Thoughts on Air Quality and Climate

S. Koplitz, J. Kelly, C. Jang, K. Baker, B. Henderson, H. Simon, S. Phillips, C. Misenis, N. Possiel, T. Fox

Overview

- Update on 5th National Climate Assessment and Other Climate Efforts

- Overview of Air Quality-Climate Relevance for OAQPS Programs/Activities

- Presentation and Discussion of Potential Screening Tools

- Leveraging AQAD Capabilities for Air Quality-Climate Applications

National Climate Assessment

- The Global Change Research Act of 1990 mandates that U.S. Global Change Research Program (USGCRP) produces a report for Congress and the President at least every four years that:

"…analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and…analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years."

- 4th National Climate Assessment (NCA4) published in 2018

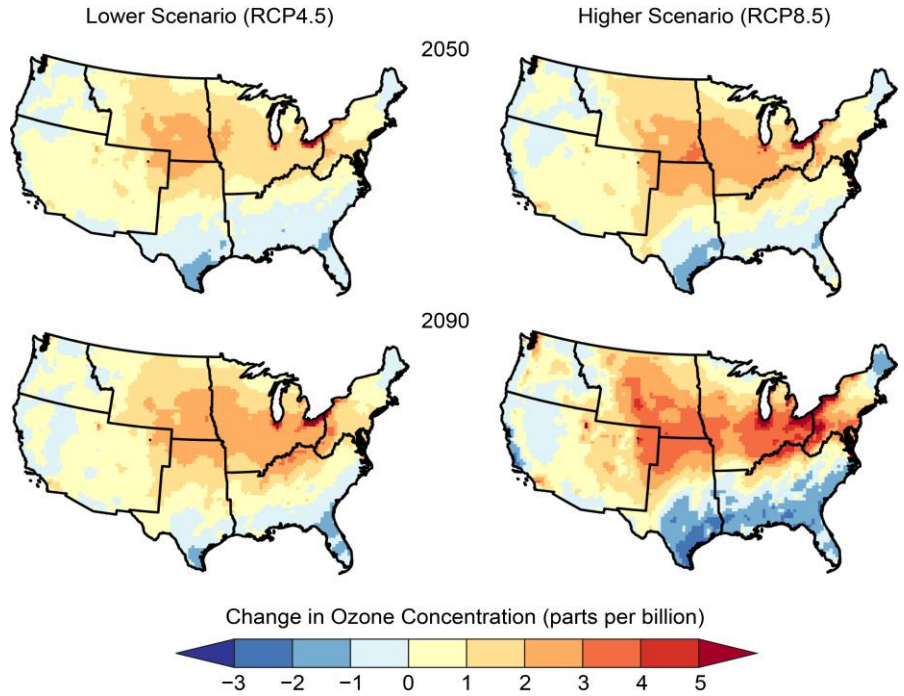
- Chris Nolte (ORD) was coordinating lead author for the Air Quality Chapter, which included sections on:

1. Air Pollution
2. Wildfires
3. Airborne Allergens
4. Co-benefits of Mitigation

- Chapter Authors from EPA:

Pat Dolwick (AQAD at the time), Neal Fann (HEID), Rob Pinder (HEID), Tanya Spero (ORD), Darrell Winner (ORD)

Projected Changes in Summer Season Ozone



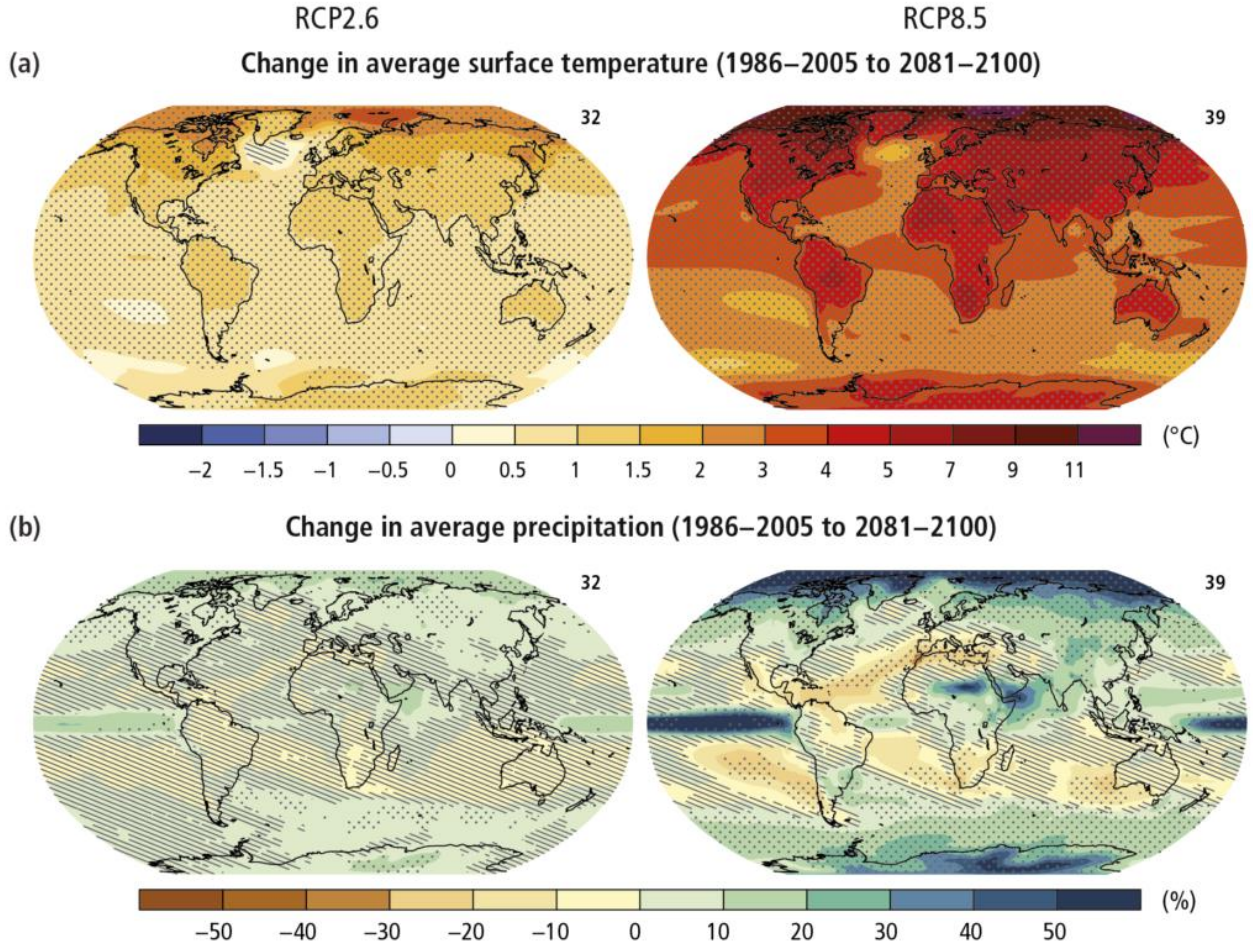
NCA4, Air Quality Chapter

Intergovernmental Panel on Climate Change (IPCC)

- Intergovernmental body jointly established by the World Meteorological Organization and the United Nations for assessing the state of climate change science

- Identifies areas of consensus in the scientific community related to:
  1. Physical science basis
  2. Impacts, adaptation and vulnerability
  3. Mitigation

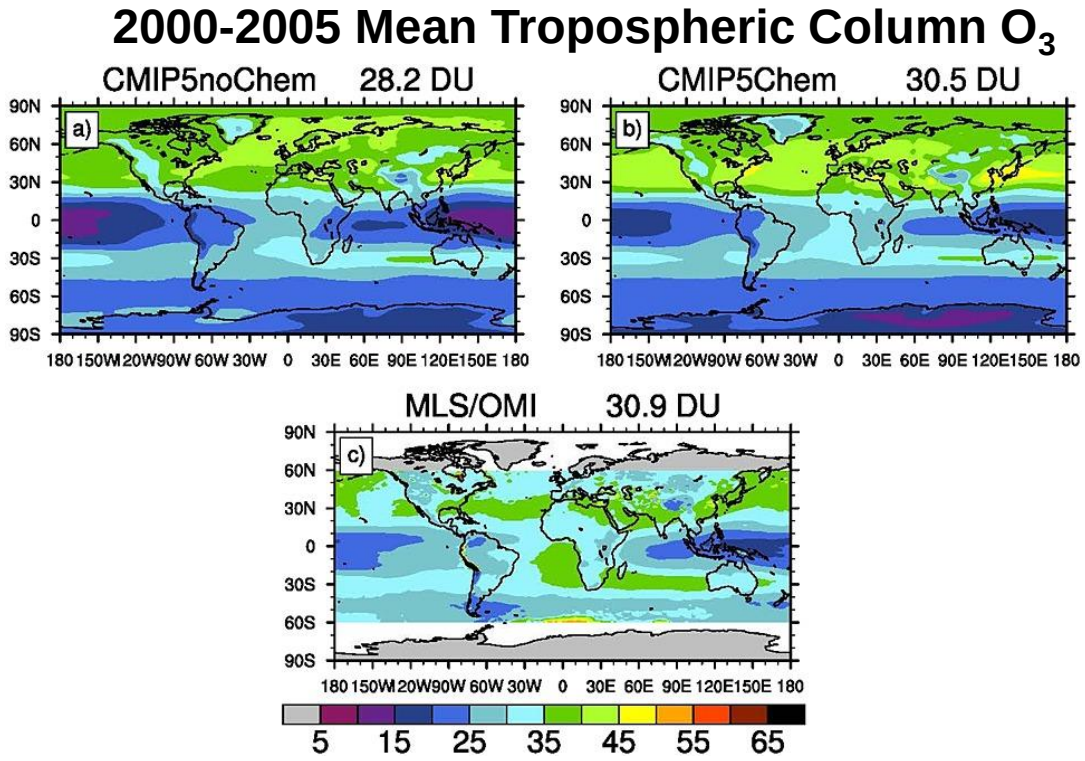
- Fifth Assessment Report (AR5) finalized in 2014



IPCC AR5

Coupled Model Intercomparison Project (CMIP)

- Suite of modeling experiments with standardized inputs designed to evaluate and compare across an ensemble of over 20 different global climate models from around the world, including groups at NASA and NCAR
- CMIP5 simulations completed in 2013 for use in the IPCC AR5
- Datasets are available publicly for download



Eyring et al., 2013

Updates to National/Global Climate Efforts

5th National Climate Assessment

- Currently undergoing chapter lead author selection for the 5th National Climate Assessment (selections expected by ~March 2021)

- OAQPS representatives: Shannon Koplitz (AQAD)*, Neal Fann (HEID), Rob Pinder (HEID)
  * role previously held by Pat Dolwick

IPCC AR6

- Working Group reports expected to be released throughout 2021: WG1 (Physical Science Basis) in April 2021; WG2 (Impacts, Adaptation and Vulnerability) in October 2021; WG3 (Mitigation of Climate Change) in September 2021

- Synthesis Report expected in early 2022

CMIP6

- Ongoing, in support of IPCC AR6

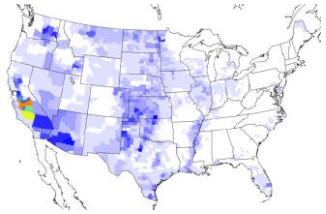
- Model simulation output being released to the public as available

Climate in OAQPS/AQAD Activities

- Within OAQPS, AQAD provides foundational technical expertise through emissions development, air quality modeling, monitoring, and data analysis to inform assessments of how pollutant distributions respond to and interact with changes in greenhouse gases and associated changes in climate

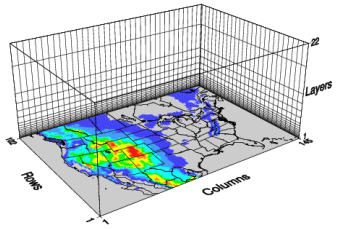
- AQAD's depth and range of technical expertise also provides opportunities to identify intersections between climate and other EPA priority action areas, e.g. Environmental Justice

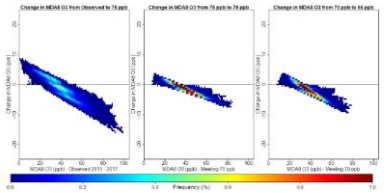
Emissions



Measurements and Monitoring

Air Quality Modeling





Data Analysis

"Projecting future climate and air quality impacts from changing emissions requires models, but their credibility is rooted in the ability to diagnose, interpret, and evaluate properly their process-level representation with high-quality measurements."

