Emissions Inventory

Emissions

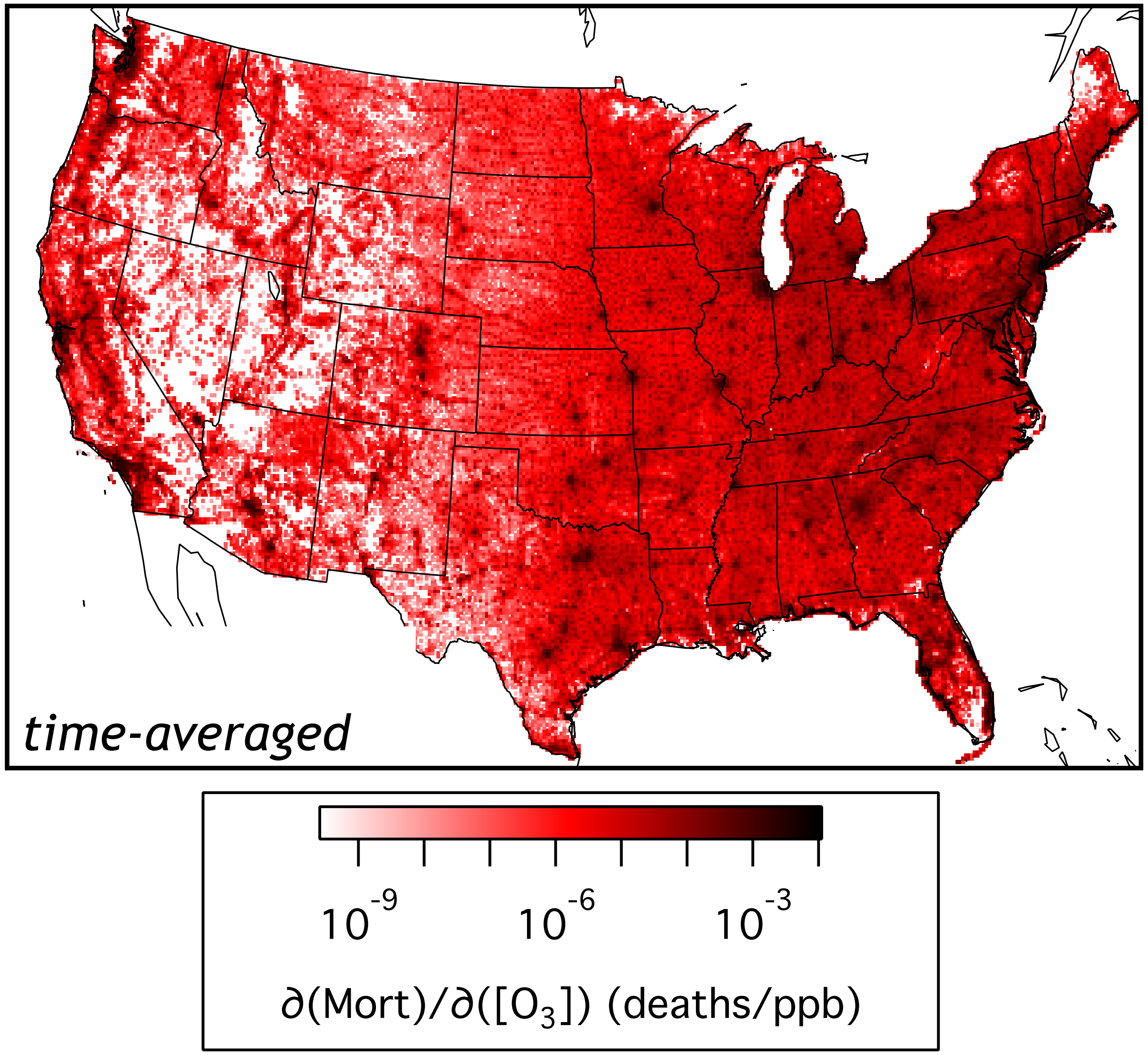


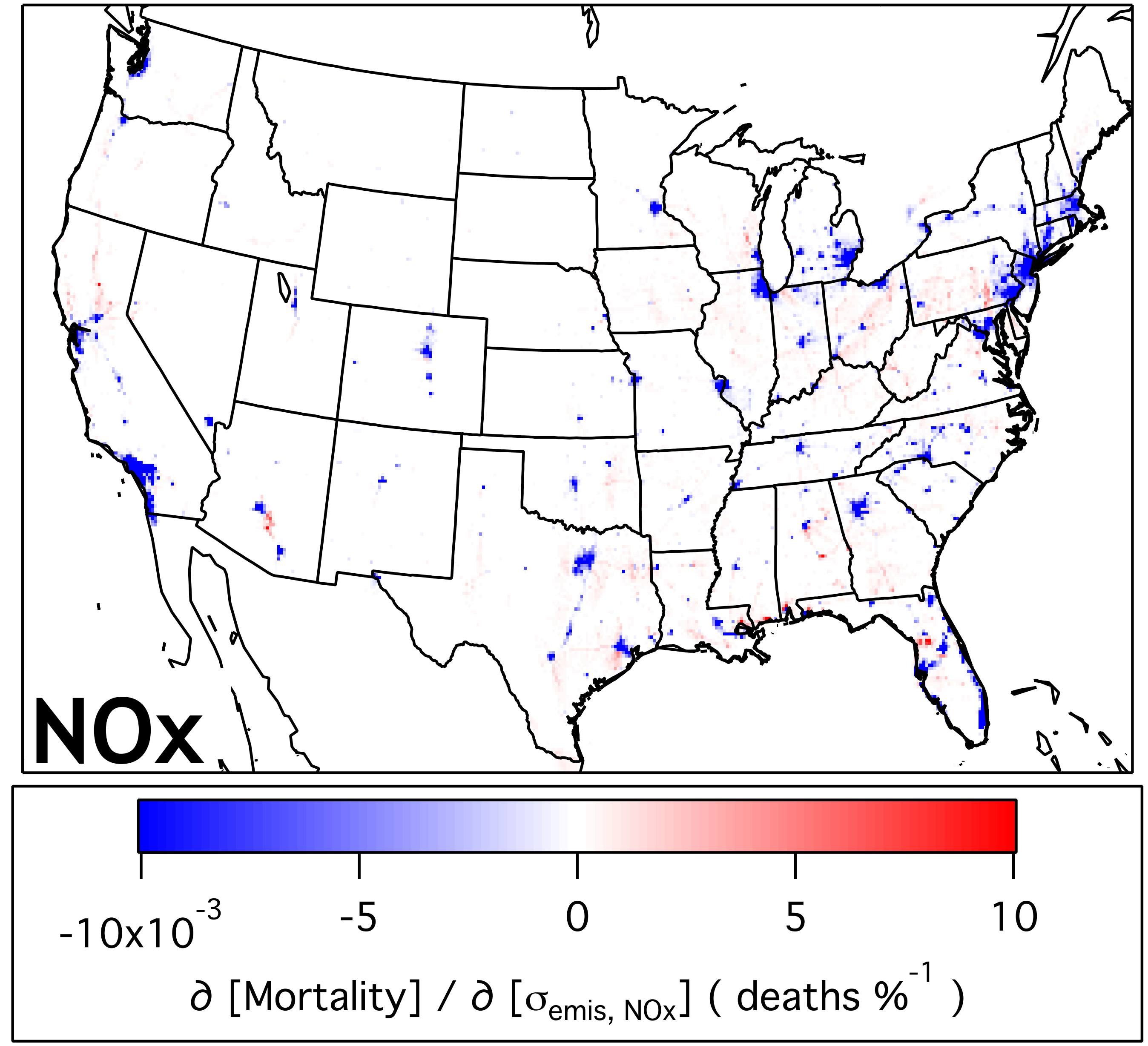






Sensitivity of Mortality to Emissions



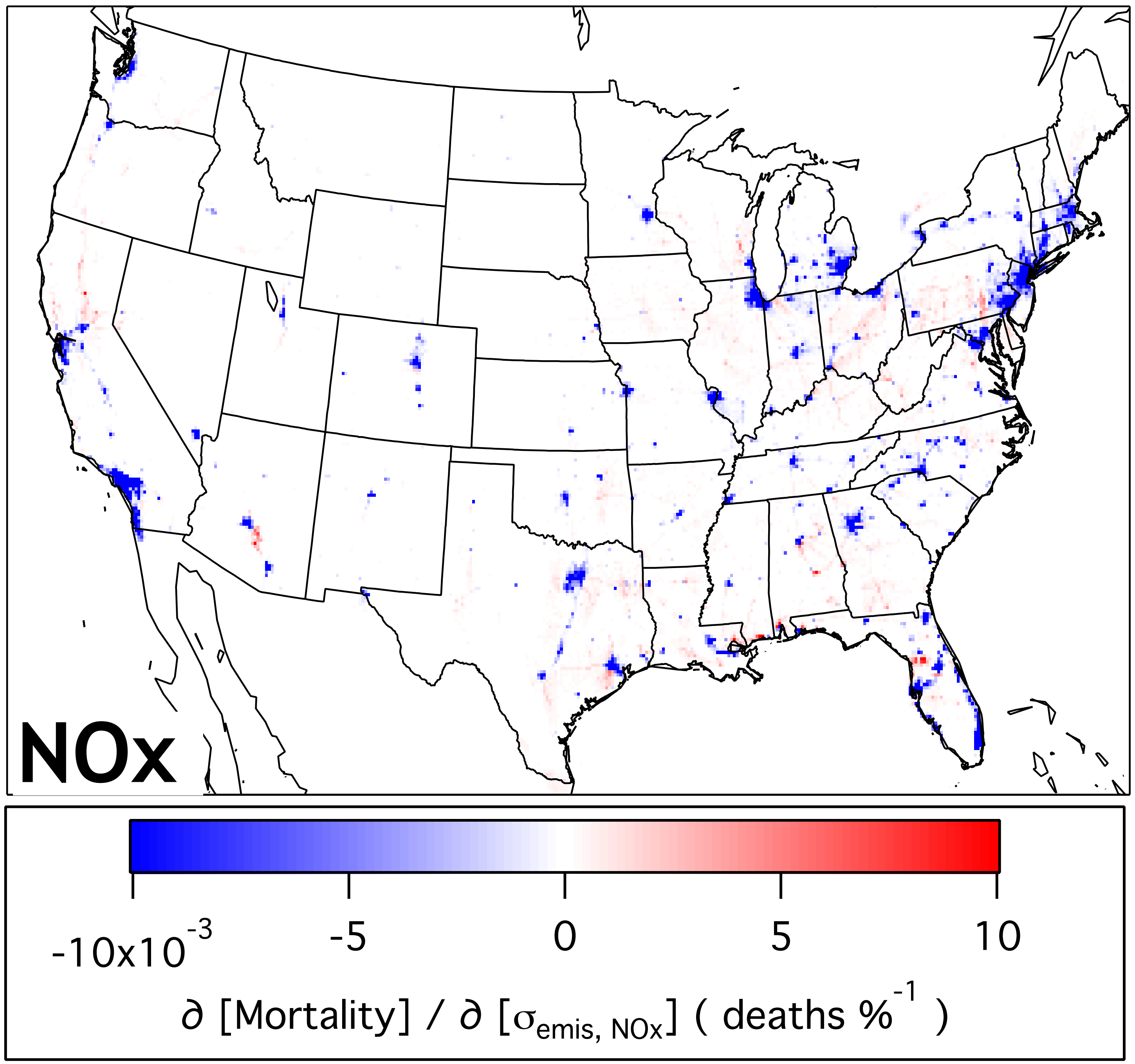


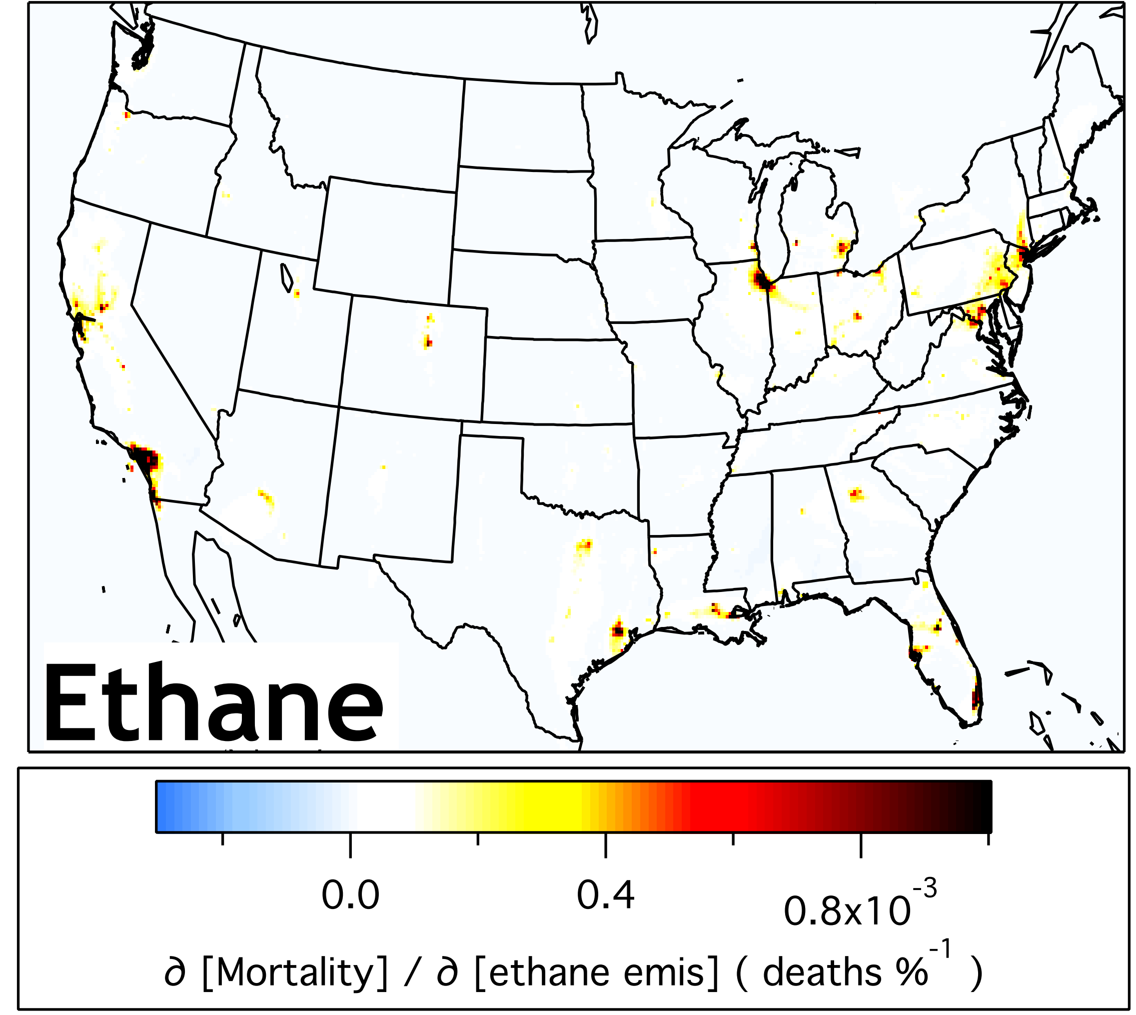
$$\Delta M = M_0 P\left(1 - e^{-\beta \Delta C}\right)$$

