HyADS: A tool for estimating nationwide exposures to emissions from large numbers of sources

Lucas Henneman (and many others)

Department of Environmental Health, Harvard School of Public Health

CMAS

21 October, 2019

The Team

Project 4 of the Harvard/MIT ACE Center
EPA STAR Grant #RD83587201

Team

- Cory Zigler
  - UT Austin
- Christine Choirat
  - ETH Zurich
- Kevin Cumminskey
  - West Point
- Chanmin Kim
  - Boston University

Harvard/MIT Center

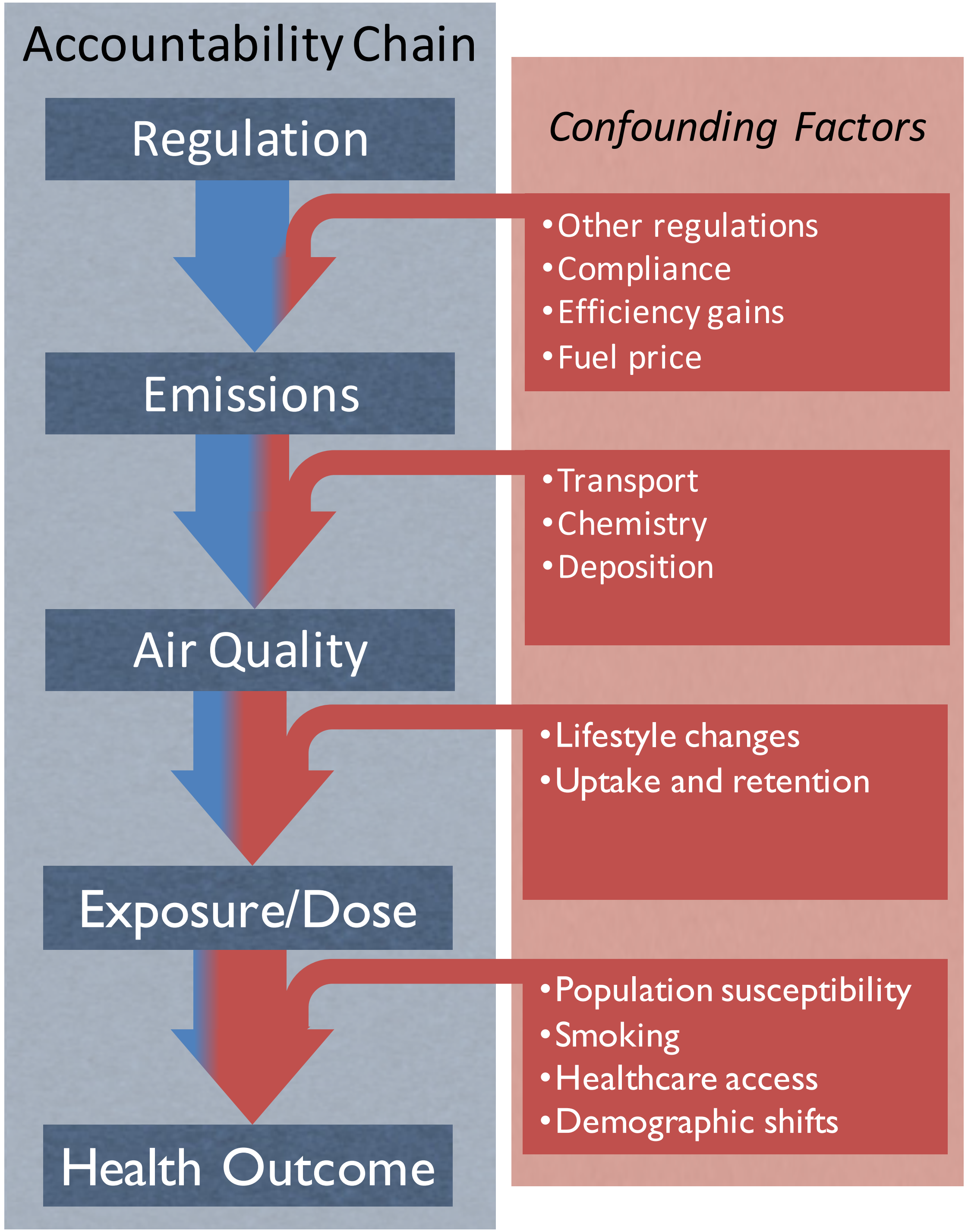
- Maja Garbulinska
- Irene Dedoussi
- Petros Koutrakis
- Steven Barrett
- Francesca Dominici

Outside Center

- Cesunnica Ivey
  - Univ. California Riverside
- Joan Casey
  - Columbia University

Motivation

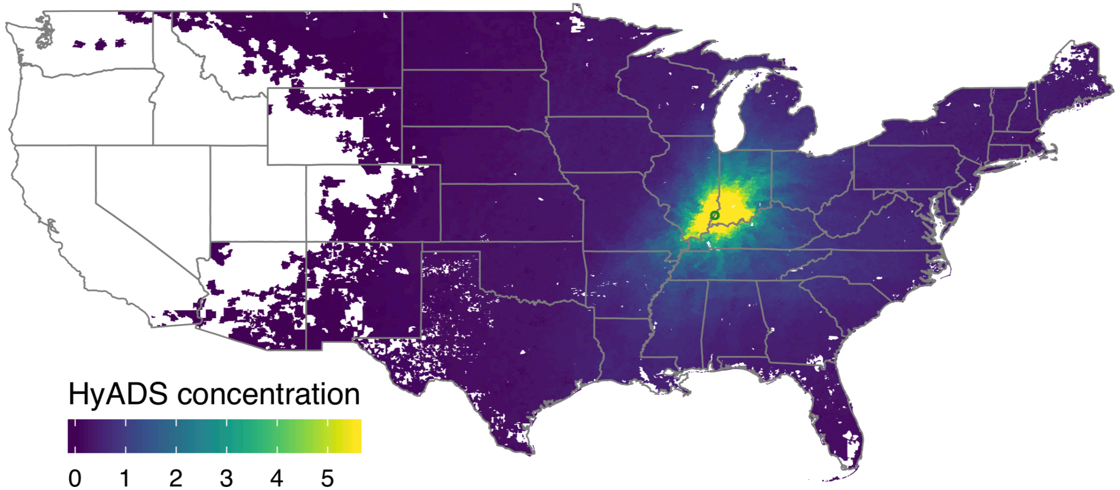
- We know:
  - The US spends tens of billion \$/yr regulating air quality
  - Regulations manifest as discrete actions on individual point sources
- We want to know:
  - Can we establish <u>direct epidemiological evidence</u> that we are healthier because of the regulations?