-Fiore et al., 2015

Climate in OAQPS/AQAD Activities: Examples

- **Regulatory Impact Analyses (RIAs)**
  - AQAD has extensive experience developing technical analyses for RIAs to quantify the air pollution impacts of rulemakings which target GHG emissions including:
    - Affordable Clean Energy (ACE) rule (H. Simon, AQMG Lead)
    - OTAQ GHG rules such as Light and Heavy-Duty Vehicles (S. Phillips, AQMG lead)
  - How do considerations of climate impacts and vulnerabilities affect cost-benefit estimates? Are there hidden co-/dis-benefits associated with specific rules or policies that emerge when considering AQ-Climate interactions, or more broadly AQ-Climate-EJ?

- **NAAQS Reviews & Implementation**
  - AQAD routinely combines air quality modeling with available monitoring data to develop future air quality projections based on changes in emissions (J. Kelly, AQMG lead for $PM_{2.5}$; H. Simon, AQMG lead for Ozone)
  - How can we account for climate when projecting future air quality? How well characterized are DV predictions by EPA and others when projected with a single meteorological year? How are contributions from natural and international sources expected to change in a future climate?

- **Exceptional Events/179B Demonstrations**
  - AQAD provides technical guidance and also conducts air quality modeling assessments of wildfire smoke (K. Baker, AQMG lead) and international pollutant transport (B. Henderson, AQMG lead)
  - How will wildfire smoke and international pollutant transport vary under future climate? How will the frequency of extreme events change? How do short-lived climate forcers (e.g. black carbon, methane) affect both climate and transported ozone?

Climate in OAQPS/AQAD Activities: Examples (cont.)

- **Regional Haze Program**
  - AQAD (EIAG/AQMG) performed extensive air quality modeling and data analysis to assess progress on Regional Haze at individual Class I areas and assist state in their SIP efforts.
  - Reductions to achieve program goals have focused mainly on aerosol species with large optical influence (e.g., sulfate), how have these changes impacted national/regional/local energy budgets?

- **State Implementation Plans (SIPs)**
  - AQAD actively engages with Regions and State/local/tribal air agencies to provide updated technical guidance and offer technical expertise on SIPs and attainment demonstrations
  - What is EPA guidance for inclusion of future climate change effects in SIPs? What is the relative influence of climate change vs. year-to-year variability in meteorology?

- **Met Adjusted Ozone Trends**
  - AQAD (B. Wells AQAG lead) leads work to statistically characterize the major meteorological drivers of ozone variability by region and use this information to produce a historical dataset of met-adjusted trends in seasonal mean and peak ozone concentrations
  - How will these relationships between meteorology and ozone change under future climate change?

Climate in OAQPS/AQAD Activities: Examples (cont.)

- **Emission Inventories**
  - AQAD/EIAG leads the development and publication of the National Emission Inventory, which includes accounting of point source GHGs and well as short-lived pollutants (i.e. relatively short atmospheric lifetimes compared to CO_2) with climate forcing potential: e.g. black carbon, other aerosol precursors, ozone precursors
  - How can the characterization of black carbon and other $PM_{2.5}$ components be improved? How will spatial patterns of short-term climate forcers change in response to national energy system/climate policies and how will that impact air quality? How will these changes impact regional climate?

- **Trends Reports**
  - AQAD/AQAG leads the development and publication of the annual Trends Report, demonstrating the progress achieved through national air quality policy and regulation relative to the historical baseline
  - How have long-term changes in air pollution levels affected local/regional/national energy balances? e.g., are long-term reductions in U.S. NO_x warming or cooling for the global atmosphere?

Climate Vulnerability

"Vulnerability is the susceptibility to the adverse effects of climate change, including both climate variability and extremes. Vulnerability measures the intersection of exposure, sensitivity to harm, and capacity to adapt to change. " - NRDC Report; Turner et al 2003

1. What populations are particularly vulnerable to the projected **effects of climate change**?

2. Where is climate change vulnerability likely to increase **baseline susceptibility to air pollution**?

3. How might these vulnerabilities intersect with vulnerabilities **relevant for EJ issues**?

How can we identify/consider **compounding vulnerabilities** in communities likely to simultaneously experience air pollution, Environmental Justice, and climate issues?

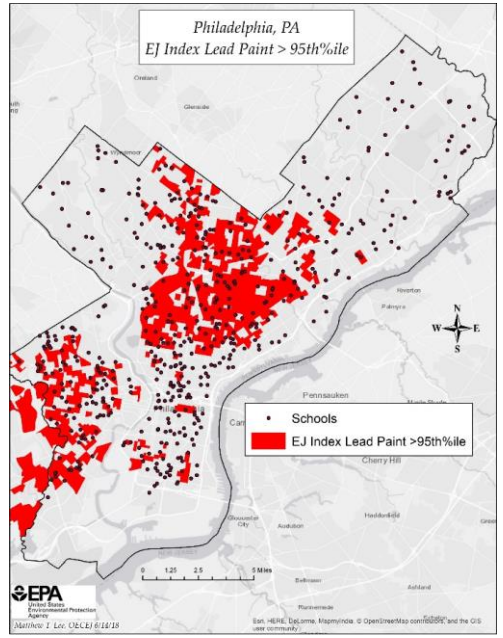
Data Driven Screening Tools

- Data driven EJ screening tools either exist (i.e., EJ Screen/OEJ) or are in development (i.e., NEXUS, C. Jang/AQMG)
  - Biden EO specifies “the development of a Climate and Environmental Justice Screening Tool, building off EPA’s EJSCREEN, to identify disadvantaged communities, support the Justice40 Initiative, and inform equitable decision making across the federal government”

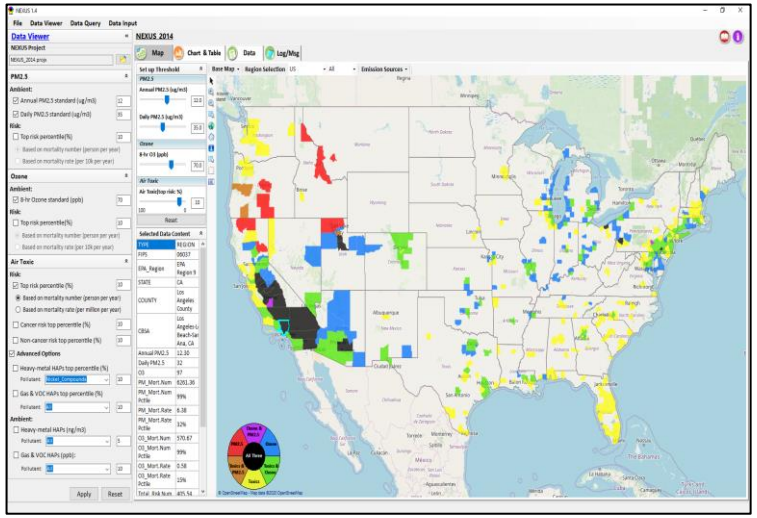
- AQAD can assist in the effort to enhance these tools to reflect climate vulnerability thereby allowing for development of strategies and programs seeking to protect public and environmental health in areas with elevated risk for climate change impacts by identifying compounding vulnerabilities across the Climate-EJ space
  - Addition of policy-relevant data layers / new indices
  - Enhanced proximity analysis capabilities

- Geographically explicit screening tools also help connect across scales, e.g., characterizing impacts of national climate strategies at the local/community level

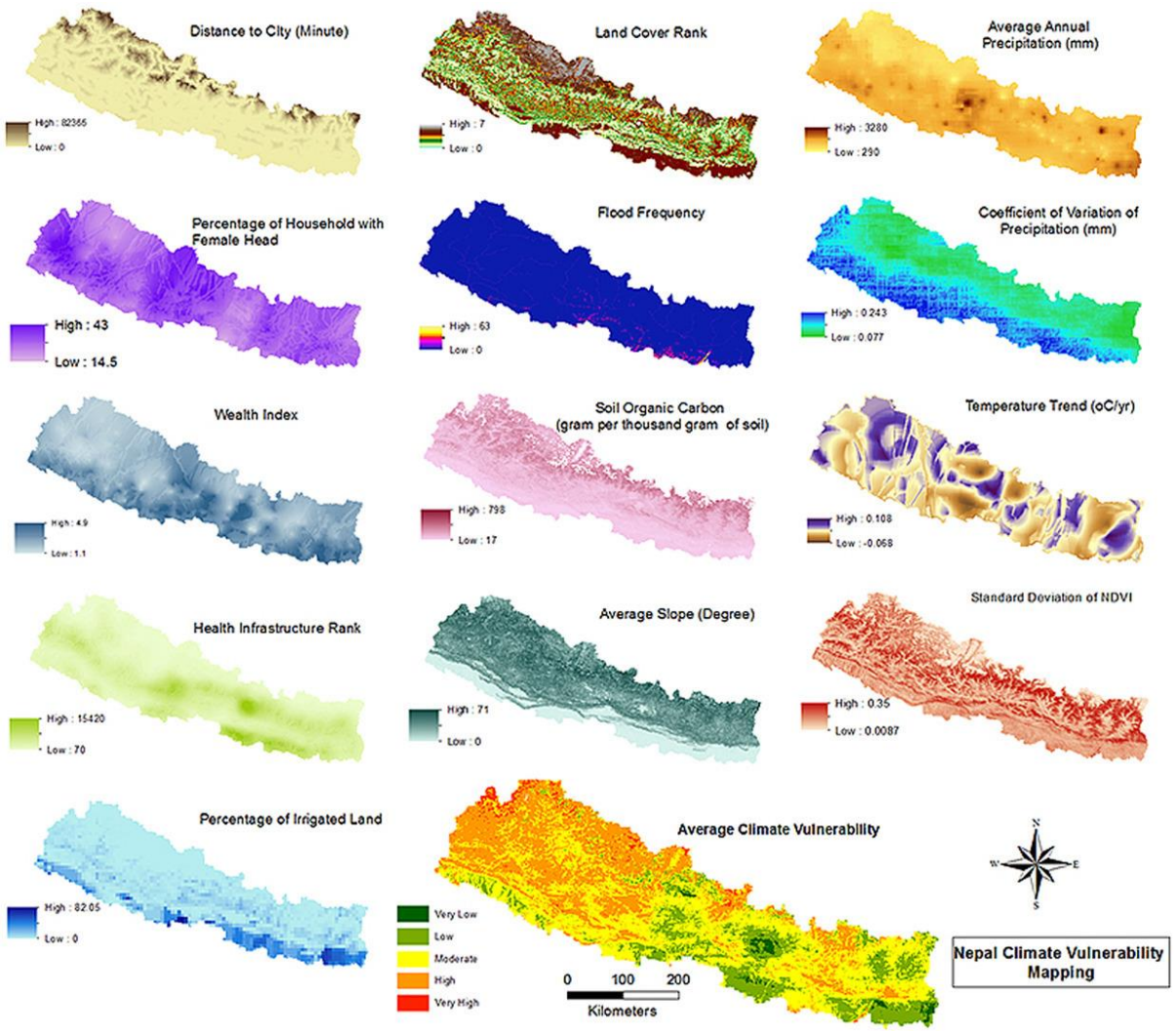
EJ Screen (OEJ)