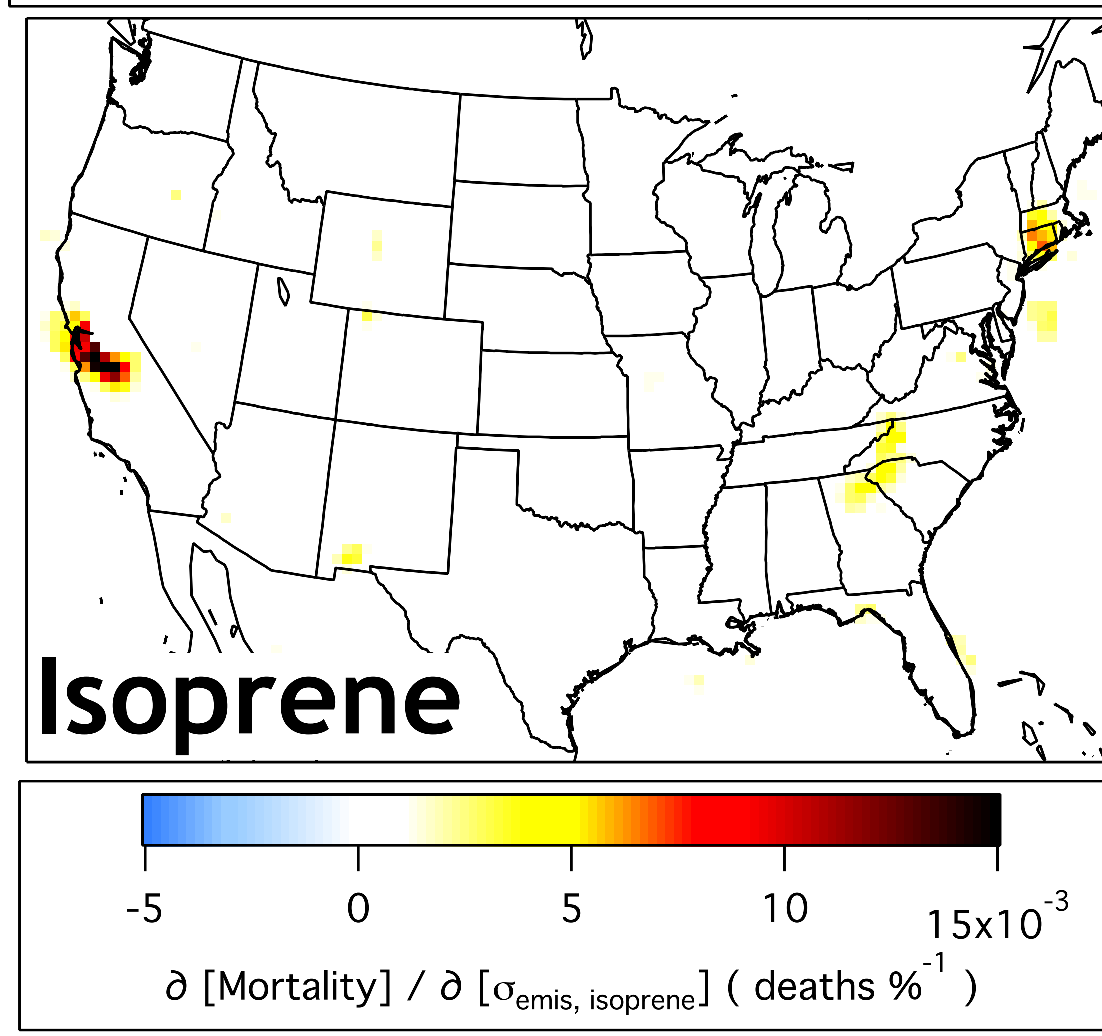
$$\partial J = \left[\frac{\partial(\text{mortality})}{180} \right]\Bigg|_{\text{max 1-hr } \left[O_3\right]}$$

Emissions Influences on Mortality

Urban nature of the cost function leads to *negative influence of NOx* and *positive influence of VOCs* on mortality.





