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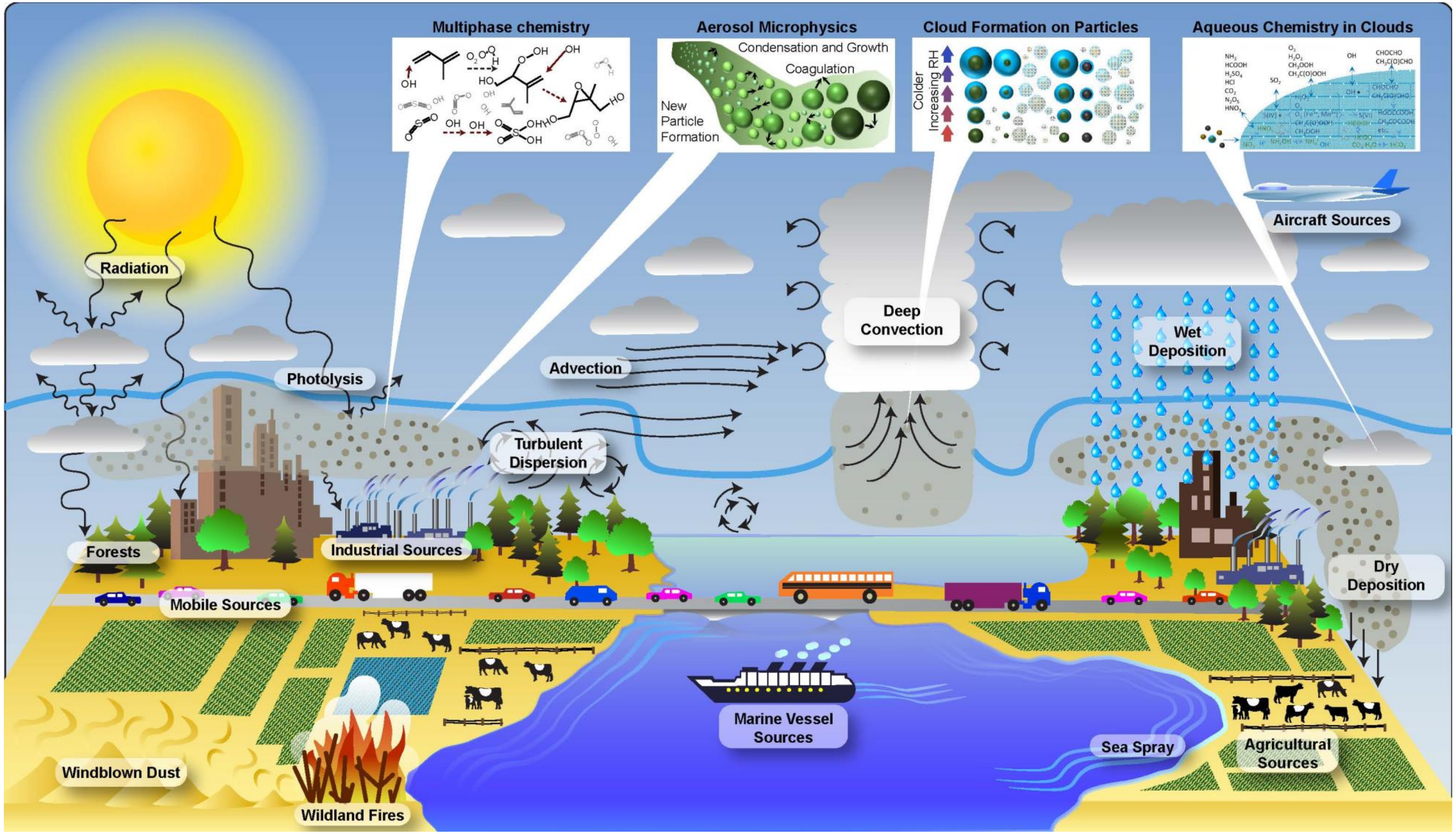
Evaluating the impacts of decarbonization scenarios on deposition

Chris Nolte, Dan Loughlin, and Uma Shankar
Chesapeake Bay Program Quarterly Meeting
June 20, 2023

Note: these are DRAFT slides that have not been cleared for dissemination

Community Multiscale Air Quality (CMAQ) model



Key Inputs:

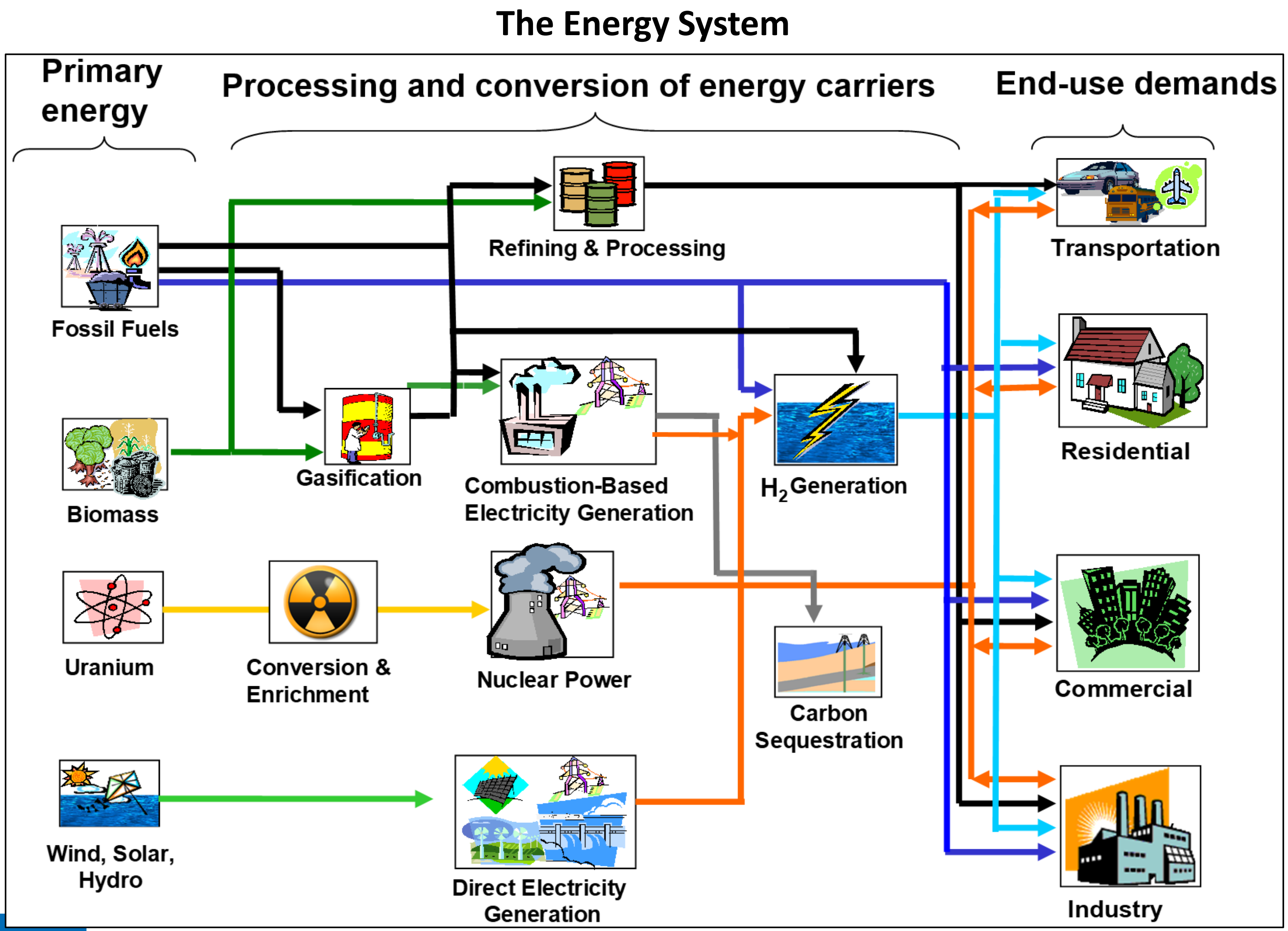
Meteorological Parameters
(temperature, pressure, wind speed, precipitation, solar radiation/cloudiness, etc.)