NEXUS Tool (slide from C. Jang)



Elements of Climate Vulnerability



Mainali and Pricope 2017

- Components of climate vulnerability include environmental, physical, social, and economic factors (United Nations 2004 Report)
- We can begin to characterize environmental and physical vulnerability with existing data sets and modeling tools
- Many components contributing to underlying vulnerability are not explicitly tied to specific areas or environmental factors, but rather are intrinsic to broader socio-economic systems (e.g. food security, income and education, etc)
- Opportunities for collaboration with HEID, ORD, OAP, and other partners with expertise in identifying and incorporating these elements of climate vulnerability
- Potential overlap with EJ vulnerabilities

Geospatial Components of Climate Vulnerability

Geographic/Demographic Indicators

- Low-lying/coastal
- High elevation
- Dense Urban
- Extremely rural

Image credit: Associated Press

Environmental Indicators*

- Wildfire smoke prevalence
- Precipitation (high and low)
- Temperature stress (hot and cold)
- Changes in meteorology (T, Precip, etc)

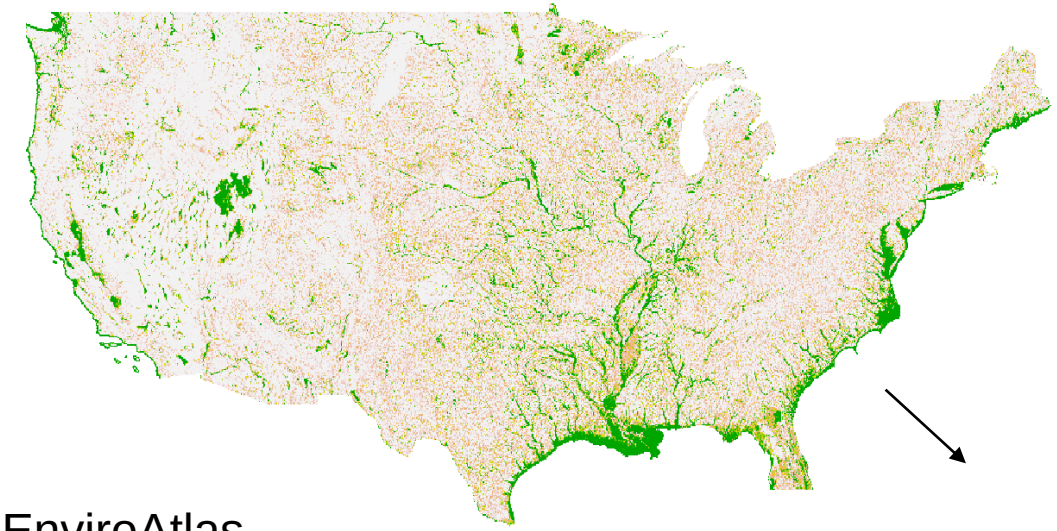
Image credit: cdc.gov

* These types of layers can be difficult to quantify directly without additional tools, e.g. meteorological or air quality models

References: IPCC, NCA4

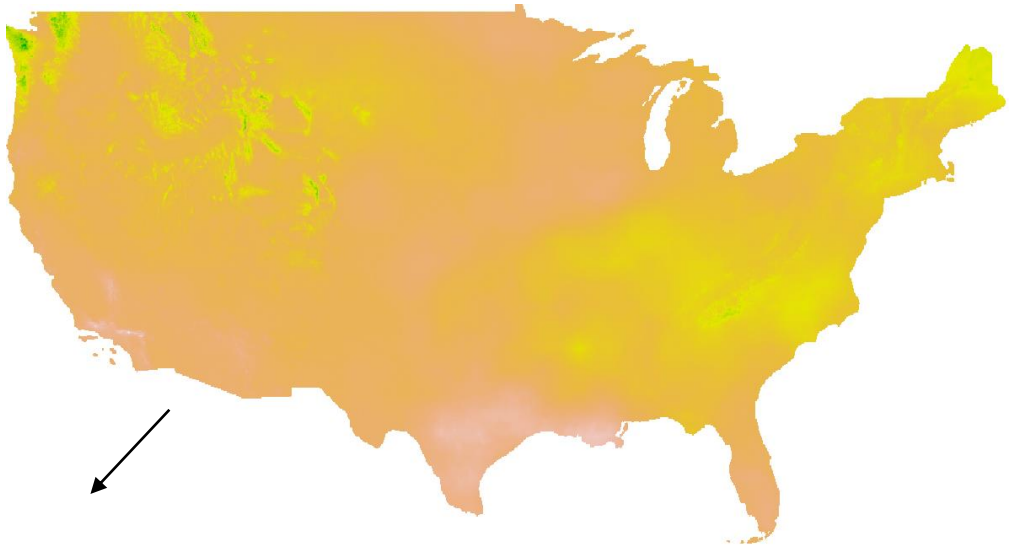
Addition of Policy-Relevant Data Layers / Indices

Floodplain



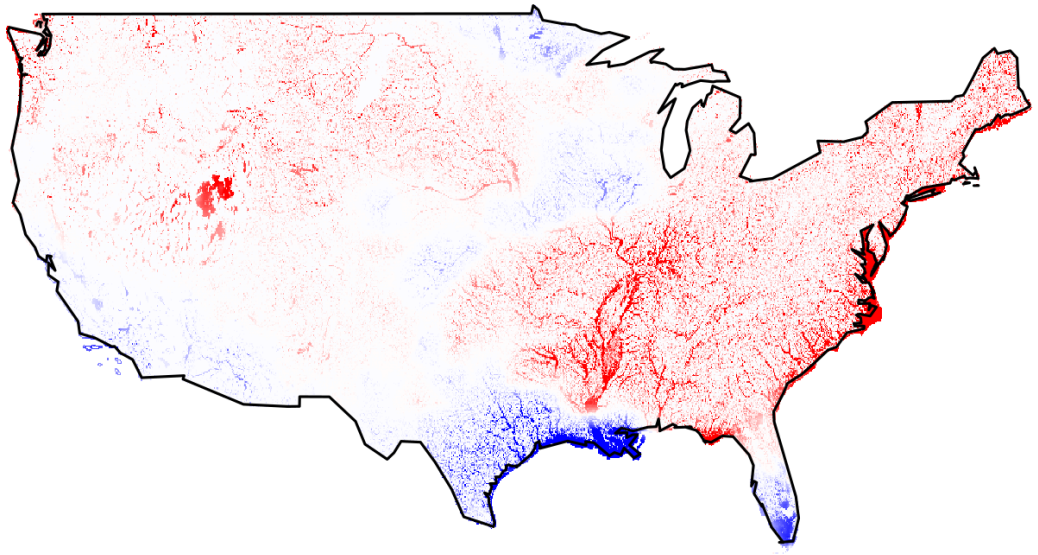
EnviroAtlas

Projected Change in Precipitation by 2050



NASA/NEX project

Combined Climate Indicators



Addition of Policy-Relevant Data Layers / Indices

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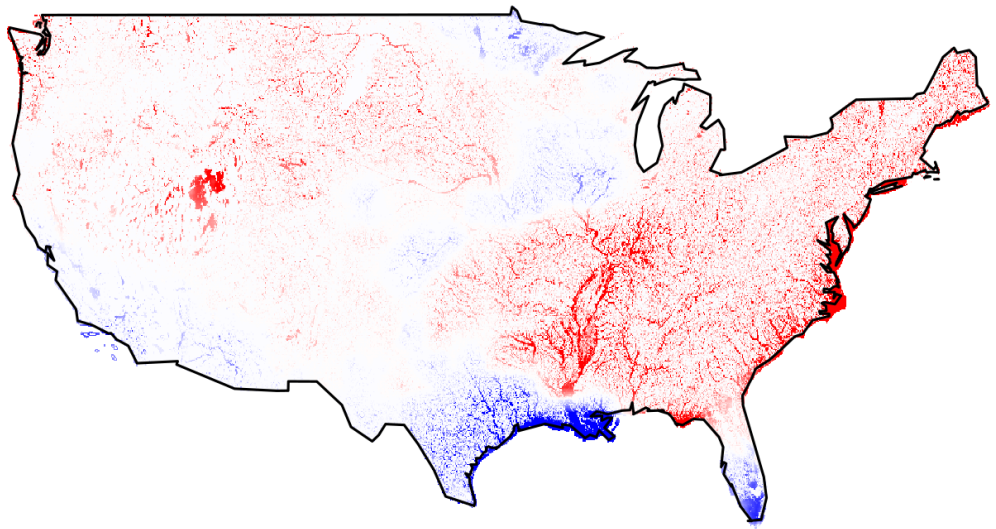