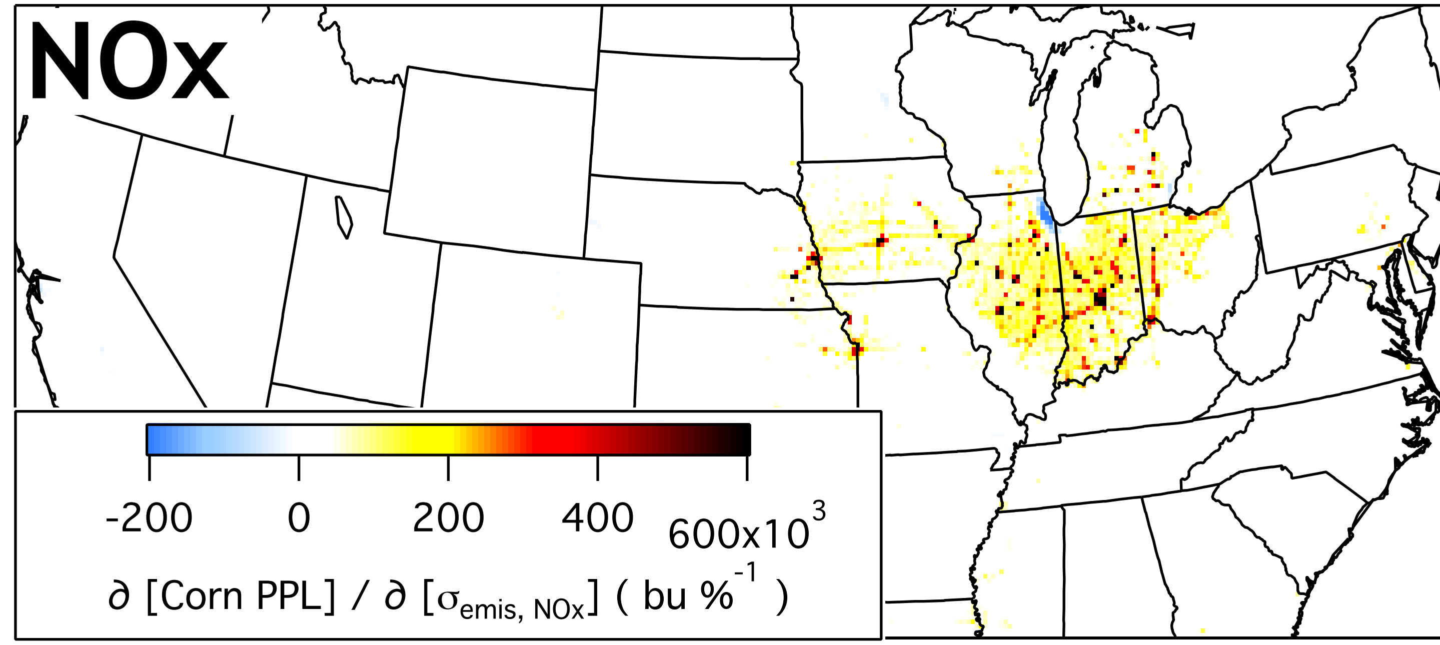


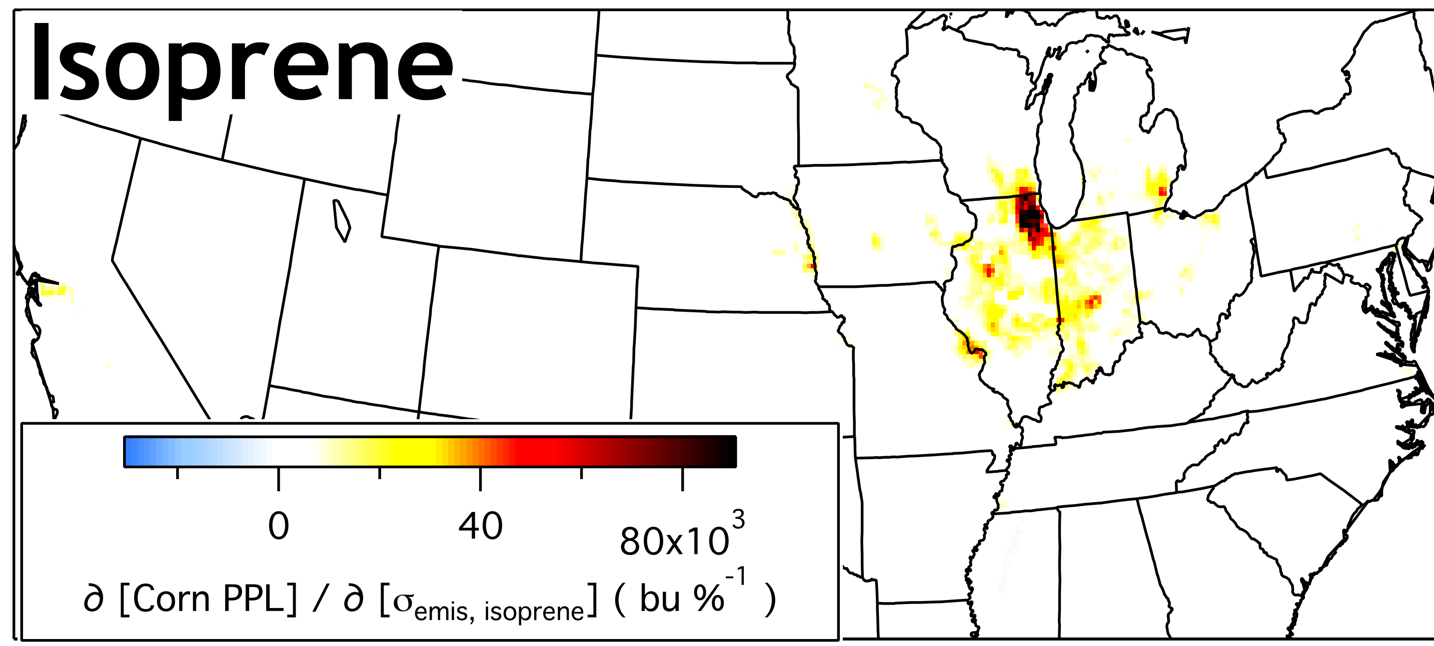
Emissions Influences on Corn PPL

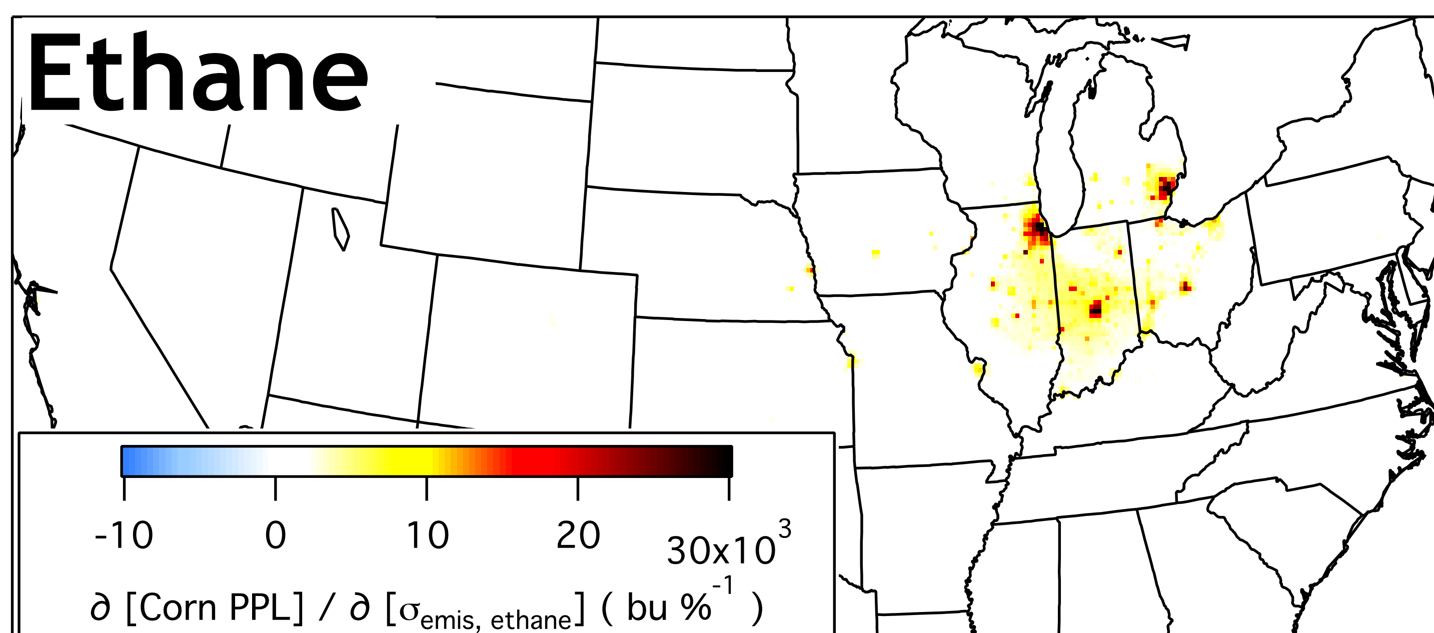
Small VOC-limited regime near Chicago leads to negative influence of NOx emissions from this location.

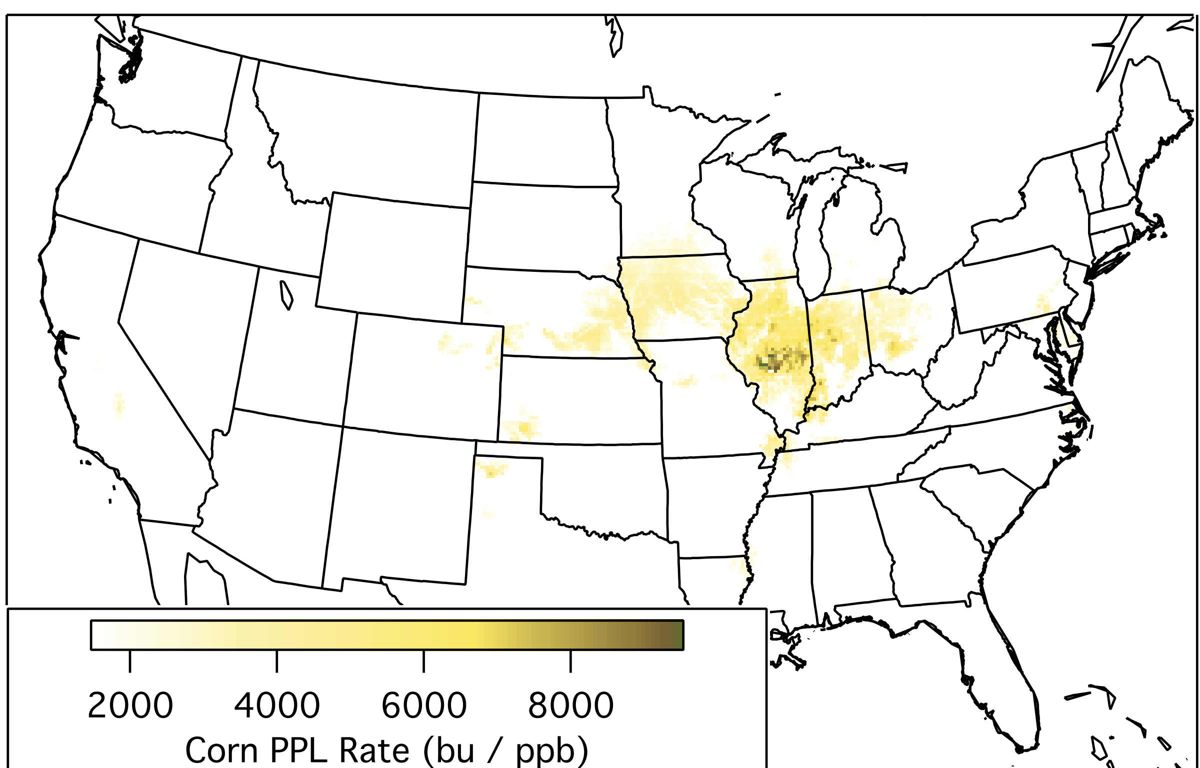
Otherwise, NOx contributes to the ozone that reducing biomass yield of corn.

Isoprene & ethane have similar levels of influence on corn degradation.





