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Chesapeake Bay Program
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Oak Ridge Institute for Science and Education

Atmospheric Deposition Modeling in the Chesapeake Bay Watershed

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October 5, 2021

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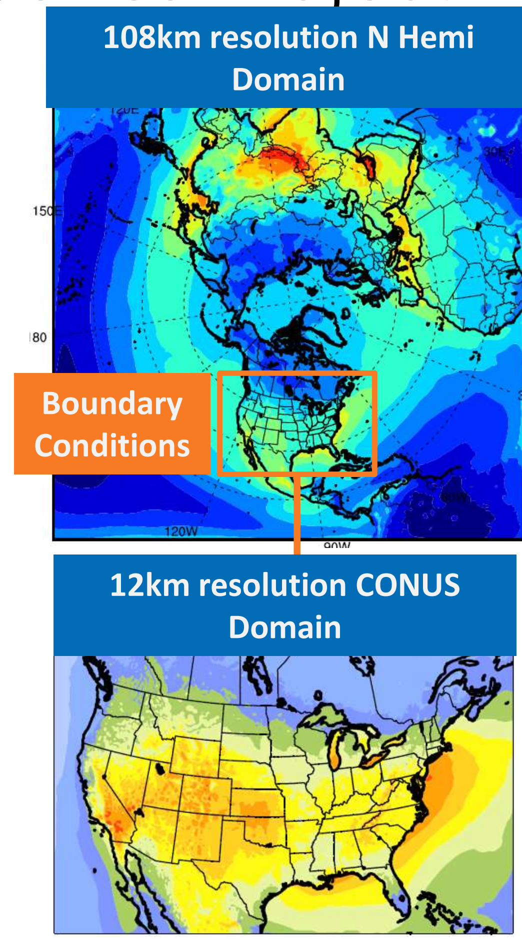
Disclaimer: The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

EQUATES: EPA's Air QUAlity TimE Series Project

- Temporal coverage: 2002-2017
- Spatial domains: Northern Hemisphere and contiguous US
- Meteorology inputs: New meteorological modeling for both domains using state-of-the-science retrospective simulations
- Emissions inputs: New inventories were developed using EPA's 2017 NEI as the base year with consistent methods used for each sector to avoid artificial step changes
- CMAQ version 5.3.2 (publicly released in October 2020)

EQUATES will supersede previous CMAQ time series and provide a unified set of modeling data across applications



Address biases	• Air quality • Meteorology • Emissions models
Unified modeling data	• Consistent emissions, meteorology, and air quality • Useful for many applications
Includes recent years	• Previous simulations completed 2002-2012 • EQUATES will extend timeseries to 2017
Useful applications	• Nutrient, Ecological, and Epidemiological: Annual deposition and concentrations used by TDEP, CASTNET, EnviroAtlas, Critical Loads Mapper

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Improvements Over Existing CMAQ Simulations

	ECODEP CMAQv5.0.2 Zhang et al. (2019)	EQUATES CMAQv5.3.2
Model	CMAQv5.0.2 (CB05TUCL-AERO6; w/ bidi NH_3)	**CMAQv5.3.2 (CB6R3-AERO7; w/bidi NH_3)**
Date range	2002 – 2012	**2002 – 2017 (2018 to follow)**
Domain/ Resolution	12km CONUS	**108km N Hemi + 12km CONUS**
Meteorology	WRF3.4	**WRFv4.1.1**
Emissions	Various NEIs / Modeling Platforms	**2017 NEI as primary base year; consistent methods used for each sector (when feasible) to avoid artificial step changes**
Boundary Conditions	GEOS-Chem	**N Hemi CMAQv5.3.2**

CMAQv5.3.2 Updates:

Aerosol and Gas Chemistry

- Improved parameterization of organic nitrates

Deposition

- New land use specific scheme available

Emissions and tools

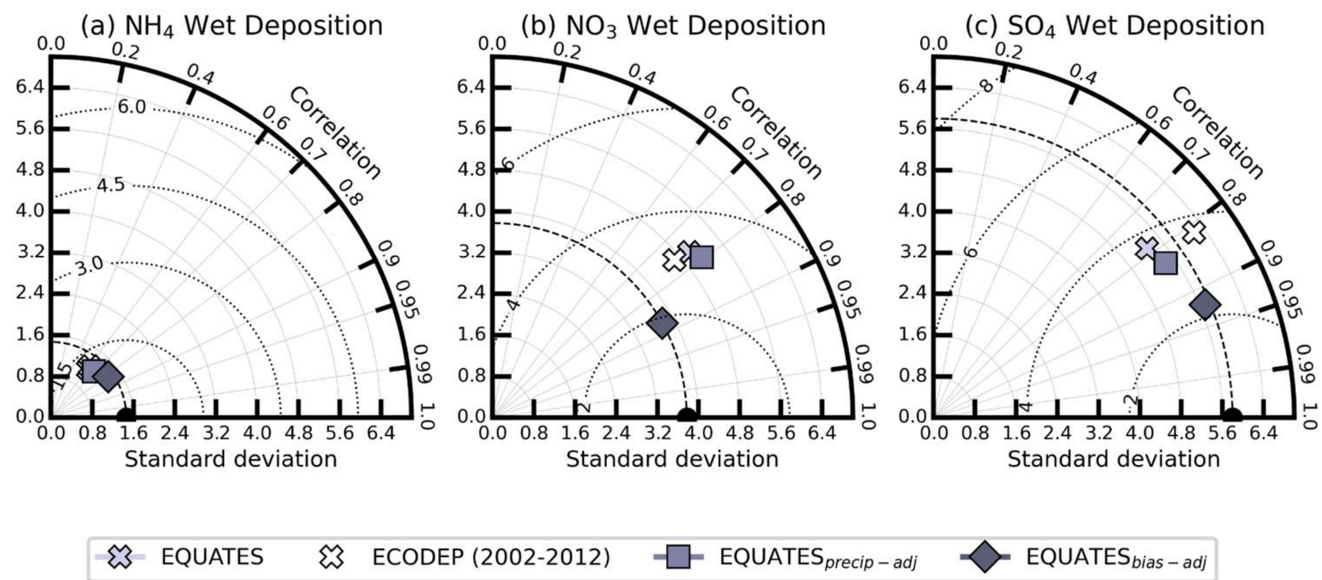
- New Detailed Emissions Scaling, Isolation, and Diagnostic, Integrated Source Apportionment method, pre/post processing tools

Measurement Model Fusion Improvements to Wet Deposition

EQUATES
- No correction

$EQUATES_{precip\text{-}adj}$
- Precipitation from PRISM is used to adjust the modeled wet deposition

$EQUATES_{bias\text{-}adj}$
- Universal kriging with exponential covariance structure applied to ratios of measured/modeled wet deposition



For more details on the MMF technique, please see Zhang et al., 2019 (doi: 10.1029/2018JD029051)

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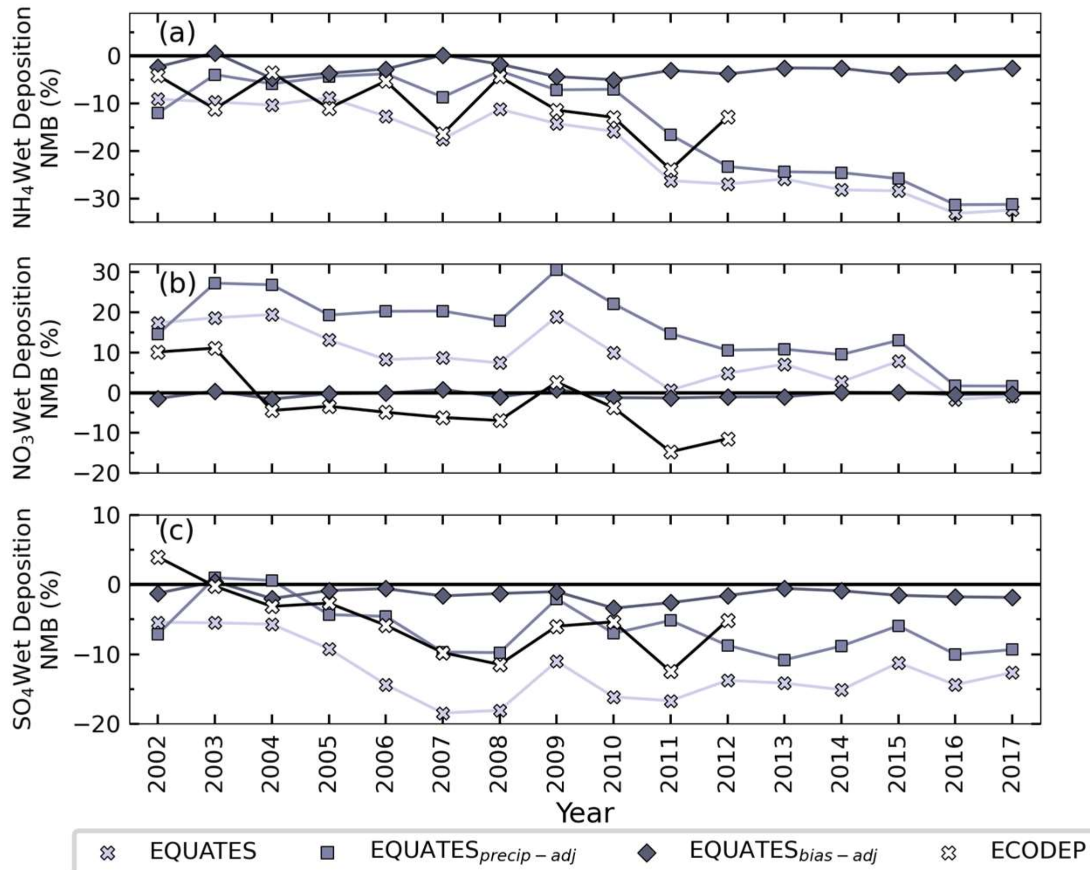