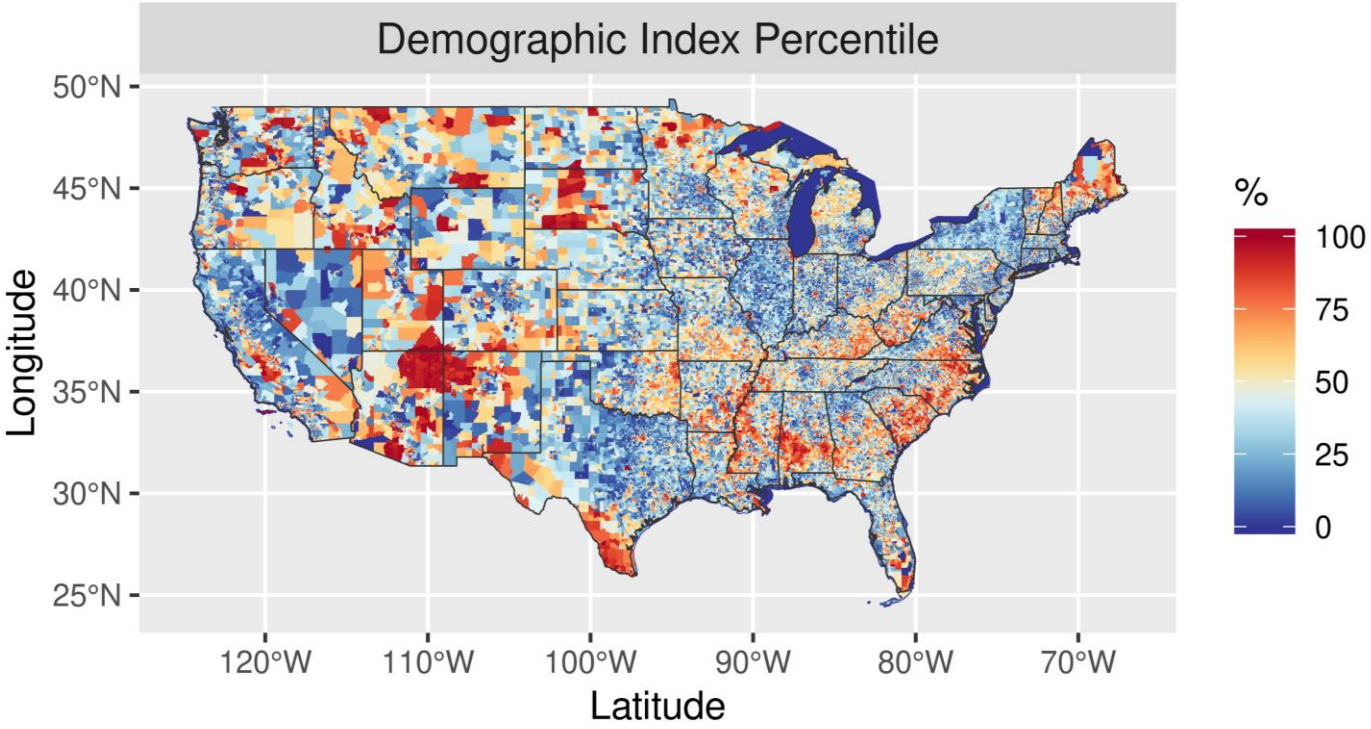
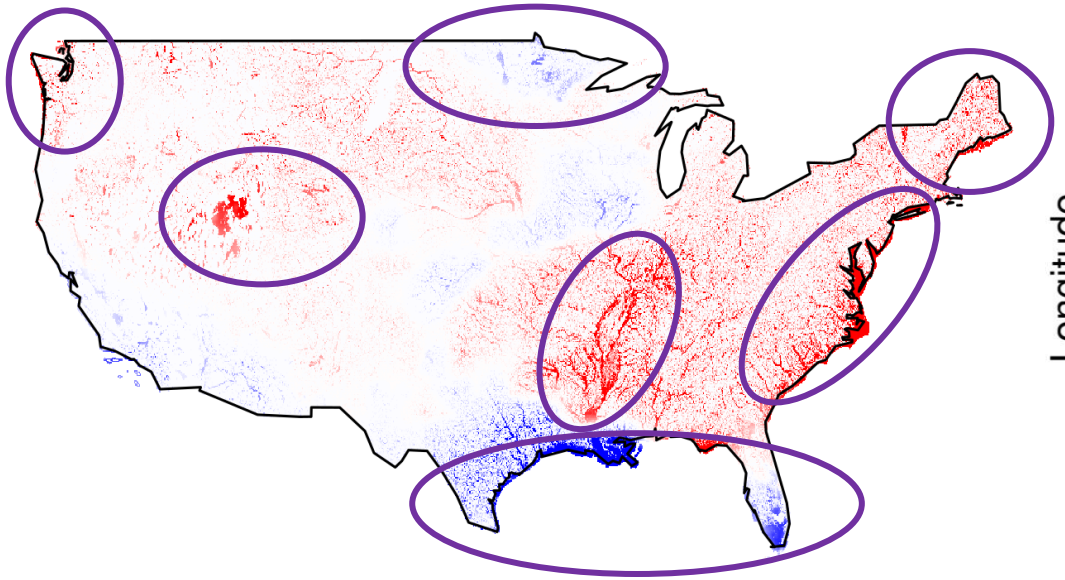


Figure courtesy of J. Kelly

Addition of Policy-Relevant Data Layers / Indices

Combined Climate Indicators



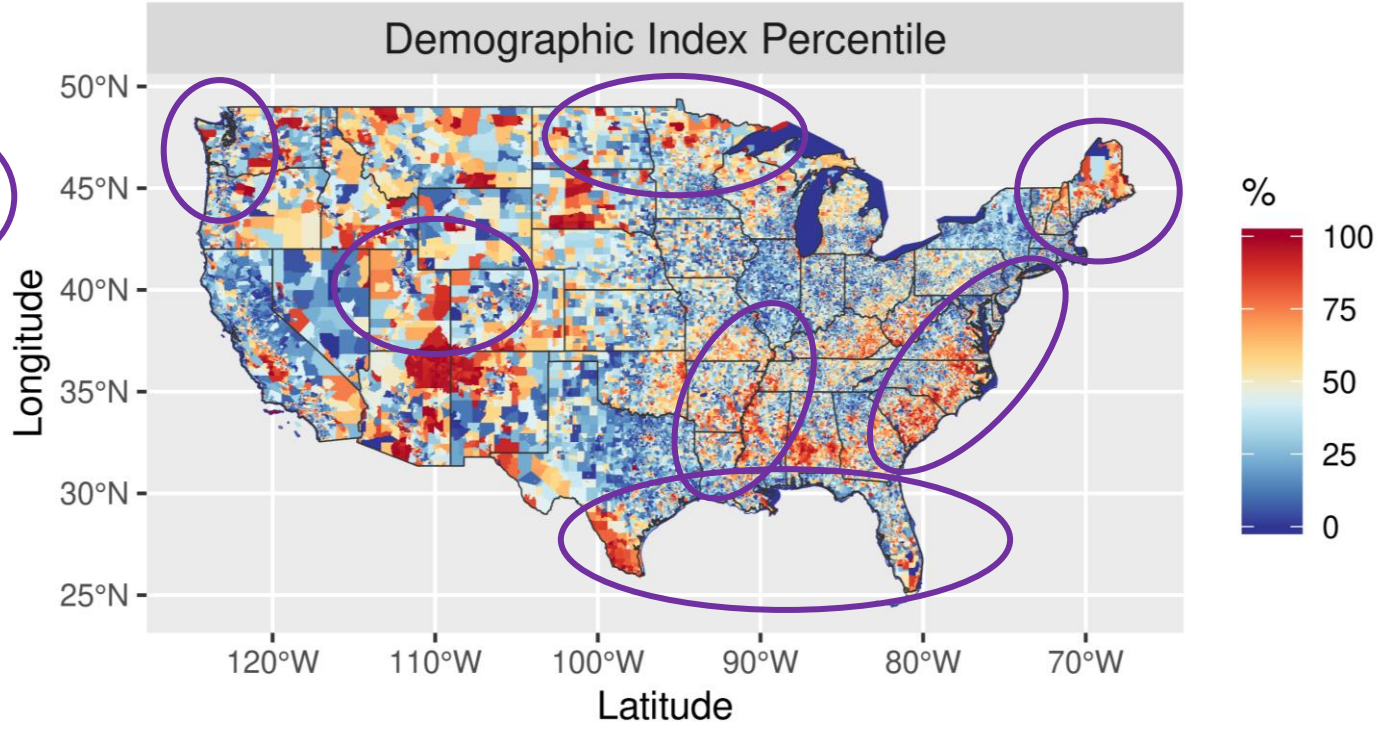
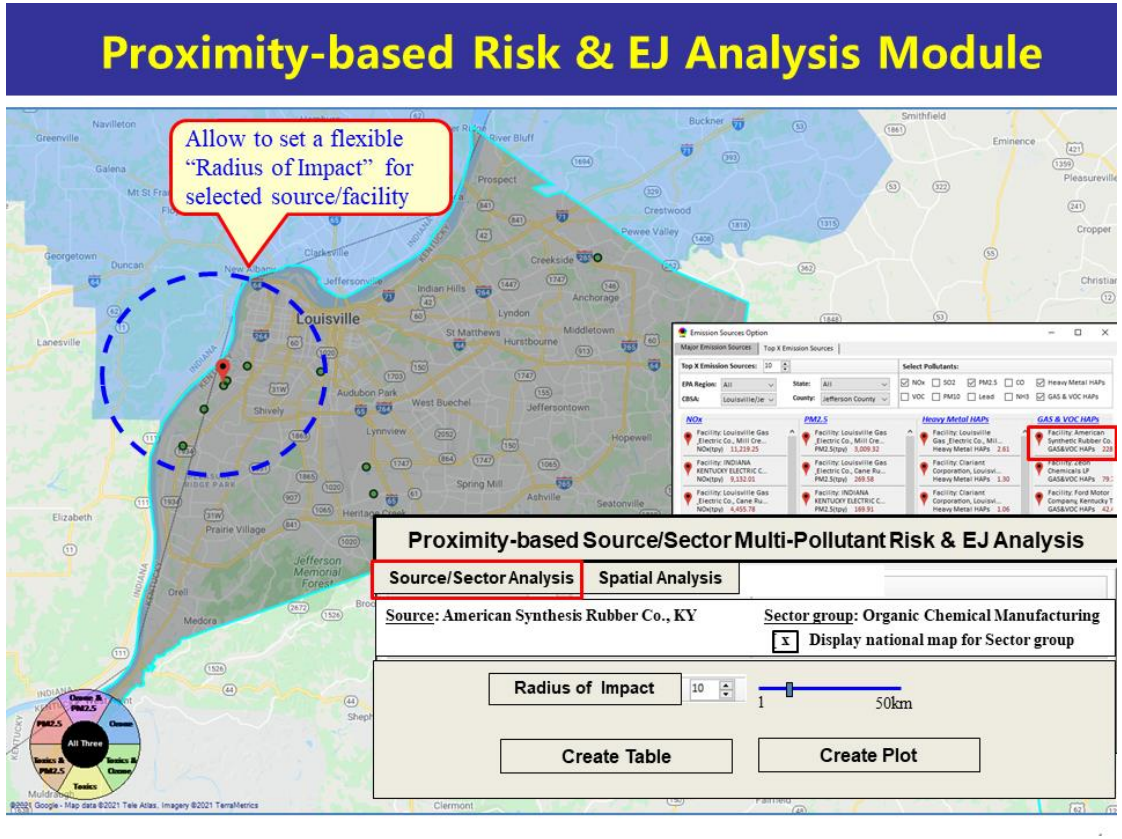