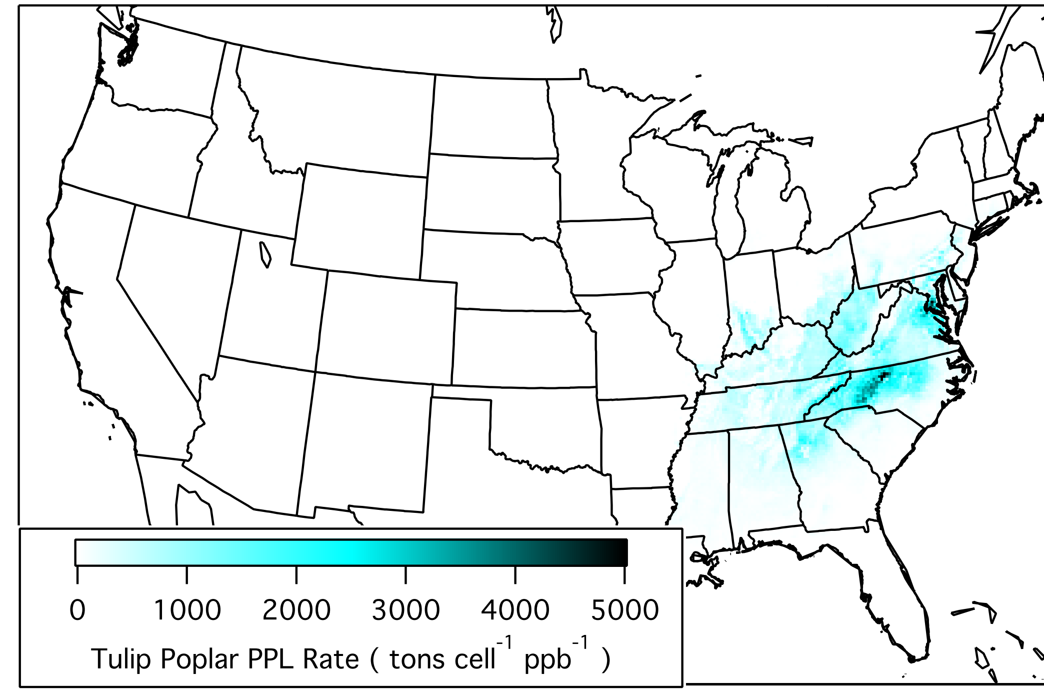


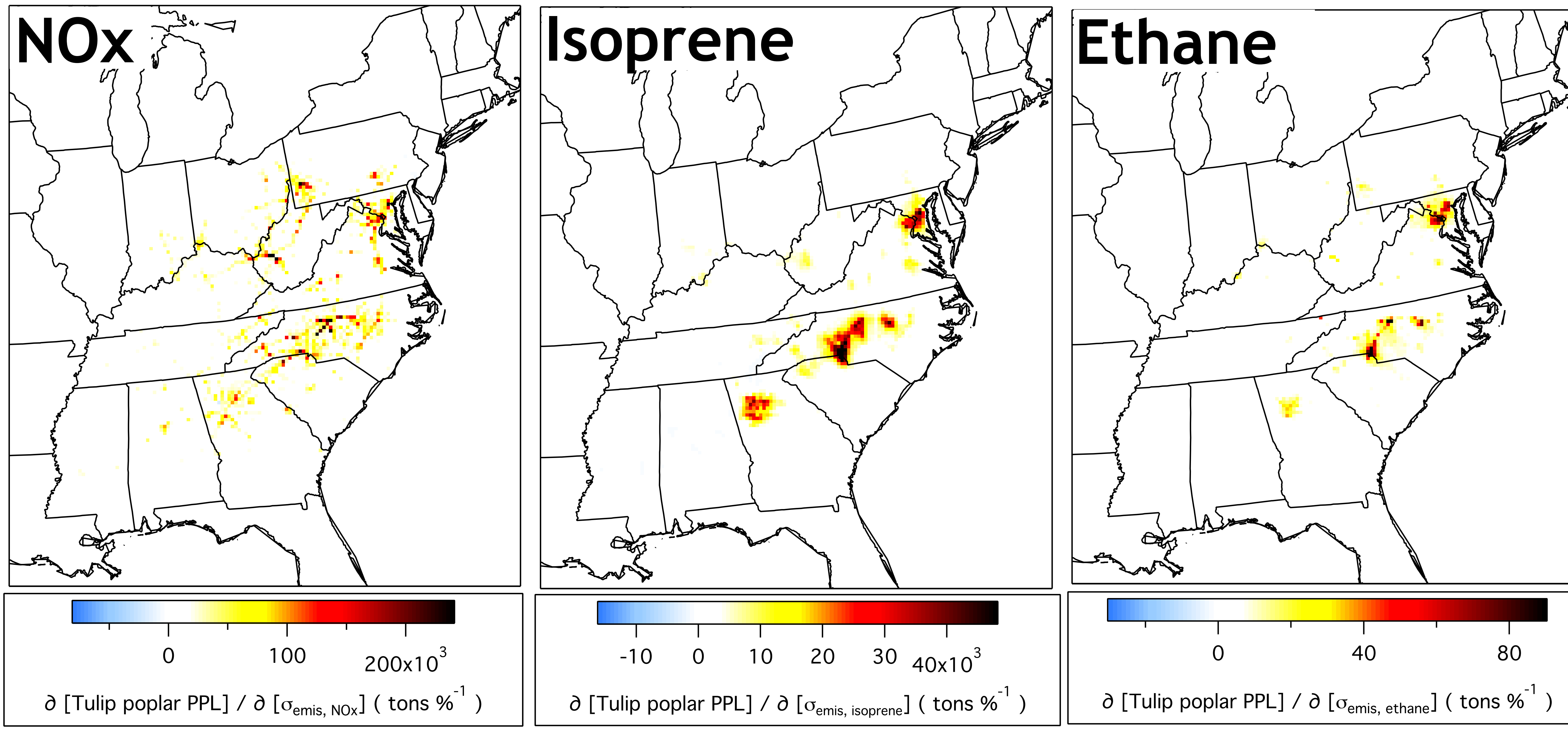


Emissions Influences on Tulip Poplar PPL

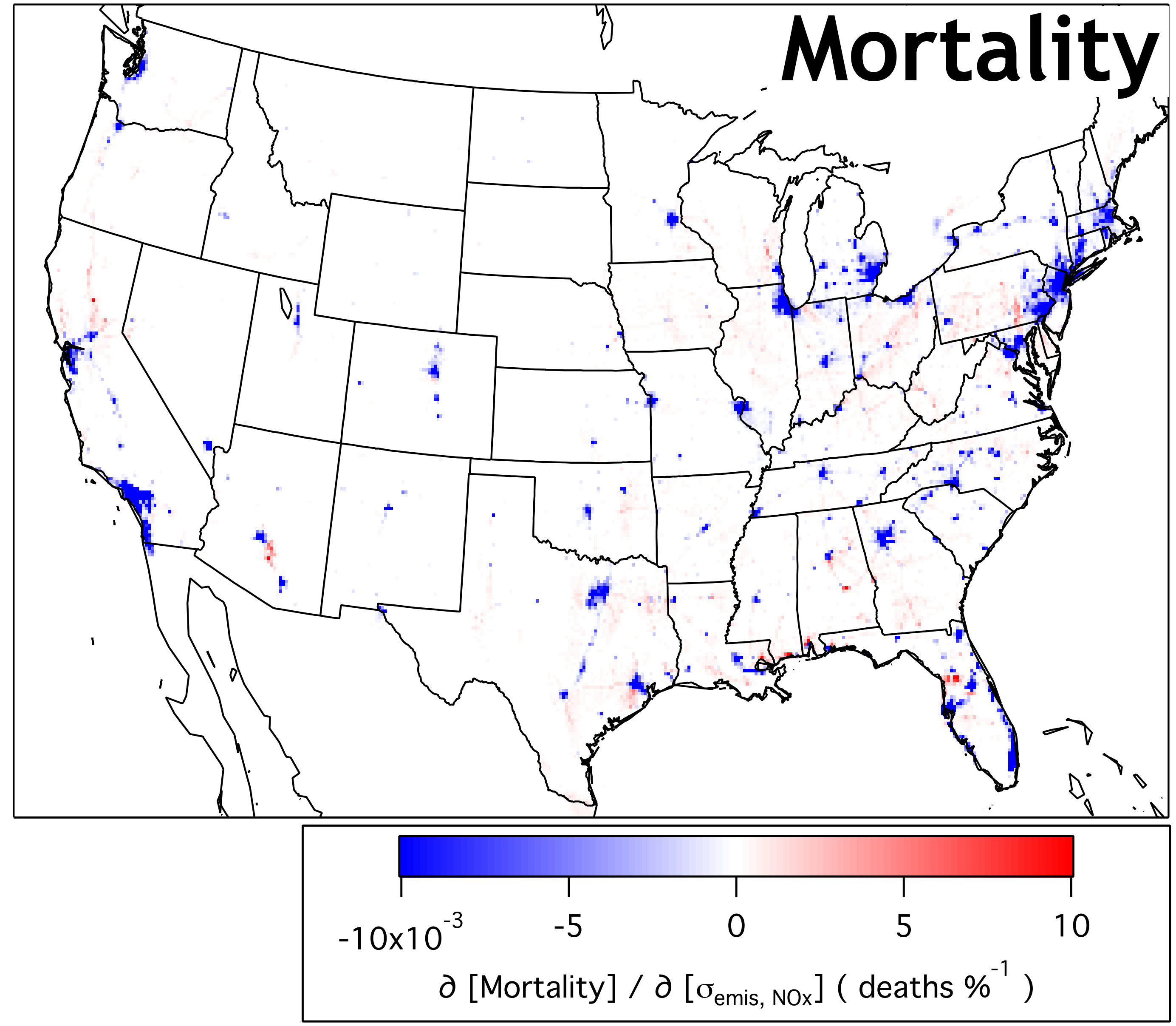
More *rural nature of cost function* leads to *positive contributions for NOx & VOCs*.

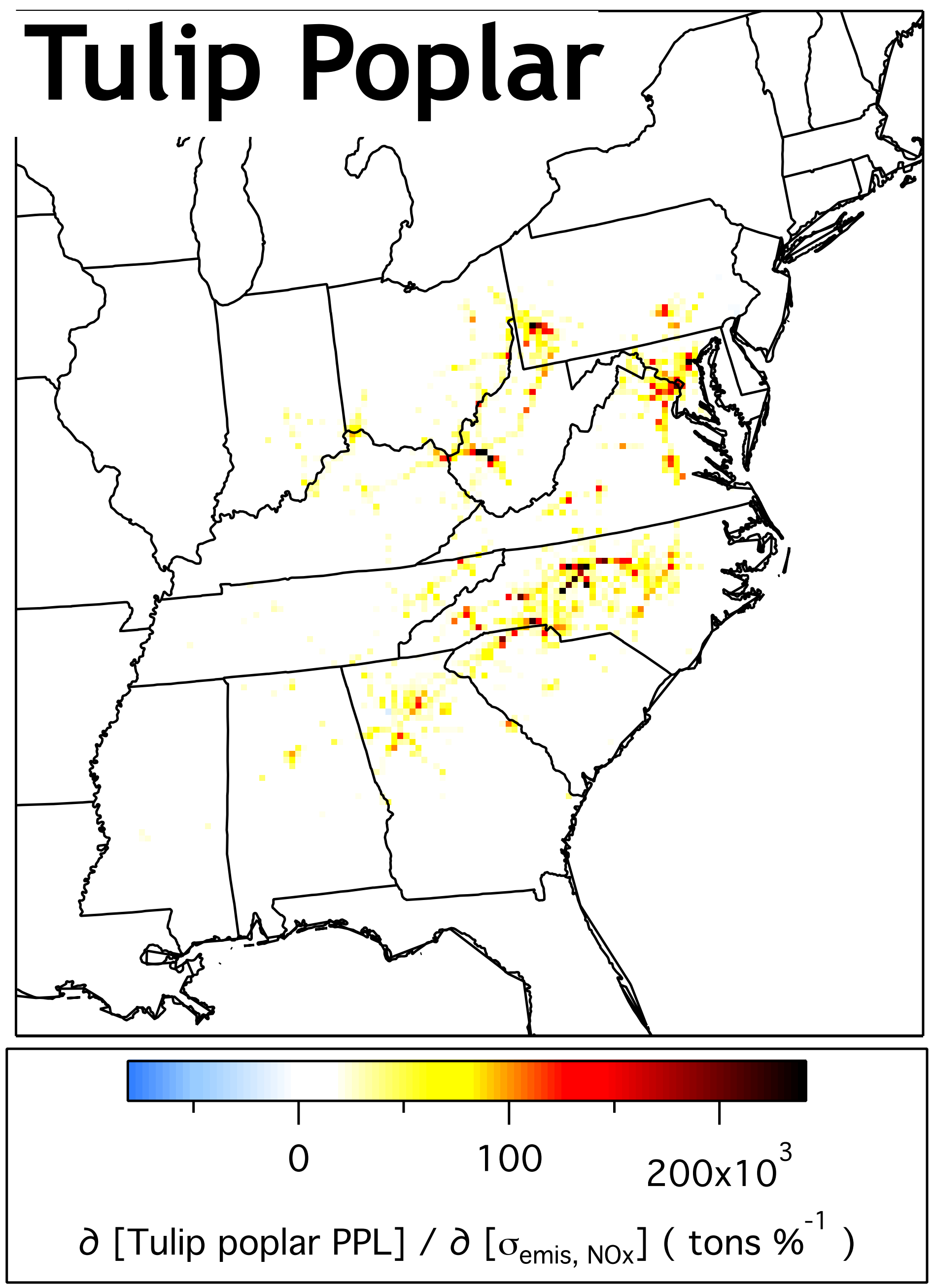
Isoprene & ethane *differ by orders of magnitude* in influence.

