Impacts of Climate Change and Emissions Reductions on Atmospheric Nitrogen Loading to the Chesapeake Bay

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Outline

- Review of the WRF-CMAQ modeling system
  - Isolating changes due to emissions and climate
- Trends in N deposition to Chesapeake Bay Watershed
  - Modeled and observed deposition and atmospheric concentrations
- Changes in N deposition due to climate
  - RCP 4.5, 6.0, 8.5 scenarios
- Future scenarios integrating emissions, land use, and climate change
  - Preliminary results
- Future outlook and conclusions

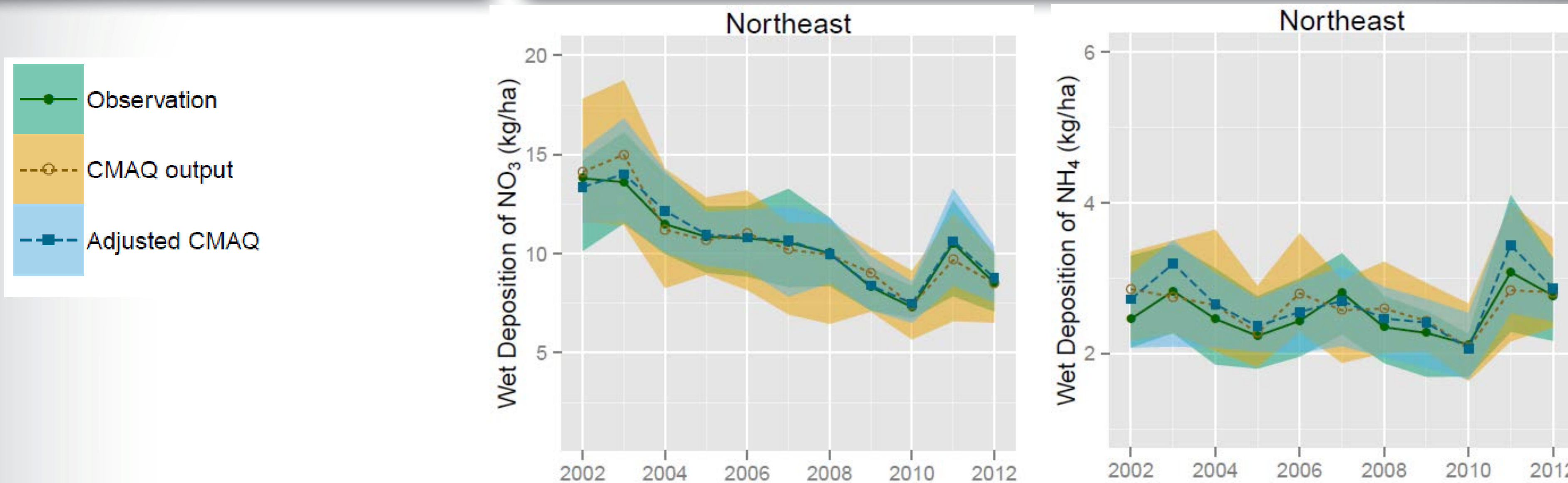
The WRF-CMAQ modeling system

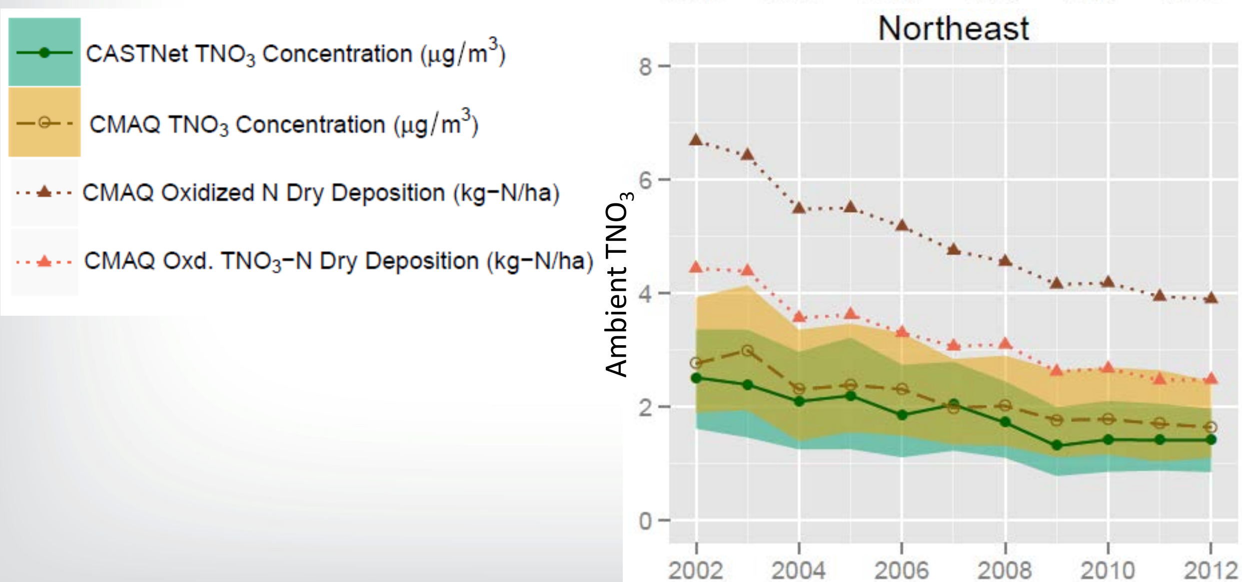
- “One atmosphere” modeling system
  - Chemistry and physics of pollutant transport and fate solved simultaneously
  - Options to Couple agricultural cropping management and soil biogeochemical processes using EPIC model
    - Dynamic air-surface exchange of trace gases and aerosols
      - NH_3 emissions from fertilizer application
      - Biogenic VOC and dust emissions
- WRF climate dynamic downscaling
  - Spectrally nudged to CESM climate simulations
- Working towards a “One biosphere” model
  - Coupled energy system, agricultural, meteorological, air and water quality models

Emission reduction simulations

- Simulations of emissions reductions from 2002-2012
- WRF-CMAQ-EPIC simulations
  - Simulates year specific meteorology, chemistry and agricultural cropping practices
- WRF meteorology incorporated observational assimilation
  - Best estimate of retrospective meteorology
- Used nearest year EPA National Emission Inventory emissions
  - Updated with observations from Continuous Emissions Monitoring Systems for point sources
  - Updated meteorological dependent emissions

