Modeling the Air Quality Impacts of Future Energy Scenarios

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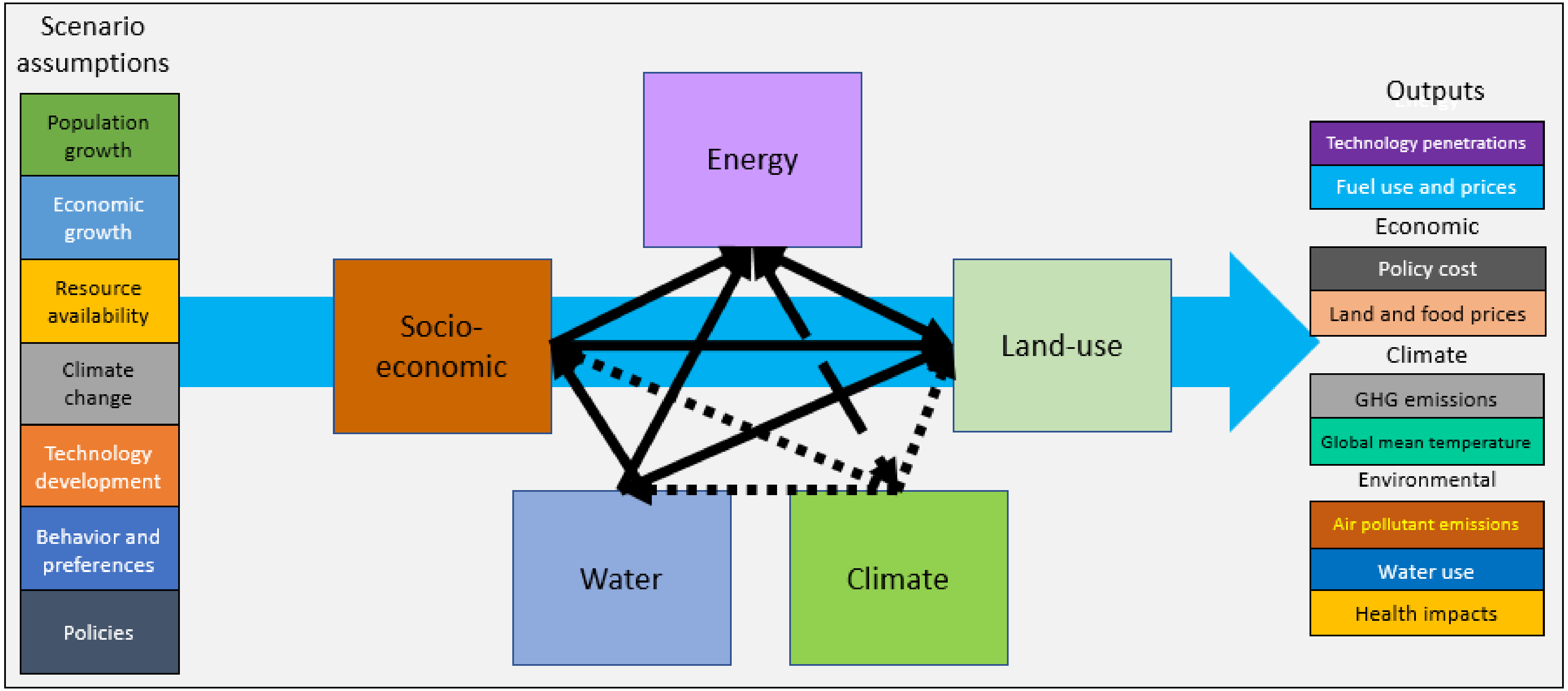
Motivation

- State and regional air quality (AQ) managers must demonstrate compliance with the NAAQS for O_3, PM, NO_x, etc., on an ongoing basis
- Many states have adopted comprehensive greenhouse gas (GHG) mitigation targets to reduce the impacts of climate change
  - Options such as renewable electricity and energy efficiency may offer AQ co-benefits
- The Global Change Analysis Model (GCAM)* can produce scenario-, state-, technology-, and pollutant-specific air pollutant emission projections
- Research objective:

Link GCAM to a comprehensive AQ model to quantify the AQ co-benefits of specific GHG mitigation strategies