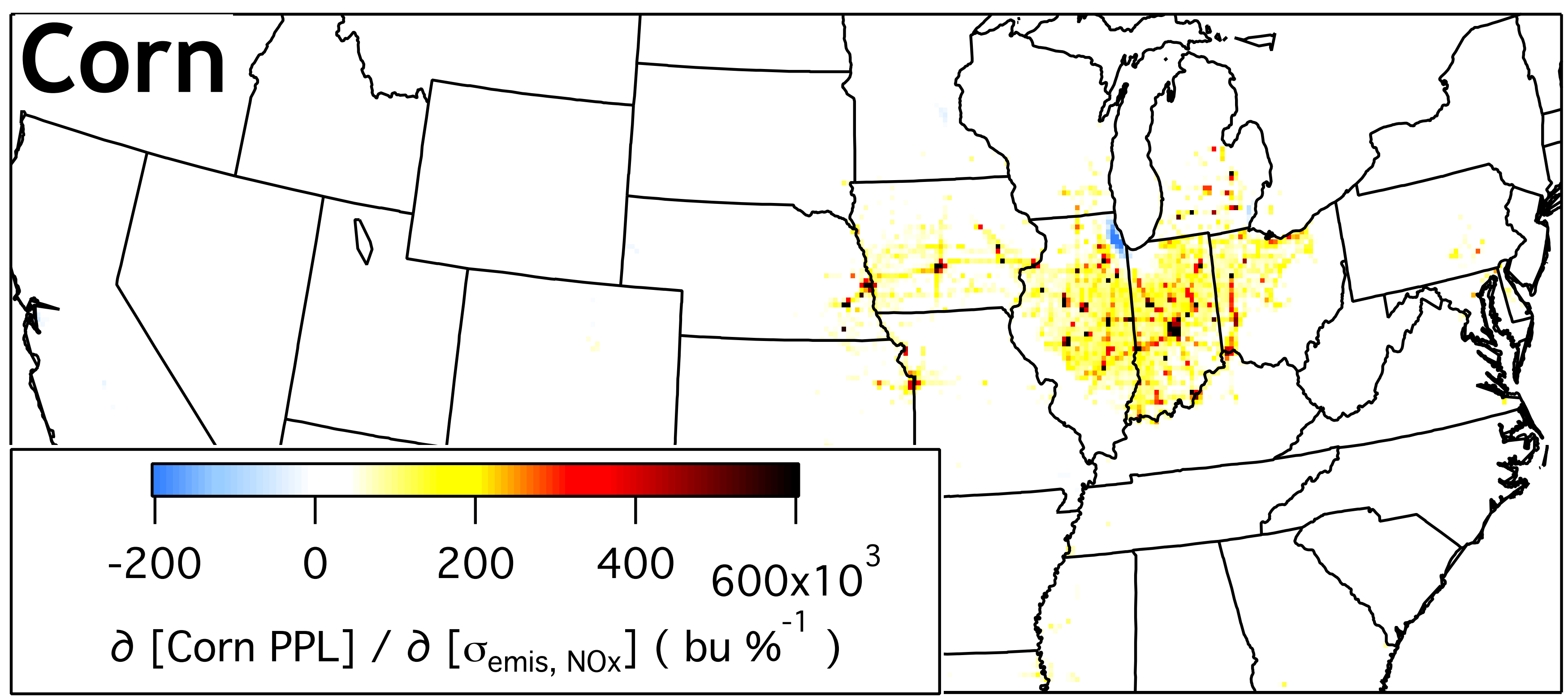




Health & Ecosystem Responses to NOx Differ Significantly





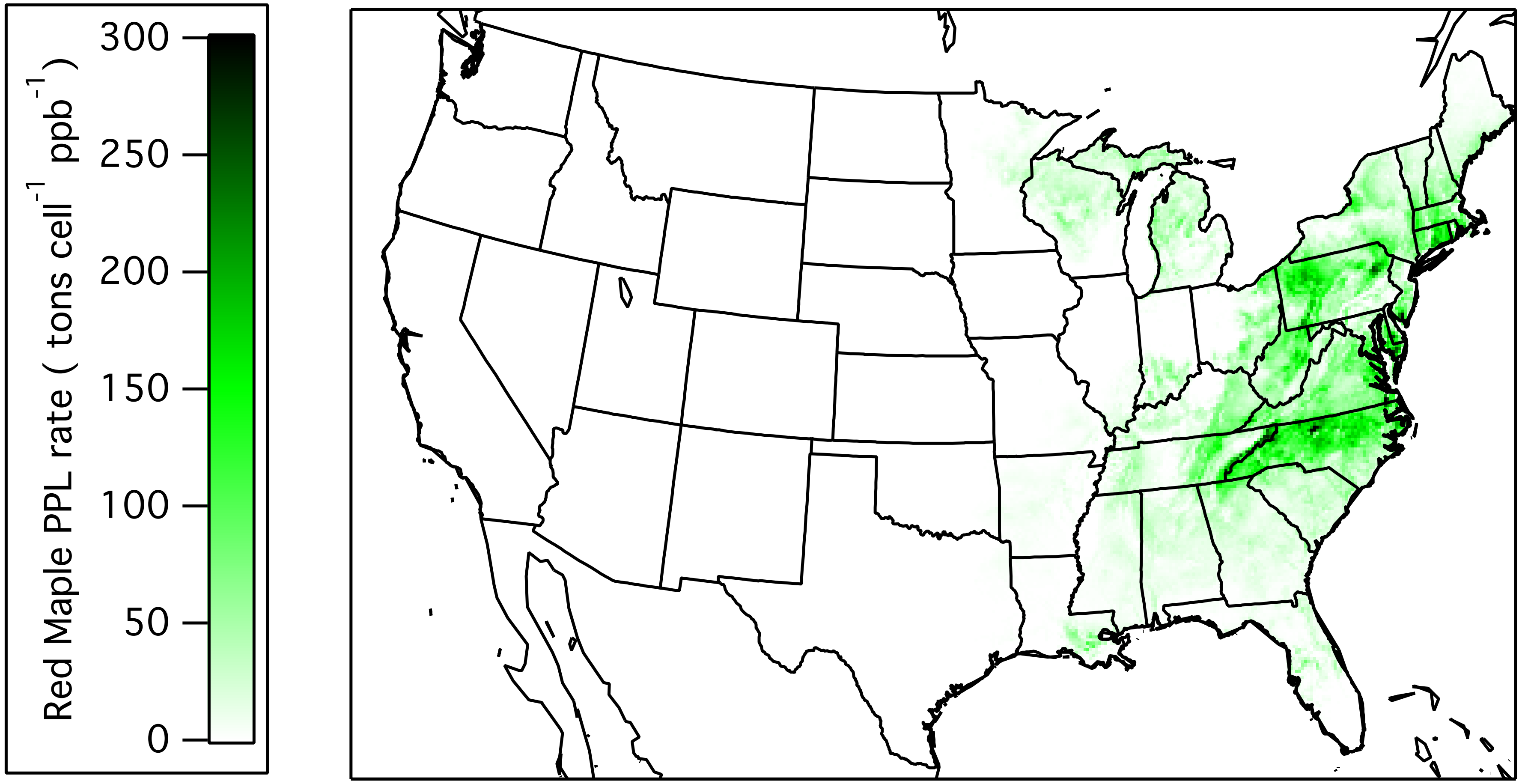


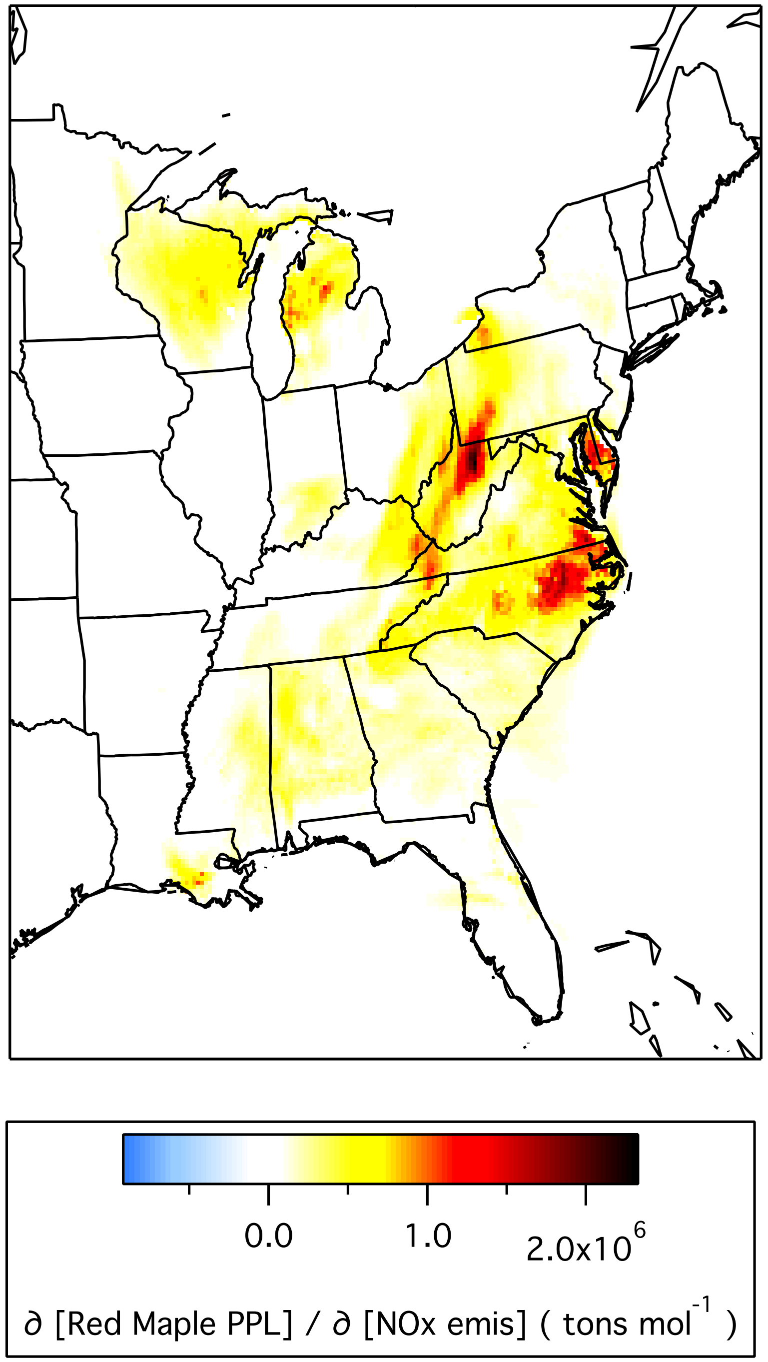
Capabilities & Next Steps

- Assessed the rate of degradation of human mortality, crop productivity, and timber biomass with O_3 exposure
- Determined relative influence of NOx and various VOC emissions on these end points for a brief episode in June 2007
- Confirmed hypothesis that ***emissions controls can benefit human health differently than ecosystems***

- Complete the modeling of May-August 2007
- Connect the NOx emissions influences to the MARKAL framework for propagating the influence of energy sector emissions changes on ozone benefits