Emissions
nitrogen oxides, sulfur dioxide, volatile organic compounds, primary particulate matter (e.g., soot)

Outputs:
Atmospheric concentrations and deposition of air pollutants

https://epa.gov/cmaq

The role of energy



Contributions to anthropogenic emissions:

GHGs:

- CO_2 – 96%
- CH_4 – 40%
- All GHGs – 82%

Air pollutants:

- NO_x – 91%
- SO_2 – 75%
- CO – 74%
- VOCs – 45%
- PM2.5 – 22% (direct)

In 2015, 41% US energy system freshwater withdrawals were for thermoelectric power plant cooling, nearly as much as for agriculture.

https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data
https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks
https://www.usgs.gov/mission-areas/water-resources/science/thermoelectric-power-water-use

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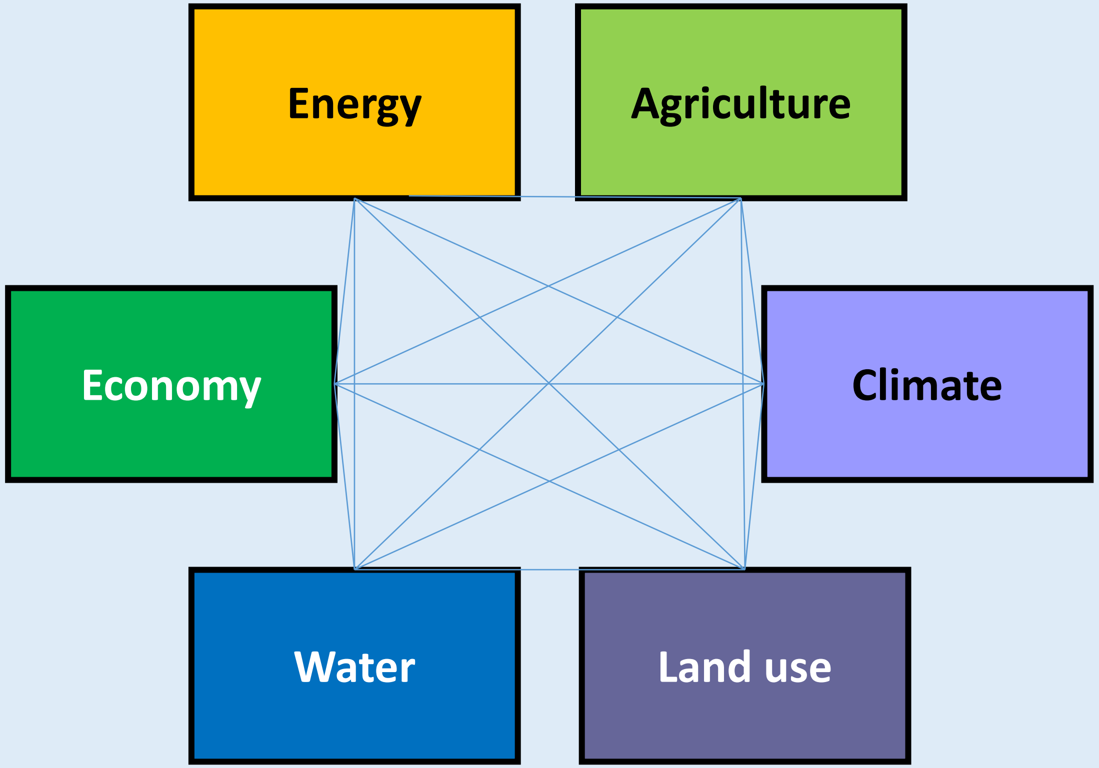
Global Change Analysis Model

GCAM

Scenario assumptions

- Population growth
- Economic growth
- Resource availability
- Climate change
- Technology development
- Behavior and preferences
- Policies



Simulates the <u>co-evolution</u> of these systems through time

End points

Energy
- Technology penetrations
- Fuel use and prices

Economic
- Policy cost
- Cost of energy services
- Land and food prices

Climate
- GHG emissions
- Global mean temperature

Environmental
- Air pollutant emissions
- Water use
- Health impacts

GCAM documentation: http://jgcri.github.io/gcam-doc/

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Global Change Analysis Model

GCAM

Scenario assumptions

- Population growth
- Economic growth
- Resource availability
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- Technology development
- Behavior and preferences
- Policies

Lead developer: Pacific Northwest National Lab

Time Horizon: 2010–2100, 5-yr increments

Spatial Resolution:

- **GCAM (core):** 32 global regions
- **GCAM-USA:** 31 global regions, 50 states + DC
- **GCAM-China:** 31 global regions, 23 provinces
- **GCAM-Canada, GCAM-Korea, GCAM-India** …