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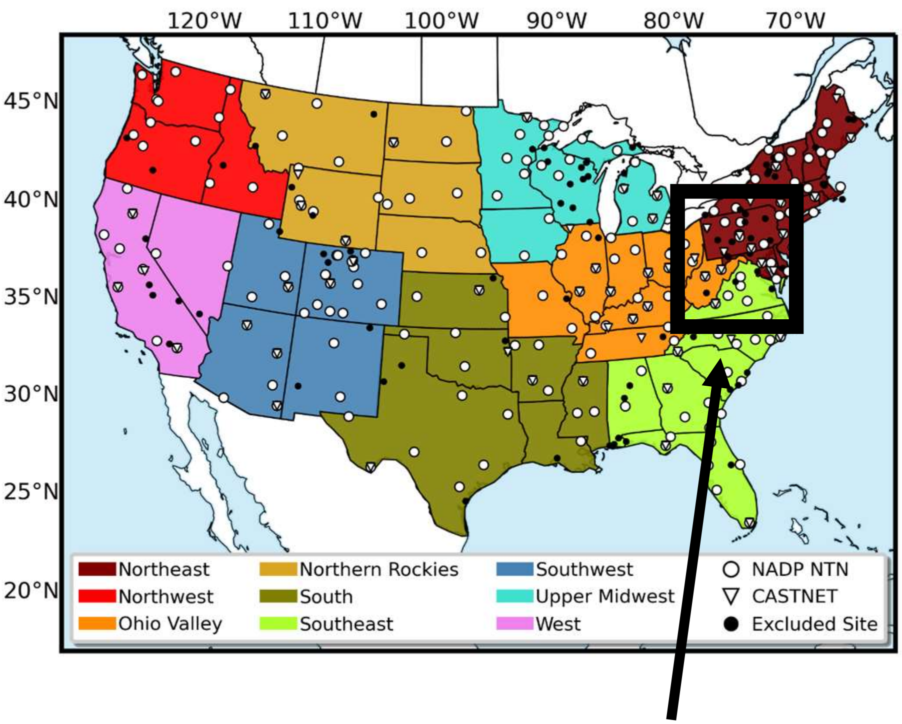
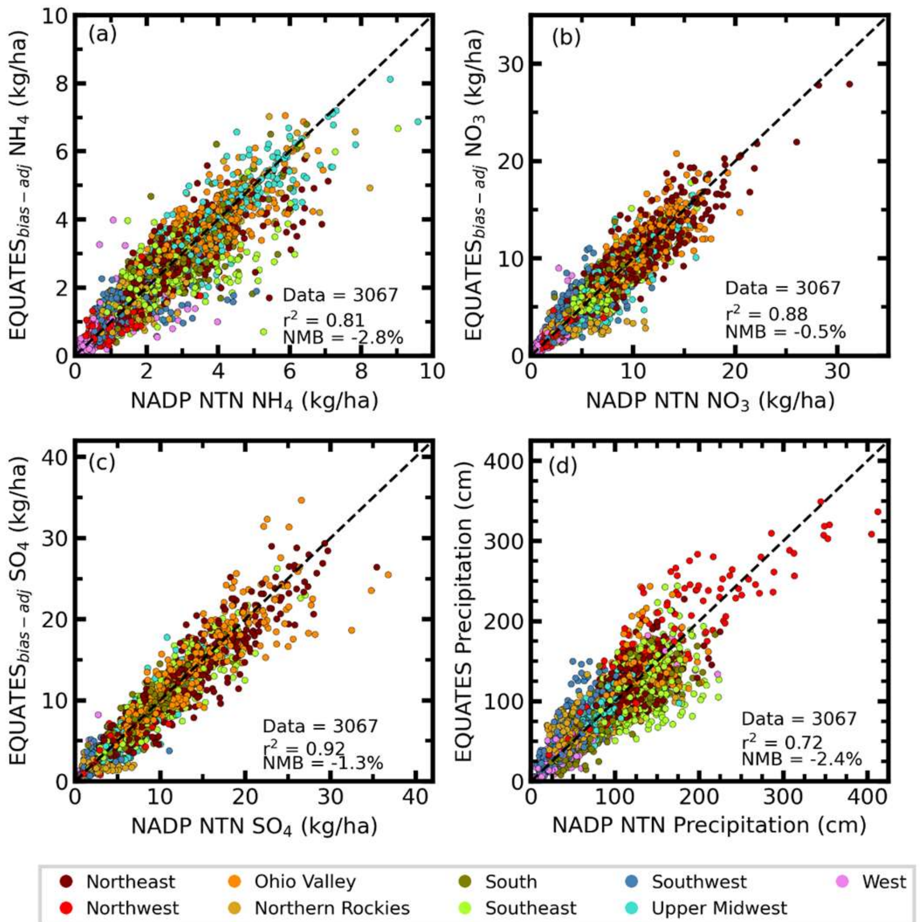
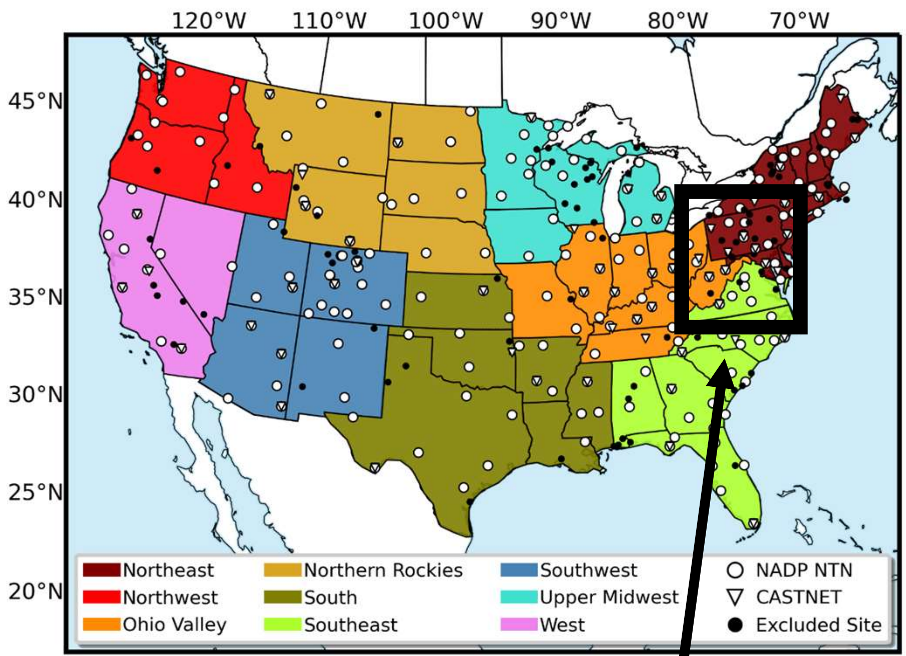
Comparison to NADP Wet Deposition Measurements



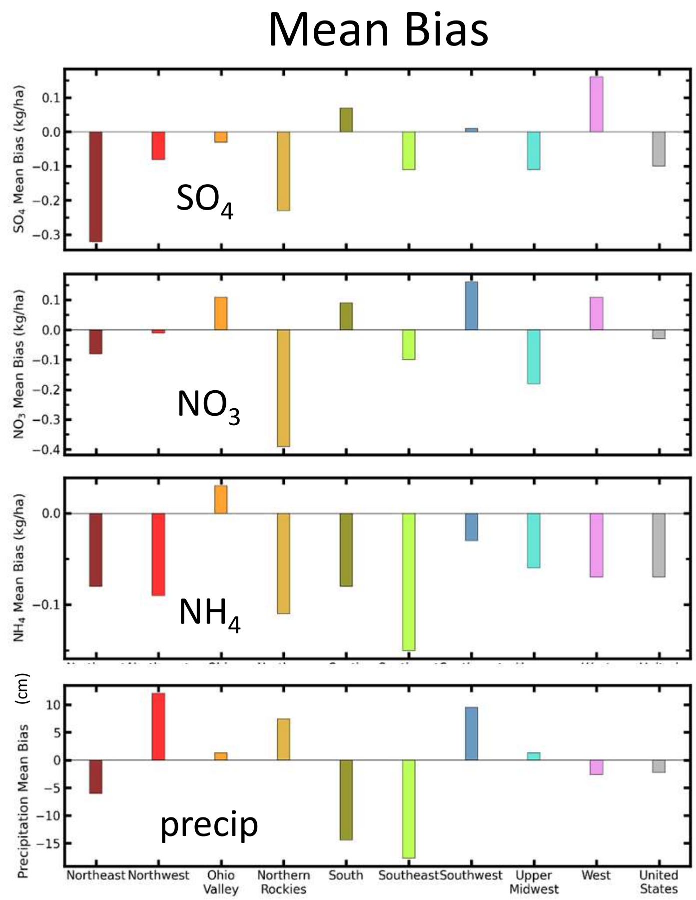
Approximate Boundary of Chesapeake Bay Watershed



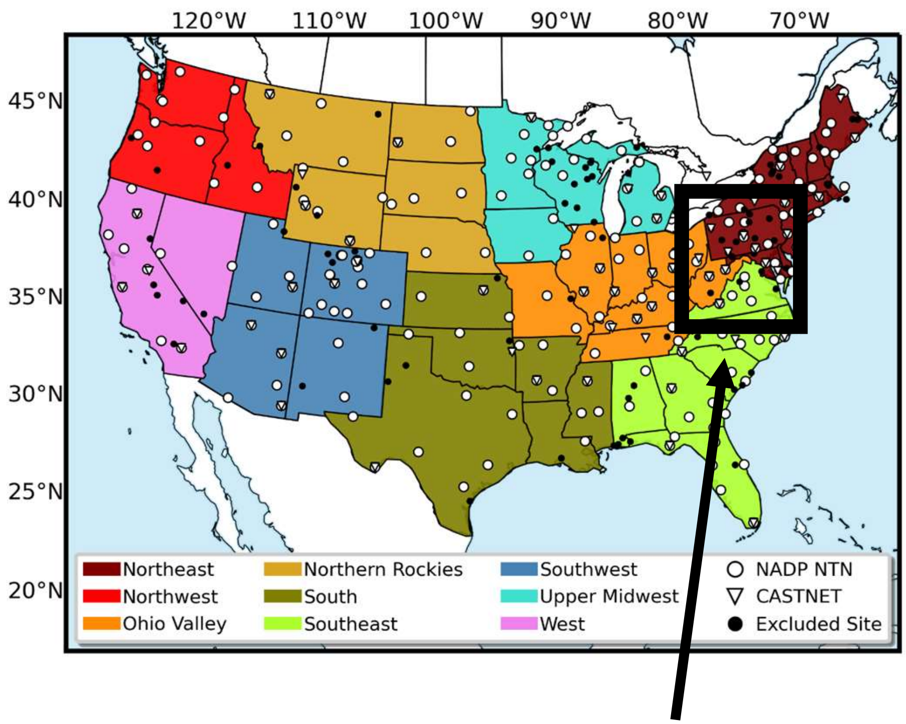
Comparison to NADP Wet Deposition Measurements



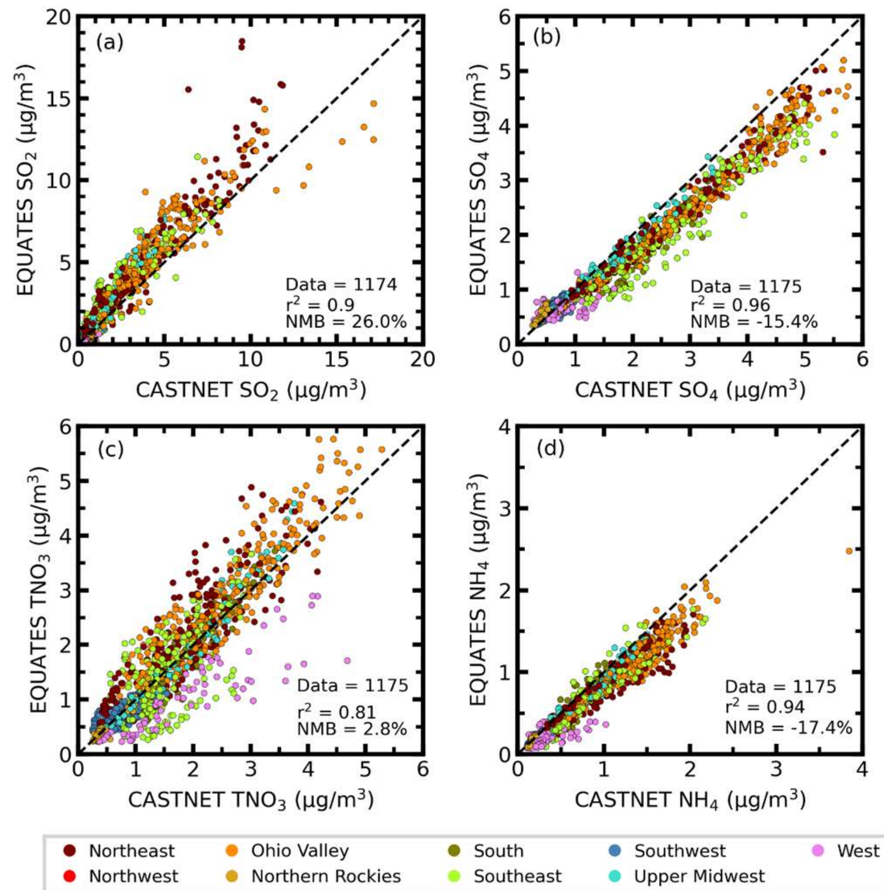
Approximate Boundary of Chesapeake Bay Watershed