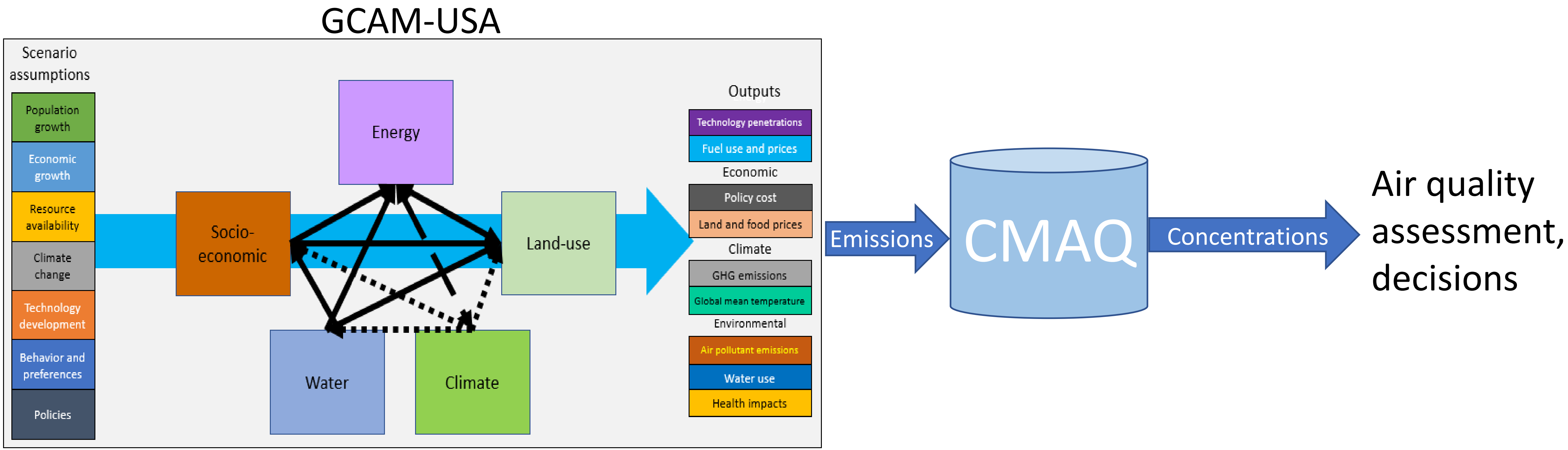
GCAM-USA



GCAM 5.4 Documentation: *https://jgcri.github.io/gcam-doc/*

Developer: PNNL
Availability: Open Source, free
Platforms: Windows, Mac, Linux
Run-time: 1-5 hours
Spatial coverage: global
Spatial resolution: 31 global regions + 50 US states
Temporal range: 2010 - 2100
Temporal resolution: 5-years
Emissions:
GHGs: CO_2, CH_4, N_2O
Air pollutants: NO_x, SO_2, VOC, PM, CO, NH_3