Connecting power plants to people with HyADS

- HYSPLIT simulates dispersion of 100 parcels from each stack
  - Parcels tracked for 10 days
  - Omit near-source impacts
  - Omit parcels above planetary boundary layer
  - Parcels not resuspended
- Repeat at 6 hour intervals daily
- NCEP Reanalysis meteorology
- Locations aggregated to 12km 3D grid with monthly boundary layer as height
- Weight by monthly SO_2 emissions

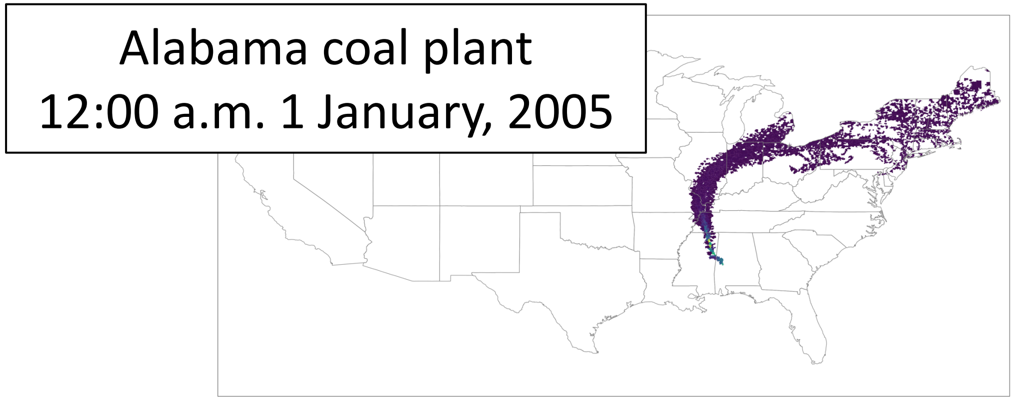
2005 HyADS exposure for facility 6113, Unit 1

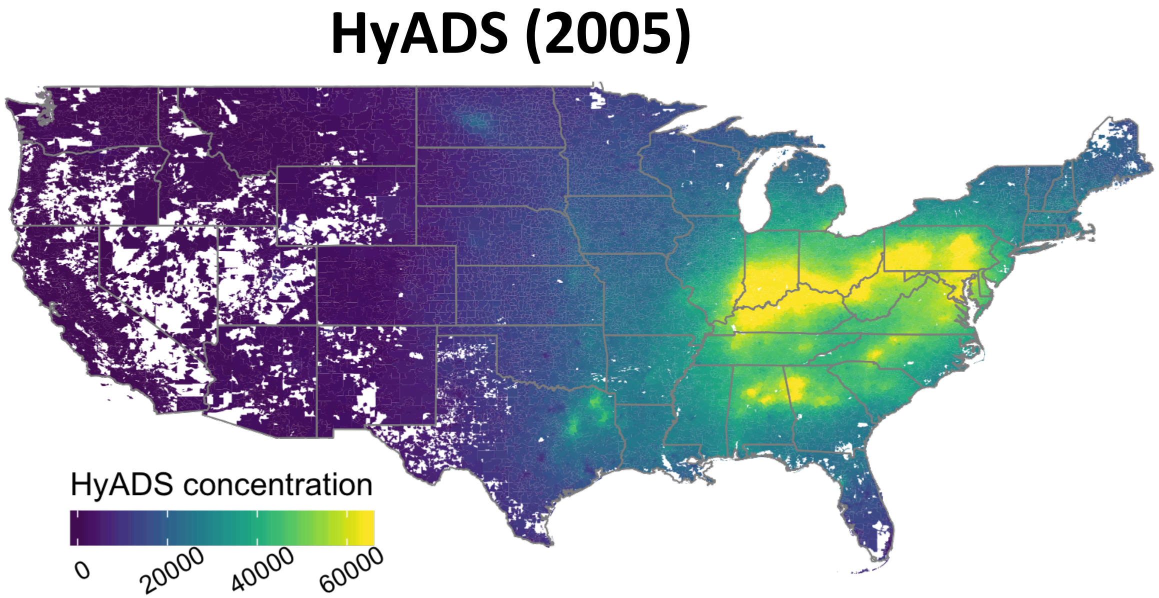


- Accessible through hyspdisp R package www.github.com/lhenneman/hyspdisp
- Thanks to hard work by Maja Garbulinska, will soon be updated to disperseR

Connecting people to power plants with HyADS

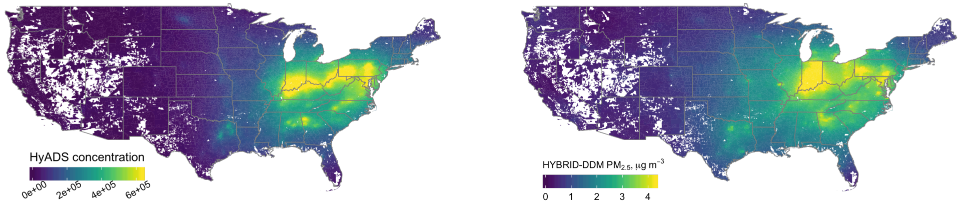
- Reduced complexity
  - Simplified chemistry/transport
  - Identifies areas impacted, not concentration
- Increased scalability
  - Source receptor matrix from ~1k sources
  - Estimate source impact changes from interventions
  - Develop counterfactual scenarios
  - 1 year run in 1 week (using R!)





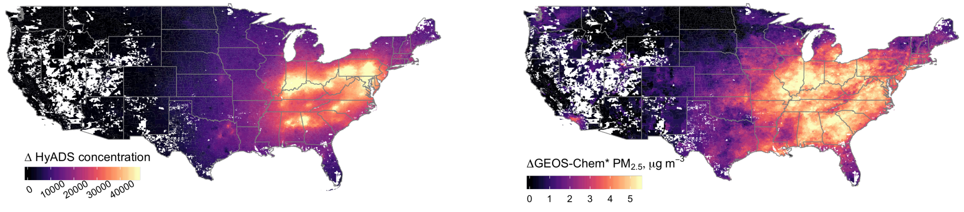
Application-specific evaluations

Annual source impacts, 2005



Hybrid CMAQ-DDM coal source impacts	**0.81**	
Observed $PM_{2.5}$	0.53	R^2
Observed sulfate	0.77	