Figure courtesy of J. Kelly

Climate Considerations to Enhance Screening Proximity Analysis

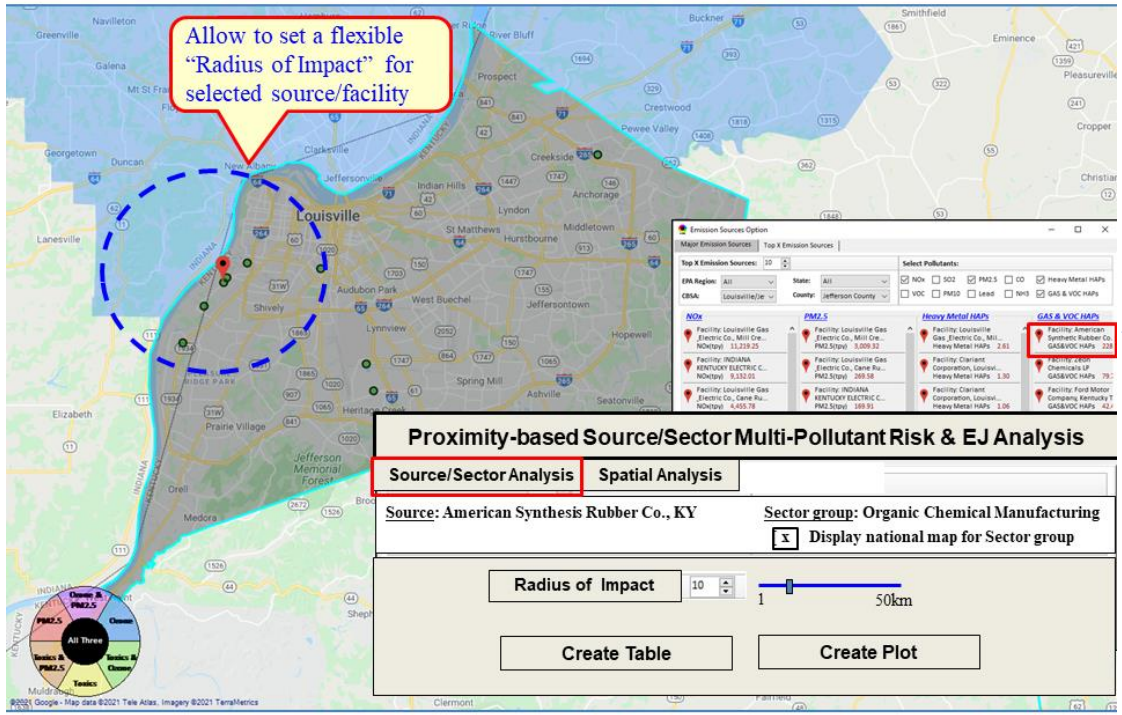


Simultaneously incorporating data layers with information relevant for multipollutant, EJ, and climate considerations offers the opportunity to perform **multidimensional screening for risks and vulnerabilities** across populations and in different locations

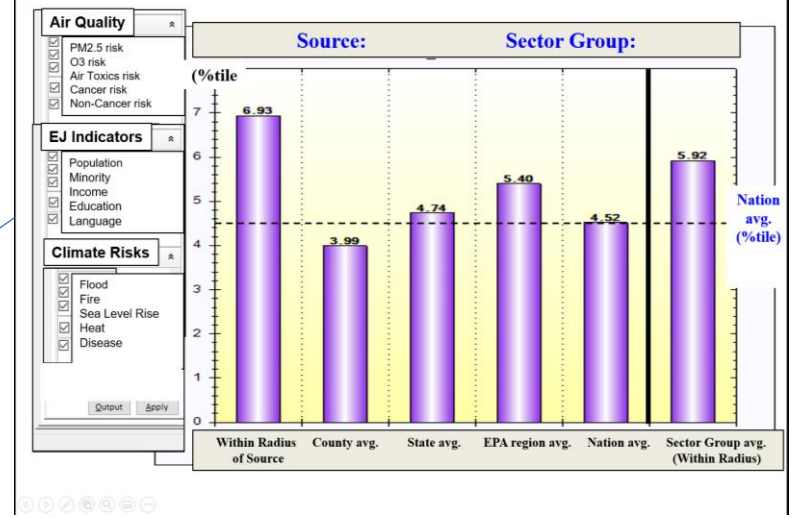
Image courtesy of C. Jang/NEXUS

Enhanced Screening Proximity Analysis in NEXUS

Proximity-based Risk & EJ Analysis Module



Proximity-based Module: Example Plot



Proximity Analysis Module: Spatial Analysis

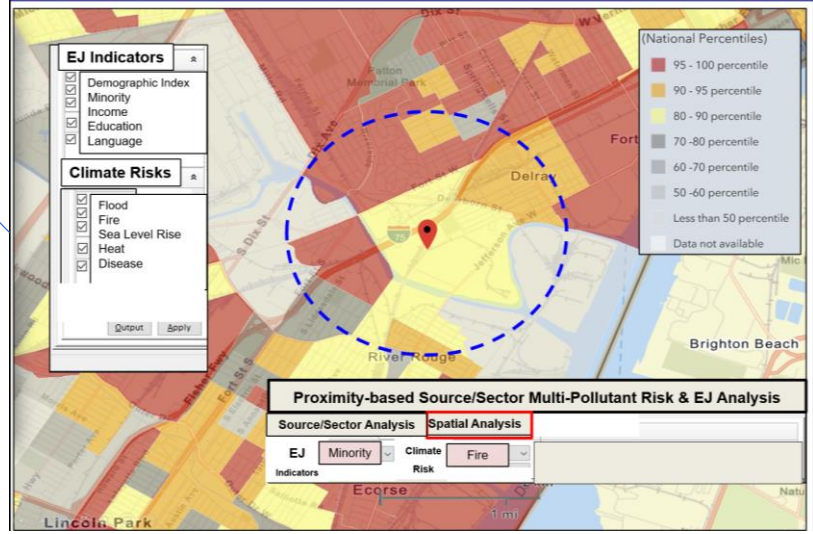


Image courtesy of C. Jang/NEXUS

Climate Enhanced Screening Proximity Analysis in NEXUS (cont)

Example Table:

	Source Name: American Synthesis Rubber Co., Louisville, KY Sector Group Name: Organic Chemical Manufacturing						
	Within Radius of Source	**County Avg.**	**State Avg.**	**EPA Region Avg.**	**Nation Avg.**	**Sector Group (within radius) National avg.**	**Sector Group (within radius) Top 25 MSAs**
Population total	x,xxx	xx,xxx	xxx,xxx	xxx,xxx	317,xxx,xxx	xxx,xxx	xxx,xxx
PM2.5 risk (%tile)	x%	x%	x%	x%	x%	x%	x%
Ozone risk (%tile)	x%	x%	x%	x%	x%	x%	x%
Air Toxics: Cancer risk (%tile)	x%	x%	x%	x%	x%	x%	x%
Climate risks: Flood (%tile)	x%	x%	x%	x%	x%	x%	x%
Sea level rise (%tile)	x%	x%	x%	x%	x%	x%	x%
Fire (%tile)	x%	x%	x%	x%	x%	x%	x%
Disease (%tile)	x%	x%	x%	x%	x%	x%	x%
EJ: Minority group (%tile)	x%	x%	x%	x%	x%	x%	x%
Low-income group (%tile)	x%	x%	x%	x%	x%	x%	x%
Demographic Index (%tile)	x%	x%	x%	x%	x%	x%	x%
Linguistic Isolation (%tile)	x%	x%	x%	x%	x%		x%

Potential Questions Related to AQ-Climate Interactions

1. What **emission sectors** contribute significantly to both greenhouse gases and local air pollution issues? How feasible are specific combinations of emission **control strategies** relevant for these sectors? What are the AQ impacts of potential strategies?
   We can use NEXUS and our sector-based AQ modeling to identify source/sector contributors and assess impacts for risk and exposure assessments

2. How robust are **future AQ projections**, and how well do we understand future responses in AQ to anticipated emissions changes in the face of climate change?
   We collaborate with ORD and others to link energy scenario projections with AQ modeling and improve characterization of meteorology, emissions, and chemistry in our future AQ projections

3. How will future changes in climate/meteorology affect 1) **exposure** and 2) **susceptibility** to air pollution?
   We have opportunities here for collaboration with HEID and ORD, e.g., provide meteorological data to inform HEID project to assess change in susceptibility due to temperature changes.

4. What are the **costs/benefits** of potential AQ-climate strategies (e.g., changes in energy policy)?
   We can leverage our reduced form modeling effort (i.e., FAST tool) in collaboration with HEID, OAP and ORD

5. What is **EPA guidance** regarding the use of climate and energy projections in SIPs and related modeling demonstrations under the Clean Air Act or NEPA?
   Engaging in internal discussions within AQMG and will expand to include Regions, AQPD, and others as implementation program changes and goals become more defined in near future.

Linking Energy Scenario Projections with Air Quality Predictions

- Collaborate with ORD and other partners to apply tools like GCAM-USA with the purpose of:
  - Assessing future air quality under broad energy policy options at regional and national scales
  - Understanding when/where such policies have significant air quality impacts

- These tools could be applied to both 1) produce energy emission scenarios given specific policy plans, and (2) inform the development of policy options based on modeled feasibility of specific scenario components (e.g. what resources would be required to implement the large-scale infrastructure development needed for widespread use of electric vehicles)

- Work with ORD/other partners to rigorously evaluate assumptions and outputs from GCAM-USA to assess relevance for policy use

- Current discussions with ORD on how to link GCAM-USA with in-house OAQPS tools (e.g. FAST-CE) to estimate air quality endpoints relevant for benefits calculations

Improving characterization of future AQ projections

- Variability and long-term changes in **meteorological** patterns
  - Long range transport
  - Precipitation
  - Changes in cloud cover → photolysis rates relevant for ozone

- Variability and long-term changes in **emissions**:
  - Climate/Land Use driven:
    - Wildfires
    - Dust
    - Biogenics
    - Fertilizer application
    - Residential wood combustion
  - Policy driven:
    - Energy scenarios
    - Mobile emissions
  - Global emissions → wildfires, global energy demand, methane, etc.