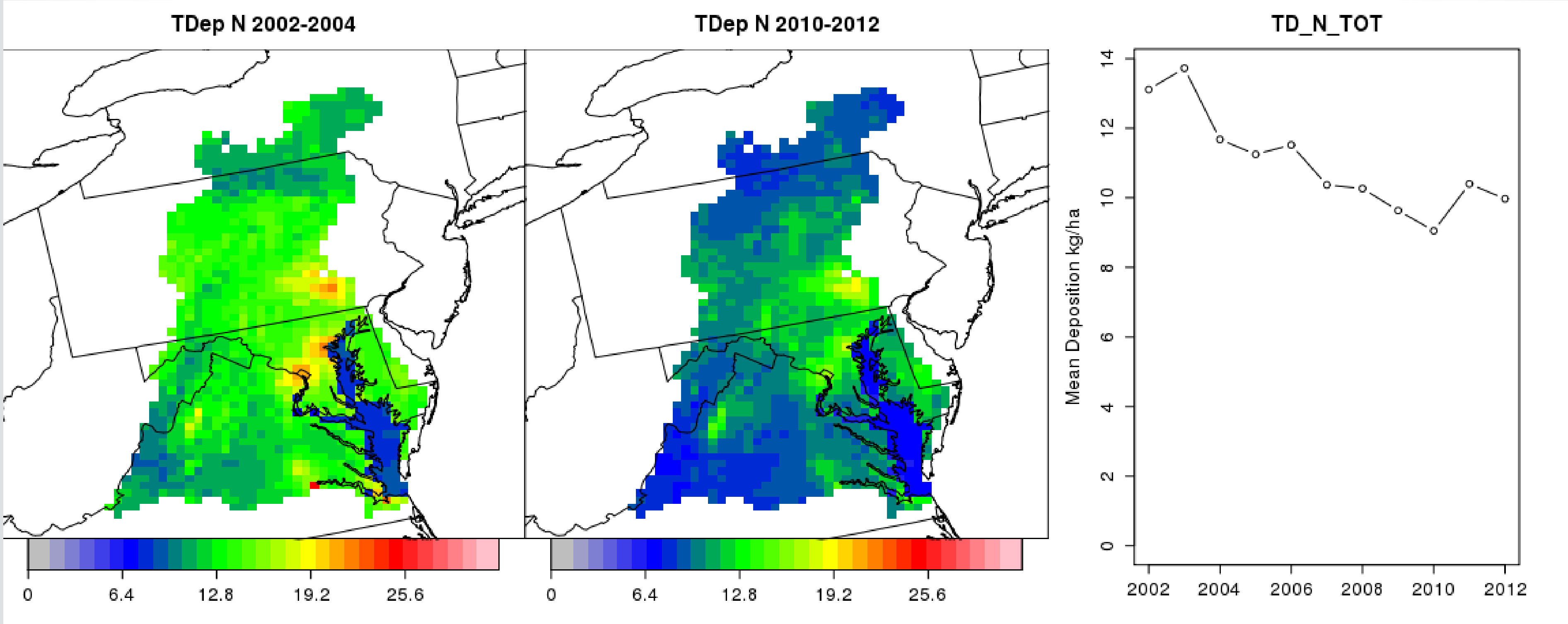
Model Evaluation





Captures the trends and magnitude in deposition and ambient concentrations well - (approximately 14% and 17% error for NO_3 and NH_4 respectively)

Total Nitrogen Deposition

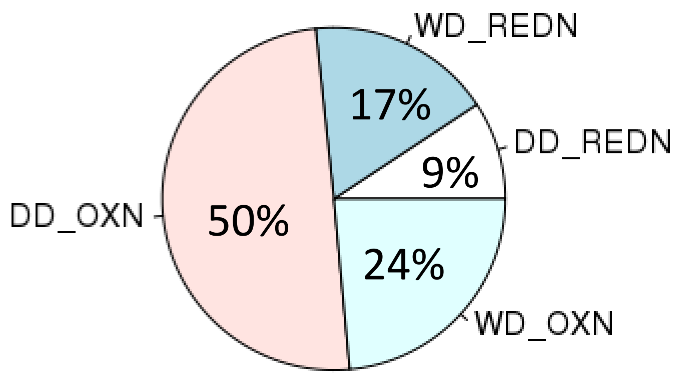


- 24% reduction in total nitrogen atmospheric deposition
- Clear benefits from air-quality standards