Change in annual impacts, 2005-2012



$PM_{2.5}$ (gridded, Dalhousie group)	**0.47**	
Observed $PM_{2.5}$	0.58	R^2
Observed sulfate	0.71	

Source impacts on specific geographies

- Geos-CHEM adjoint sensitivities
- State-level, averaged $PM_{2.5}$ from emissions perturbations anywhere in the 3D domain
- Power plant rank correlations
  - High for states near sources (e.g., PA)
  - Lower for far states (e.g., CA)

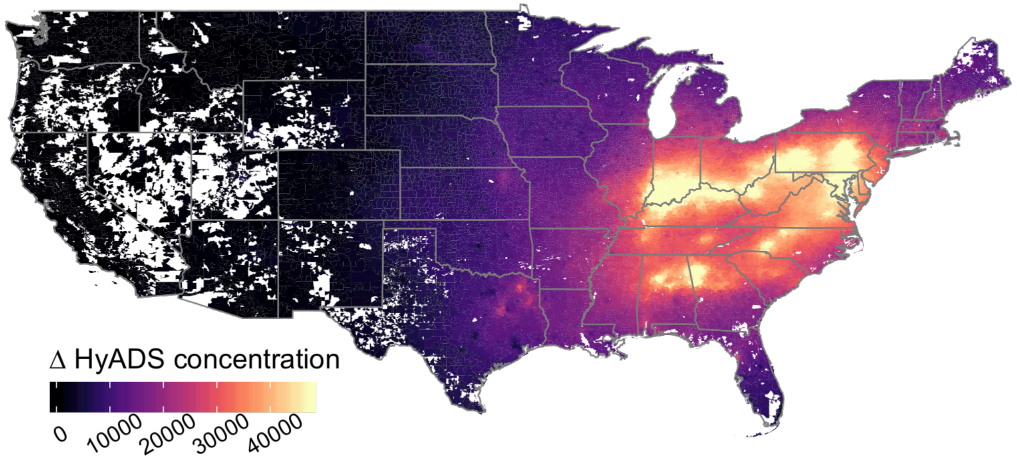
HyADS reproduces features in more complex models important for health analyses

Ivey *et al*. 2015 *ES&T*
Dedoussi et al. 2019 ERL
Henneman *et al*. 2019 *Atmospheric Environment*

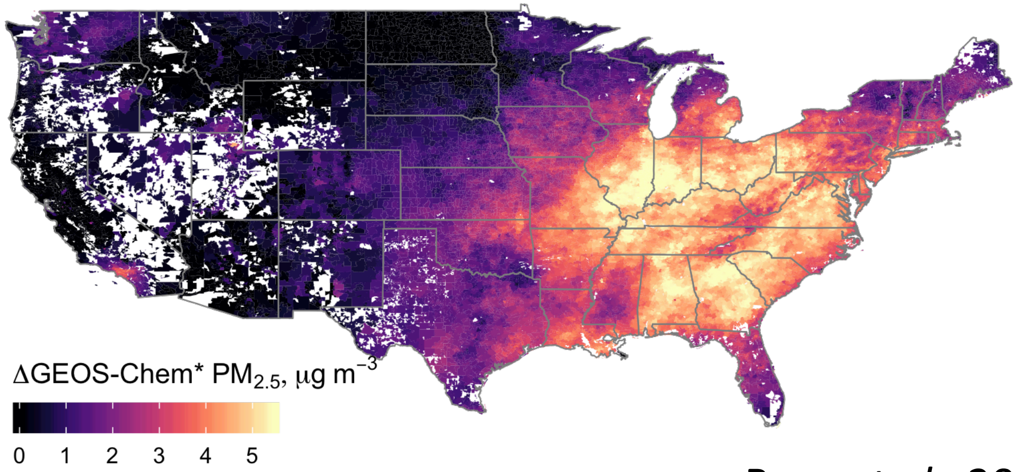
Emissions changes and national reductions in HyADS exposure

- 65% reduction in coal power plant SO_2 emissions, 2005-2012
- 69% reduction in HyADS exposure, 2005-2012
- 32% reduction in average $PM_{2.5}$ concentration, 2005-2012
- Questions
  - Did adverse health outcomes decrease with decreasing coal emissions?
  - Are associated decreases different in HyADS and total $PM_{2.5}$?

Decrease in HyADS

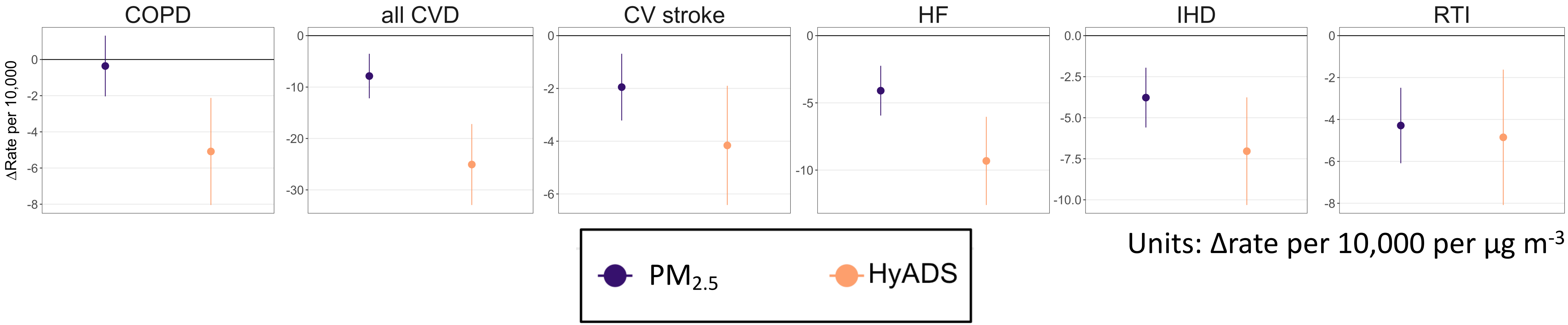


Decrease in $PM_{2.5}$



Boys *et al.*, 2014 *ES&T*

Changes in Medicare hospitalization rates associated with coal exposure reductions