Comparison to CASTNET Concentration Measurements



Approximate Boundary of Chesapeake Bay Watershed



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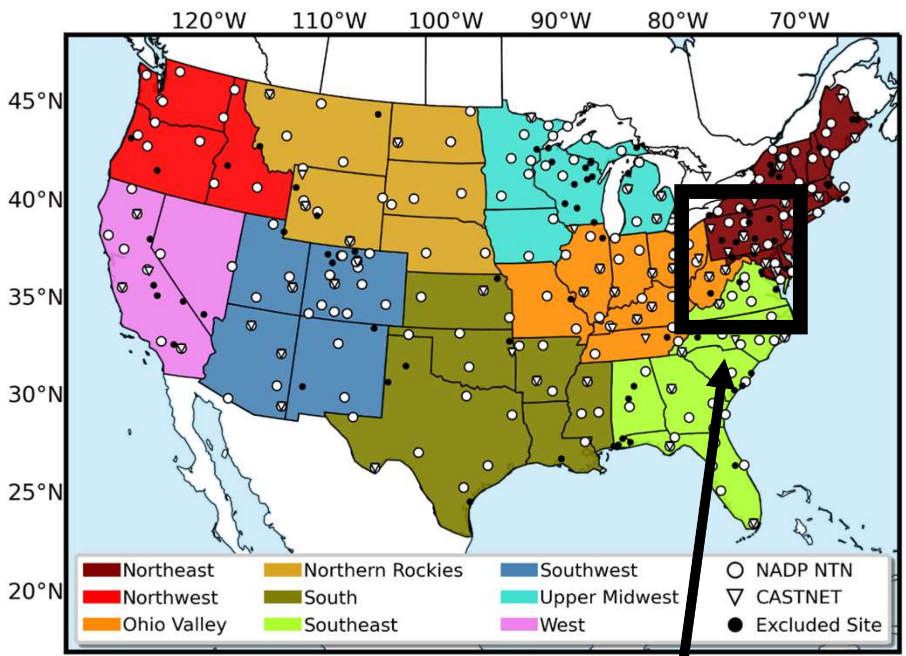

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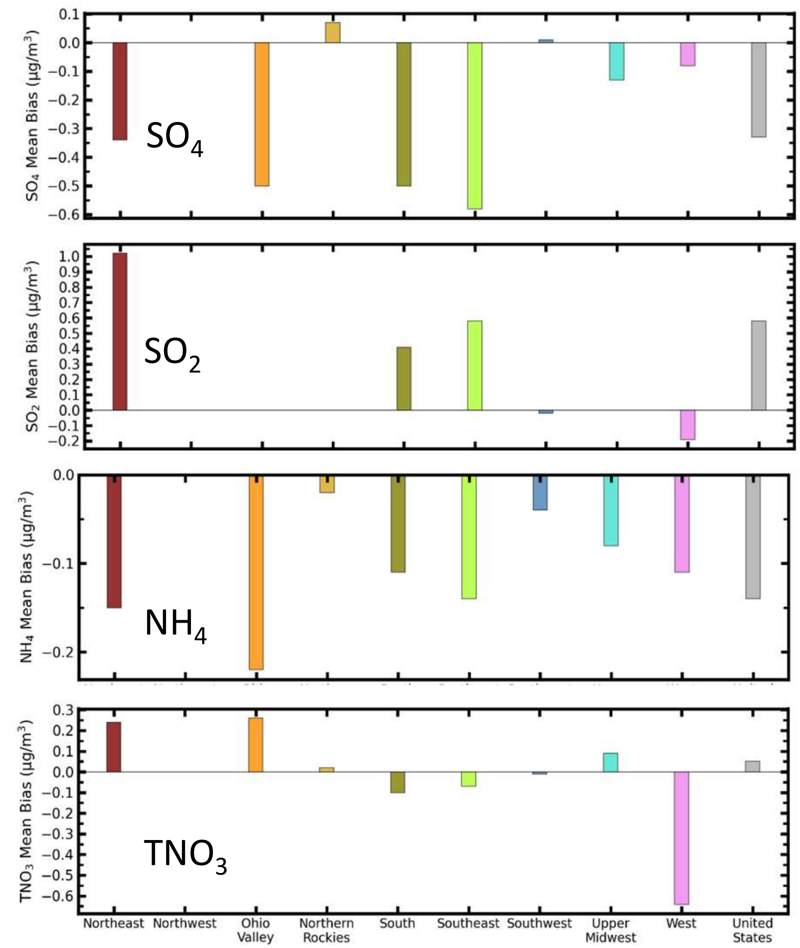


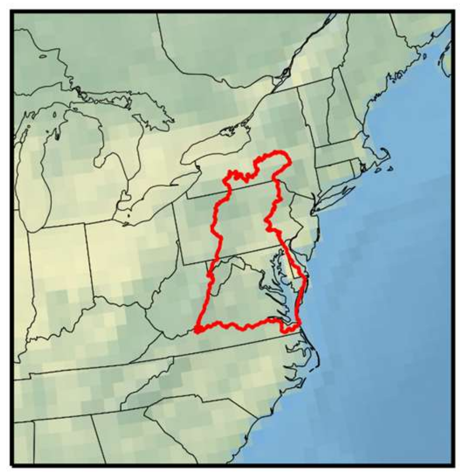
Application: Nitrogen Source Apportionment using ISAM

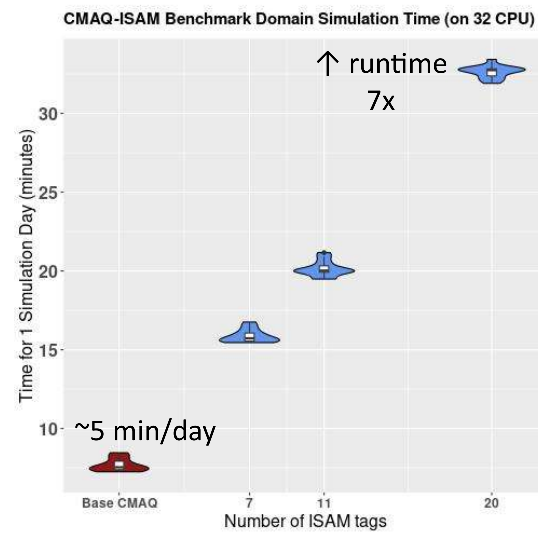
Quantifies the contributions of various emissions (source sectors and geographic regions) to pollutant levels in the domain, tracking concentration and deposition with near perfect mass closure.

Can calculate source attribution of a large number of sources directly in the model in one simulation.

For each species, the production and loss terms from each chemical reaction is tracked (generalized for the available mechanisms) and propagate changes to tags based on stoichiometry and production/loss rates of the precursors.

- **Model**: CMAQv5.3.2
- **Time**: January-December 2016 *(completed)*
- **Grid**: 12 km windowed domain





ISAM=Integrated Source Apportionment Method

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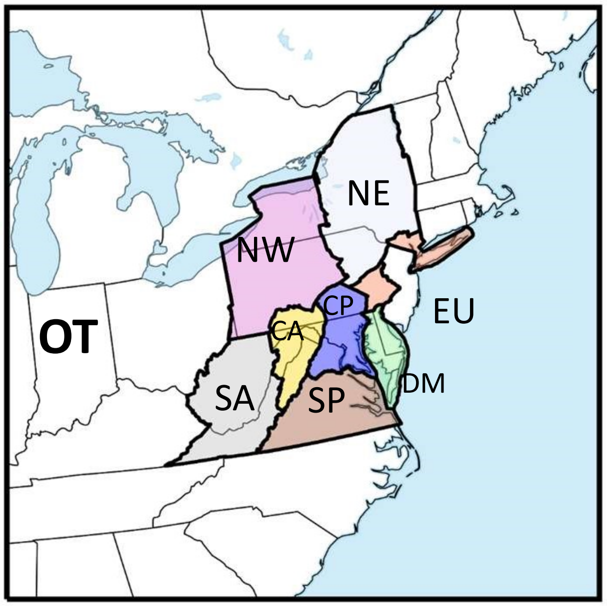
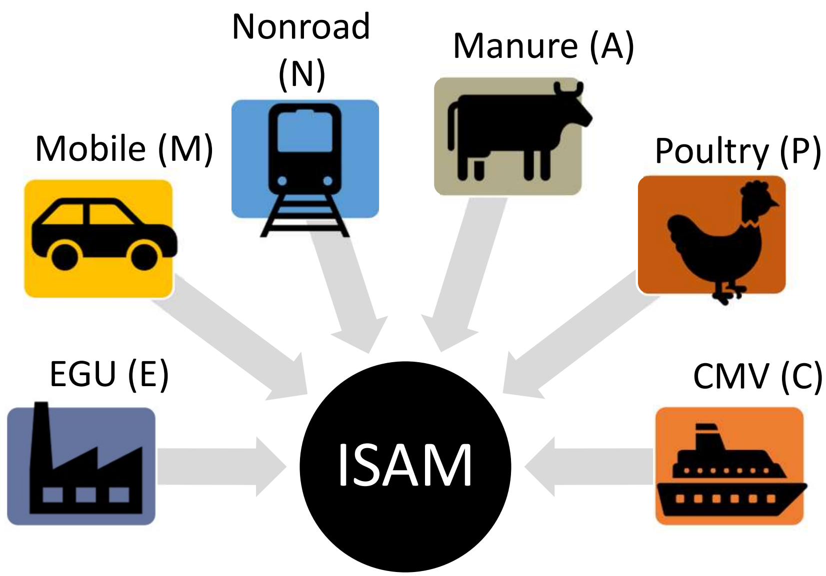
Model Set Up
Run CMAQ with ISAM options:

1. Geographic regions



2. Emission streams



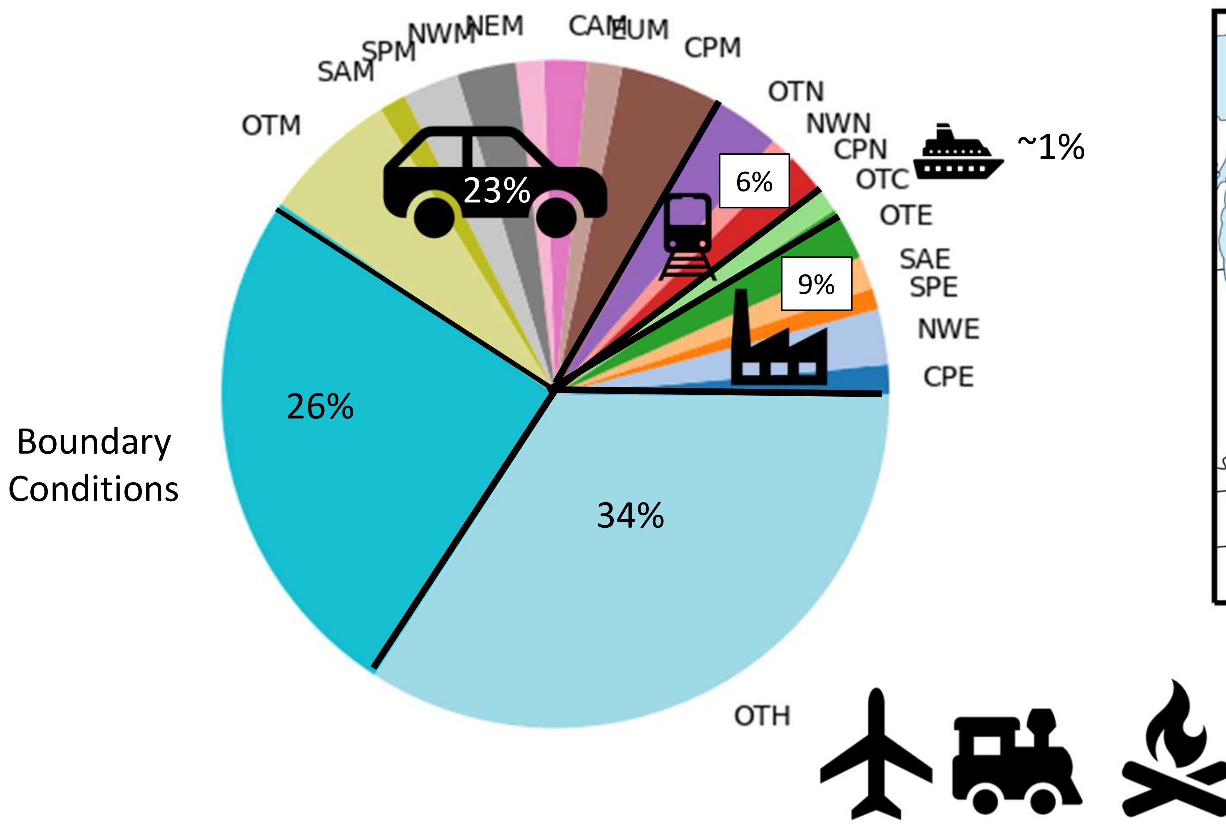
3. Compounds of interest

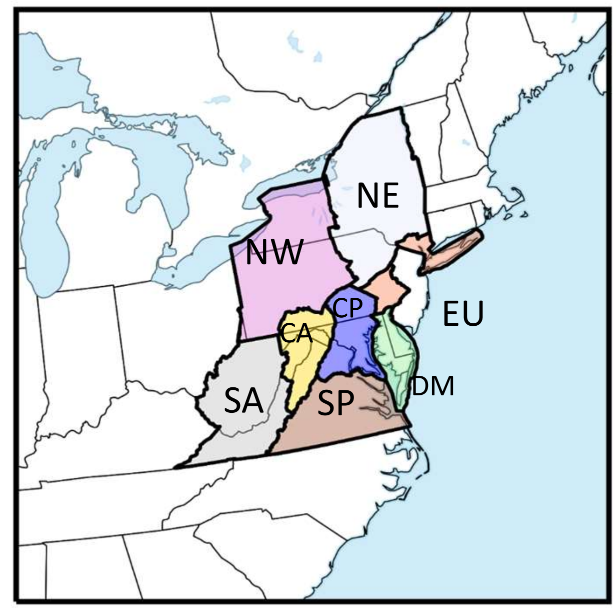
Tag Class	Model species
Sulfate	SO_2, H_2SO_4, SO_4^{2-}
Nitrate	HNO_3, HNO_2, NO_3^-, NO_3, NO_2, NO, Organic Nitrates
Ammonium	NH_3, NH_4^+
EC	Elemental Carbon Aerosols
OC	Organic Carbon Aerosols
VOC	Volatile Organic Aerosols
PM25_IONS	Cl, Na, Mg, K, Al, Si, Mn, and other aerosol cations
CO	CO
Ozone	All Nitrate species + all VOC species

2-letter region identifier + 1-letter emission identifier Appended to each compound

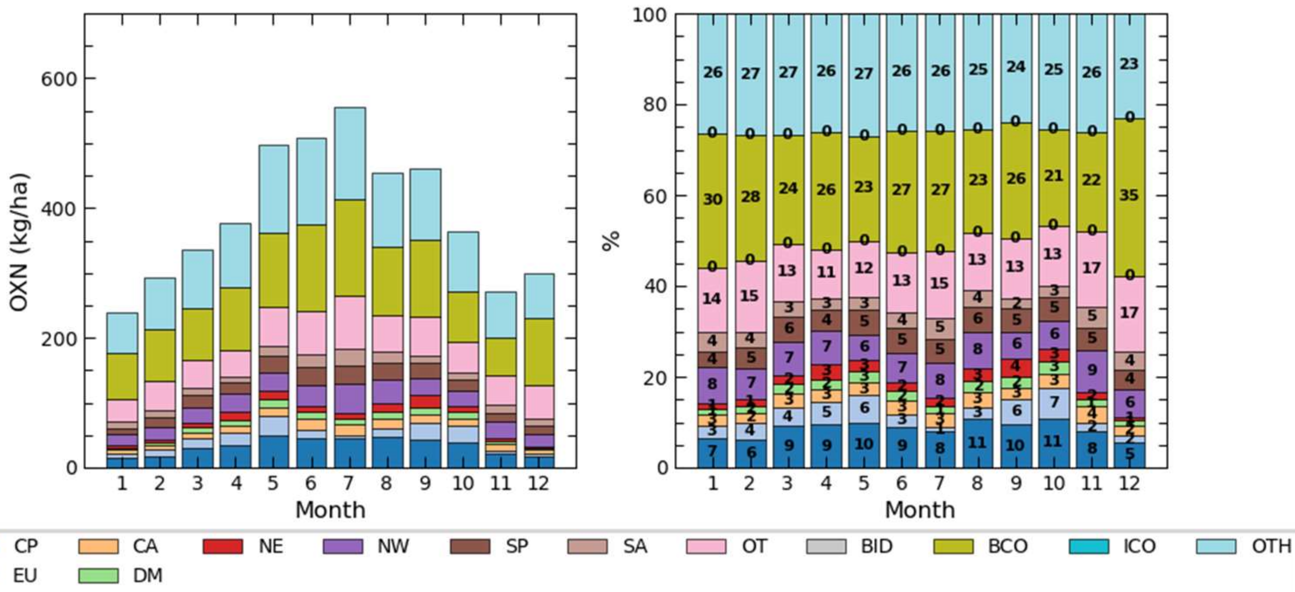
Nitrogen Deposition in the Chesapeake Bay Watershed

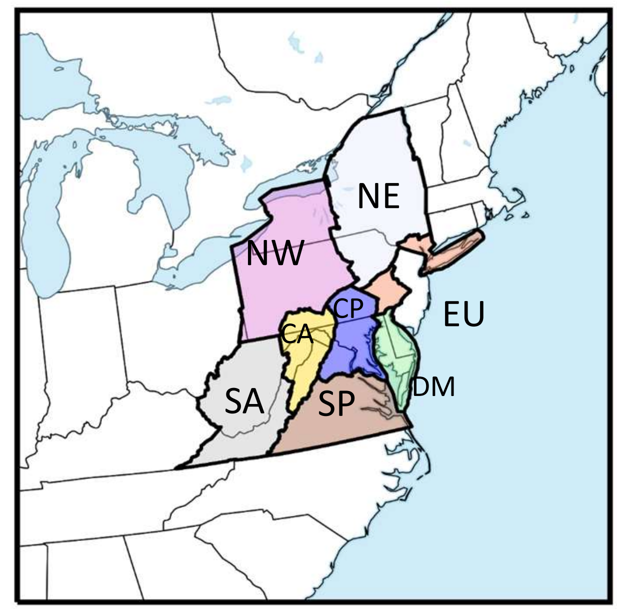
Total Oxidized N





Monthly Total Oxidized Nitrogen by Region





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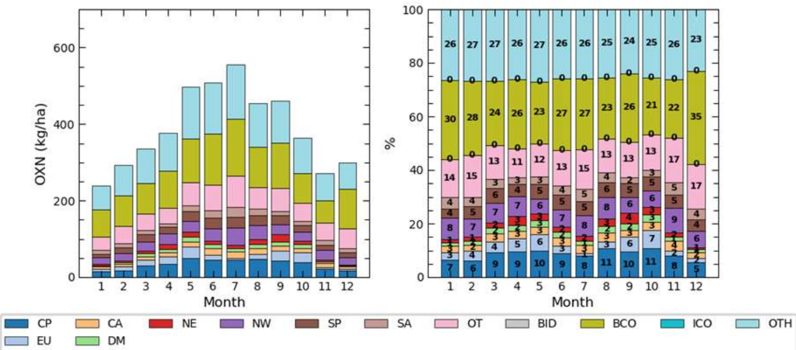
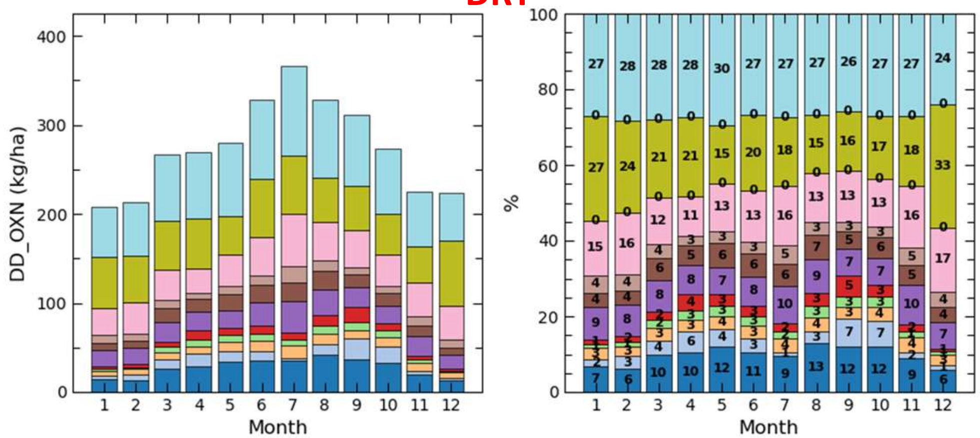
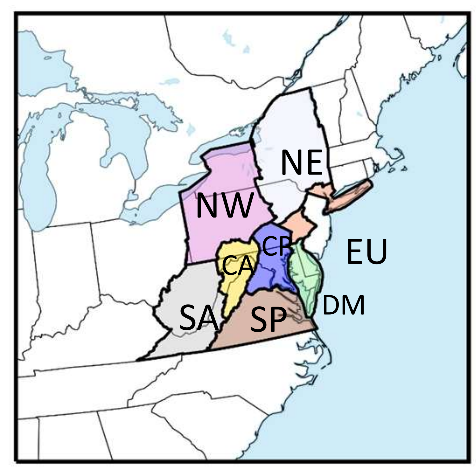
TOTAL