GHGs: CO_2, CH_4, N_2O, HFCs

Air pollutants: NOx, SO_2, $PM_{2.5}$, VOCs, CO, NH_3

Runtime: 1 to 5 hours for EPA's GCAM-USA v5.4

Requirements: Desktop PC, Mac, Linux, or Cloud

Availability: Public domain, open source, free

End points

Energy
- Technology penetrations
- Fuel use and prices

Economic
- Policy cost
- Cost of energy services
- Land and food prices

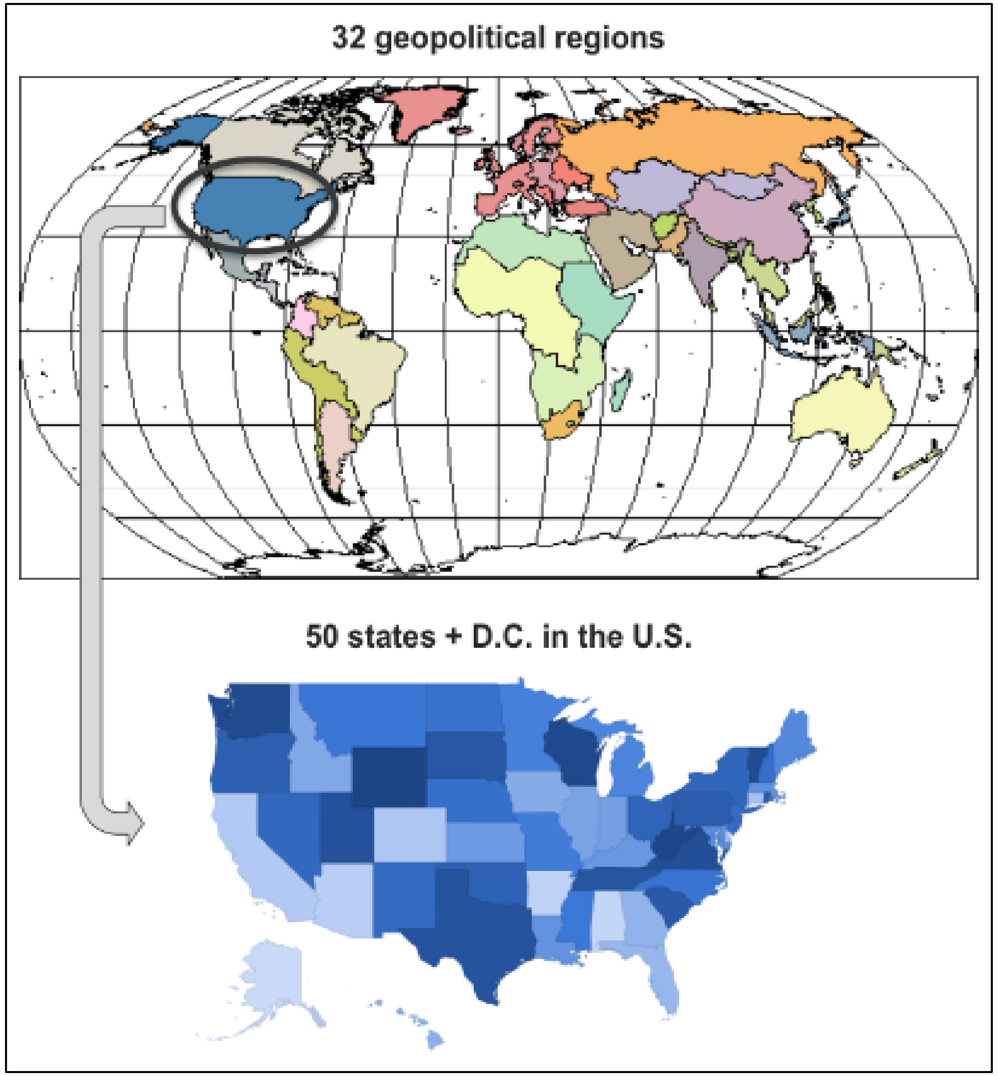
Climate
- GHG emissions
- Global mean temperature

Environmental
- Air pollutant emissions
- Water use
- Health impacts

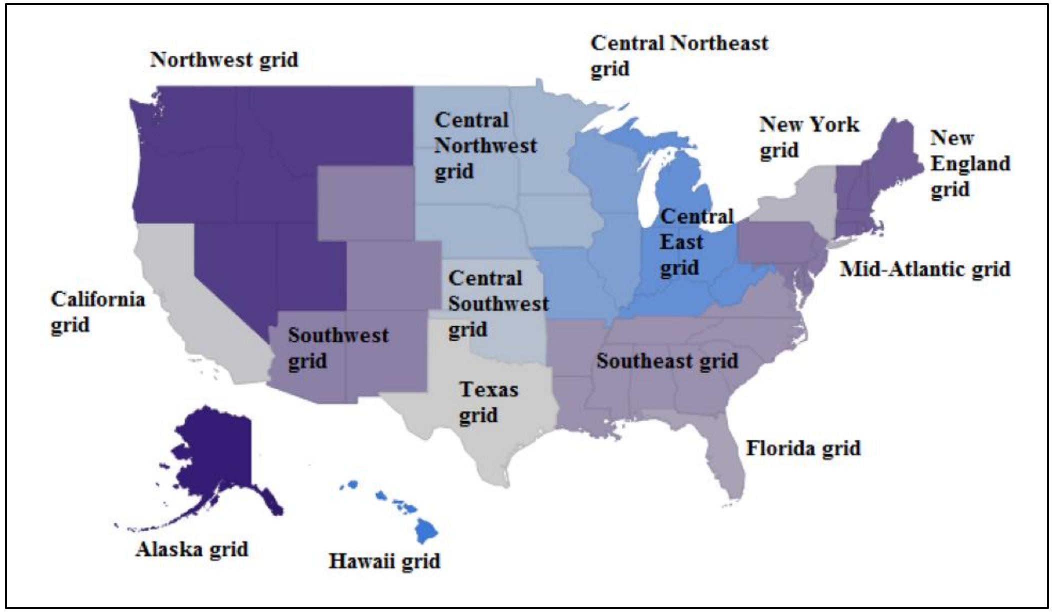
GCAM documentation: http://jgcri.github.io/gcam-doc/

GCAM-USA spatial resolution

Socio-economic and energy regions



Electric grid regions



Land regions and water supply basins

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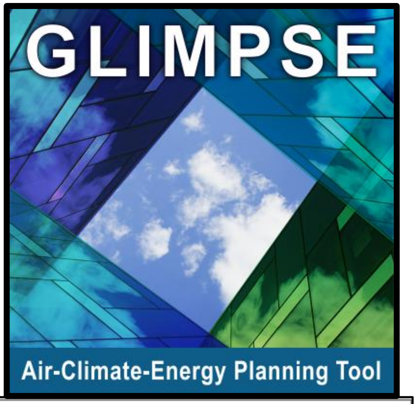
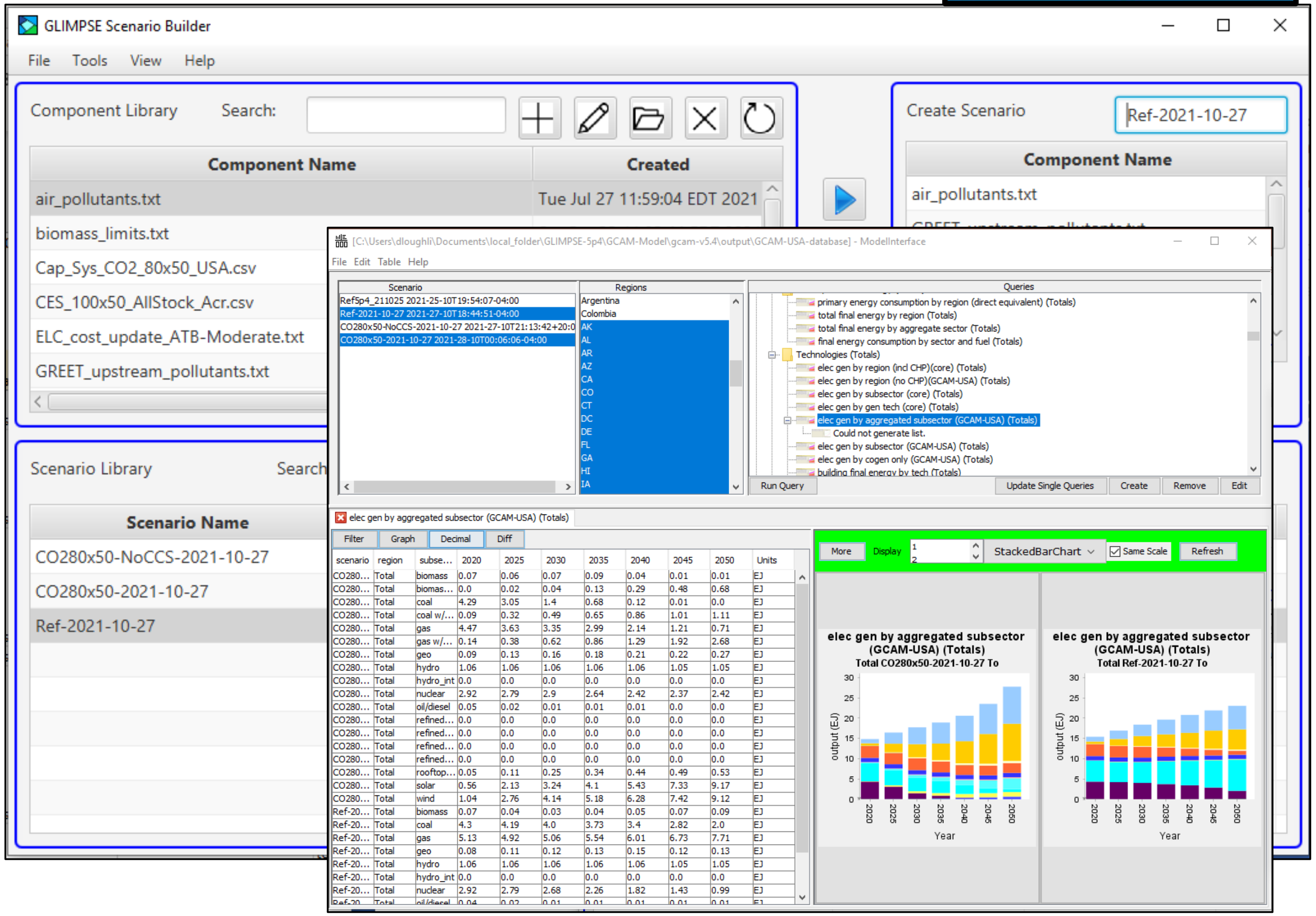
EPA GLIMPSE Project