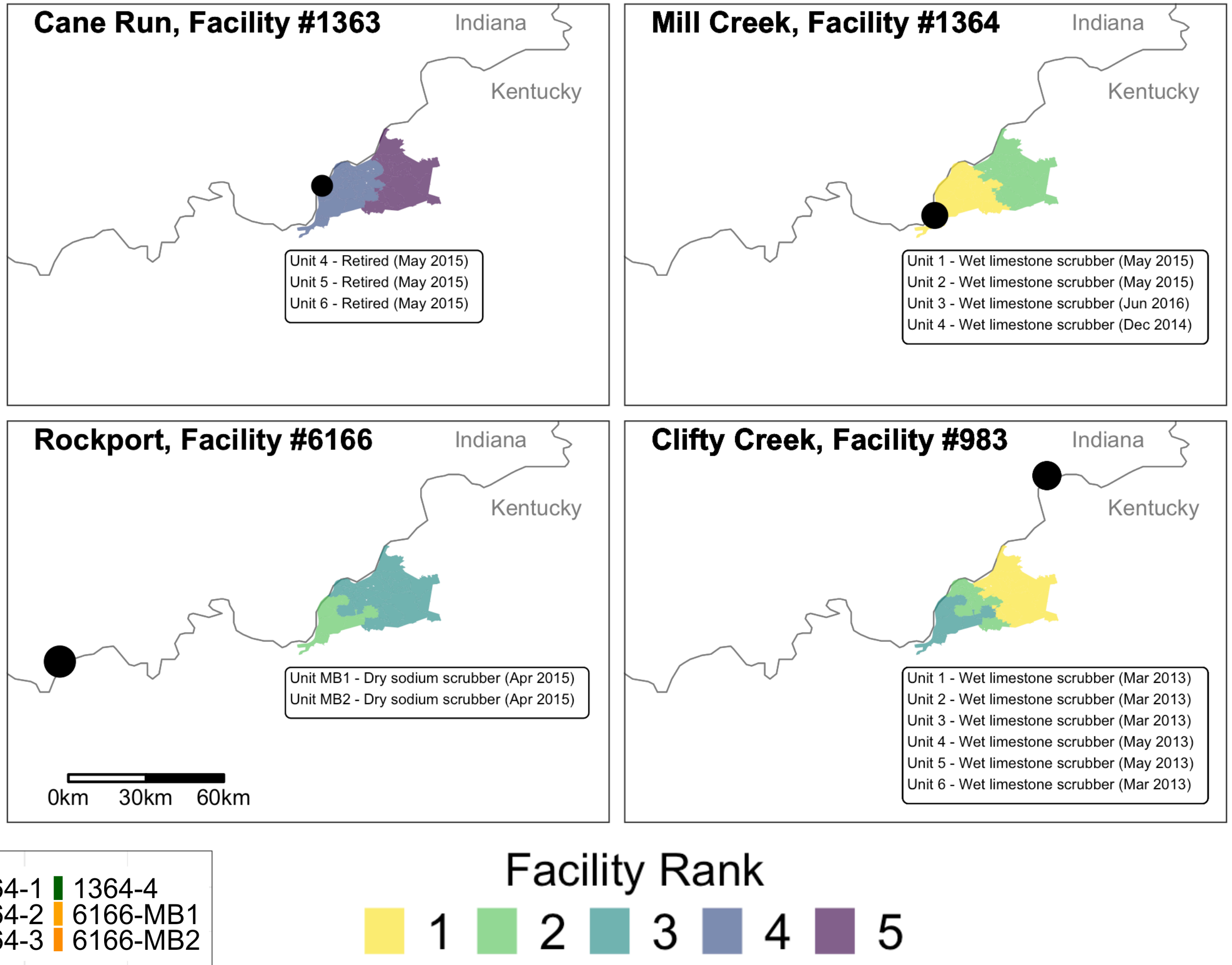
Units: Δrate per 10,000 per μg m^{-3}

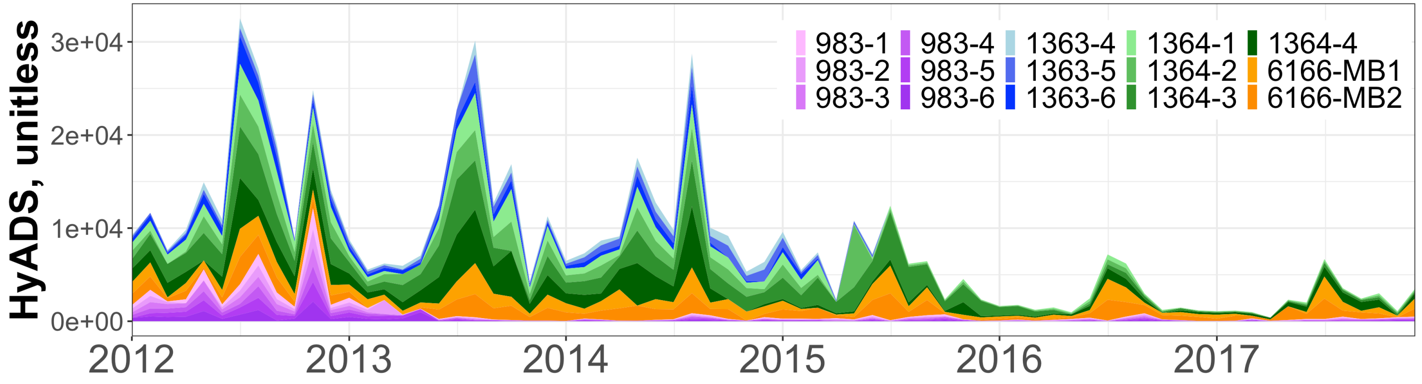
- Reduced health outcomes associated with reduced coal emissions and $PM_{2.5}$ exposure
- Regression with Hybrid CMAQ-DDM to convert HyADS to coal $PM_{2.5}$
- Evidence of larger health reductions for coal exposure reductions than $PM_{2.5}$ reductions

Henneman *et al*. 2019 *Epidemiology*

Energy transitions near Louisville, KY

- Identified top four facilities impacting Louisville in 2012 using HyADS
- All units installed SO_2 emissions control or shuttered by 2016
- HyADS exposure decreased over time
- Question – did these interventions lead to reduced asthma?