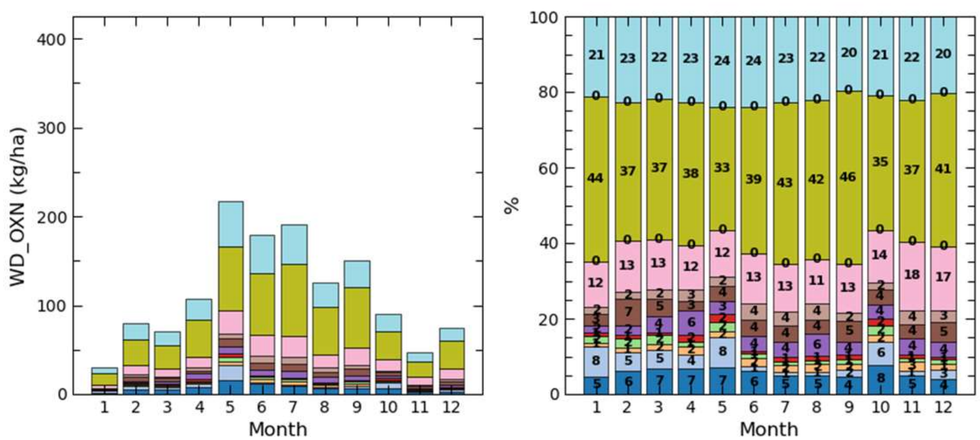


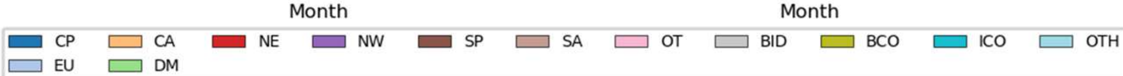
DRY



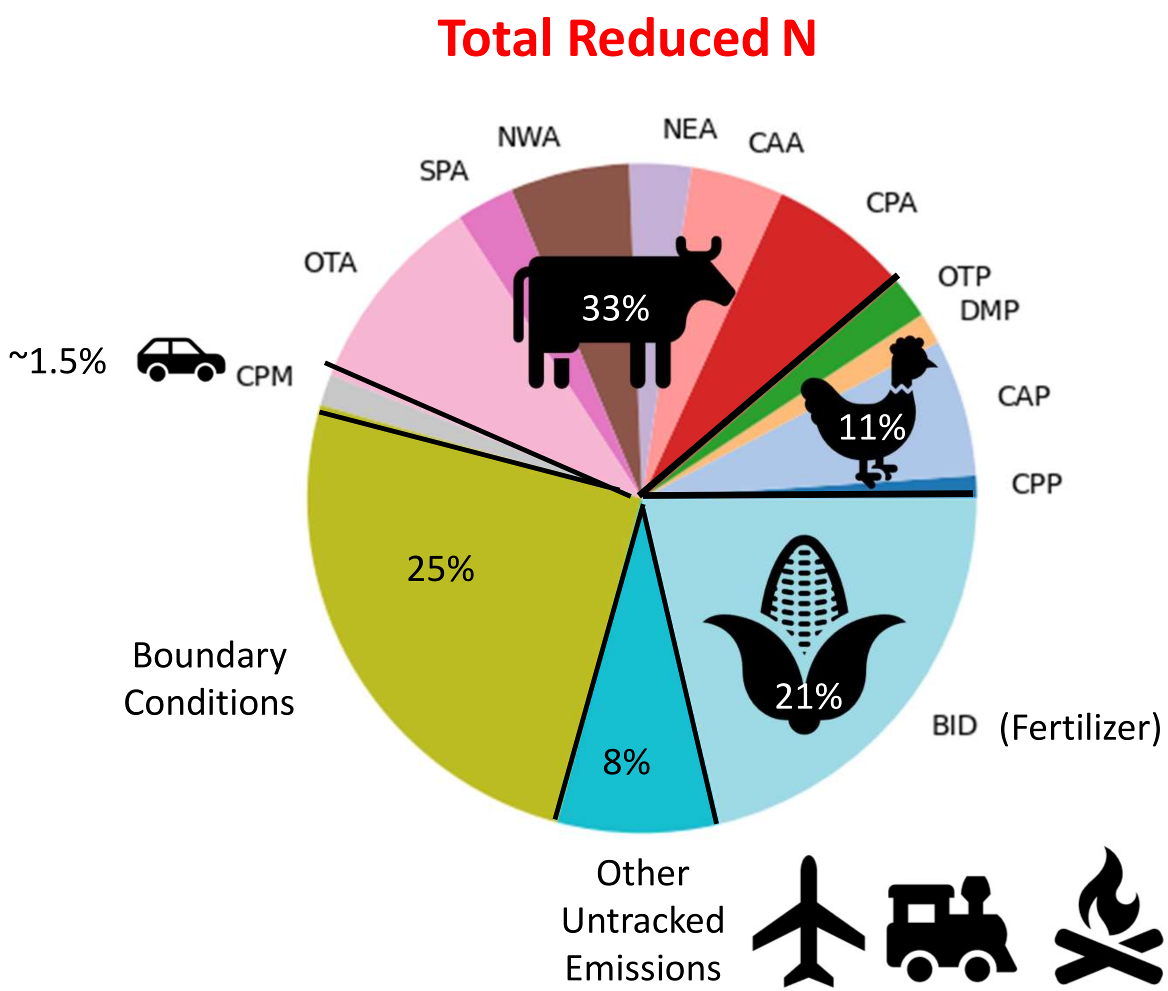


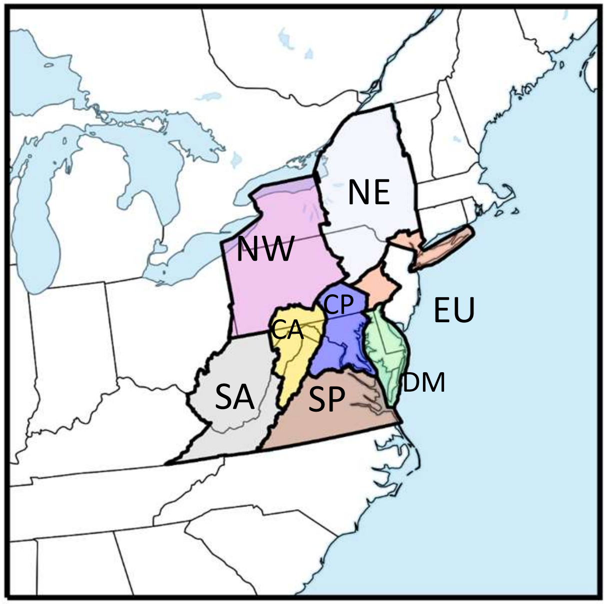
WET





Nitrogen Deposition in the Chesapeake Bay Watershed





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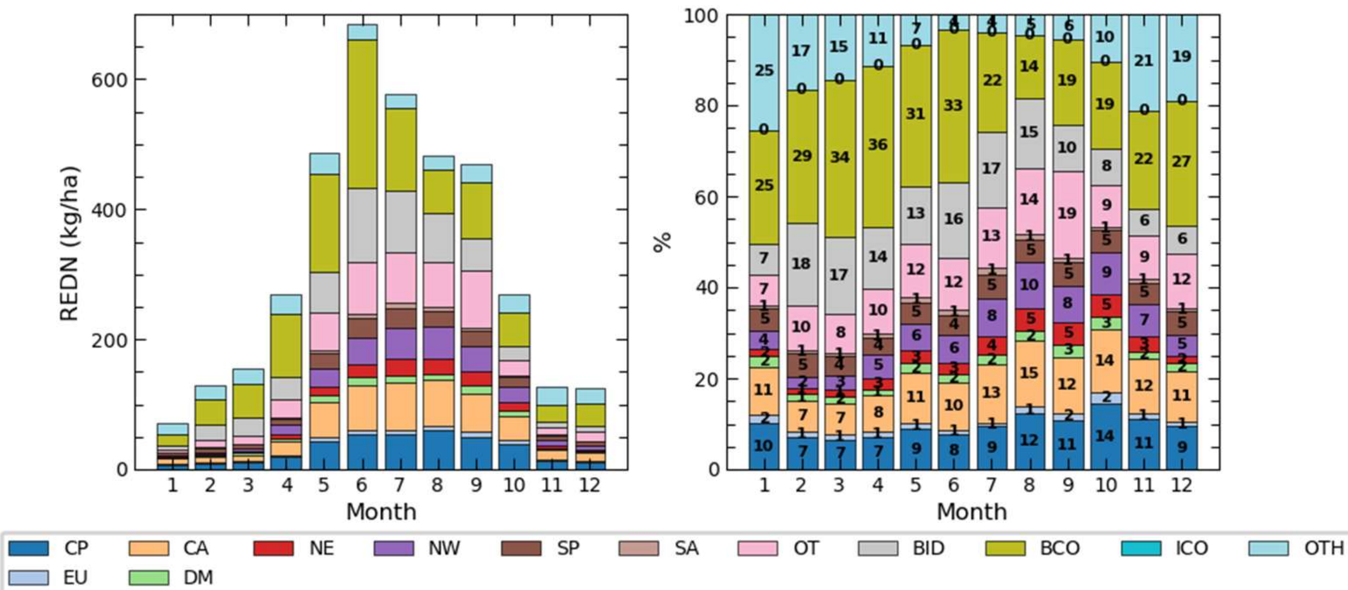
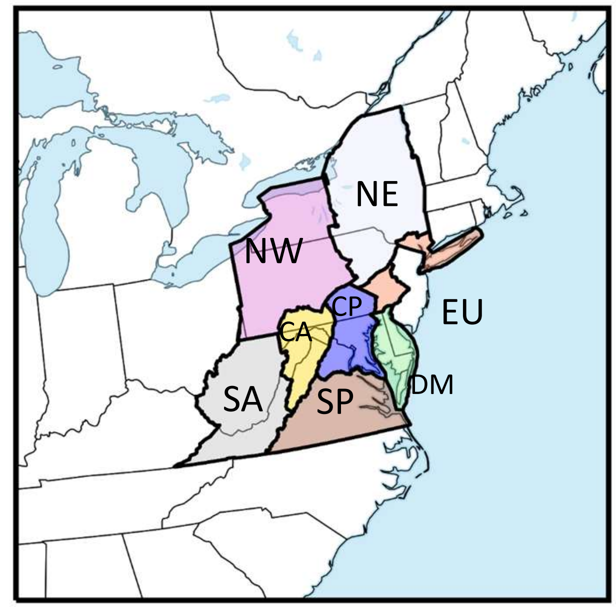
Monthly Total Reduced Nitrogen by Region





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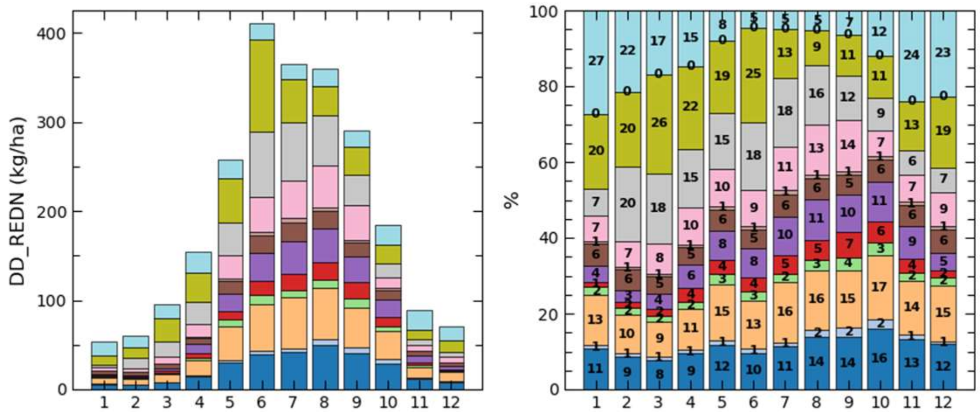
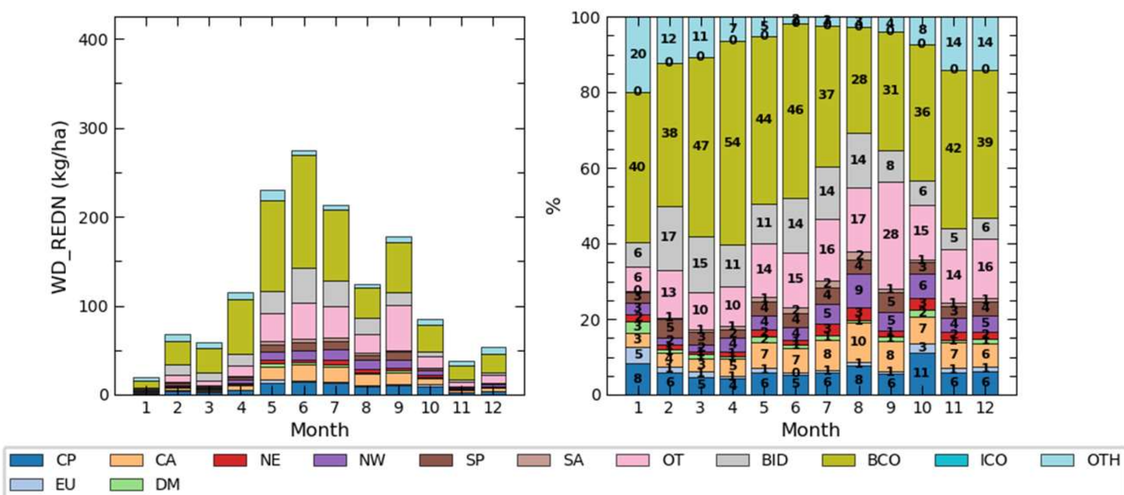
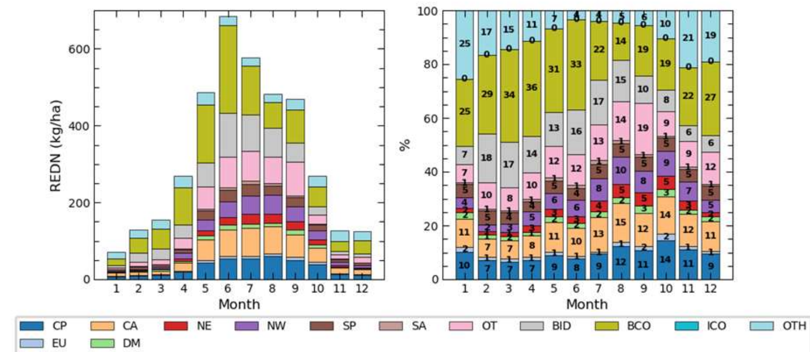
DRY