- Changes in **chemistry-climate** interactions:
  - Methane
  - Aerosol-cloud feedbacks
  - Wintertime aerosol formation chemistry

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Influence of Meteorology on Design Value Predictions

- Previous work by K. Foley/ORD conducted dynamic evaluation of ozone in the Northeast U.S. across 2002-2005 met years by scaling emissions from EGUs and mobile sources

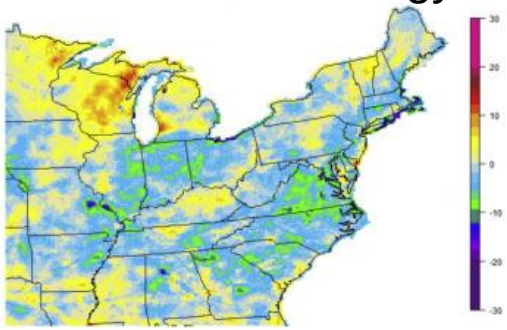
- Recent work by B. Wells/AQAG used statistical methods to link peak ozone levels with key meteorological parameters by region

- Build on previous analyses by performing sensitivity simulations combining meteorology and emission years to better characterize the influence of meteorology on model-predicted DV calculations for different parts of the country *(currently in progress through Global Transport budget item due to relevance for characterization of background ozone/PM*)

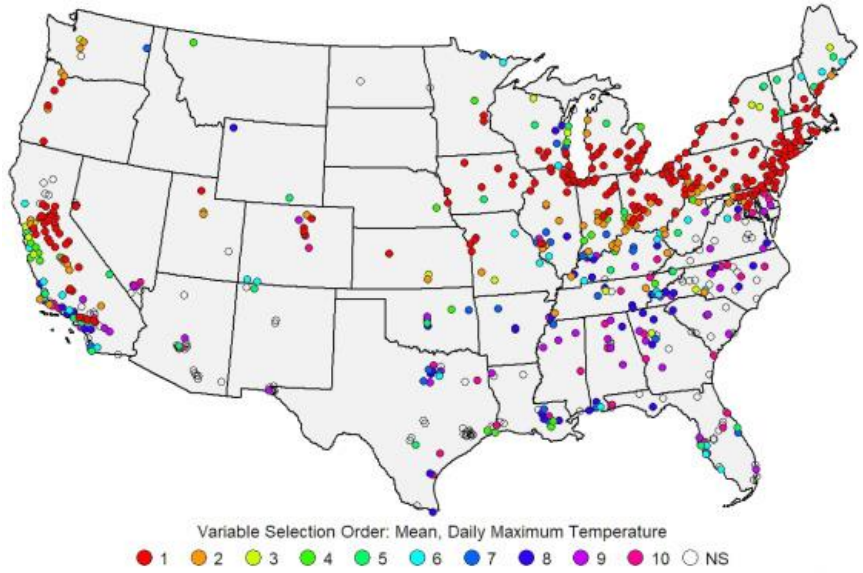
- Synthesis across these and other efforts could help answer questions related to **stationarity assumptions in DV projections** and how these relationships may (or may not) be expected to evolve in a future climate

ΔOzone: Emissions

ΔOzone: Meteorology



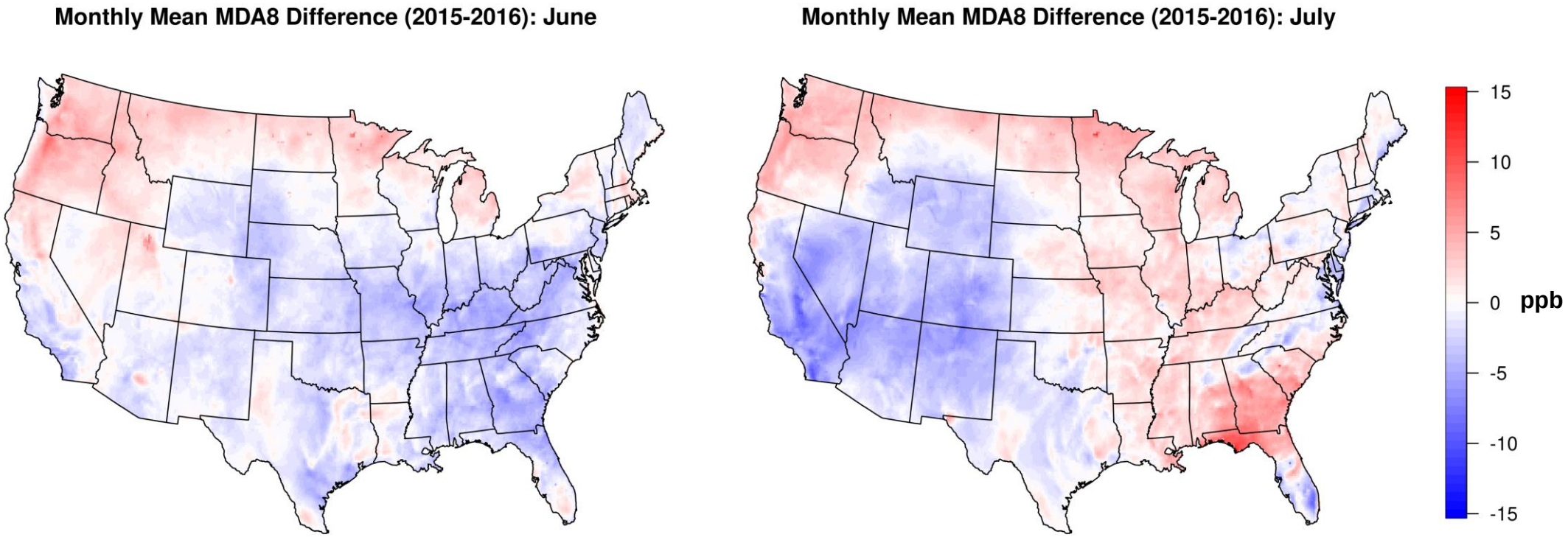
Foley *et al*., 2015



Wells *et al*., 2021

Influence of Meteorology on Design Value Predictions

Preliminary Results:



Currently testing 2016v1 emissions platform with available meteorological configurations for June/July 2014-2018

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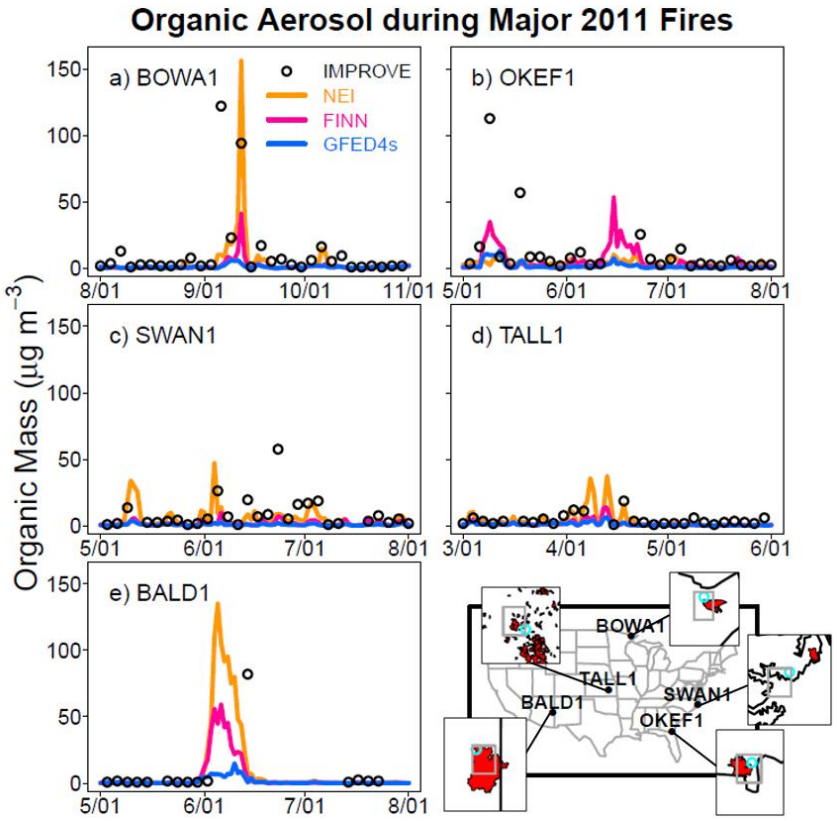
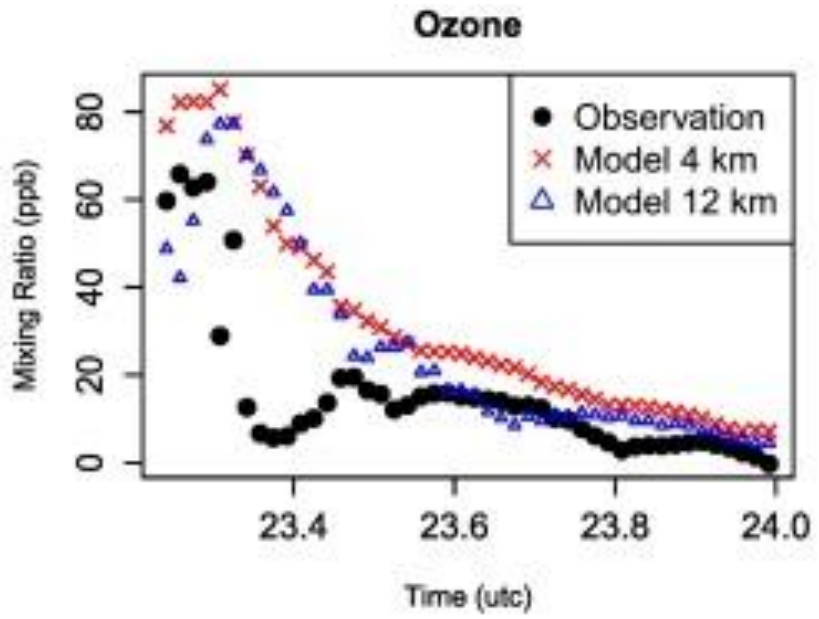
Improving model characterization of smoke informs projections

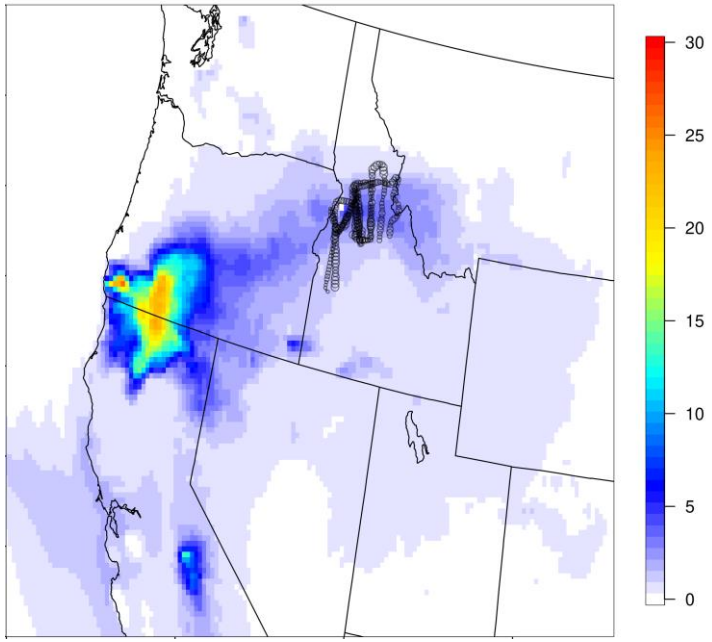


Koplitz et al., 2018



Baker et al., 2018

Evaluation of CMAQ during WECAN



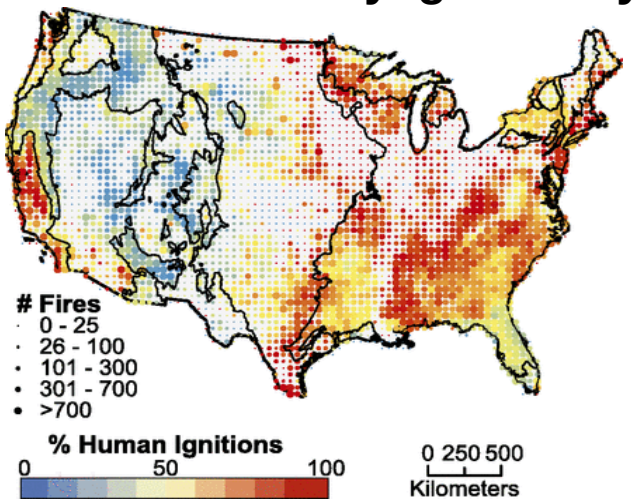
Koplitz and Baker, ongoing

We are continually evaluating the representation of wildland fire smoke plumes in CMAQ and CAMx to improve model representation of emissions, chemistry, and transport during these extreme events. These evaluations require frequent collaboration with EIAG, ORD, Regions, and external partners.

