Dynamically controlling daily power plant emissions to avoid ozone exceedances: Coordinating air quality forecasts with electricity dispatch models

Evan Couzo[1*], James McCann[1], Nick Johnson[2], Clayton Barrows[2], Seth Blumsack[2], William Vizuete[1], Kirk Baker[3], and Jason West[1]

[1]University of North Carolina at Chapel Hill, [2]Pennsylvania State University, [3]US EPA
*now at Massachusetts Institute of Technology

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

PENNSTATE 1855

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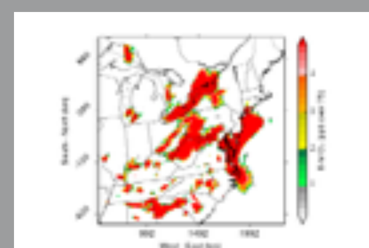
Motivation for dynamic air quality management

- Electricity generating units (EGUs) contributed 14% of total anthropogenic NOx in 2013.
- Permanent emissions reduction strategies (e.g. low-NOx burners, stack controls) are expensive.
- Air quality forecasts are routinely used to predict high ozone episodes at least one day in advance, and generally not to influence emissions.
- But air quality forecasts can be coordinated with electricity dispatch models to temporarily shift generation (and emissions) to an area not expected to violate the ozone standard.
- As standards tighten and background concentrations rise, dynamic management could prove more cost-effective.

Ozone and electricity demand forecasts are isolated

The way things are.

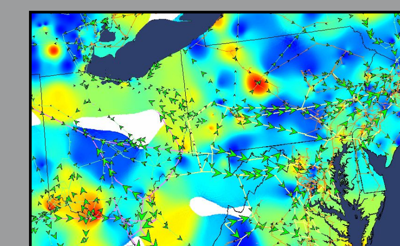
AQ forecast



regional alerts

altered behavior

demand forecast



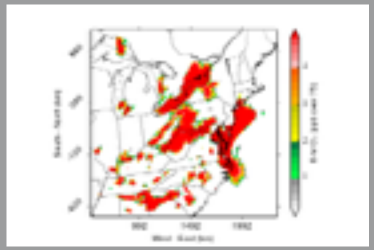
decision rules/ market creation

electricity dispatch

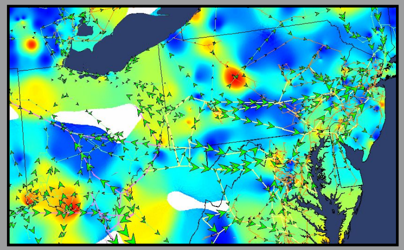
Ozone and electricity demand forecasts are isolated, but don't have to be

A smarter way.