N Deposition Budget

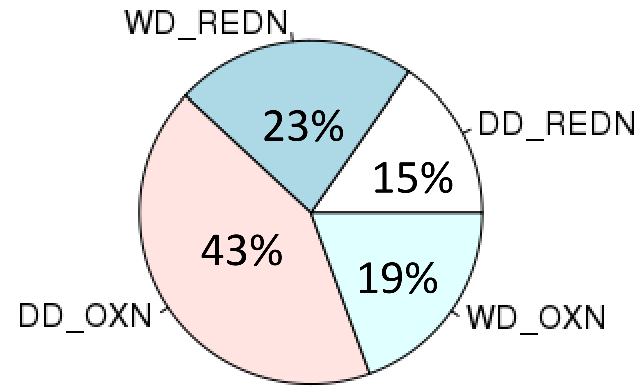
2002-2004

Mean: 13 kg N/ha



2010-2012

Mean: 10 kg N/ha

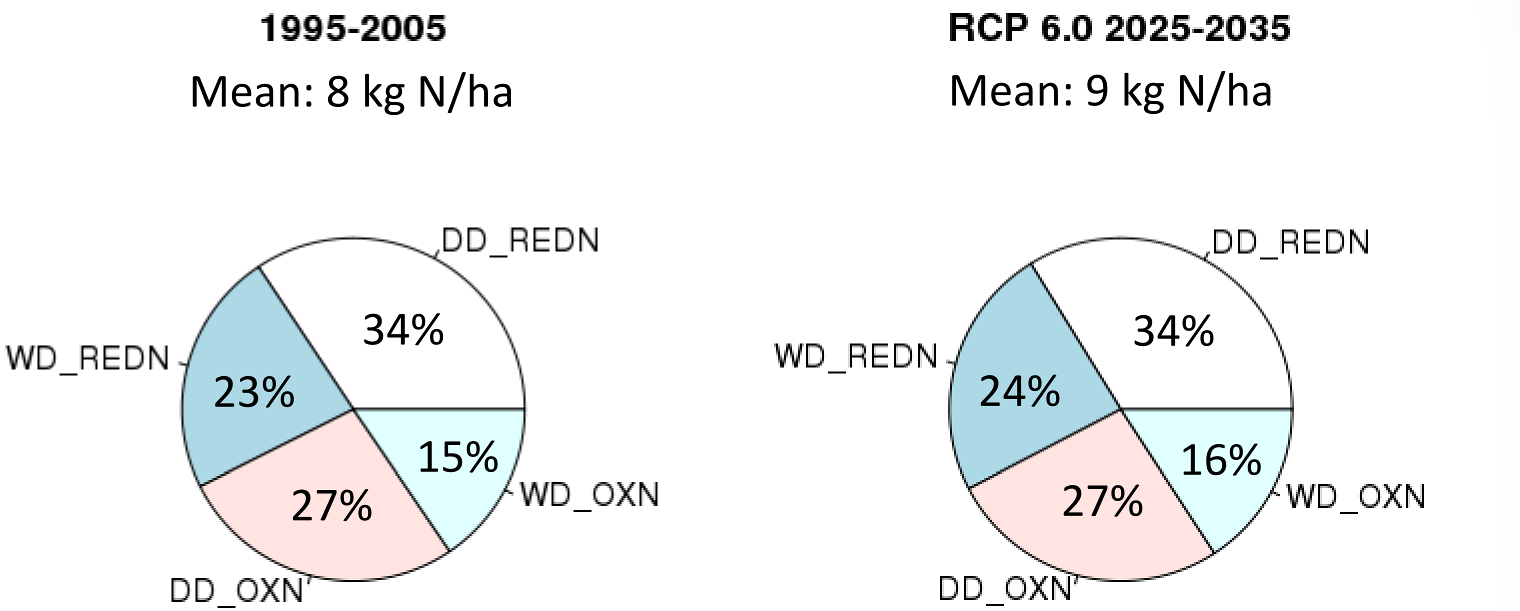


- Overall N deposition has decreased due to air quality standards
- Ratio of oxidized to reduced N deposition is changing
- Oxidized N deposition is decreasing
  - In response to controls on combustion sources
- Reduced N deposition is increasing
  - In response to changes in atmospheric composition and a lack of controls on NH_3 emissions

Climate scenario simulations

- Based on Community Earth System Model v1.0 (CESM) GCM simulations
- Dynamically downscaled using Weather Research and Forecasting (WRF) v3.4.1 model using spectral nudging
  - Preserves large scale atmospheric motions from CESM and allows WRF to provide the more detailed regional scale dynamics
- Air quality and deposition simulated using climate conditions for 2000 and 2030
- Emissions and boundary conditions based on 2030 projections for both 2000 and 2030 scenarios
  - Used to isolate the impact that climate has on air-quality and deposition