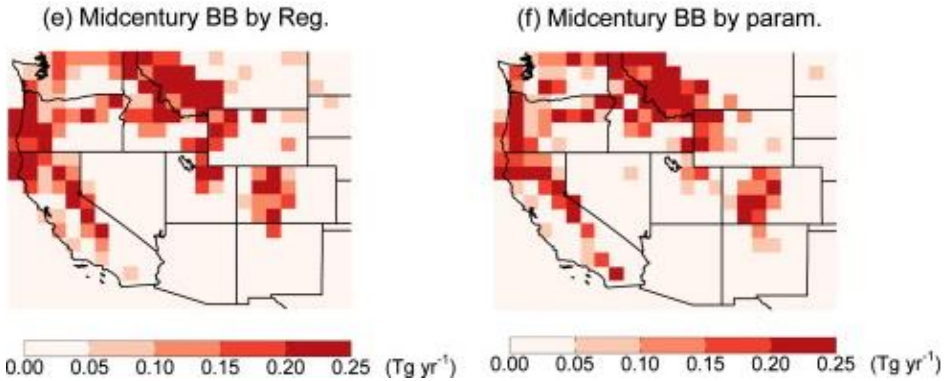
Previous Projections Lack Linkages with Land Management

"Forests are actively managed, and the frequency and severity of wildfire occurrence in the future will not be determined solely by climate factors. Humans affect fire activity in many ways, including increasing ignitions and conducting controlled burns and fire suppression. Forest management decisions may outweigh the impacts of climate change on both forest ecosystems and air quality." *- 4th National Climate Assessment*

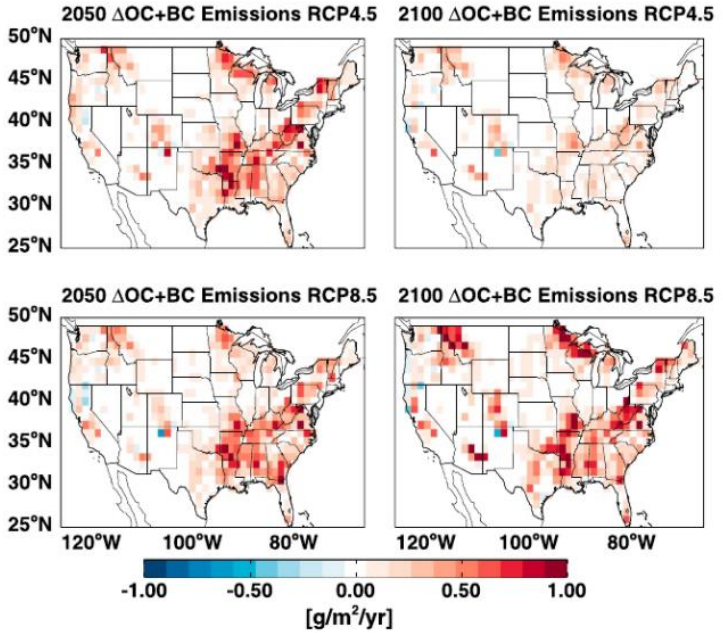
Historical Fires by Ignition Type



Balch et al., 2017



Yue et al., 2013



Ford et al., 2018

How will future land management decisions affect wildfire occurrence and therefore future smoke prevalence?

Wildfire and prescribed burn air quality tradeoffs

- K. Baker, Modeling Lead on Wildland Fire Leadership Council Project with ORD and HEID
- Evaluate air quality tradeoffs of controlled and uncontrolled fires by developing hypothetical land management alternatives for two actual wildfires that occurred, use CMAQ to model compare $PM_{2.5}$ and O_3 produced across scenarios
- Partners include EIAG, ORD, Regional Offices, USFS, DOI, BLM
- Also working with Sadia Afrin, Fernando Garcia-Menendez at NC State

Partnerships and technical approaches developed through these ongoing efforts could offer a path forward for quantitatively characterizing future changes wildfire air quality under different scenarios of land management

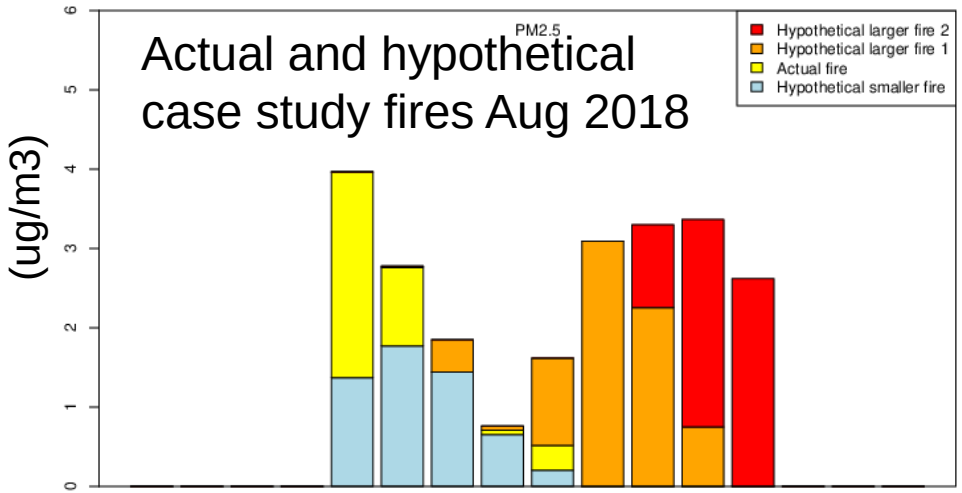
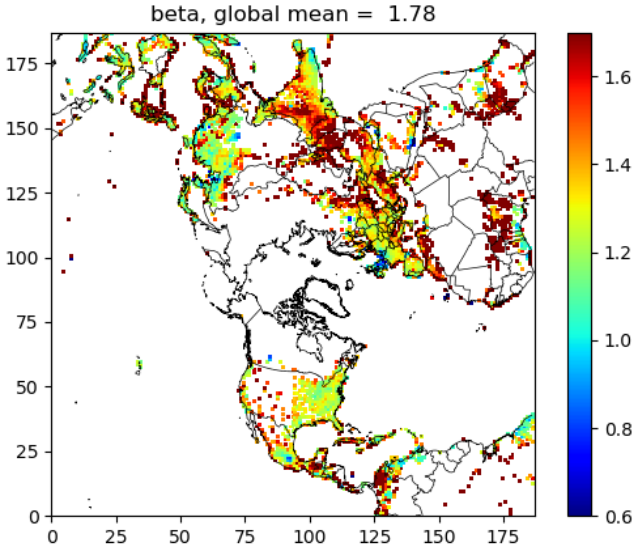
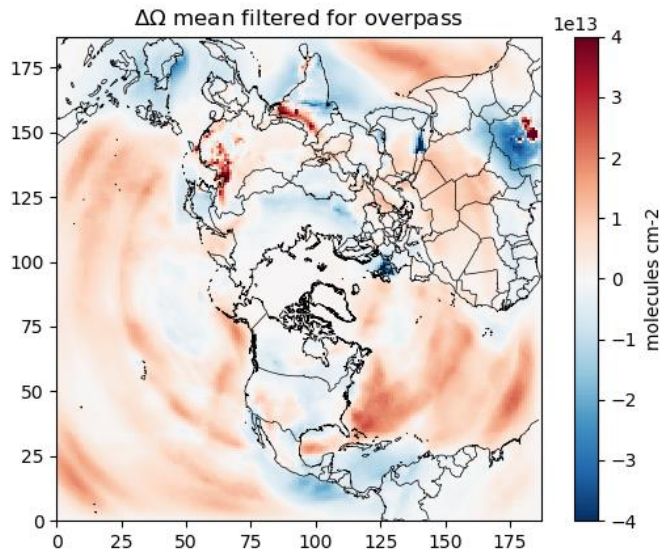


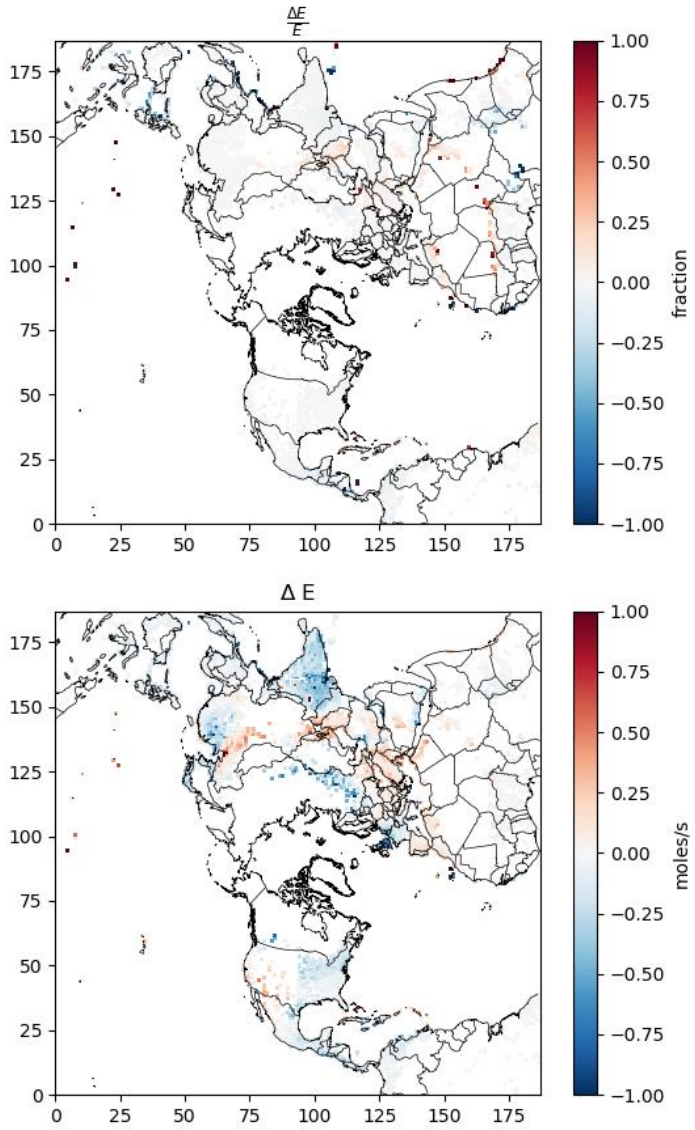
Figure from K. Baker, WFLC report (draft)

Changing Global Emissions in Response to Evolving Air Quality, Energy and Climate Policies

- James East (ORISE Fellow working with B. Henderson, S. Napolenok (ORD) and S. Koplitz)
- Developing in-house capacity for data assimilation (as presented to AQAD on 9/24/20)
- Possible applications include constraints of global emission fluxes







(Figures from J. East, preliminary results)