Estimating air quality impacts

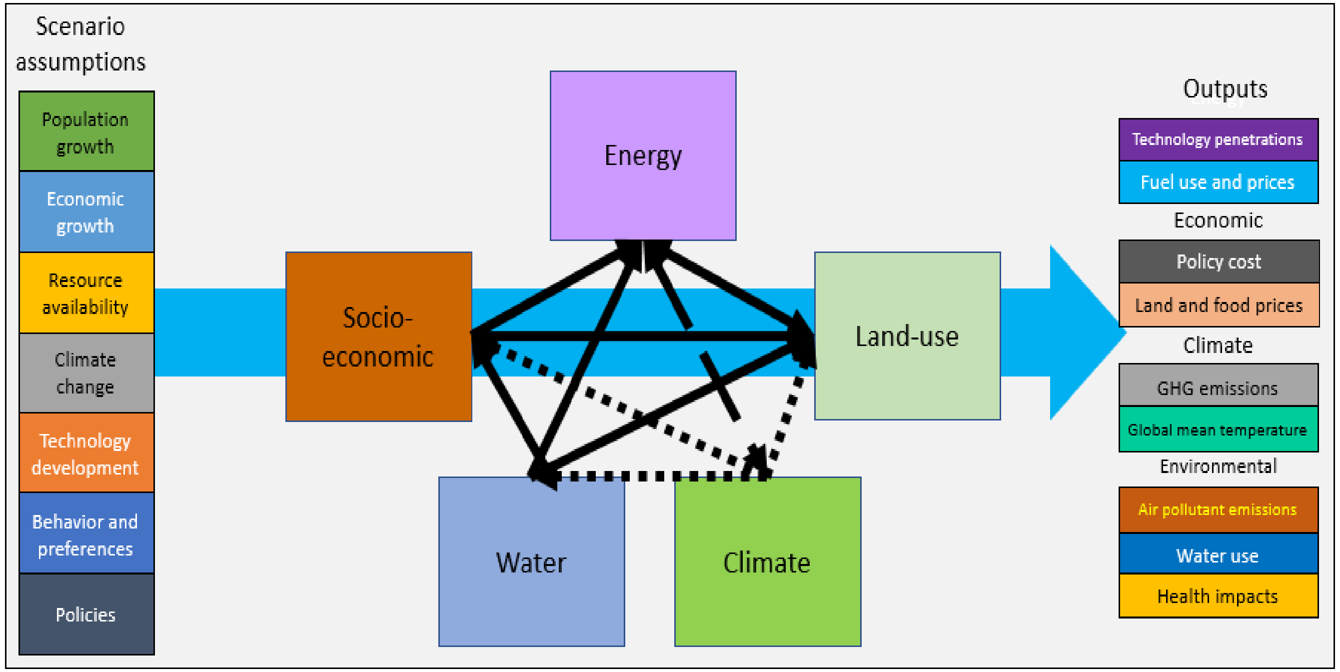


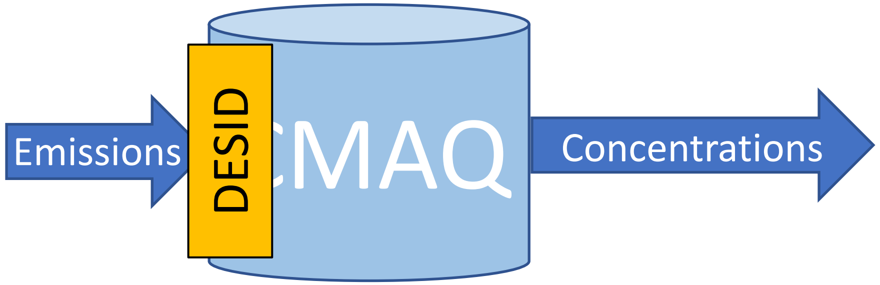
Challenge:

Translating GCAM-projected emissions into hourly CMAQ inputs

Estimating air quality impacts

GCAM-USA





Approach:

Develop state-, sector-, pollutant-specific growth factors using GCAM

Use them in CMAQ DESID module to scale emissions to future

CMAQ DESID* Module

- DESID: Detailed Emission Processing, Scaling, Isolation and Diagnostic module
- Developed to scale emissions in CMAQ by region, sector, and pollutant
- Advantages
  - Avoids the emissions overhead for the sectors and scenarios simulated
  - A flexible and efficient way to ingest projected emissions from energy system and integrated assessment models and analyze their impacts

* Murphy, B. et al., GMD, 2021

Illustrative Application

- Two scenarios were run in GCAM-USA v5.2
  - **ref50:** a reference case through 2050 that reflects current legislation
  - **80x50:** a mitigation scenario requiring 80% reduction in CO_2 emissions from 2010 to 2050
- Emissions for CMAQ base year (2015 – **baseyr)** are from the EQUATES* project
- GCAM emissions were aggregated to the existing EQUATES categories
  - Most GCAM emission categories could be mapped to the EQUATES categories
  - GCAM provides only national outputs for oil and gas operations, so those growth factors were applied to all states in DESID and aggregated in 'oilgas' sector
    - Included refinery emissions

*__E__PA's Air __Qua__lity __T__ime __S__eries Project, presentation 2588 by K. Foley in the Multiscale Model Applications and Evaluations session

GCAM-to-CMAQ Sector Mapping

GCAM Source Sector		CMAQ Emissions Stream
Electricity generation from all non-biomass fuels	→	ptegu
Electricity generation from biomass Gasification, coal-to-liquids, and biomass-to-liquids Industrial energy use and feedstocks Cement, fertilizer, and H_2 production	→	ptnonipm
Unconventional oil production, oil refining, gas pipelines	→	oilgas
All commercial and residential sectors except residential wood heating Regional biomass production for bioenergy and biofuels	→	nonpt
Residential wood heating	→	rwc
Onroad heavy-duty freight vehicle	→	onroad_diesel
Onroad light-duty vehicles and buses	→	onroad_gas
Domestic and international aviation	→	airports (LTO only)
Nonroad passenger and freight rail transport	→	rail
Domestic shipping	→	pt_cmv_c1c2_12
International shipping	→	pt_cmv_c3_12