Emissions Influences on Red Maple Biomass PPL

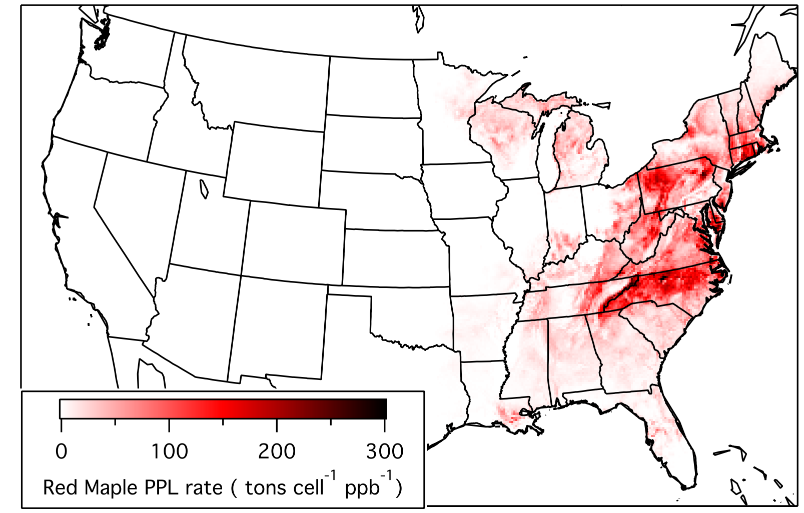


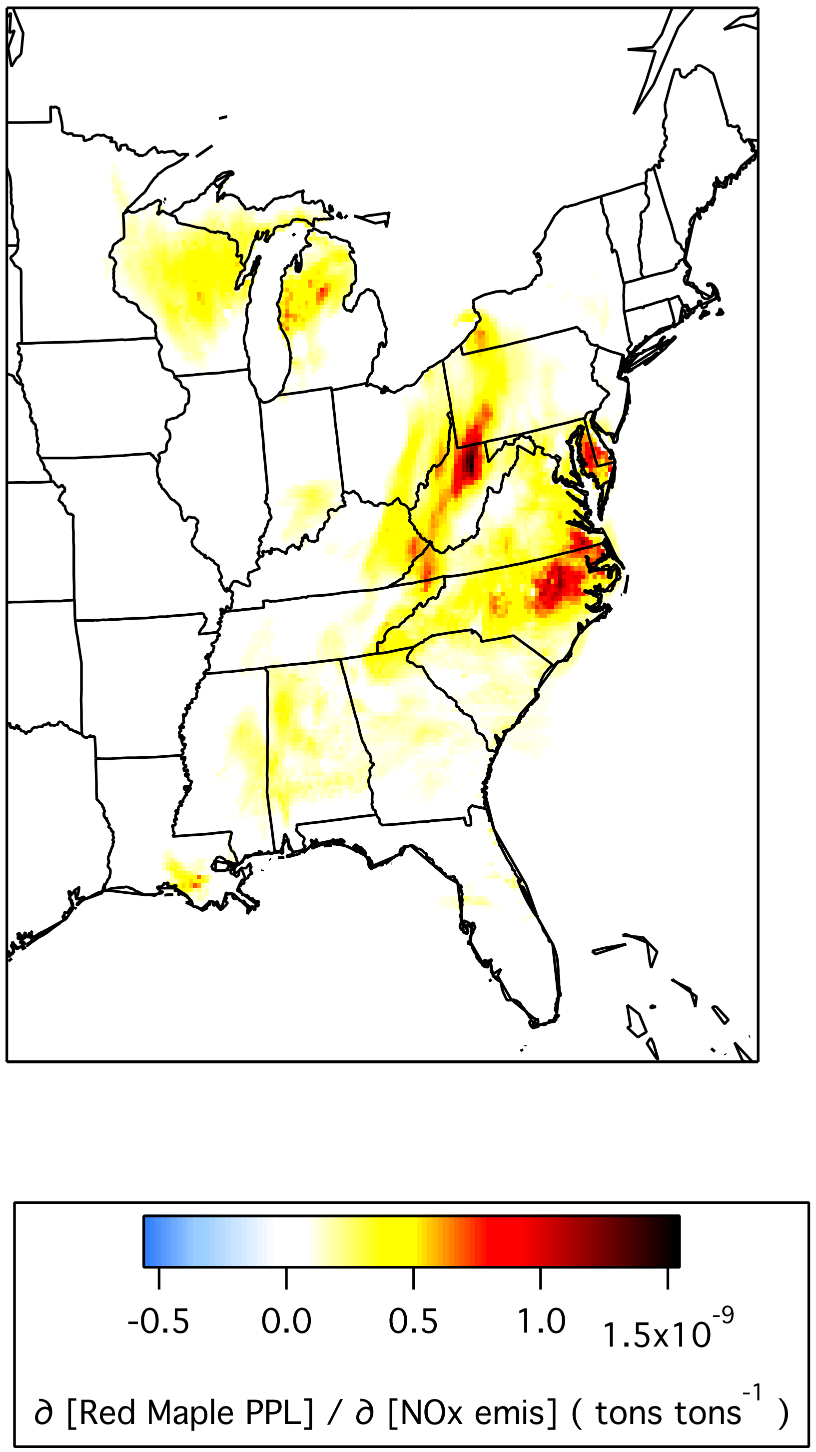


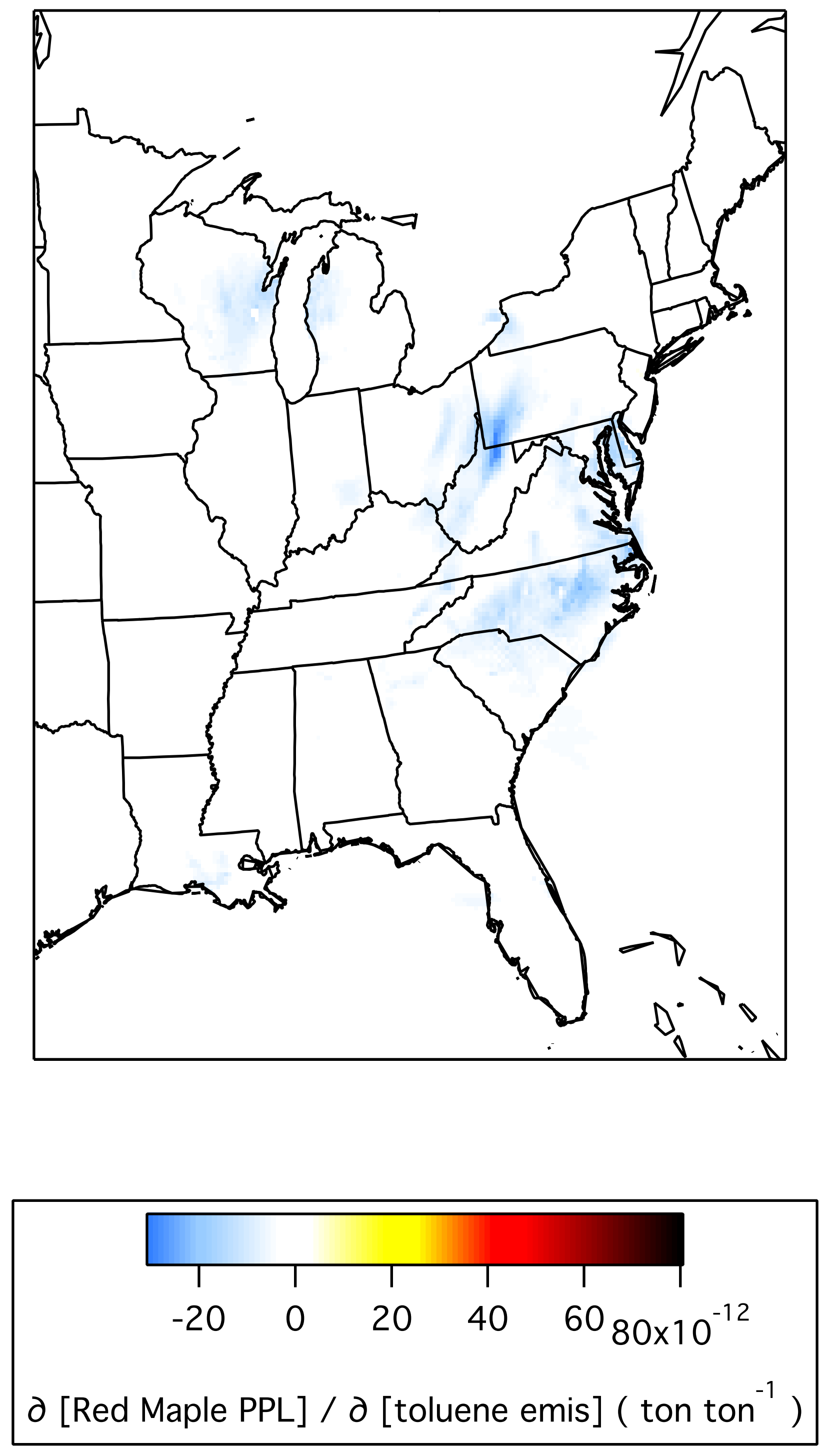
Based on W126 calculated from summer 2007, potential productivity loss rates can be applied for each specific day of the early June episode.

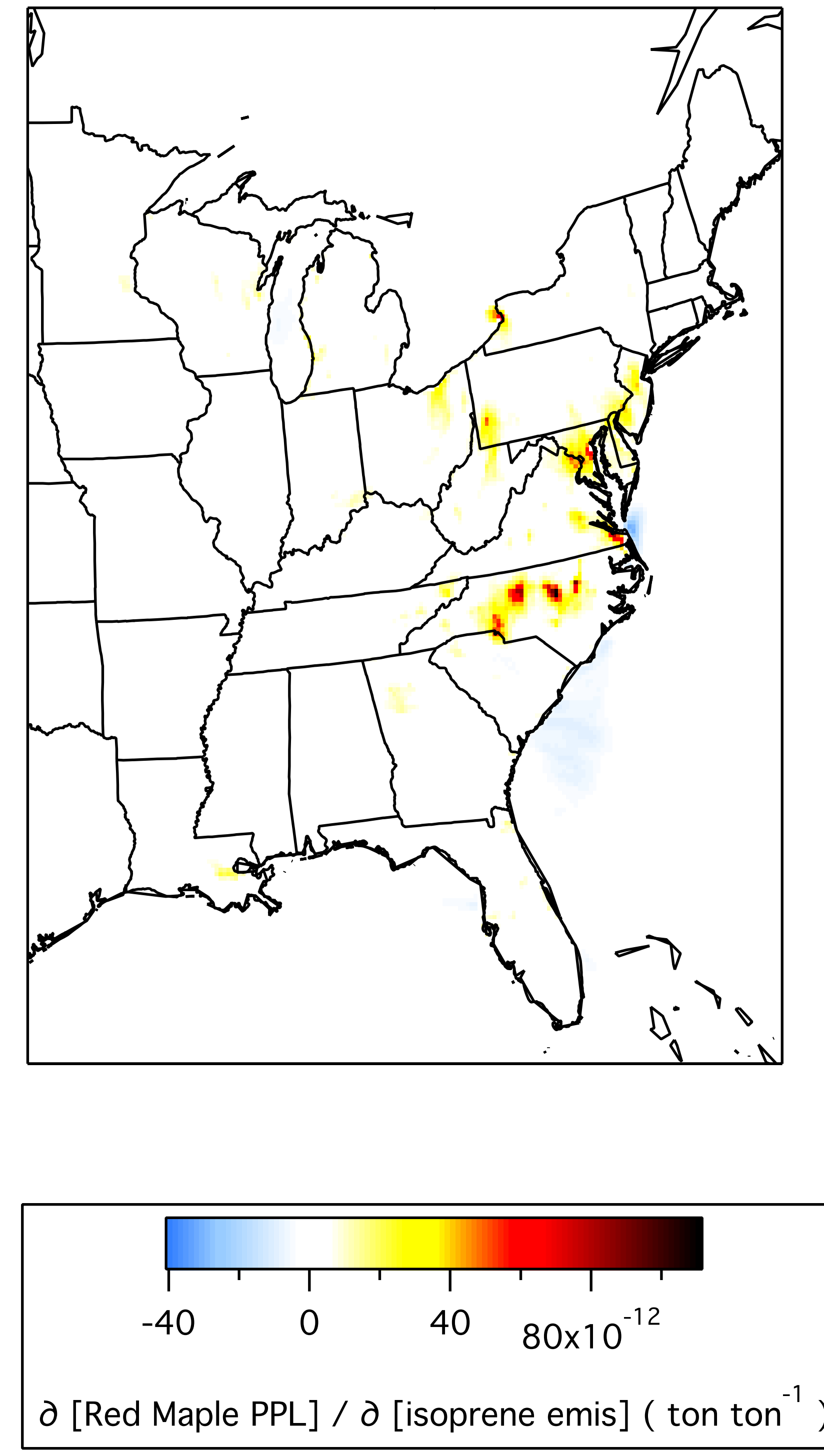
Through the adjoint, these are related to the influence of emissions of each species.