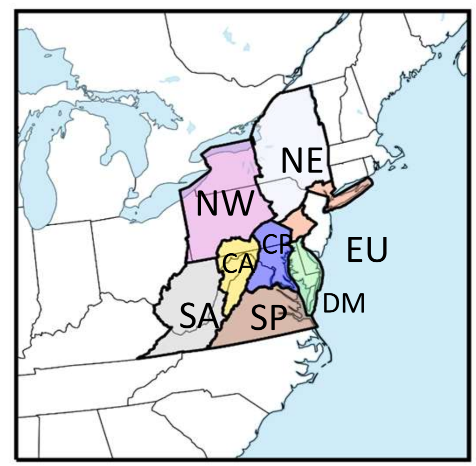


WET



TOTAL





Mobile Impacts in the Watershed

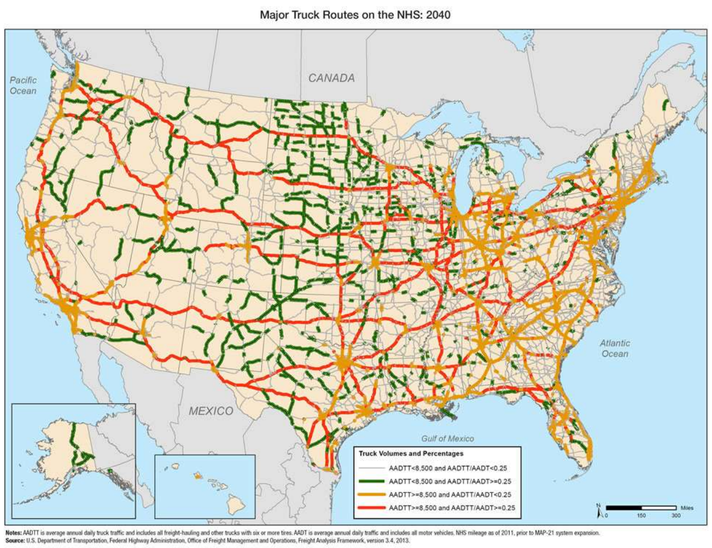
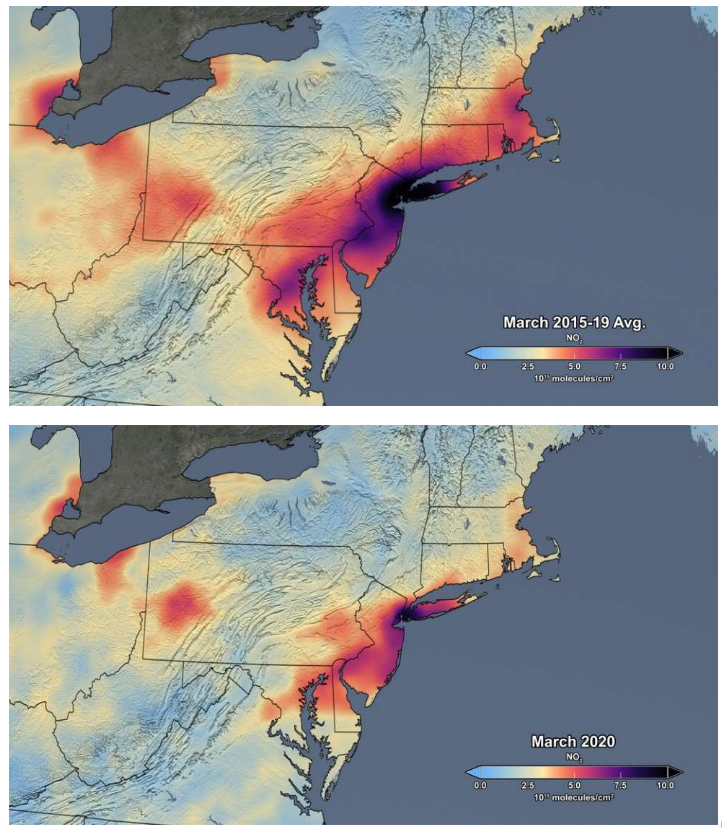
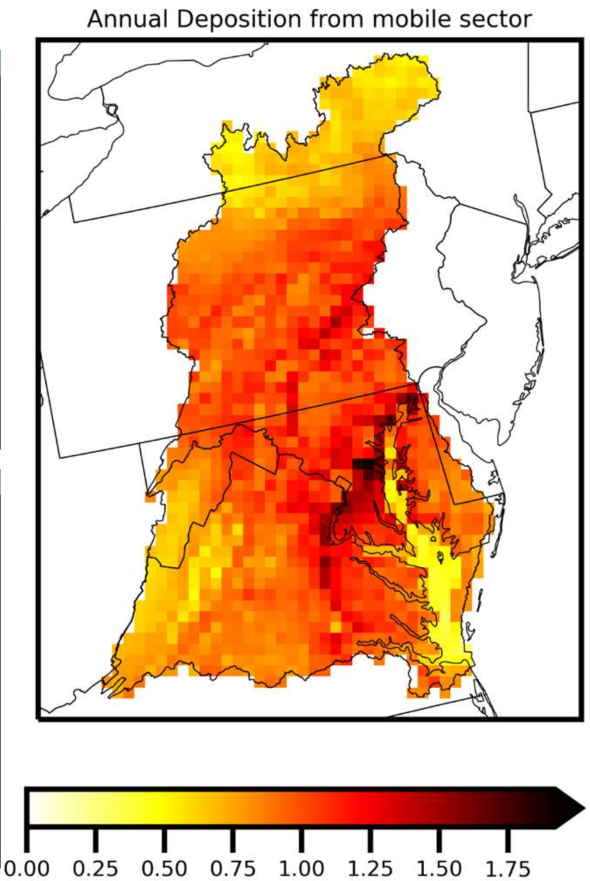
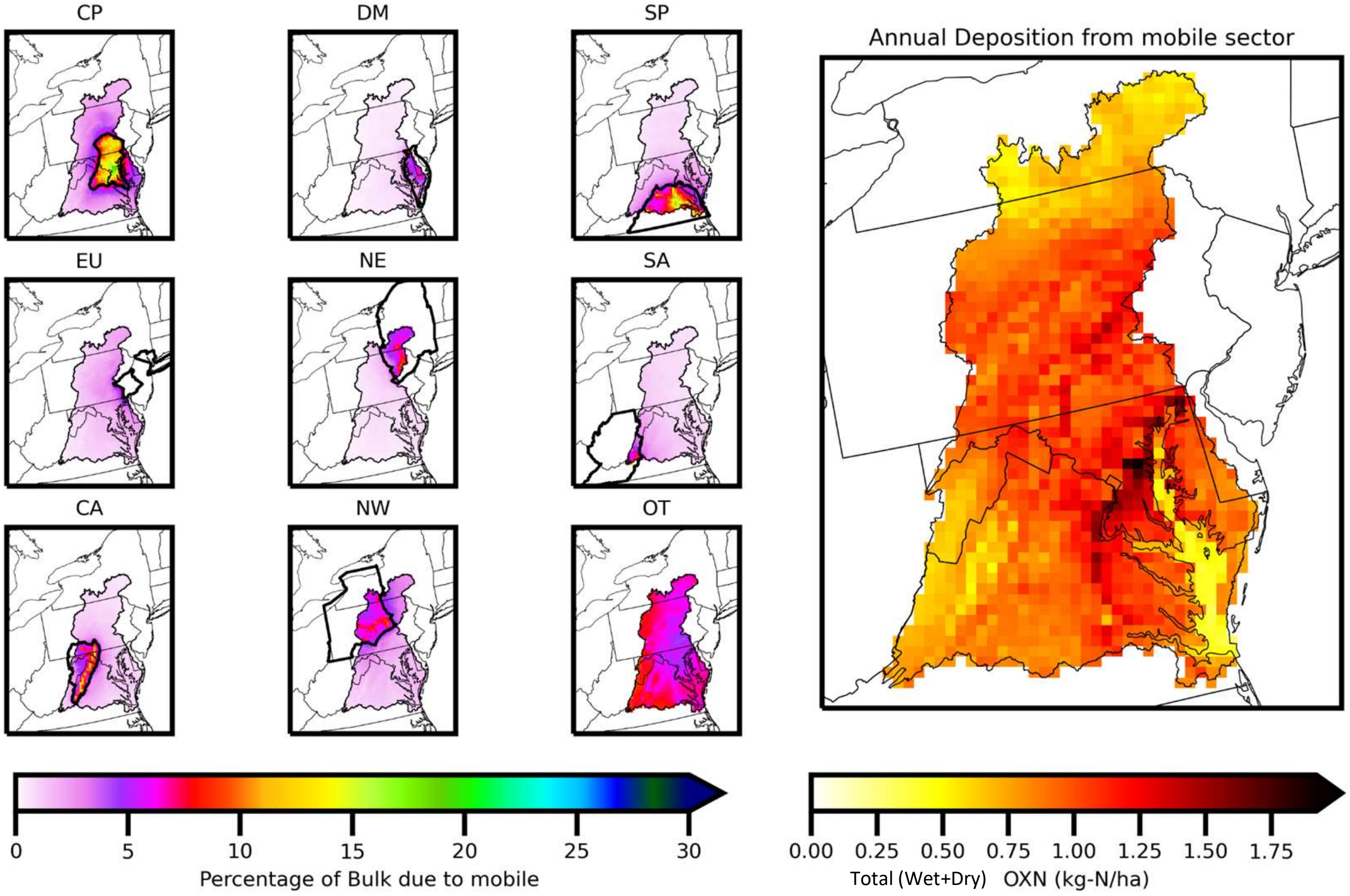


Image from: https://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/nhsmajortrkrts2040.htm



Images from: https://www.nasa.gov/feature/goddard/2020/drop-in-air-pollution-over-northeast





- Roadways can be identified in the mobile sector tag
- Mobile emissions from each source region contribute ~5% to oxidized N deposition across the Bay Watershed
- Mobile sources from each source region contribute at most ~20% to the total oxidized N deposition at a particular location within the source region