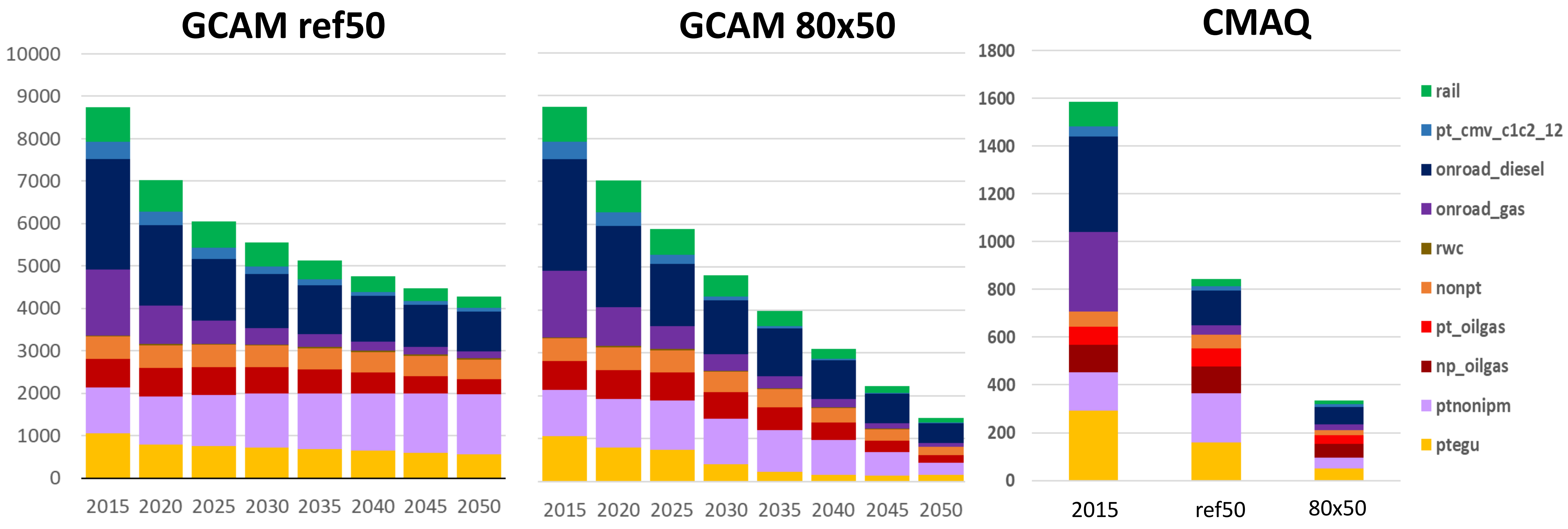
Methods: Bridging GCAM and CMAQ

- An R script was developed to link GLIMPSE output files to DESID
  - Calculates scaling factors using GCAM emissions from the base year and each 2050 scenario
  - Generates the CMAQ Emissions Control name list file including the list of emission scaling rules for each emissions stream, region and pollutant
    - SF = GCAM future-year (FY) emissions ÷ GCAM base-year (BY) emissions
    - CMAQ Emissions_{FY} = SF x CMAQ Emissions_{BY}
- CMAQ emission surrogate species from R Script:
  - CO, NOX, VOC, NH3, SO2, PM25 and PMC
  - VOC, PM25 emissions further speciated in chemical family definitions:
    - 20 VOC species
    - 18 primary $PM_{2.5}$ components