GLIMPSE: GCAM Long-term Interactive Multi-Pollutant Scenario Evaluator



Decision support system

- GLIMPSE graphical user interface for GCAM
- Supports exploratory analyses
    - Constructing scenarios
    - Managing GCAM execution
    - Visualizing results
- Facilitates policy evaluation
    - Technology market share targets
    - Technology and fuel subsidies or taxes
    - Pollutant taxes and caps
    - Technology availability
- Operational modes
    - Test specific policy or scenario
    - Outline goals; GCAM identifies strategy



New website: https://www.epa.gov/glimpse

Scenario "levers" supported by GLIMPSE

Policy levers

Emissions:

- tax
- reduction target or cap

Technologies:

- subsidy
- market share targets:
  + *Renewable Portfolio Standards*
  + *EV market share targets*
  + *High efficiency technologies*
  + *Biofuels*
- specific output targets
  + *e.g. offshore wind*

Fuel prices:

- coal, natural gas, oil, and biomass

Technology attributes:

- availability
- cost
- efficiency
- lifetime

Behavior and choice:

- technology preference or bias
  (via shareweights)

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Application

Exploring the air pollutant emission co-benefits deep decarbonization pathways strategies

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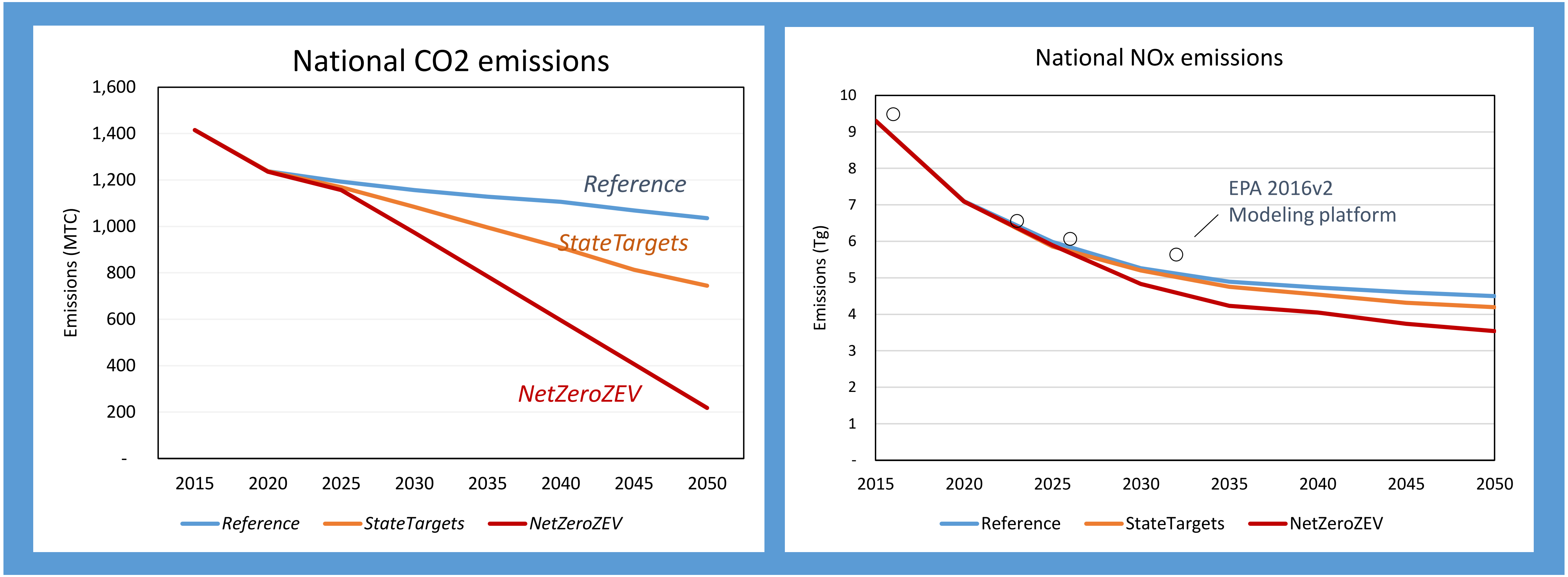
Scenario Design

- *Reference*: A baseline scenario that includes:
  - limited GHG mitigation and no additional air pollutant control requirements
- *StateTargets:* A mitigation scenario that includes:
  - State GHG reduction goals, implemented as regional CO_2 targets
  - New CA light-duty electrification targets adopted by Section 177 states
  - Medium- and Heavy-Duty Electrification MOU adopted by signatory states
- *NetZeroZEV*: A mitigation scenario that includes:
  - A national, economy-wide declining CO_2 cap reaches Net-Zero by 2050
  - Transportation electrification targets in *StateTargets* adopted nationally

National CO2 and NOx projections from GCAM



	2023	2026	2028	2032	2050
StateTargets	-1.2%	-2.9%	-4.5%	-8.4%	-28%
NetZeroZEV	-1.9%	-5.6%	-11%	-22%	-79%

	2023	2026	2028	2032	2050
StateTargets	-1.2%	-2.0%	-1.8%	-2.2%	-7.0%
NetZeroZEV	-0.9%	-2.7%	-5.3%	-10%	-21%