Emissions Influences on Red Maple Biomass PPL

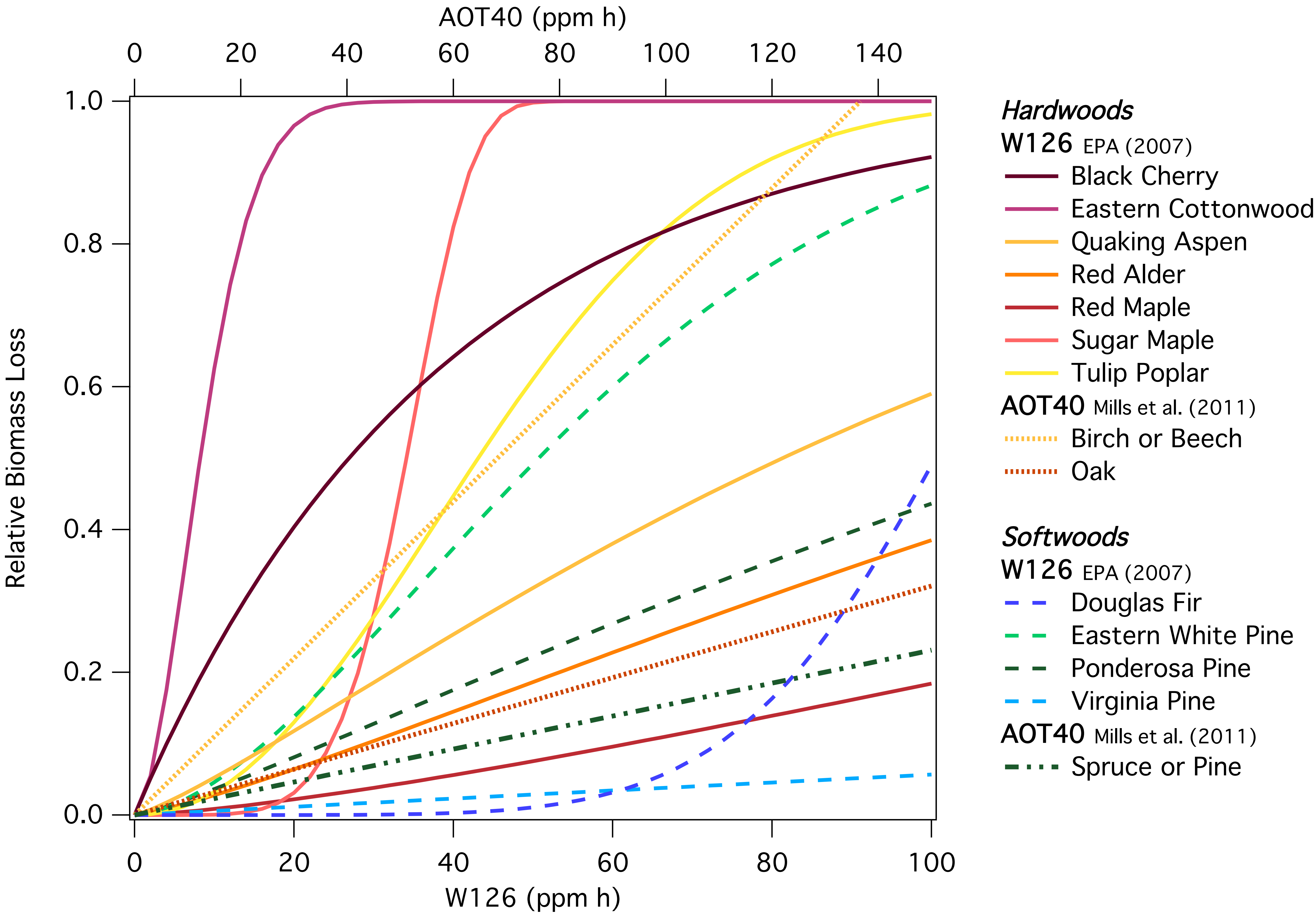








Timber Ozone Exposure Effects



Connecting Ozone Effects to Emissions with CMAQ adjoint

Spatial Distribution of Relative Contributions

$$\frac{\partial(\{O_{3,exposure}\})}{\partial(\text{emissions})}$$

Modeling domain: Continental US

2007

CMAQ adjoint

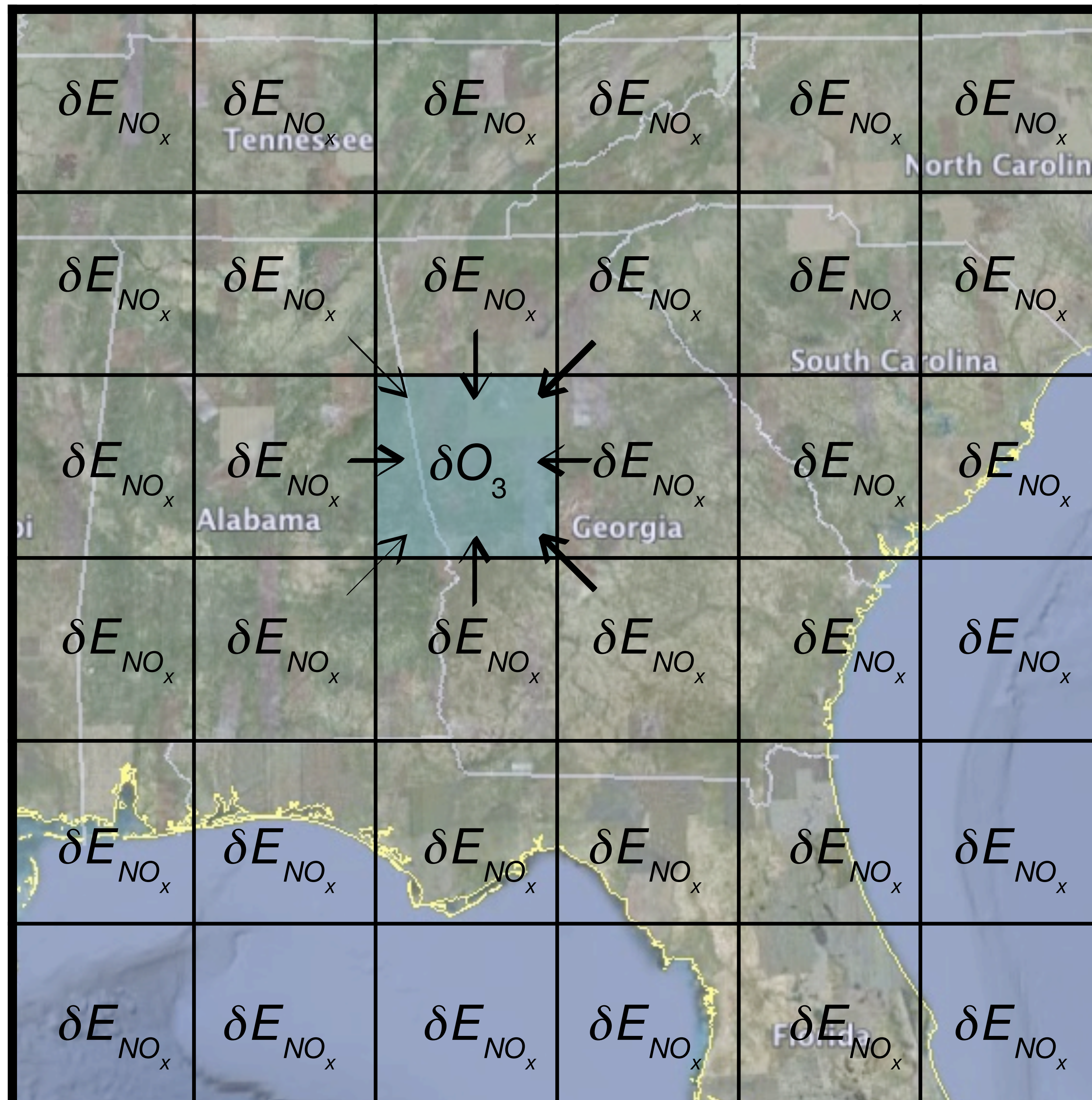
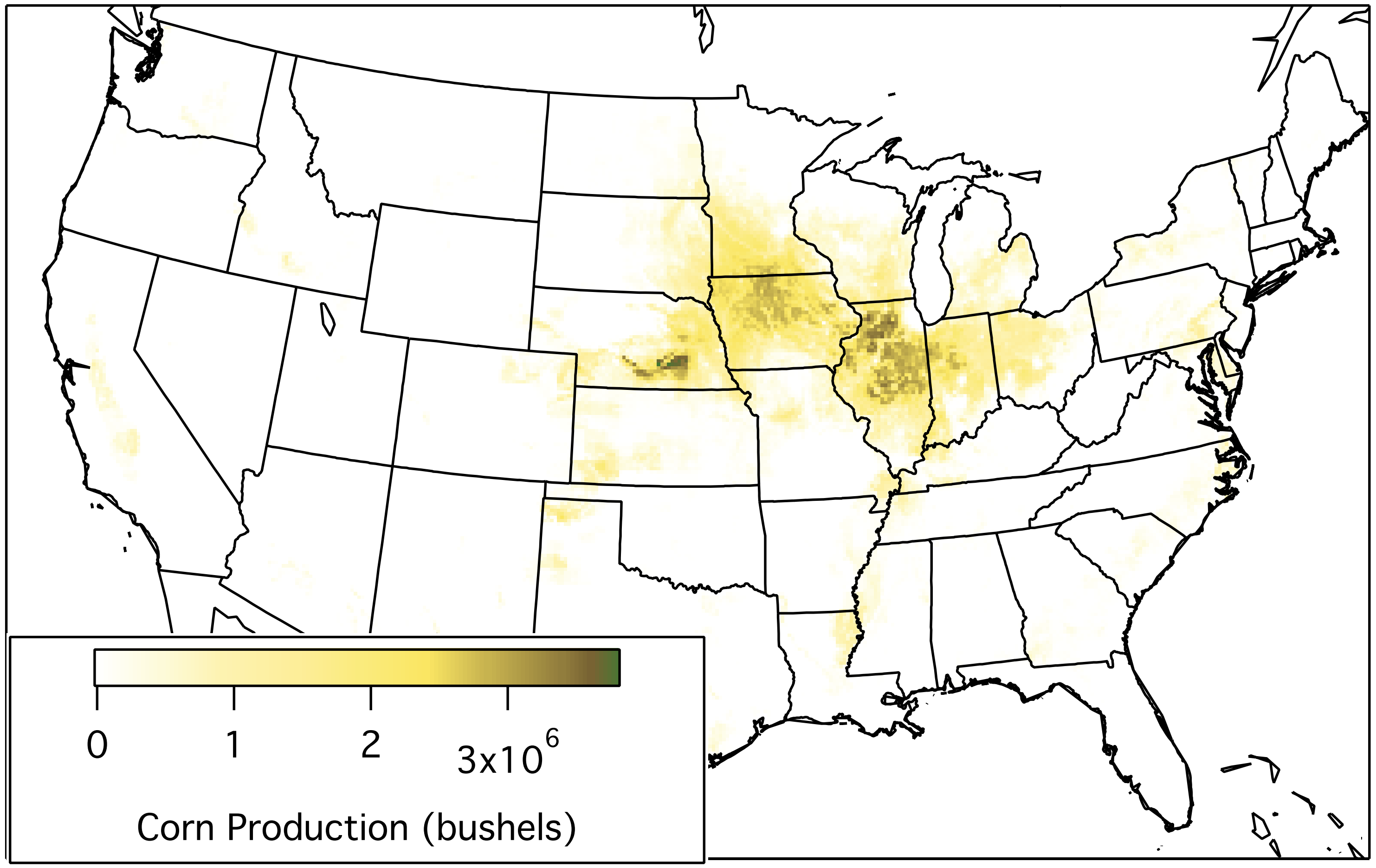
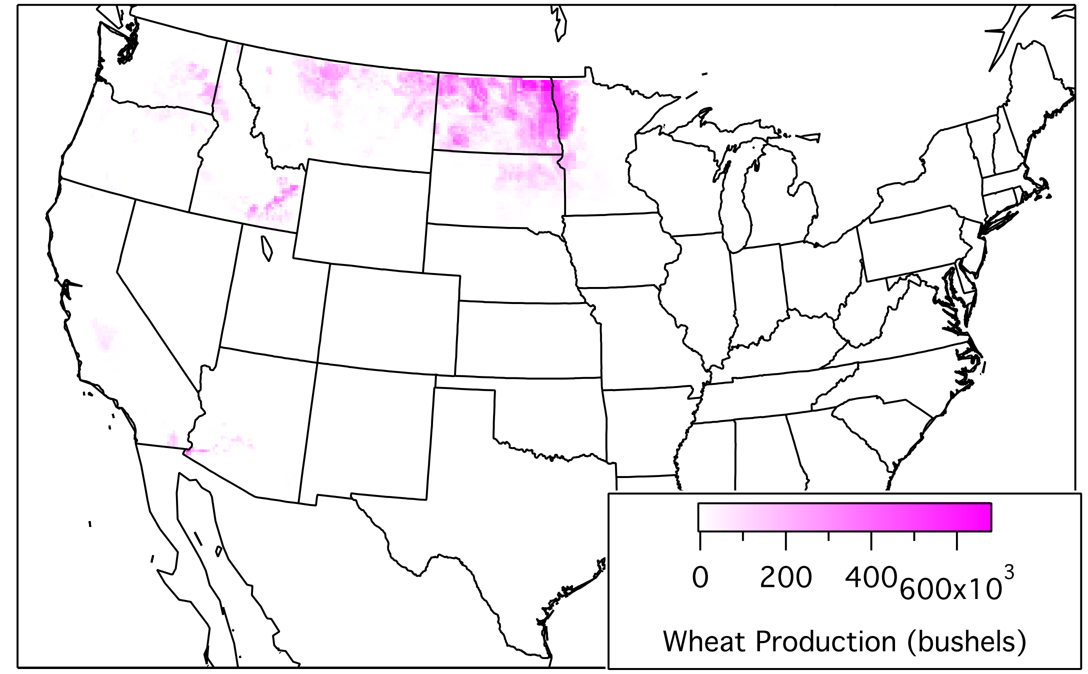
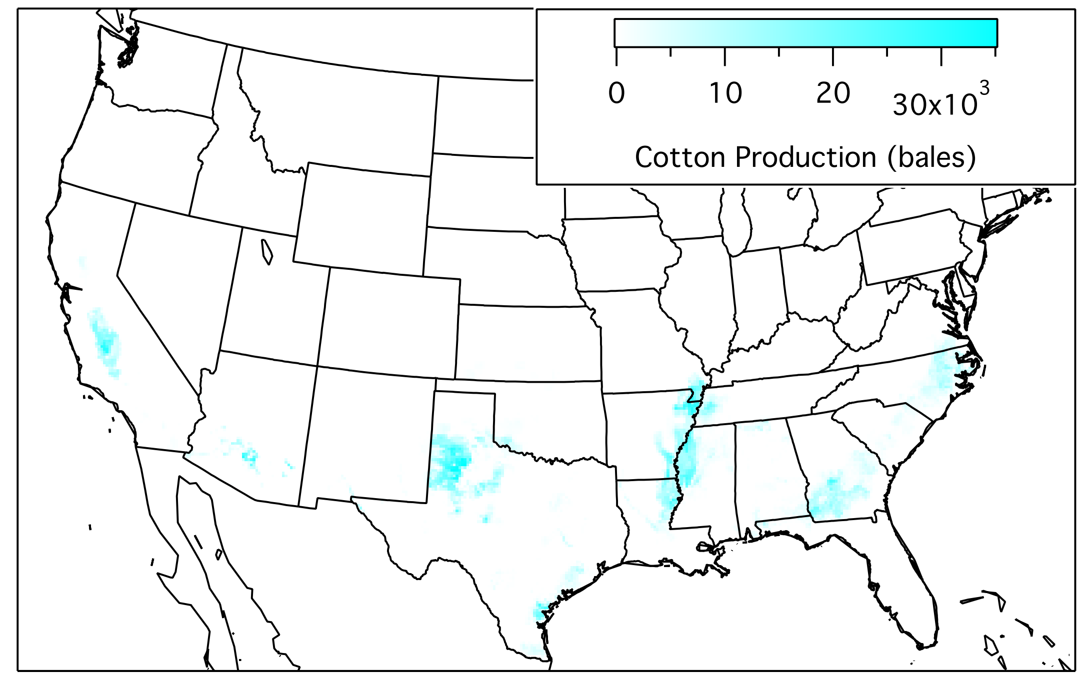