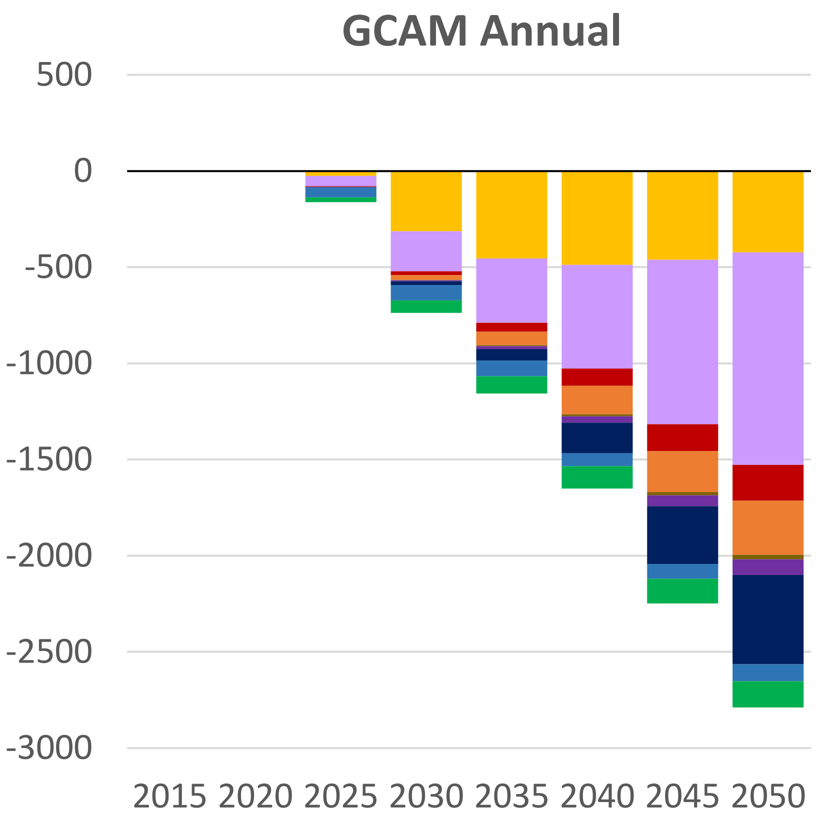
Methods: CMAQ Simulations

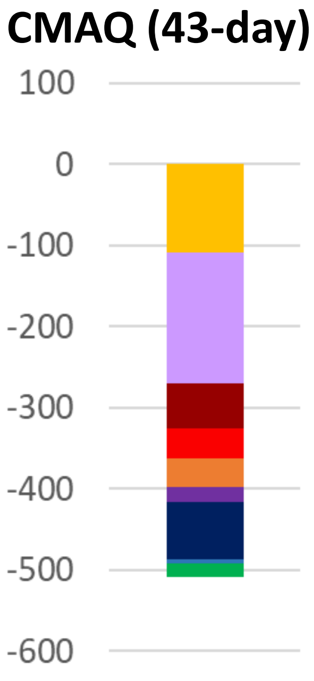
- All inputs (met, icbc, emissions and surface) **except the Emiss_Ctrl files** for the 2050 scenarios are from the EQUATES 2015_12US1 (CONUS 12-km resolution)
  - cb6r3_ae7_aq chemical mechanism
  - STAGE dry deposition scheme
  - Inline biogenic, sea spray, lightning NO_x
- NH_3 and Hg bi-di flux models and MOSAIC (land use-specific deposition velocities) turned off since fertilizer emissions are not projected to 2050
- **baseyr, ref50 and 80x50 time slice simulations for June 20 – July 31**

Total Sector NO_x Emissions (kT) in GCAM and CMAQ



Sector NO_x Emissions Reductions (kT): 80x50 – ref50





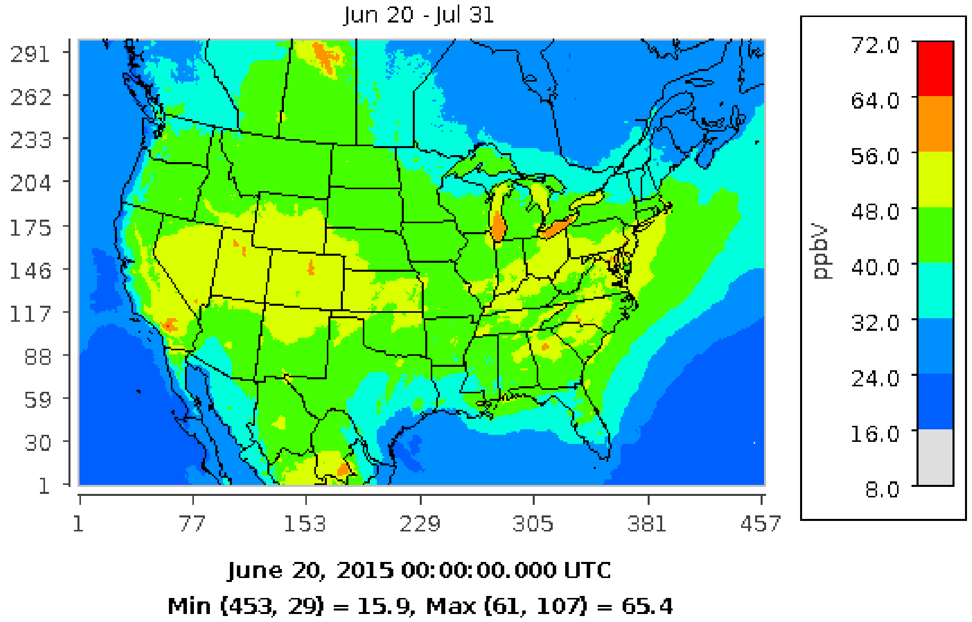
80x50 minus ref50 (%)

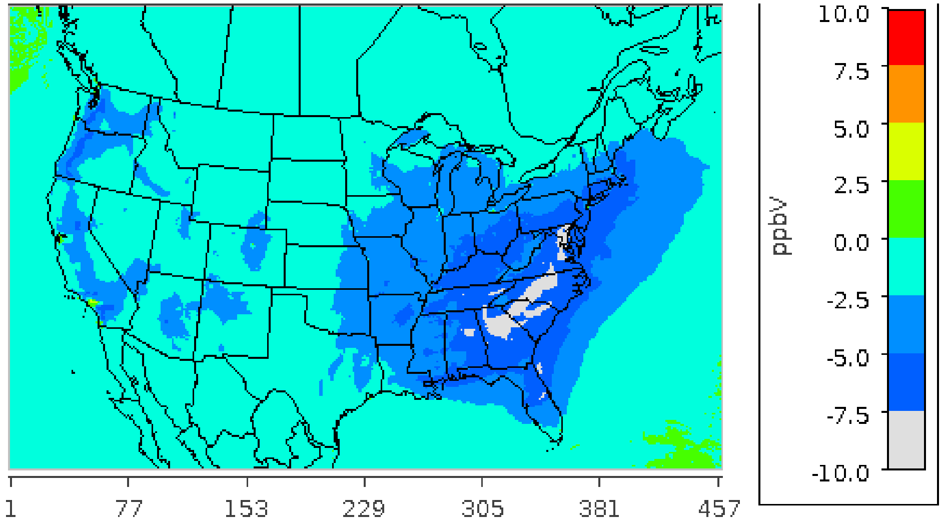
	GCAM	CMAQ
ptegu	-75	-69
ptnonipm	-79	-78
np_oilgas	-51	-50
pt_oilgas	-51	-50
nonpt	-61	-62
rwc	-86	-84
onroad_gas	-48	-44
onroad_diesel	-50	-49
pt_cmv_c1c2_12	-33	-34
rail	-55	-53