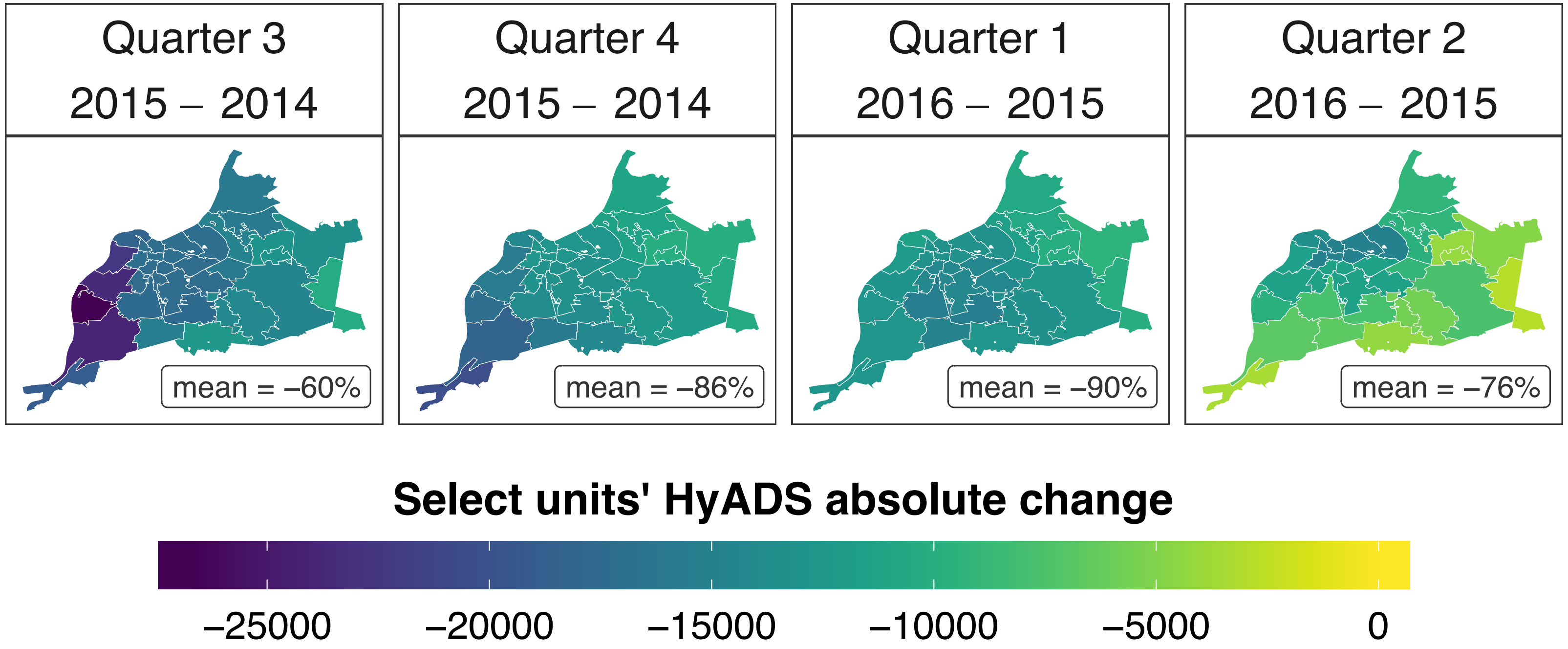




J. Casey *et al. In review*

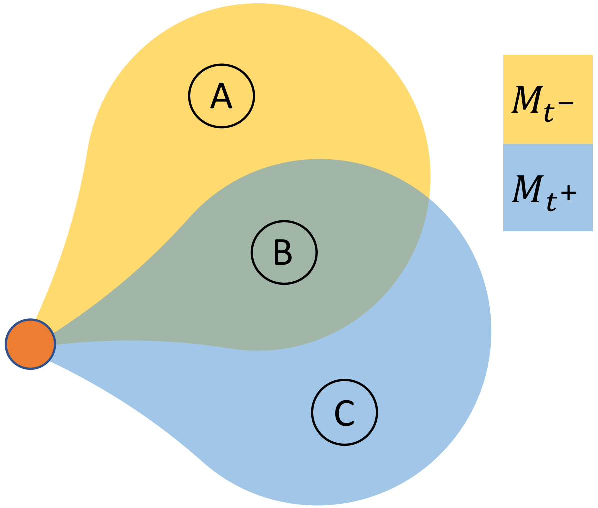
Louisville energy transitions natural experiment

- Largest emissions change spring 2015 (Quarter 2)
- Spatial variability across Louisville in who benefited
- ~20% reduction in asthma risk following intervention
- Benefits of transition strongest in areas identified by HyADS



Casey *et al. In review*

Exposure change and interventions: not all attributable to emissions



- Two reasons for changing exposure:
  - Meteorological variability
  - Emissions change

Exposure = *f* (**Meteorology** | **Emissions**)

ΔExposure = *f* (**Met** **after** | **Emiss** **after**) − *f* (**Met** **before** | **Emiss** **before**)

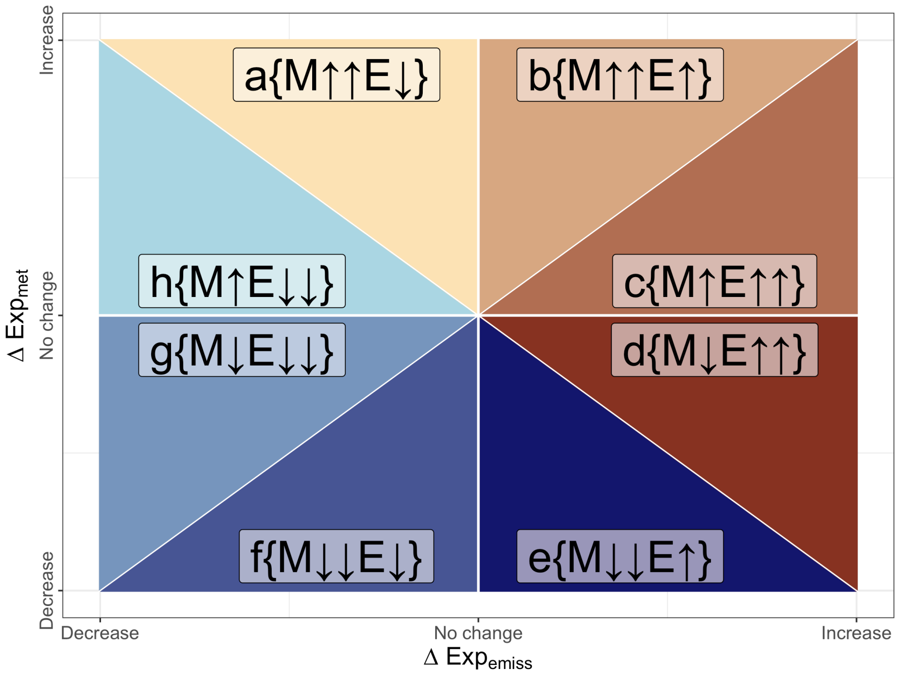
ΔExposure$_{met}$ = *f* (**Met** **before** | **Emiss** **before**) − *f* (**Met** **after** | **Emiss** **before**)