image credit: Google Earth; adapted from Daven Henze's representation of sensitivity methods

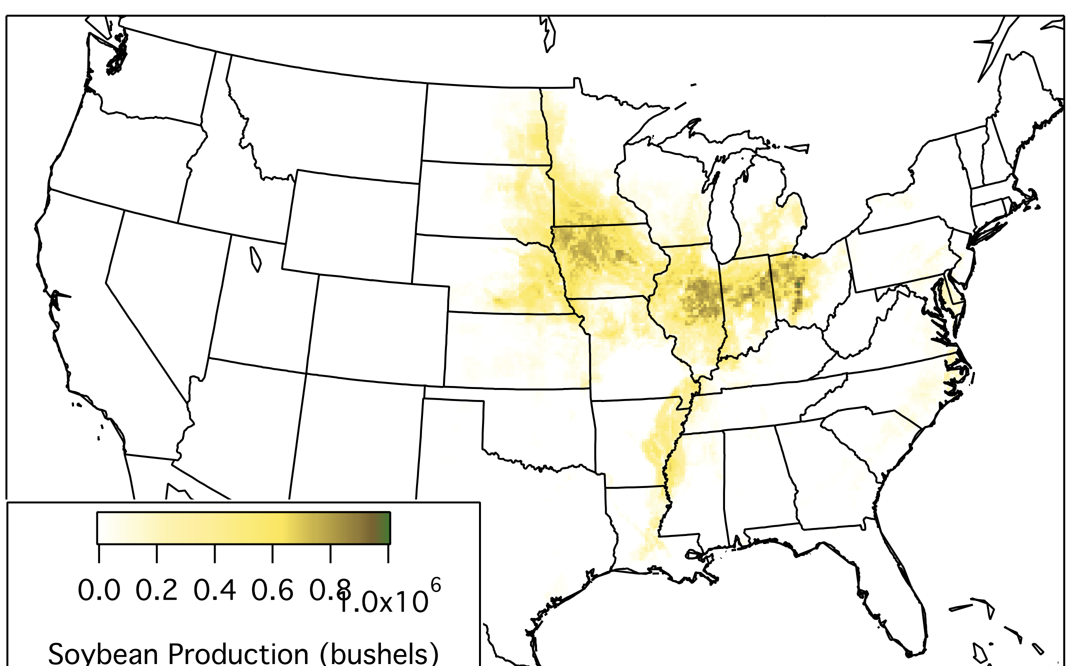
2007 Crop Production

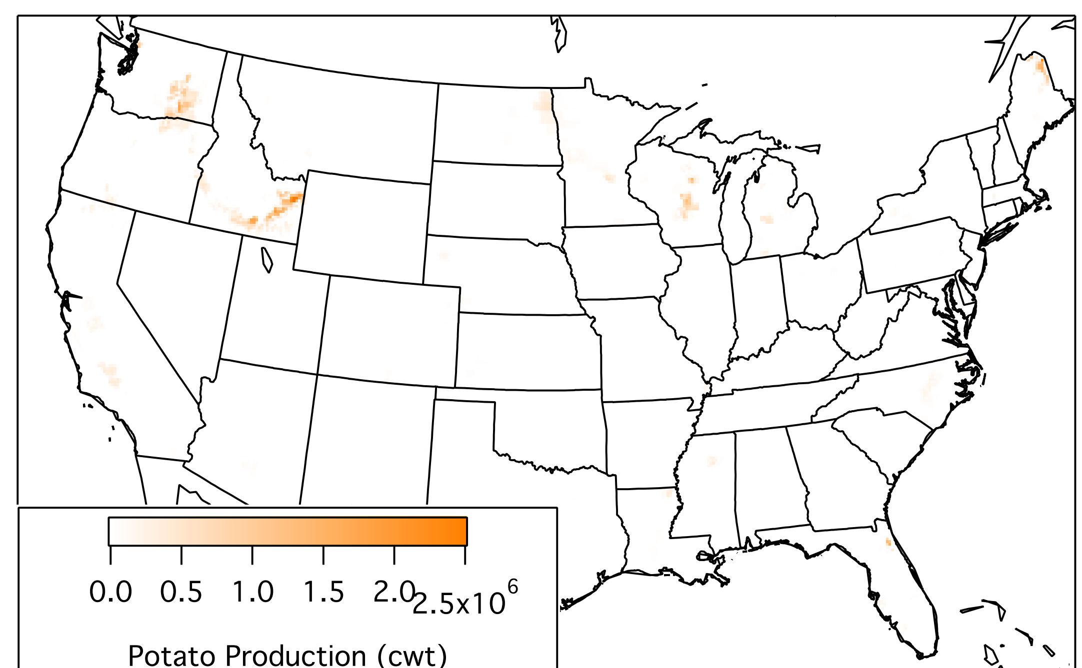






USDA National Agricultural Statistics Survey (NASS) 2007 crop production distributed in accordance with the Biogenic Emissions Landuse Database (BELD) v.4





Effects of Ozone Exposure on Crops

$$\partial J = \frac{\partial W126}{\partial C_{O_3}} \frac{\partial RYL}{\partial W126} \frac{\partial YL}{\partial RYL}$$