CMAQ NO_x emissions reductions using the DESID scaling approach for 2050 compare well with GCAM (diff of 1% - 6%)

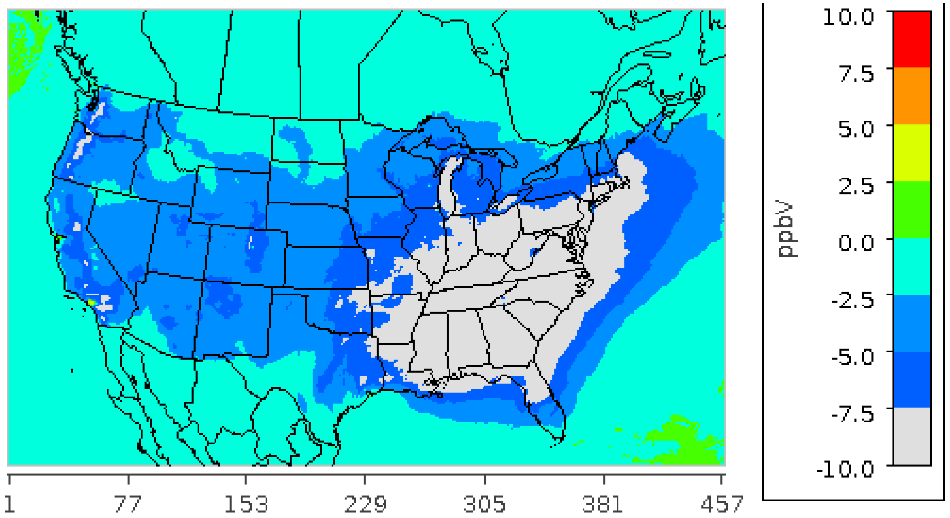
Average MDA8 and Differences from Base Year