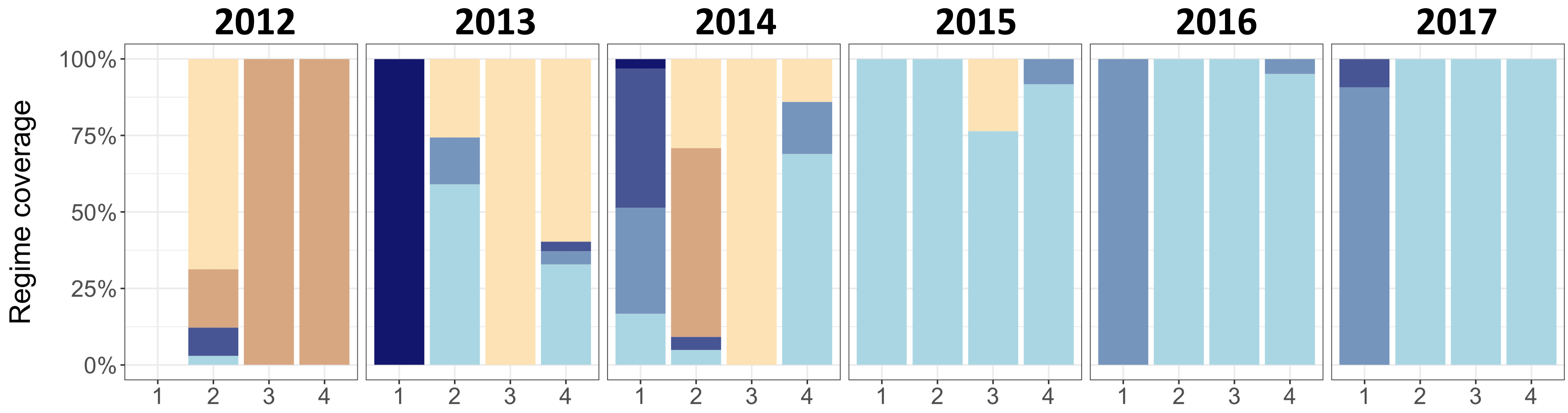
ΔExposure$_{emiss}$ = *f* (**Met** **after** | **Emiss** **before**) − *f* (**Met** **after** | **Emiss** **after**)

Henneman *et al*. 2019 *Env. Res. Letters*

Changes in Louisville exposure

- HyADS change relative to 2012, first quarter
- HyADS exposure changes before 2015 primarily attributable to meteorological variability

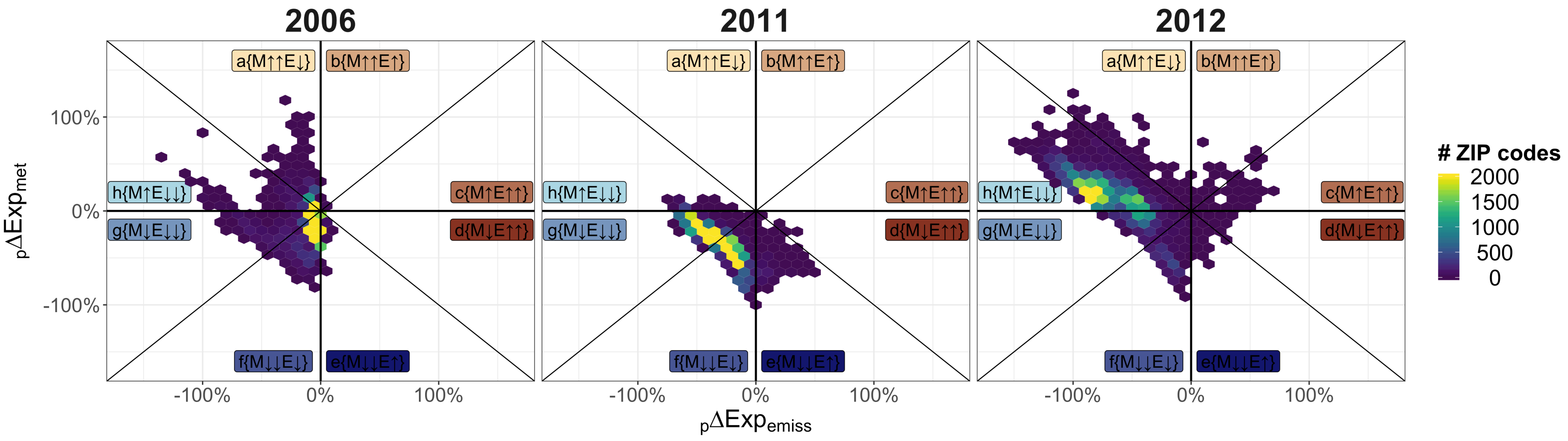




Henneman *et al.* 2019 *Env. Res. Letters*

Attributing changes national exposure to emissions/meteorology

- Meteorology plays role in who benefits from emissions reductions
  - ΔMeteorology led to **<u>smaller</u>** ΔExposure, 2005-2011
  - ΔMeteorology led to **<u>larger</u>** ΔExposure, 2005-2012
- Attributed to greater recirculation winds around the continent in 2012