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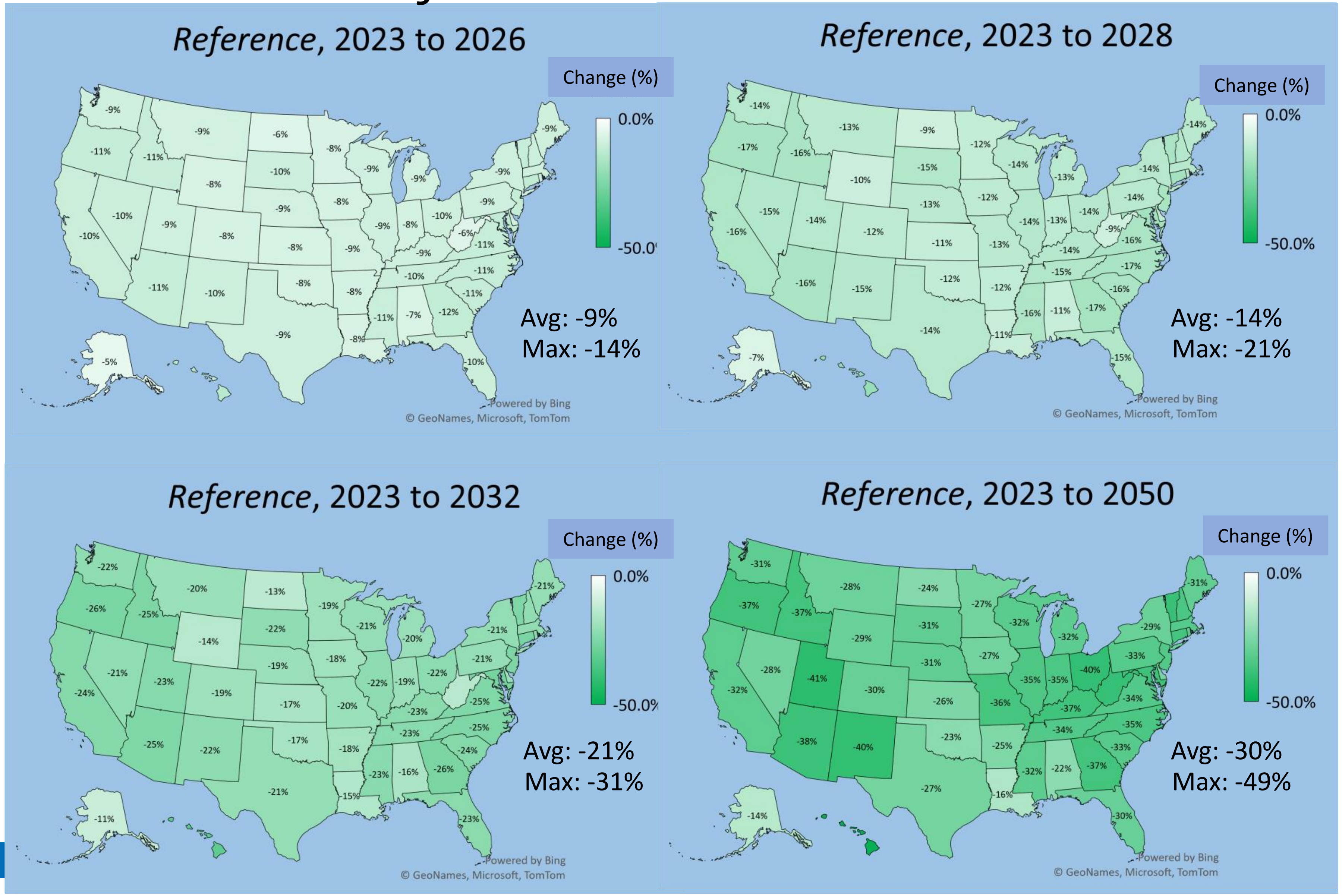
Spatial distribution of NOx reductions in *Reference*



National NOx vs. 2023

Scenario	2026	2028	3032	2050
Reference	-9%	-14%	-21%	-30%

State-level NOx vs. 2023

	2026	2028	2032	2050
NY	-9%	-14%	-21%	-29%
NJ	-11%	-17%	-25%	-34%
PA	-9%	-14%	-21%	-33%
CT	-12%	-17%	-26%	-36%
OH	-10%	-14%	-22%	-40%
WV	-6%	-9%	-14%	-39%
VA	-11%	-16%	-25%	-34%
MD	-12%	-18%	-27%	-38%
MI	-9%	-13%	-20%	-32%
KY	-9%	-14%	-23%	-37%
IN	-8%	-13%	-19%	-35%
Other	-1%	-2%	-3%	-5%
All states	-6.0%	-9.0%	-14%	-20%

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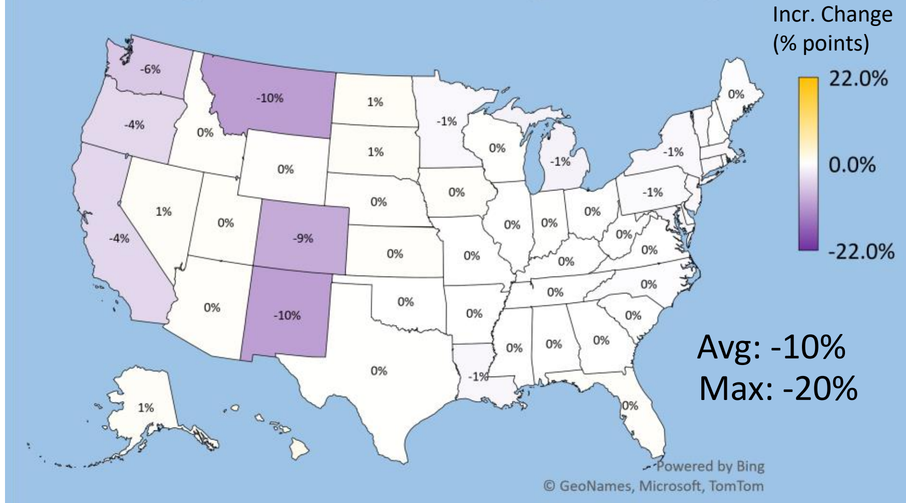
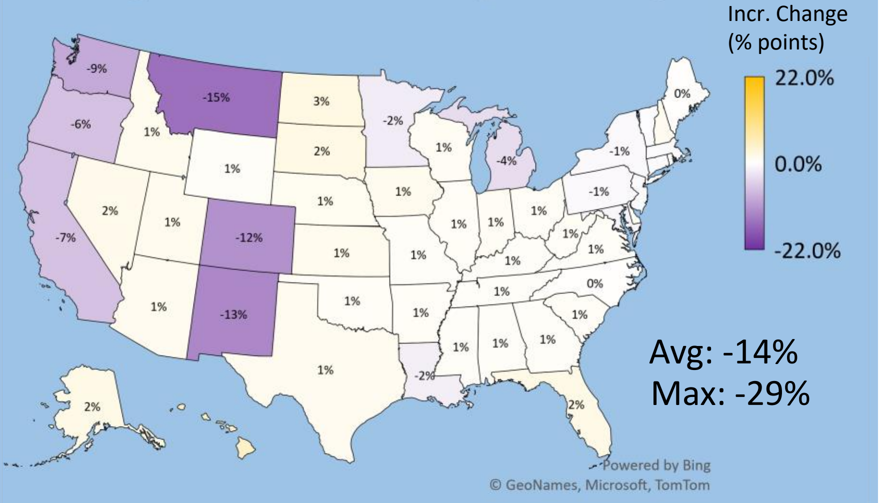
Additional NOx reductions from *StateTargets*

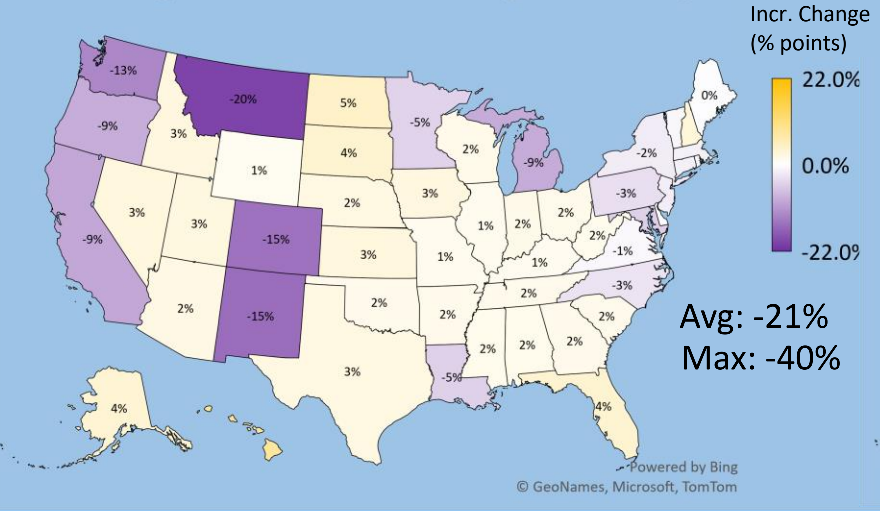
Change in 2026, *StateTargets vs. Reference*