Improving characterization of future AQ projections

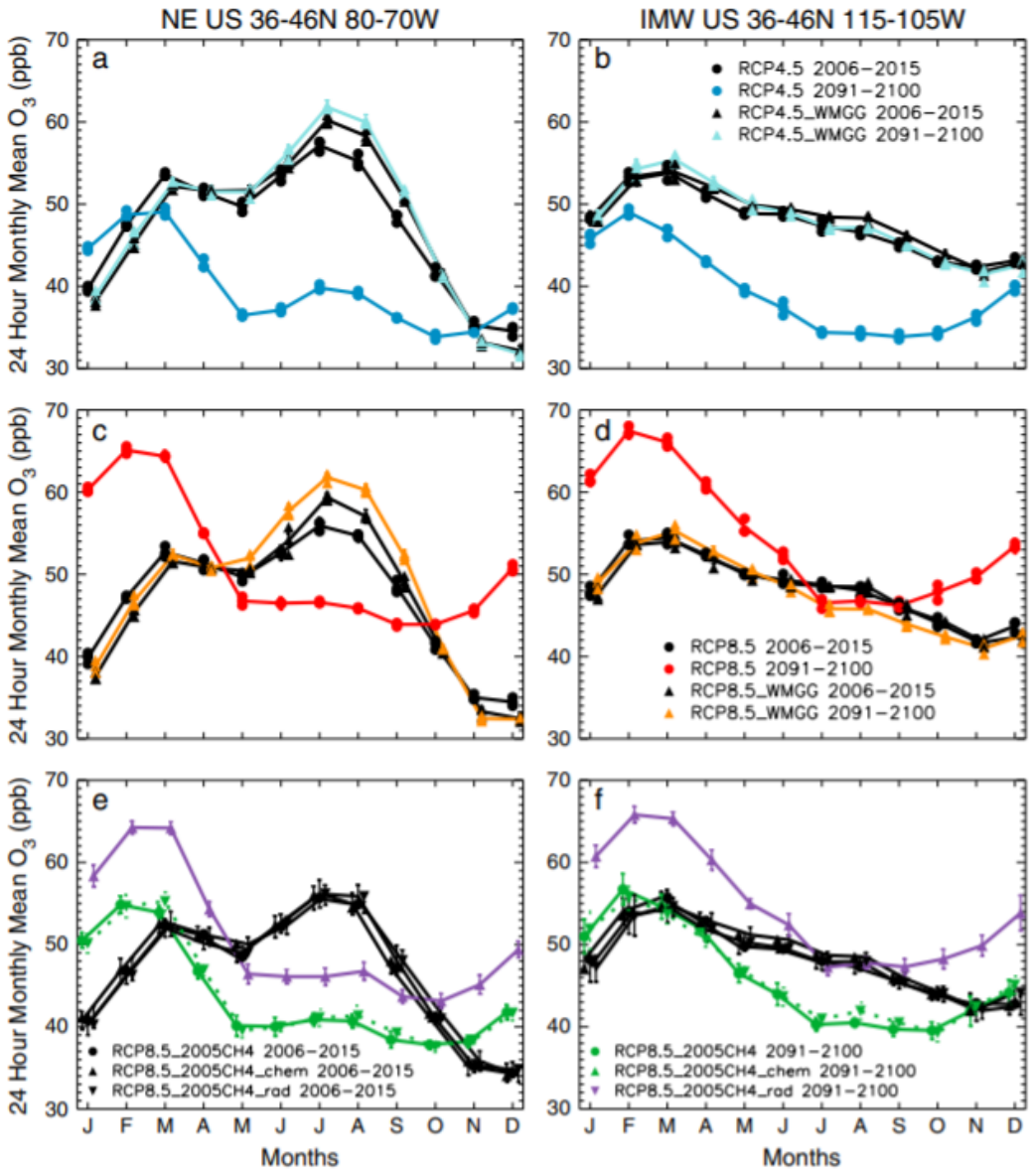
- Variability and long-term changes in **meteorological** patterns
  - Long range transport
  - Precipitation
  - Changes in cloud cover → photolysis rates relevant for ozone

- Variability and long-term changes in **emissions**:
  - Climate/Land Use driven:
    - Wildfires
    - Dust
    - Biogenics
    - Fertilizer application
    - Residential wood combustion
  - Policy driven:
    - Energy scenarios
    - Mobile emissions
  - Global emissions → wildfires, global energy demand, methane, etc.

- Changes in **chemistry-climate** interactions:
  - Methane
  - Aerosol-cloud feedbacks
  - Wintertime aerosol formation chemistry

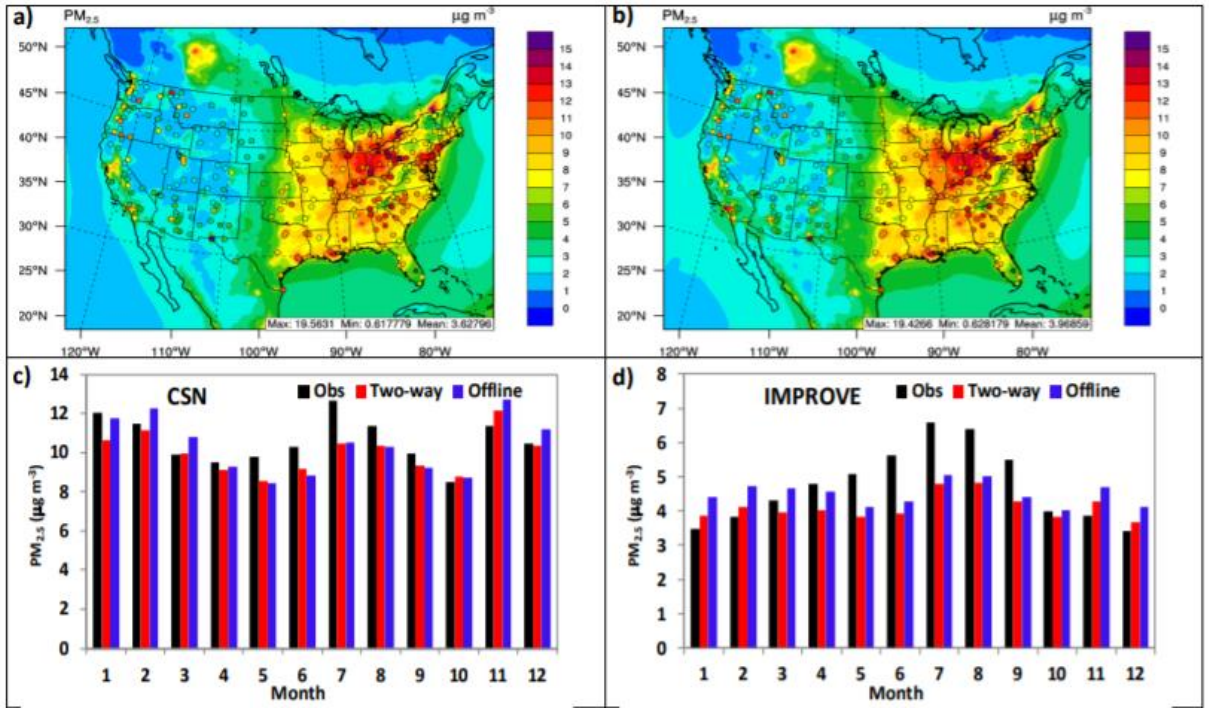
Assessing Air Quality Impacts of Methane Chemistry

- Methane affects oxidant budgets and therefore the atmospheric chemical environment relevant for formation of other pollutions (e.g. ozone)
- How can we better characterize/bound the impacts of methane chemistry assumptions in existing modeling tools/chemical mechanisms?
- How can we improve the characterization of methane in model-ready emission inventories?
- How might changes in methane concentrations and other species affecting atmospheric oxidants (e.g. NO_x) due to changes in climate/energy policies further affect pollutant distributions?



Clifton et al., 2014

Investigate aerosol feedbacks in coupled air quality models



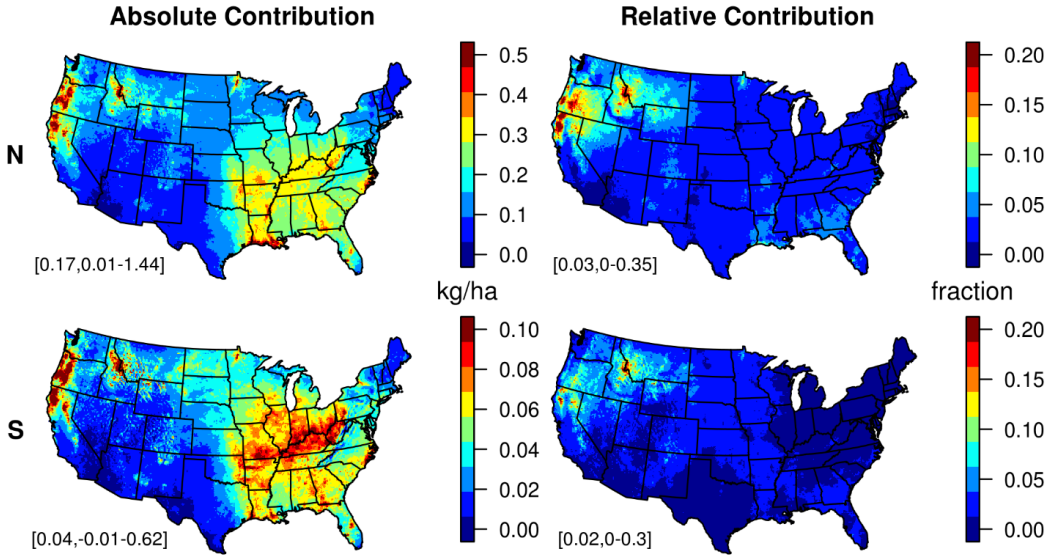
K. Wang, … J. Pleim, R. Mathur, ***J. Kelly*** *et al., 2020*

- Coupled models are very computationally expensive and may not generally make a big enough difference to justify the additional computational expense of running routinely for OAQPS purposes
- However, these systems could offer an opportunity to investigate in more detail the interactions between changes in pollutant concentrations and regional/national climate
- Such analyses could inform cost/benefit assessments of individual policy options or broader strategy options in the context of climate change

Consideration of Ecosystem Impacts

- Relevant for consideration of secondary NAAQS standards
- How will future climate change affect sensitive ecosystems also experiencing air pollution effects?
- How will changes in emissions under different energy scenarios and climate strategies impact ecosystems?
- How will other strategies implemented to combat the consequences of climate change impact ecosystems? E.g., nitrogen impacts from increased prescribed burning to offset increased wildfire severity

Contribution of Wildland Fire Emissions to Nitrogen Deposition



Koplitz et al., 2020 (work done while in ORD)

Connecting to Other In-House Activities/Capabilities

AQAD
- Future emissions projections (EIAG)
- GHG monitoring (AAMG)
- Emission control technologies (MTG)
- DV calculations/met adjusted DVs (AQAG)
- Future air quality projections (AQMG)

HEID
- Identifying vulnerabilities at national to community scales (e.g. Fann et al)
- Emission control costs/feasibility
- Benmap (co-benefits)

ORD
- GCAM USA/energy scenario modeling
- Long term time series (EQUATES)
- Downscaled climate modeling (e.g. Nolte, Spero et al.)
- EnviroAtlas layers/team (screening tool development)

OID
- Climate-EJ considerations for outreach efforts
- Climate indices for EJSCREEN

OAP
- GHG inventory
- CIRA climate impacts effort