N Deposition Budget



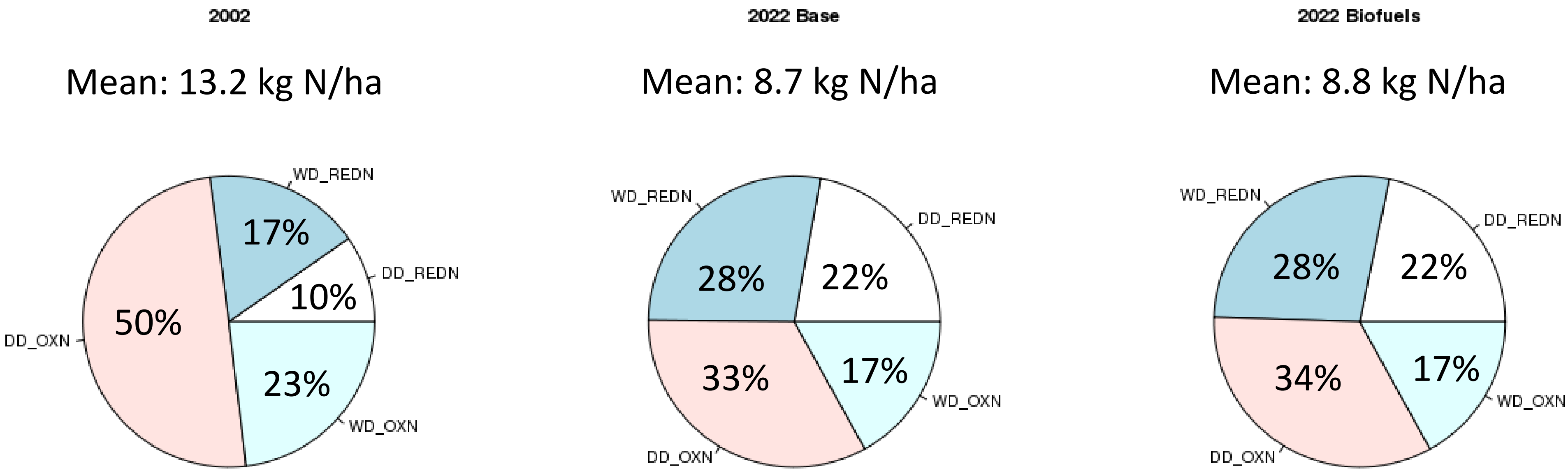
- Climate downscaling in WRF requires different configuration of CMAQ
  - Likely overestimates NH_3 dry deposition
- All Representative Concentration Pathways (RPC) scenarios result in increased N deposition
  - Deposition increase closely mirrors the air quality changes

Scenario	Precipitation Change (%)	N Deposition Change (%)
RCP 4.5	+3.9%	+2.2%
RCP 6.0	+8.9%	+2.9%
RCP 8.5	+1.0%	+3.3%

Future Emission Scenarios

- **WRF-CMAQ-EPIC simulations**
  - 2002 following retrospective analysis
  - 2022 with reductions on the books
  - 2022 with reductions on the books and with additional corn based biofuels
- **Emissions grown using the MARKet Allocation (MARKAL) energy system model coupled to the Center for Agricultural and Rural Development (CARD) to develop 2022 and 2022 ethanol scenarios**
  - MARKAL/CARD simulations combined with EPIC provide feasible future agricultural and biofuel futures
  - Constrained by economic and biological productivity factors
- **2002 WRF meteorology was used to isolate emission changes**

N Deposition Budget



- Deposition changes are dominated by 2002-2022 emission reductions
- Additional corn production for biofuels increased N deposition by 0.7%
    - Largely responds to slightly higher NOx emissions from mobile sources
    - Impacts are likely larger in areas where agricultural production changed more.

Conclusions

- The CMAQ modeling system captures the observed deposition and ambient concentrations trends well
- Future nutrient deposition is dominated by emission reductions
  - This may change with a more climate-land use-biogeochemistry integrated model
- Oxidized nitrogen deposition primarily from combustion sources has decreased more rapidly than total N deposition
- Future reductions in NOx will likely plateau
- Reduced N (i.e. NH_x) deposition will likely represent a larger portion of the N deposition budget
- More comprehensive coupled climate, energy sector and air and water quality models are needed to better assess nutrient loading

Future Directions

- **Model development work is needed to integrate future climate and emissions work**
  - Primarily, land use surrogates and some meteorological dependencies
- **Model development needs to incorporate future land use in future simulations**
  - Current climate land use schemes are simple
  - Need dynamic vegetation and soil processes
- **Developing model simulations for the Conterminous US circa 2050 that will include impact of emissions, meteorology, land use, and agriculture**
  - Explore the impact of non-linear interactions between emissions and climate, e.g. N & C biogeochemistry