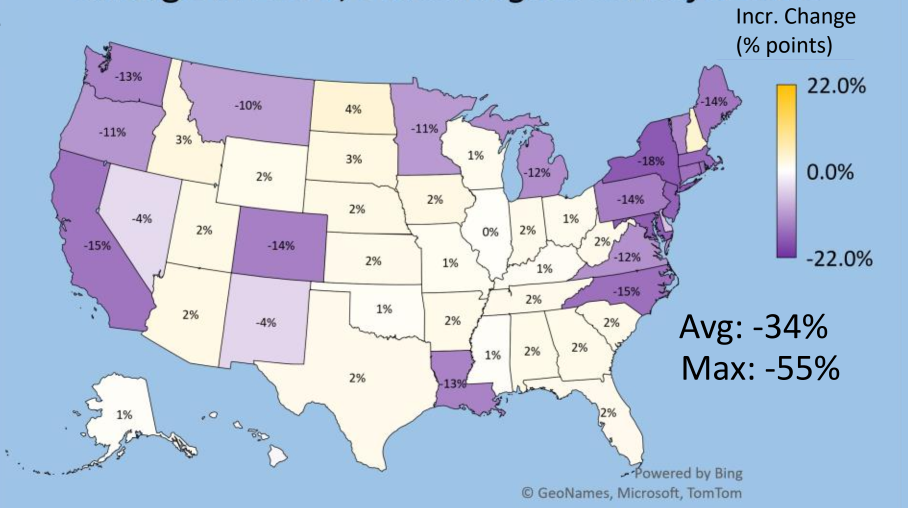
Change in 2028, *StateTargets vs. Reference*



Change in 2032, *StateTargets vs. Reference*



Change in 2050, *StateTargets vs. Reference*



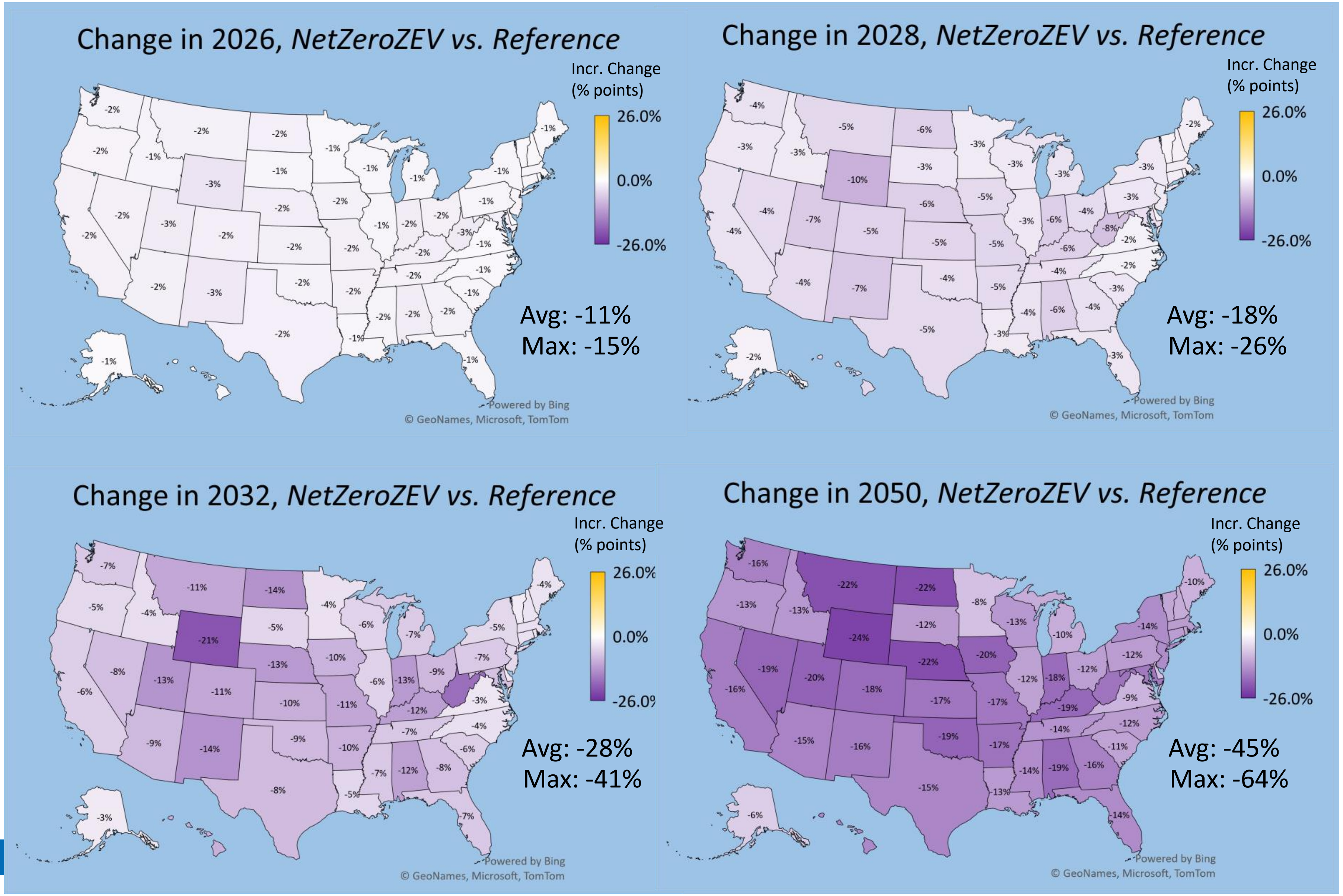
National NOx vs. 2023

Scenario	2026	2028	3032	2050
Reference	-9%	-14%	-21%	-30%
StateTargets	-10%	-14%	-21%	-34%

State-level NOx vs. 2023

	2026	2028	2032	2050
NY	-10%	-15%	-23%	-47%
NJ	-12%	-17%	-27%	-50%
PA	-10%	-14%	-24%	-47%
CT	-13%	-18%	-27%	-51%
OH	-10%	-14%	-21%	-38%
WV	-6%	-8%	-12%	-38%
VA	-11%	-16%	-25%	-45%
MD	-13%	-19%	-32%	-55%
MI	-10%	-17%	-29%	-44%
KY	-9%	-14%	-21%	-36%
IN	-8%	-12%	-18%	-33%
Other	-1%	-2%	-3%	-5%
Total	-6.4%	-9.3%	-15%	-28%

Additional NOx reductions from *NetZeroZEV*



National NOx vs. 2023

Scenario	2026	2028	3032	2050
Reference	-9%	-14%	-21%	-30%
StateTargets	-10%	-14%	-21%	-34%
NetZeroZEV	-11%	-18%	-28%	-44%

State-level NOx vs. 2023

	2026	2028	2032	2050
NY	-11%	-17%	-26%	-44%
NJ	-13%	-19%	-30%	-48%
PA	-11%	-17%	-27%	-45%
CT	-13%	-20%	-29%	-49%
OH	-12%	-19%	-31%	-52%
WV	-9%	-17%	-32%	-57%
VA	-12%	-18%	-28%	-43%
MD	-14%	-22%	-34%	-54%
MI	-10%	-17%	-27%	-42%
KY	-12%	-20%	-35%	-56%
IN	-11%	-19%	-32%	-53%
Other	-2%	-3%	-4%	-7%
Total	-6.9%	-11%	-17%	-28%