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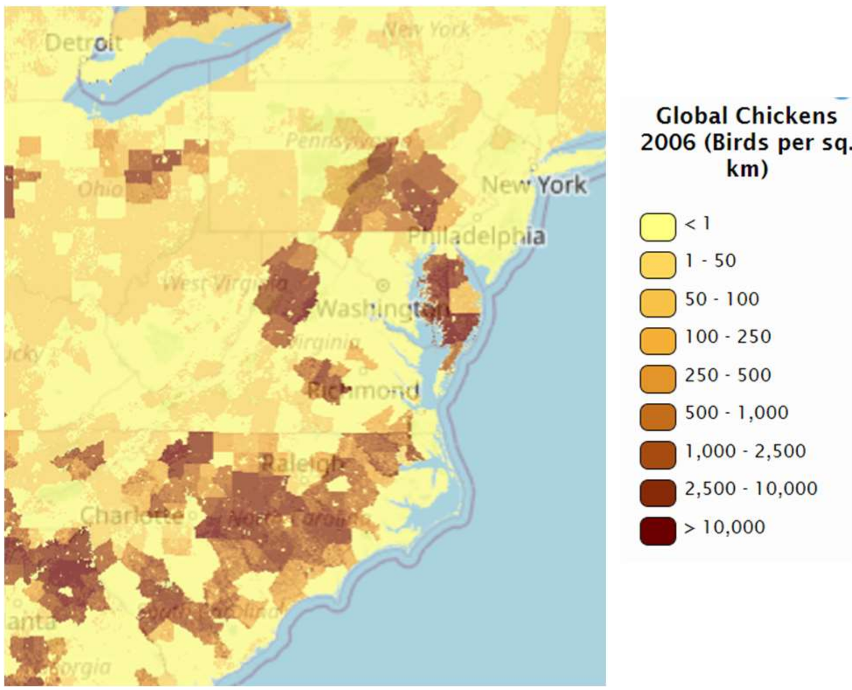
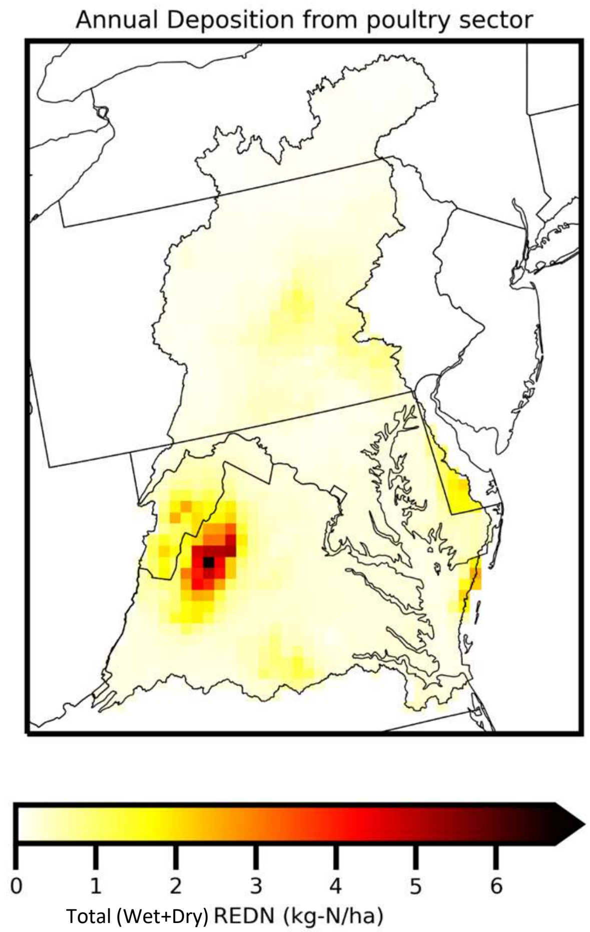
Poultry Impacts in the Watershed



Screenshot from https://livestock.geo-wiki.org/



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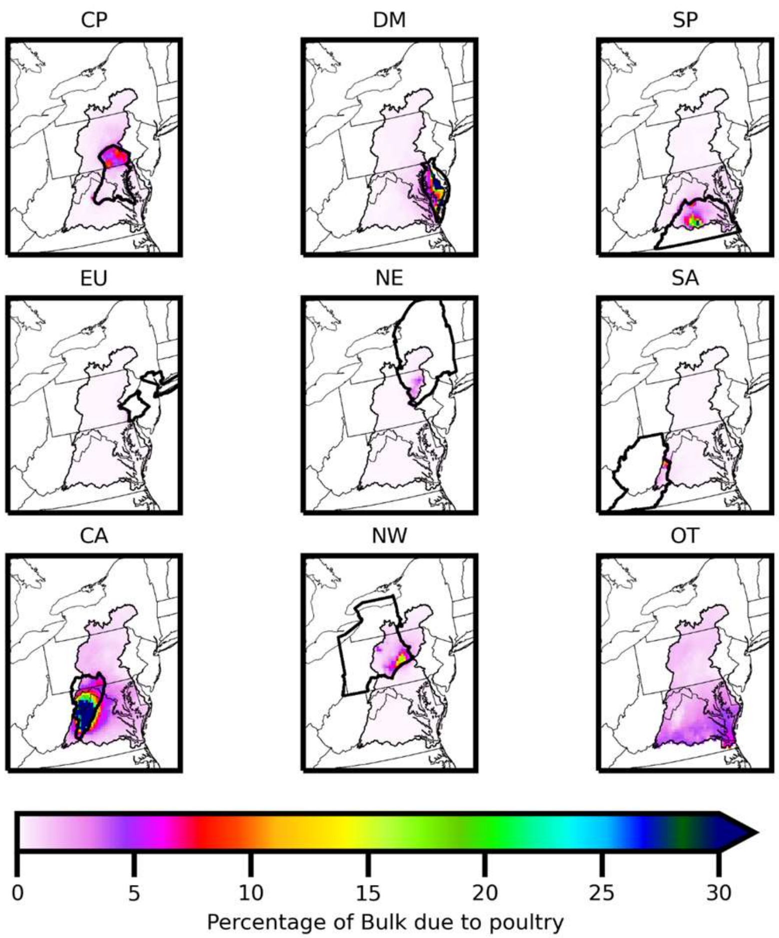
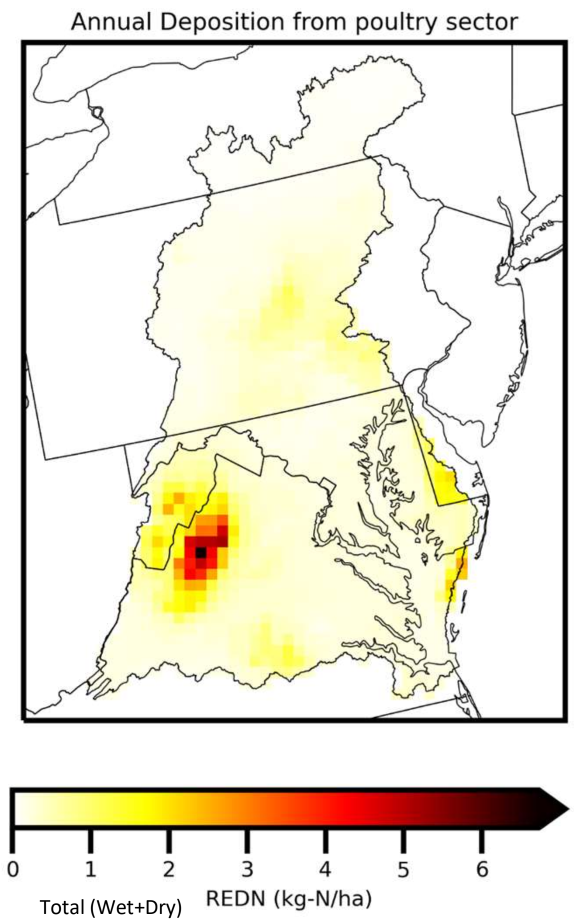
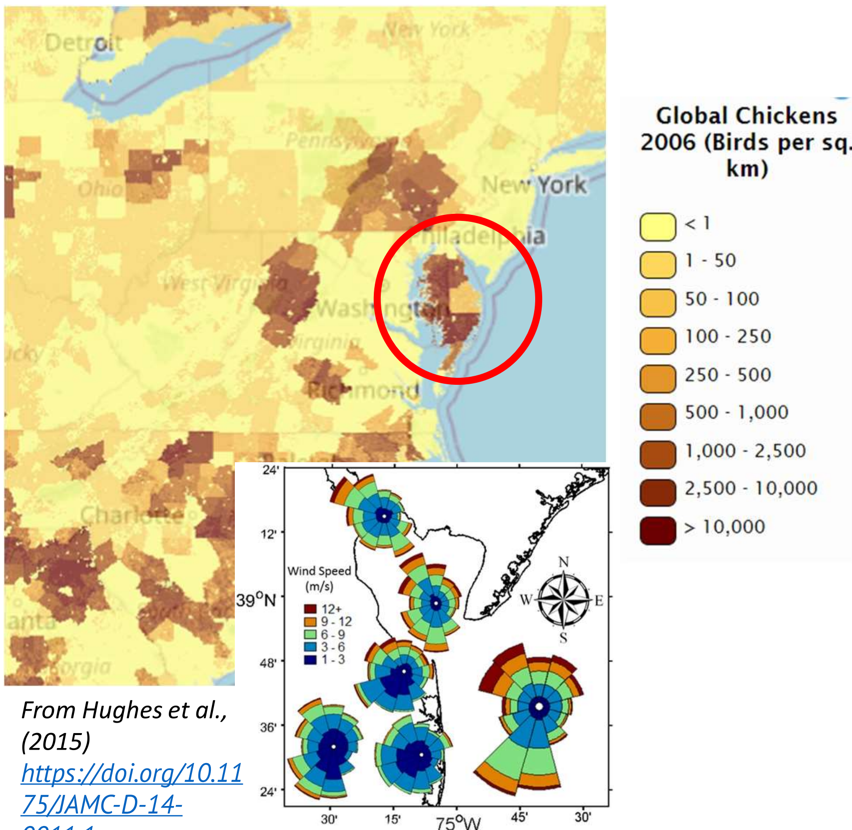


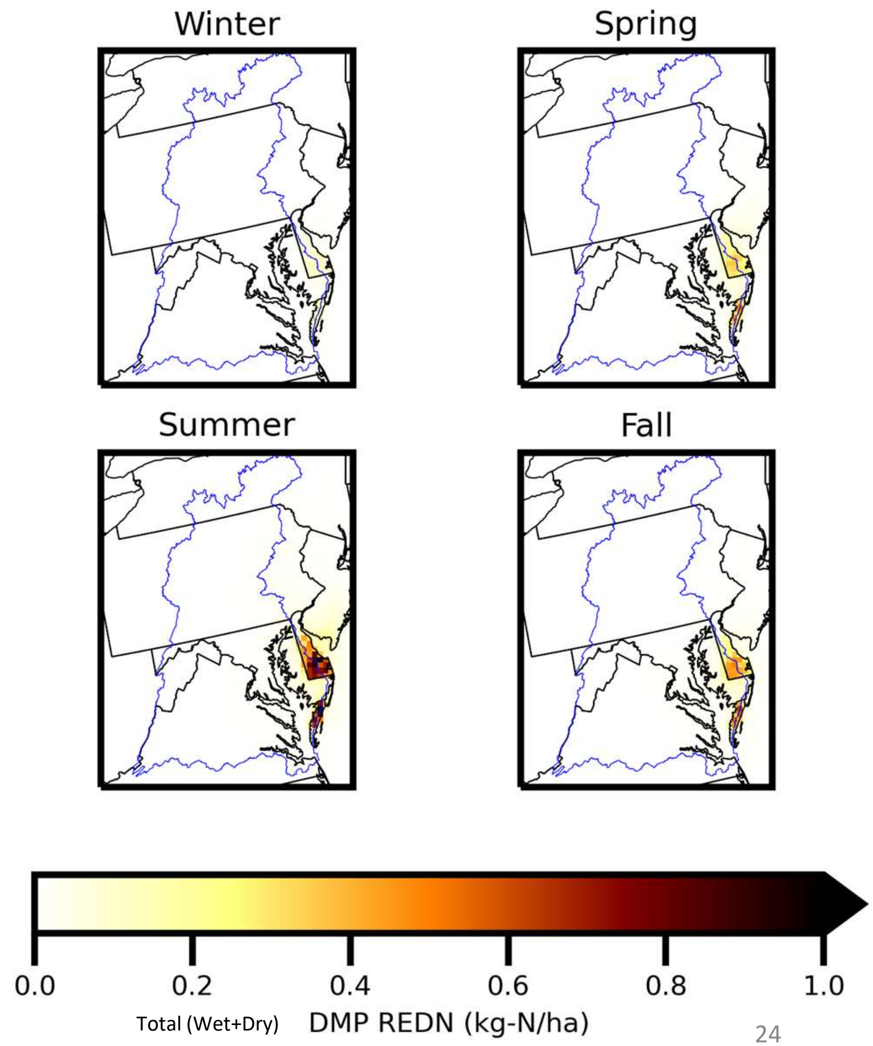


- Poultry locations can be identified in the poultry tag
- Poultry emissions from each source region contribute a smaller amount (generally <3%) to reduced N deposition across the Bay Watershed
- Poultry sources from each key source regions comprise a large amount (>30%) of the total reduced N

What about the Delmarva poultry?