Henneman *et al.* 2019 *Env. Res. Letters*

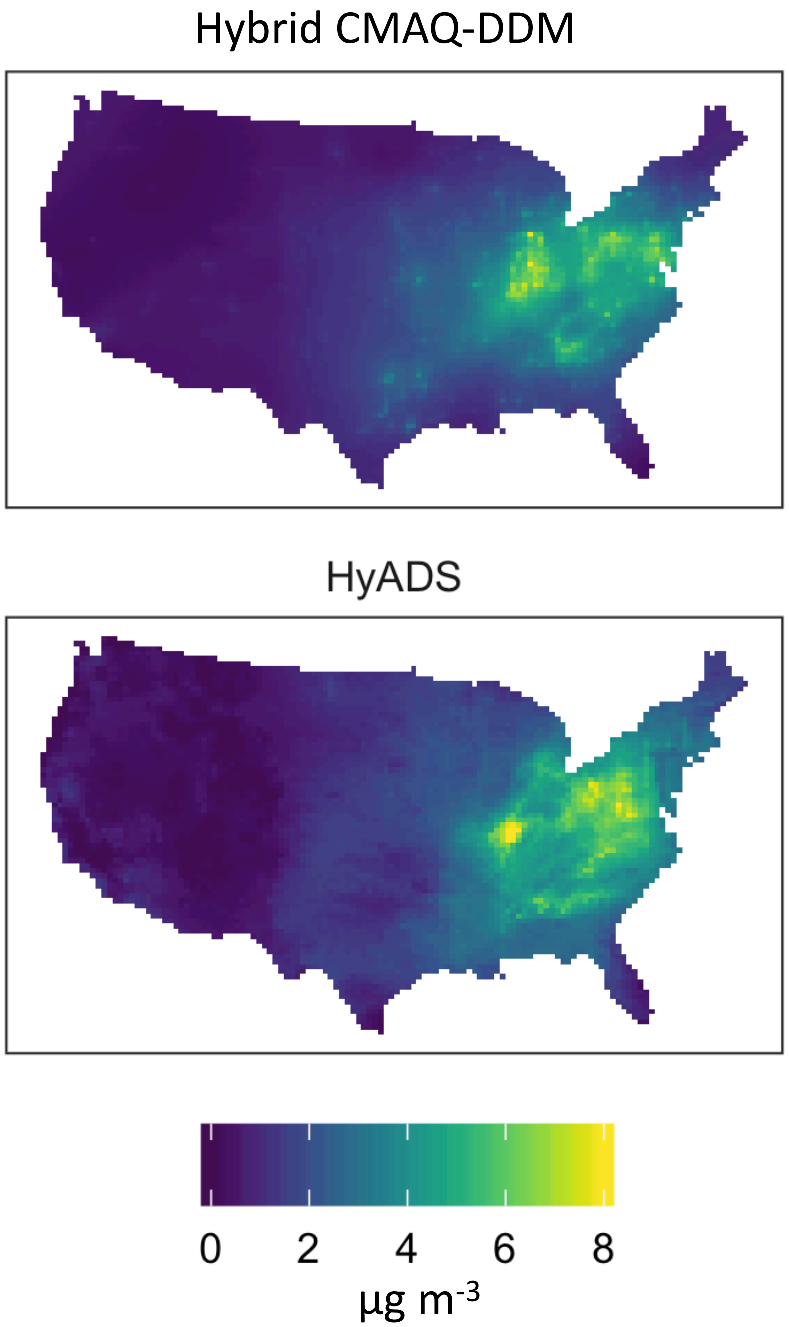
In the works – conversion to μg m^{-3}

- Primarily based on Hybrid CMAQ-DDM
- Accounts for monthly trend, precipitation, temperature

- Annual NMB: 11%
- Annual NME: 22%
- Annual R^2: 0.88

The goal: alternative interpretation of HyADS

(Not to reproduce CMAQ-DDM)



Conclusions

- HyADS – reduced complexity, but…
  - Nimble way to create source-receptor matrix
  - Captures spatial-temporal variability important for environmental health research

- National health benefits achieved through coal emissions reductions
- Asthma reductions in Louisville following multiple interventions
- Meteorology has substantial impacts on calculated benefits

- HyADS currently available as R package

www.github.com/lhenneman/hyspdisp

References

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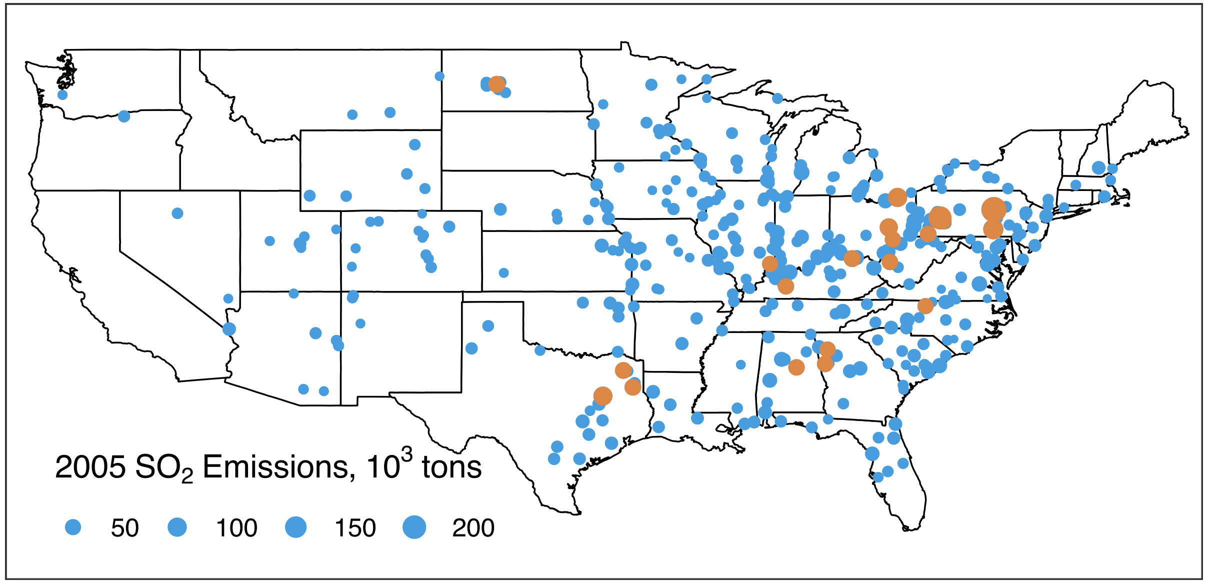
Extra slides