AQ forecast



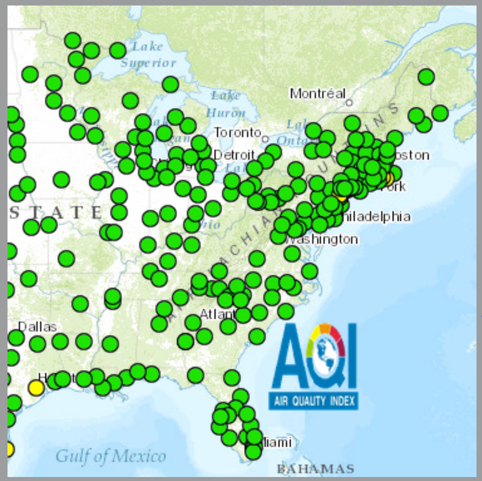
demand forecast



online sensitivity tools

decision rules/
market creation

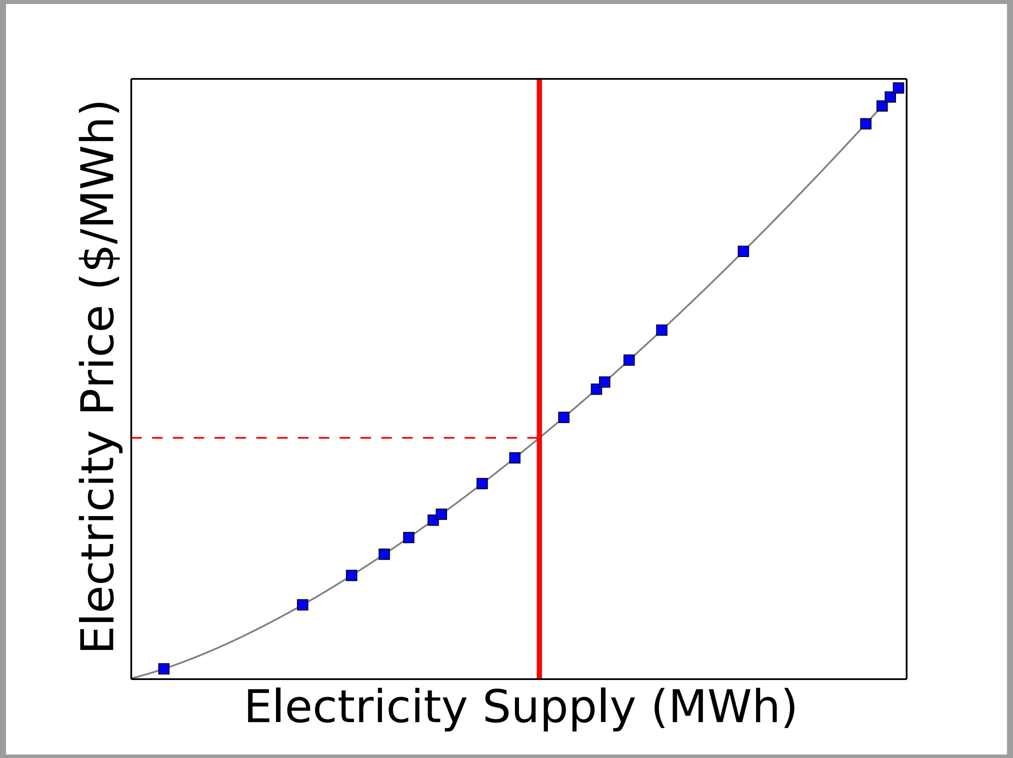
avoided
exceedance



electricity
dispatch

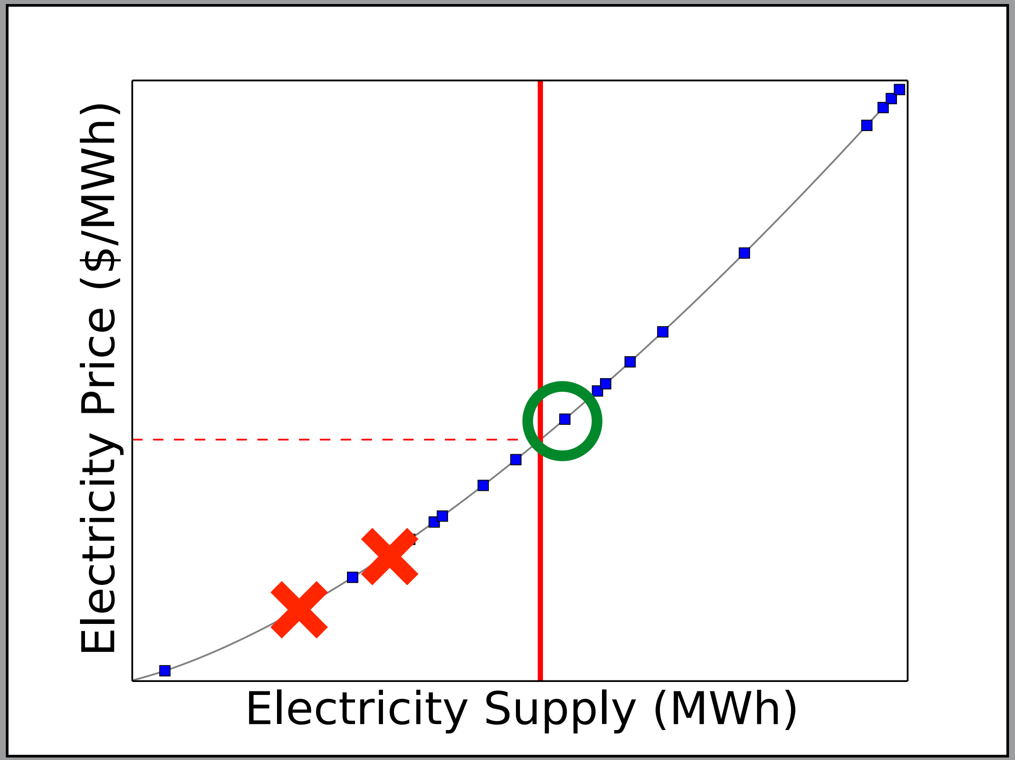
Revising electricity dispatch decision rules