From Hughes et al., (2015) [*https://doi.org/10.1175/JAMC-D-14-0011.1*](https://doi.org/10.1175/JAMC-D-14-0011.1)



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"Why shouldn't [cows] be able to learn how to use a toilet?"

Current Biology Magazine

Correspondence

Learned control of urinary reflexes in cattle to help reduce greenhouse gas emissions

Neele Dirksen[1], Jan Langbein[1,*], Lars Schrader[2], Birger Puppe[1,3], Douglas Elliffe[4], Katrin Siebert[1], Volker Röttgen[1], and Lindsay Matthews[4]

Indiscriminate voiding of excreta by cattle contributes to greenhouse gas (GHG) emissions and soil and water contamination[1,2]. Emissions are higher in animal-friendly husbandry offering cattle more space[2] — a trade-off we call the 'climate killer conundrum'. Voiding in a specific location (latrine) would help resolve this dilemma by allowing ready capture and treatment of excreta under more spacious farming conditions. For

- MooLoo approach to teach calves to use a toilet area of the barn so that urine can be collected and treated

- Initial estimates suggest that if 80% of cattle urine was collected from a barn, the ammonia emissions would be reduced by more than half.

- News article: https://www.theguardian.com/environment/2021/sep/13/cows-potty-trained-in-experiment-to-reduce-greenhouse-gas-emissions

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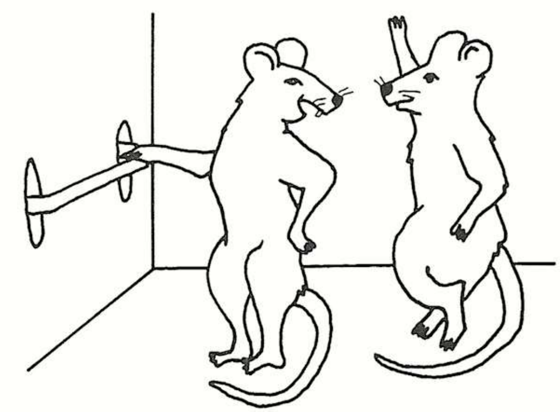


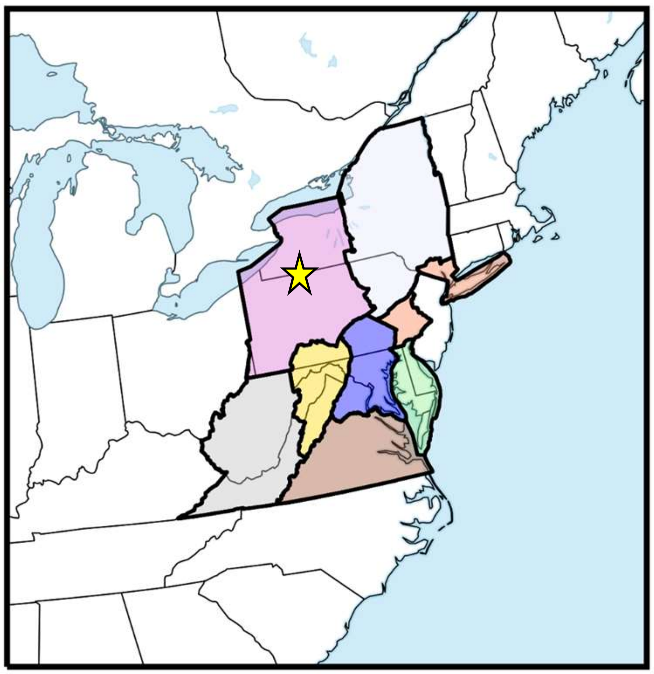
"Boy, have I got this guy conditioned! Every time I press the bar down he drops in a piece of food."

[*Used by permission of* JESTER, *Columbia College.*]

THE GOLDEN GOOSE AWARD

???

Next Steps: Efficiency Calculation



Example Calculation:

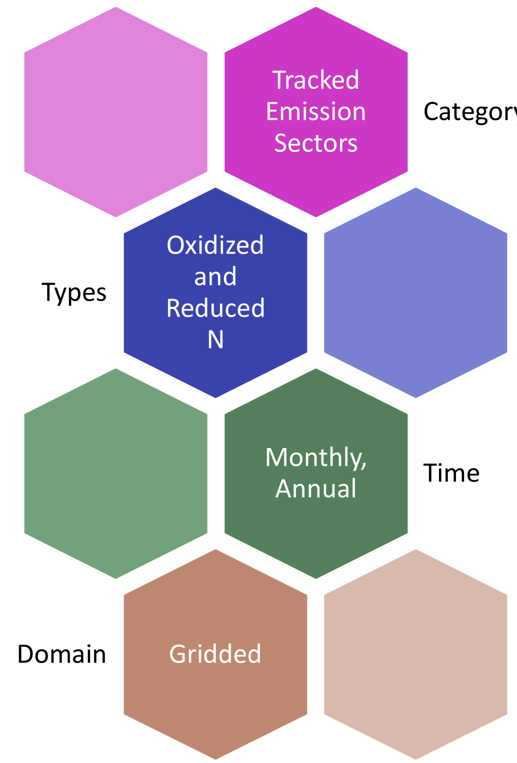
Coefficient at ☆ from Delmarva (DM)=

Annual Accumulated Total REDN Deposition at ☆

Annual Accumulated Emissions Summed over the DM Source Region

Repeat for all source regions

Additional Analysis:



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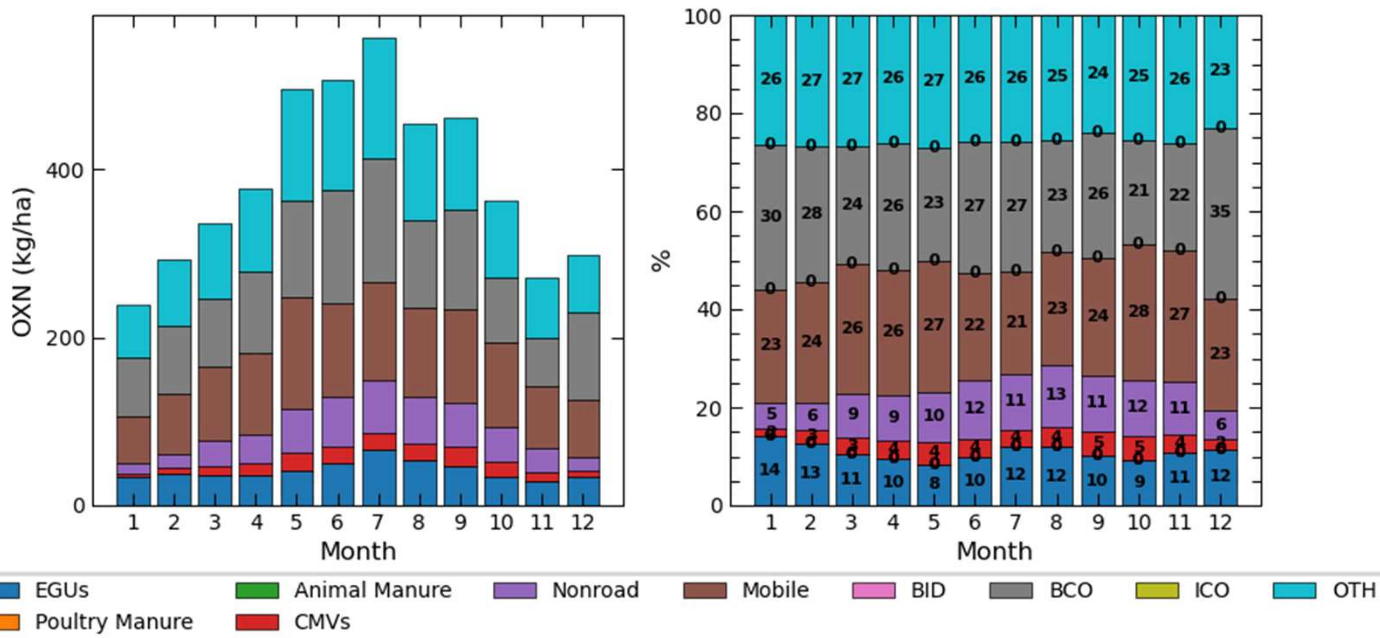
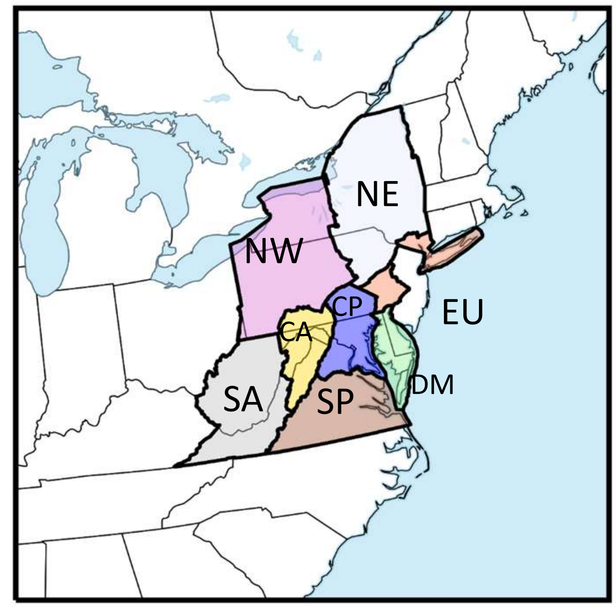
Summary & Next Steps

- EQUATES model simulations for 2002-2017 completed:
  - Precipitation and bias corrections to modeled wet deposition improve agreement with NADP NTN wet deposition measurements
  - Adjustment decreases the annual NMB of wet deposition across the US by ~20-30% annually compared to CMAQv5.3.2
  - Manuscript in prep
- ISAM simulations completed for 2016:
  - Boundary conditions and other untracked sources are the largest contributors to N deposition inside the Chesapeake Bay Watershed
  - Mobile sources constitute a large amount to total oxidized nitrogen deposition (~25%)
  - Non-poultry animal manure is an important source of total reduced nitrogen deposition (~30%)
  - Next steps: efficiency calculation

Monthly Total Oxidized Nitrogen by Emission





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Monthly Total Reduced Nitrogen by Emission