Linking GCAM to CMAQ

- Energy system models such as GCAM and chemical transport models such as CMAQ operate on very different spatial and temporal scales

GCAM…

  - spatial: global coverage, often with 32 "regions", where each region might be a single large country (US, China) or a collection of countries (Eastern Africa, Northern South America). We are using GCAM-USA, which uses the same 31 other global regions as GCAM, but the US is broken down into 50 states + DC.
  - temporal: 5-year time steps to around 2050

CMAQ…

  - spatial: typically continental US, 12km x 12 km grids, sometimes finer (4 km x 4 km) for a region like the Chesapeake Bay, or finer for an urban area
  - temporal: time steps of a few minutes, outputs typically hourly, simulations usually 1 year or less in duration

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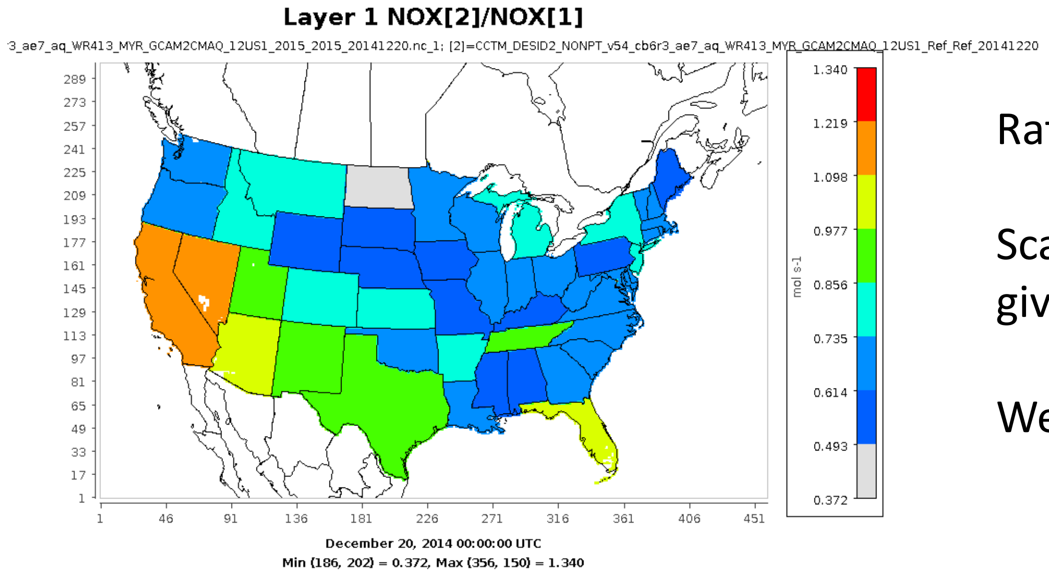
Procedure

- Employ new emissions module in CMAQ (Murphy et al., Geosci Model Dev 2021)
- Apply regional (state level) and sectoral scaling factors for NOx, SO2, primary PM25, VOCs, and NH3
  - applied to sources modeled by GCAM, i.e., those related to energy system. While GCAM has an ag sector, we are not linking changes in cropland simulated by GCAM to changes in fertilizer application



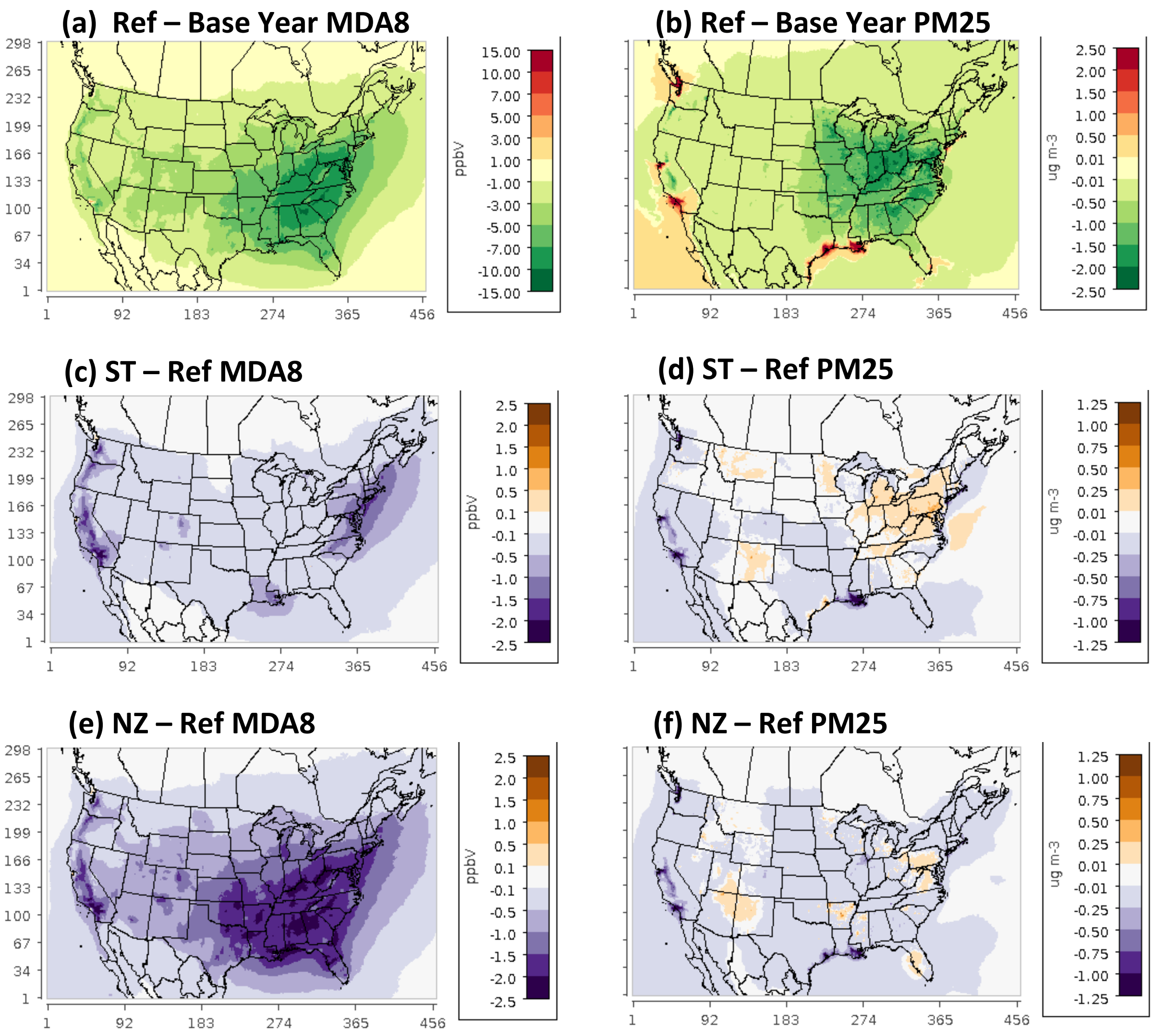
Ratio of NOx NONPT (area) emissions, Ref2050 to 2015.