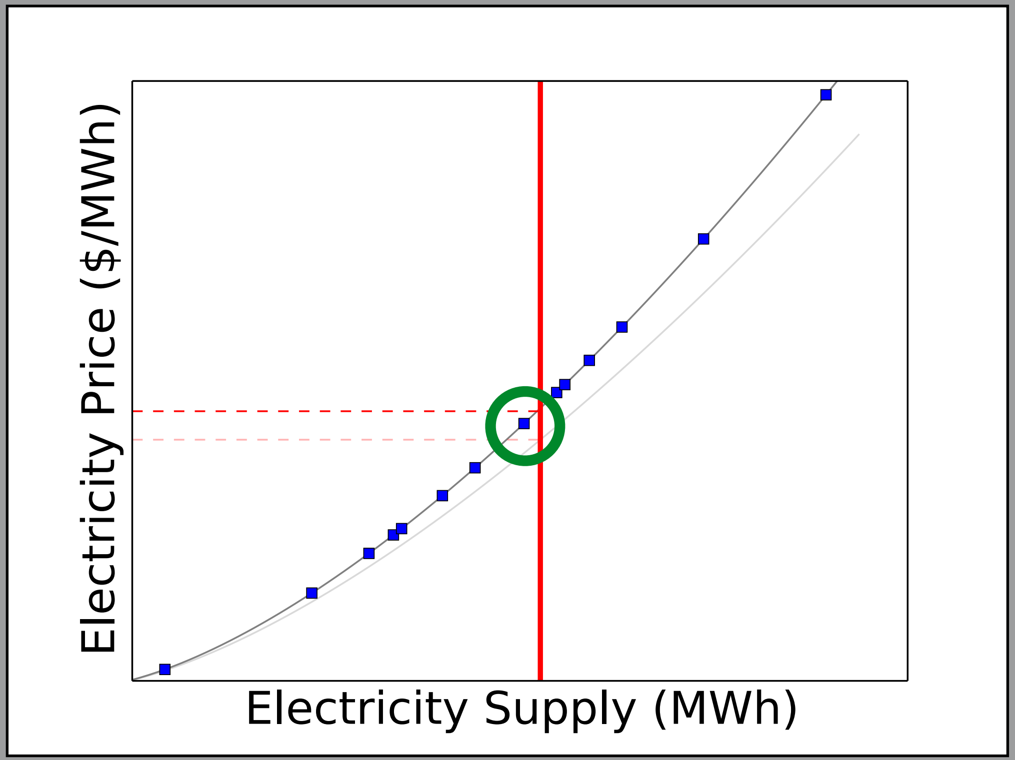
- EGUs submit bids ~one day ahead guaranteeing to supply a quantity of electricity.
- Regional Transmission Operator builds a supply curve and forecasts demand.
- This sets the system marginal price.



Revising electricity dispatch decision rules

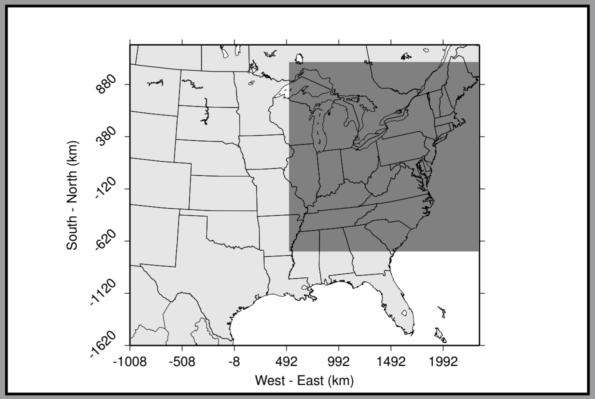
- EGUs submit bids one day ahead guaranteeing to supply a quantity of electricity.
- Regional Transmission Operator builds a supply curve and forecasts demand.
- This sets the system marginal price.
- Implement a rule that eliminates certain EGUs because of their influence on downwind ozone formation.
- Demand curve stays the same, but supply curve shifts.
- System marginal price increases.