Large reduction in emissions from United States coal power plants

Coal facilities in operation, 2005



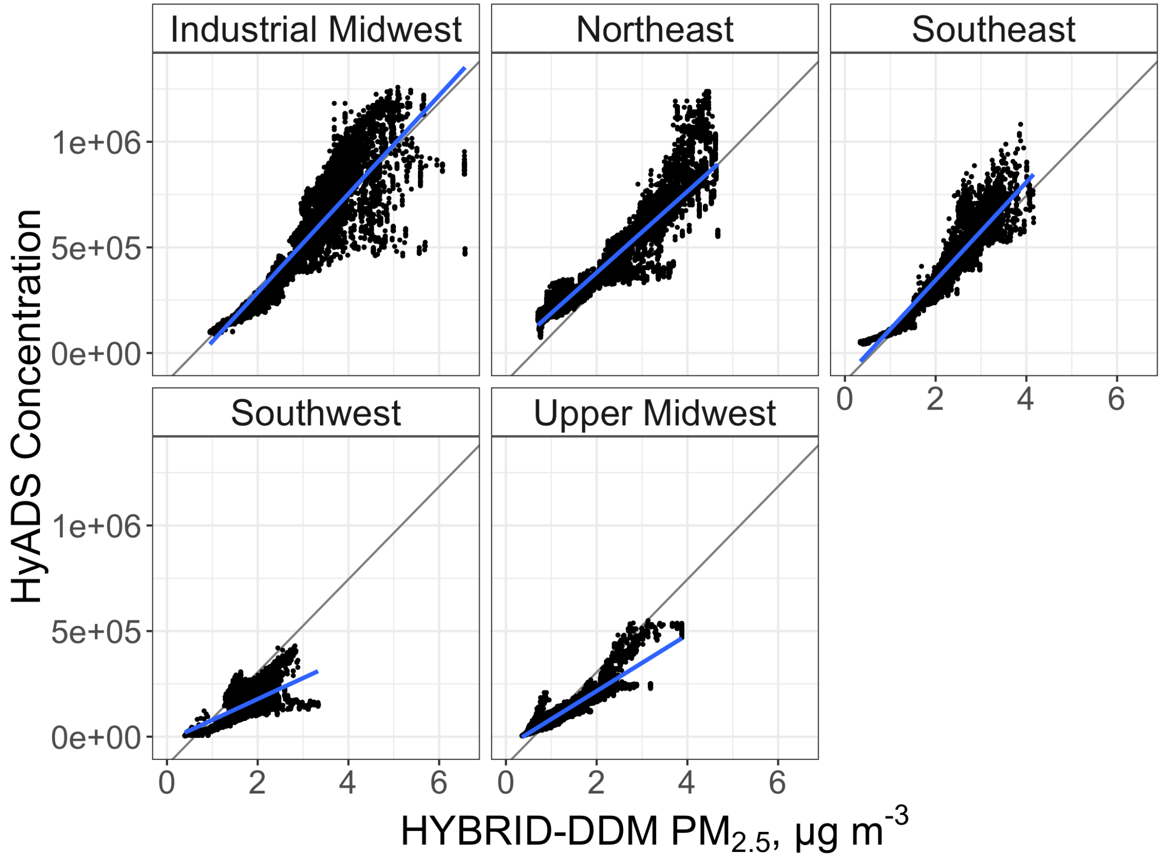
25 largest facilities

- ~ 1,000 coal electricity generating units (power plants) operating in 2005 and 2012
- SO_2 emissions decreased 65% between 2005 and 2012
- Interventions are costly ($10's of billions year^{-1})

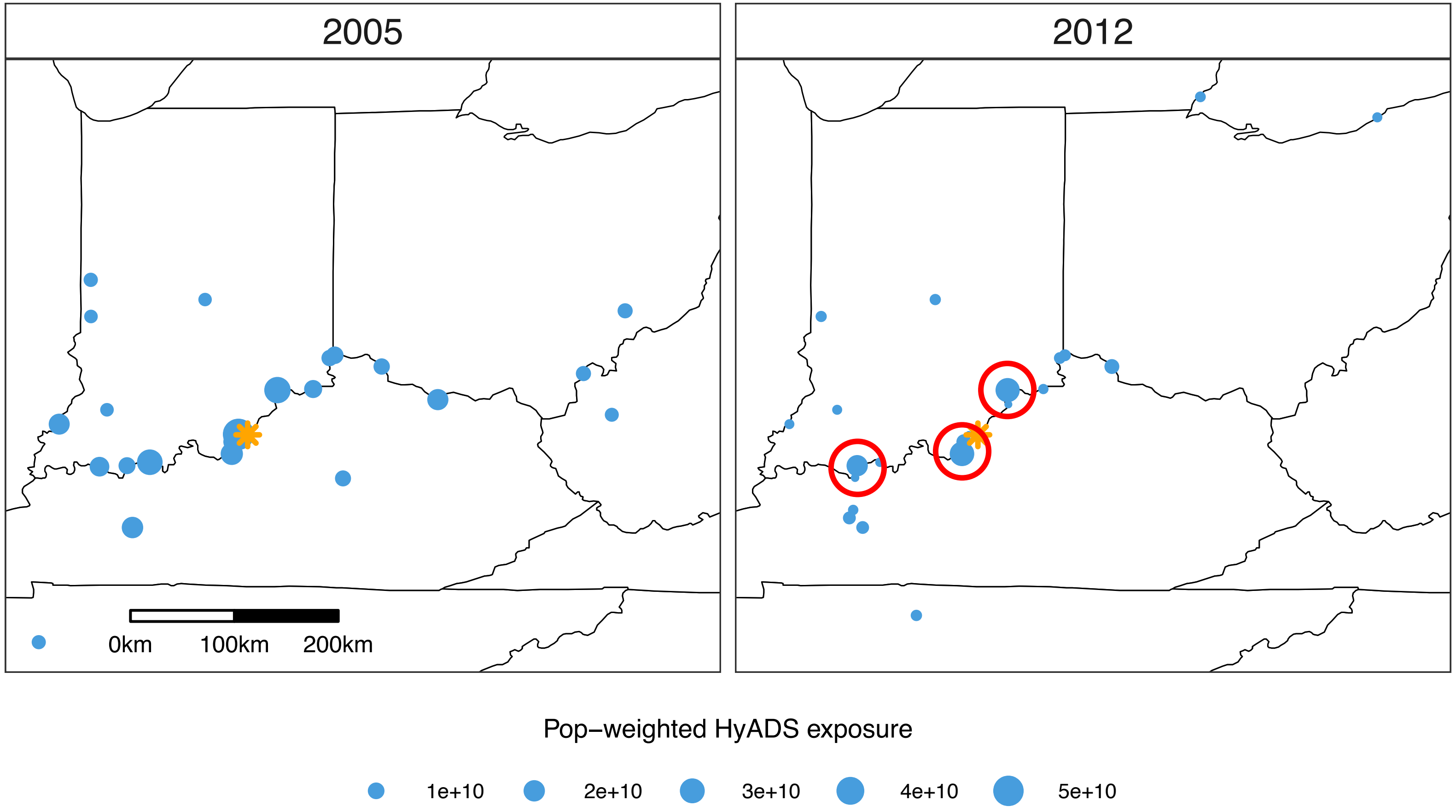
https://www.flickr.com/photos/wigwam/2630349031

HyADS Evaluations: Regional comparison with CMAQ-DDM hybrid sensitivities

- Application-specific evaluation important for reduced complexity models
- CMAQ-DDM hybrid $PM_{2.5}$ coal sensitivities seen as gold standard
- High correlation in all regions



Ranking facilities by population-weighted impact in Louisville, KY



- Top 20 facilities that impact Louisville are spread through the Midwest
- Three facilities with large impacts remained in 2012