Average MDA8: baseyr





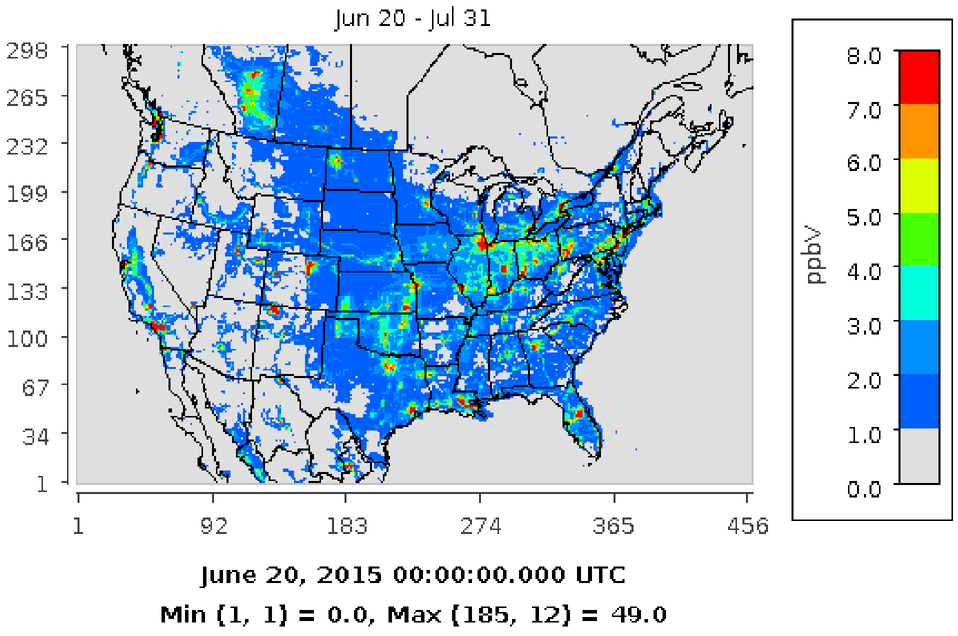
ref50 - baseyr
min = -10.6 ppb

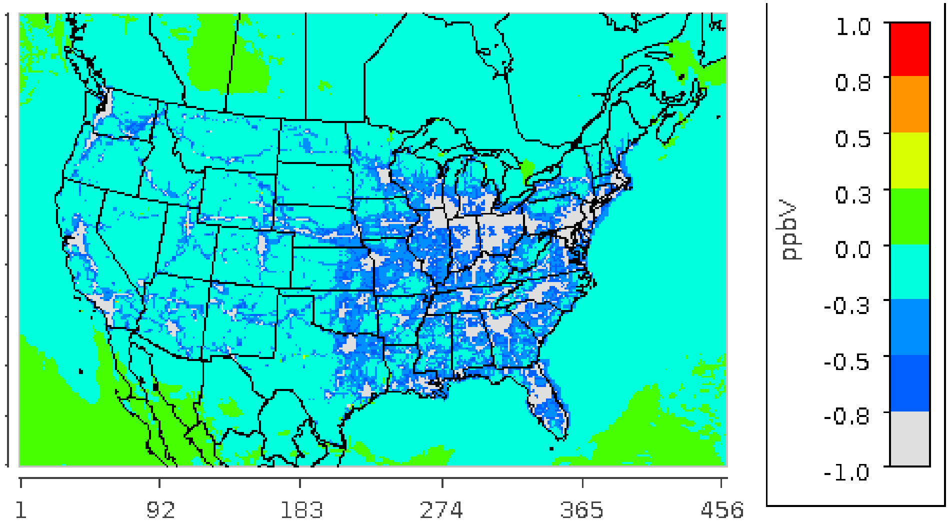


80x50 – baseyr
min = -18.6 ppb

Average NO_x and Differences from Base Year

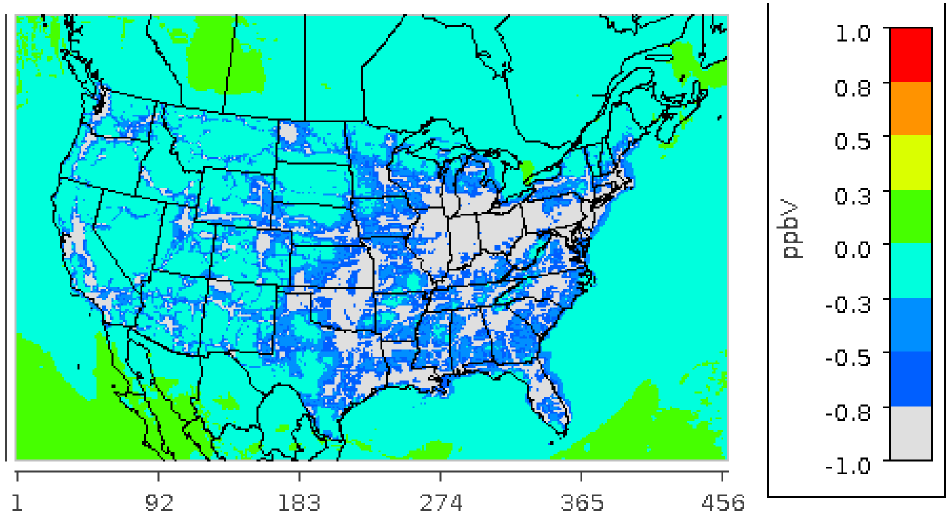
Average NO_x: baseyr





ref50 – baseyr

min = -20.2 ppb

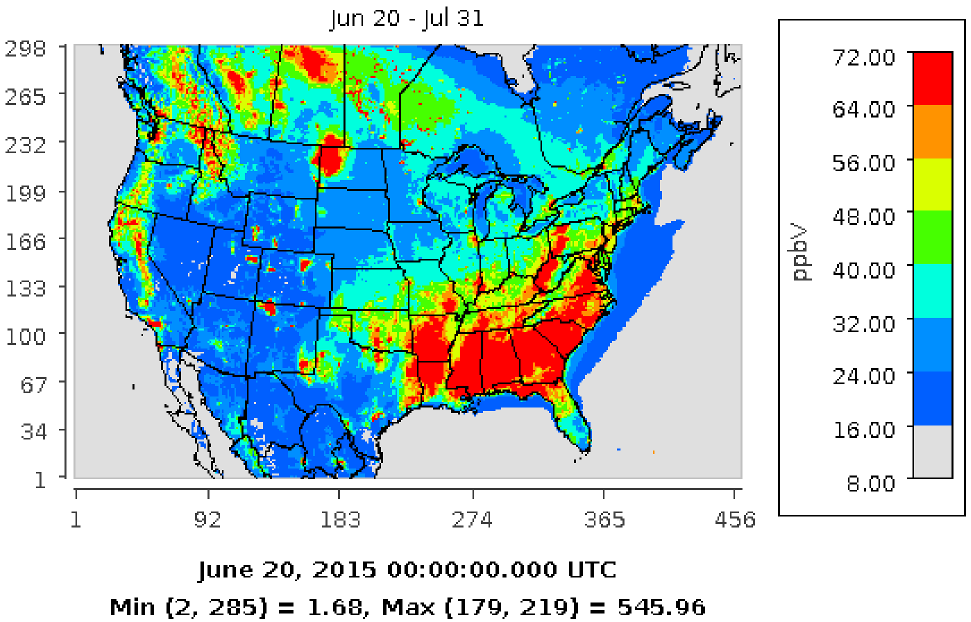


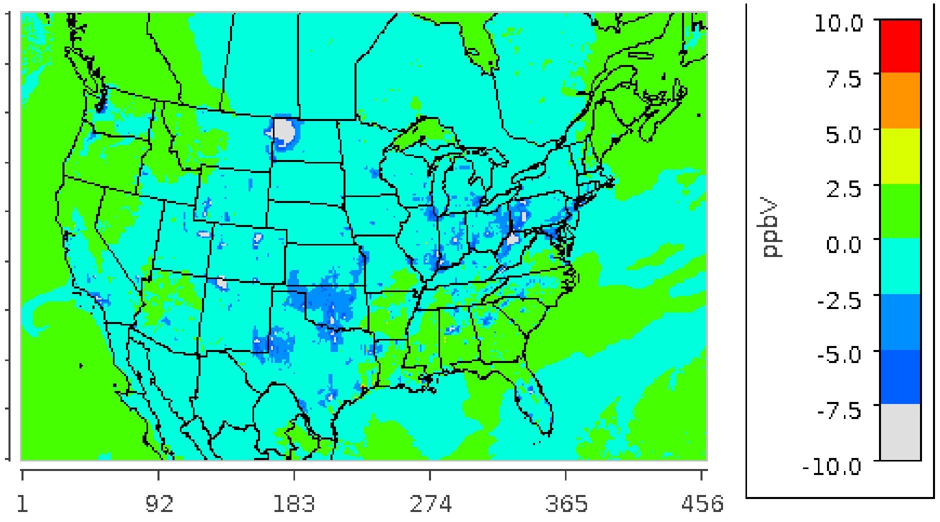
80x50 – baseyr

min = -26.5 ppb

Average VOC and Differences from Base Year

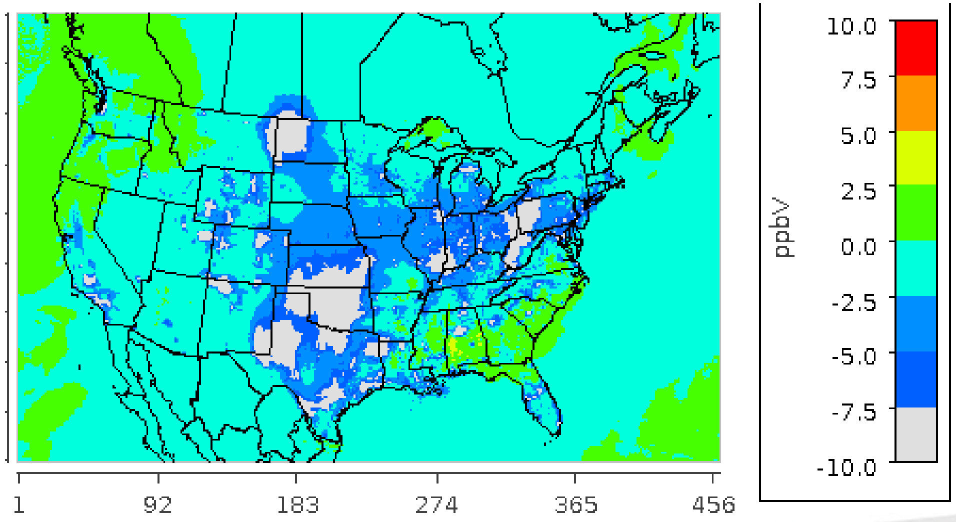
Average VOC: baseyr





ref50 – baseyr

min = -76.6 ppbC



80x50 – baseyr

min = -349.3 ppbC

Preliminary Findings

- NO_x emissions for 2050 are lower in 80x50 than in ref50 (all sectors, both models)
- NO_x and VOC emissions are greater in ref50 in 2050 than in 2015 for
  - **ptnonipm** in every state
  - **ptegu** in VT
  - **rwc** in CA, CO and the New England states
- Differences between GCAM and CMAQ in the 80x50 – ref50 sector NO_x emissions are relatively small (up to 6% in ptegu) given differences in:
  - model formulations
  - base year emissions and the aggregation of their source categories
  - aggregation periods for the results (annual in GCAM vs. 43 days in CMAQ) and intra-annual variability in emissions
- This lends support to the scaled emissions approach
- Ozone air quality shows *improvement* over the base year
  - max decrease in average MDA8 of 18.4 ppb in 80x50 compared to 10.6 ppb in ref50
  - mostly over the eastern US, agrees well with spatial pattern of NO_x, rather than VOC decreases

Next Steps

- Next set of simulations will extend the 6-week runs to annual.
- $PM_{2.5}$ will be analyzed in greater detail.
  - Technology switching to CCS in coal-powered EGUs in the 80x50 scenario does appear to have consequences for ptegu $PM_{2.5}$ over all states but needs to be analyzed further.
  - ptegu emissions of $PM_{2.5}$ increase dramatically in the 80x50 case relative to base year and to the ref50 case.
- Future work will also analyze the AQ impacts of targeted CO_2 reduction scenarios in GCAM (e.g., increased electric vehicle use, renewable energy portfolio standards).

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