Scaling factors follow state boundaries, as specified via instructions given to CMAQ based on GCAM simulations

We are applying scaling factors like this for 11 emissions sectors

CMAQ MDA8* and $PM_{2.5}$ Concentration Changes from 2015

MDA8 May-Sept Avg | $PM_{2.5}$ Annual Avg



Panels a, b: *Reference* – Base Year

Panels c, d: *StateTargets* – *Reference*

Panels e, f: *NetZeroZEV* - *Reference*

Maximum Co-benefit -3.8 ppb

Maximum Co-benefit -14.1 μg/m³

Maximum Co-benefit -4.1 ppb

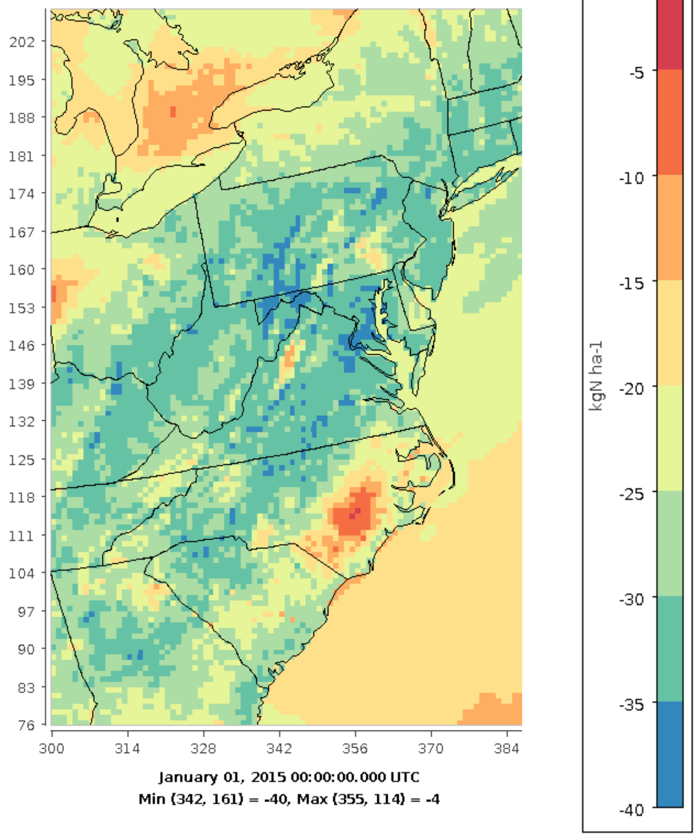
Maximum Co-benefit -9.0 μg/m³

*MDA8: Maximum Daily 8-Hour Average Ozone

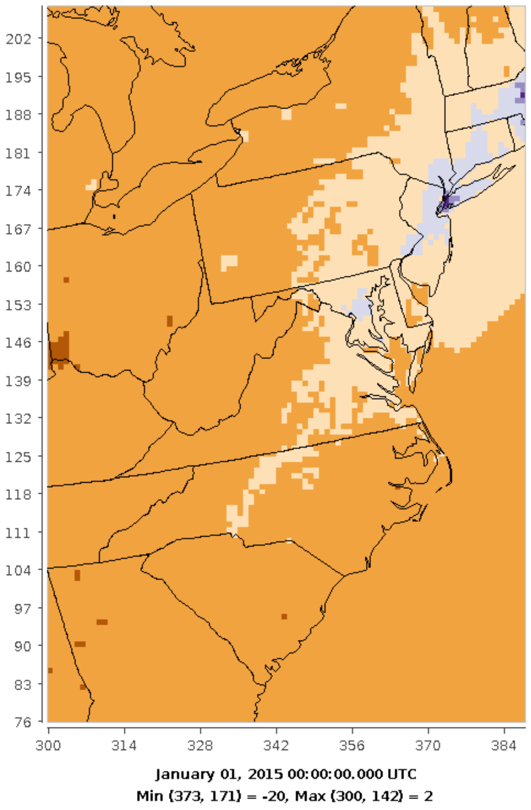
Relative Changes in total N Deposition

Note: these are all relative differences, in percent. Ignore the kg N ha^{-1} label on the legend!

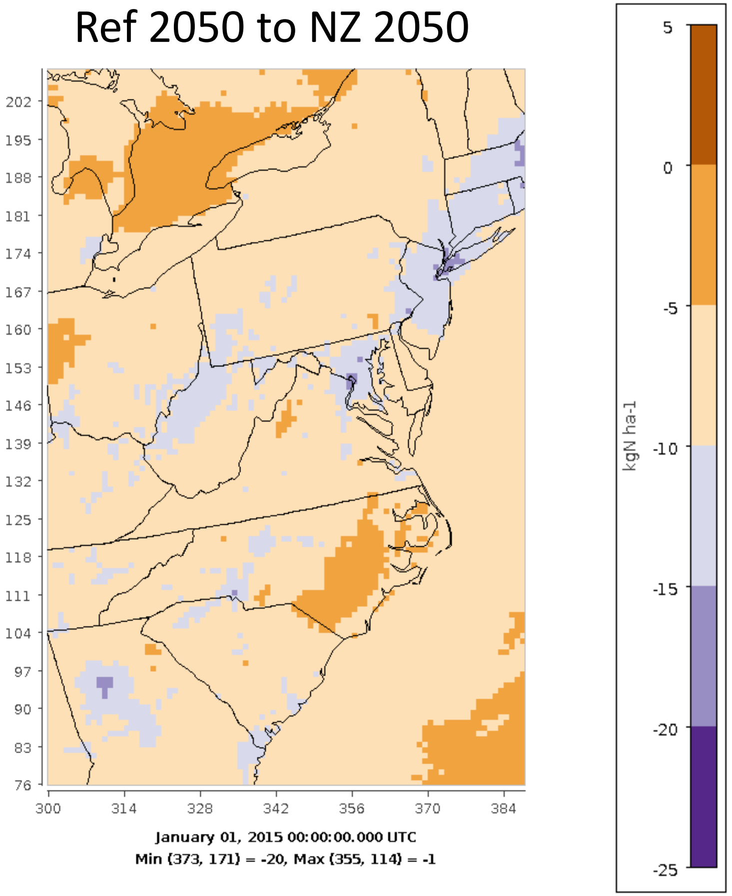
2015 to Ref 2050



Ref 2050 to ST 2050



Ref 2050 to NZ 2050



A few further details…

- All simulations used 2015 meteorology
- Future simulations used GCAM projections for 2050.
  - Plan to focus on 2035 for next set of simulations conducted specifically for Chesapeake Bay program
- These simulations used CMAQ's M3DRY deposition option
  - Plan to use STAGE for next set of runs; among other differences, separately calculates deposition to different landuse categories within a grid cell

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Discussion

GCAM-to-CMAQ Emission Sector Mapping

GCAM Source Categories

- ptegu
- oilgas
- rwc
- air
- marine
- biomass
- ptnonipm
- nonpt
- onroad
- rail
- other

Eleven GCAM source categories are mapped to CMAQ emission streams and scaled:

1. Point non-biomass electricity generating utilities (**ptegu**)
2. Point non-EGU industrial sources including biomass electricity generation (**ptnonipm**)
3. Oil and gas sources, including refinery and pipeline emissions with national-average scaling (**oilgas**)
4. Area sources including residential and commercial building energy use, and regional biomass production for energy and biodiesel feedstocks (**nonpt**)
5. Residential wood combustion (**rwc**)
6. Onroad diesel vehicles (**onroad**)
7. Onroad gasoline vehicles (**onroad**)
8. Passenger and freight rail (**rail**)
9. Airports (**air**)
10. Commercial marine vessels, classes 1 and 2, for domestic shipping (**marine**)
11. Commercial marine vessels, class 3, for international shipping (**marine**)

GCAM also tracks emissions in **biomass** from biomass and biofuel use, and in **other** from Direct Air Capture and other sources not listed above