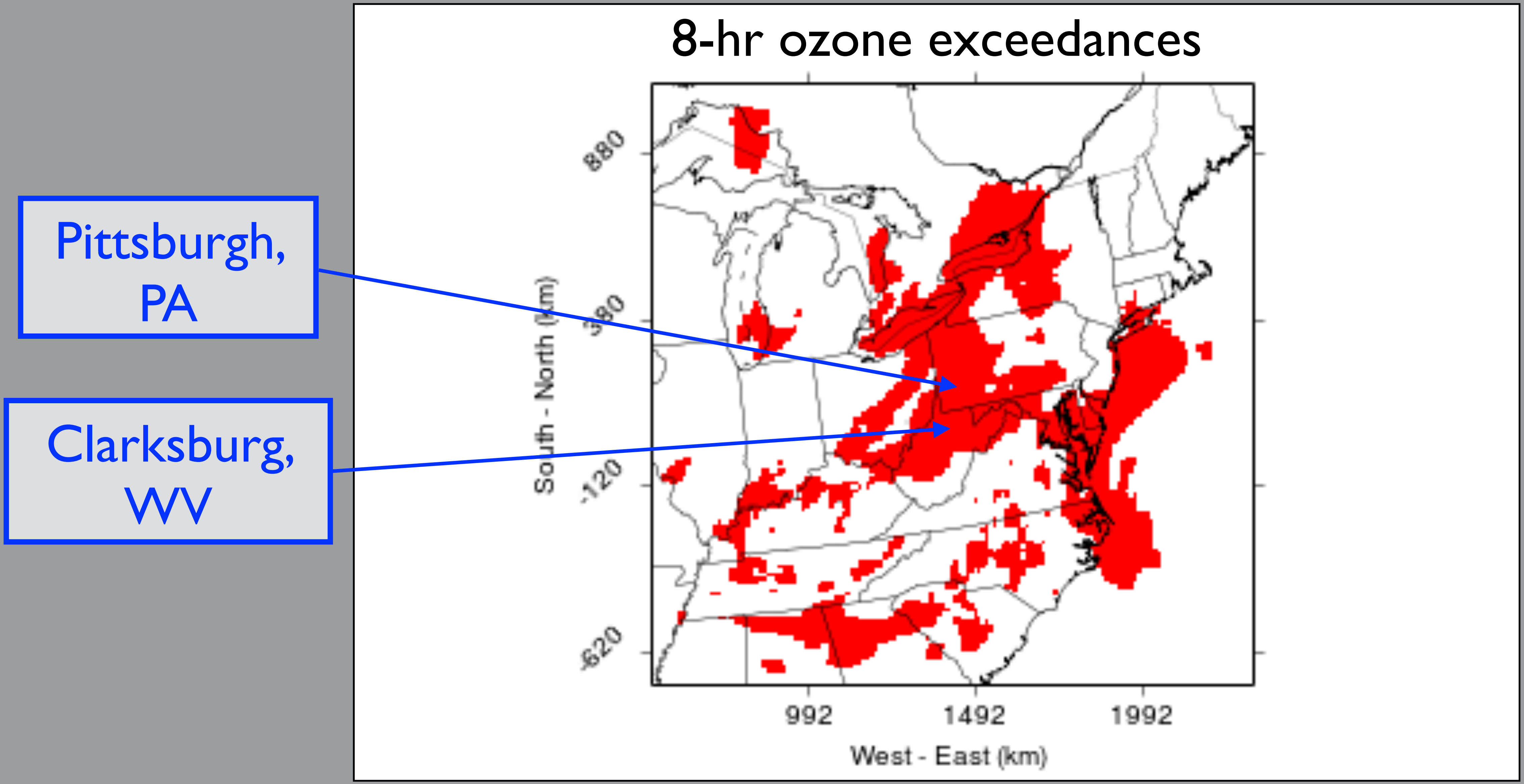




August 4, 2005 - a high O_3 day

- CAMx v5.30 @ 12 km
- developed by US EPA (Transport Rule)
- Carbon Bond V and MM5
- Seven urban regions (only showing two in this presentation)





Research questions

1. What is the maximum effect that EGU NOx has on ozone?

2. Does the timing of the (temporary) EGU shut down matter?

3. Can an online sensitivity tool (direct decoupled method) be used to calculate individual EGU contributions to ozone?

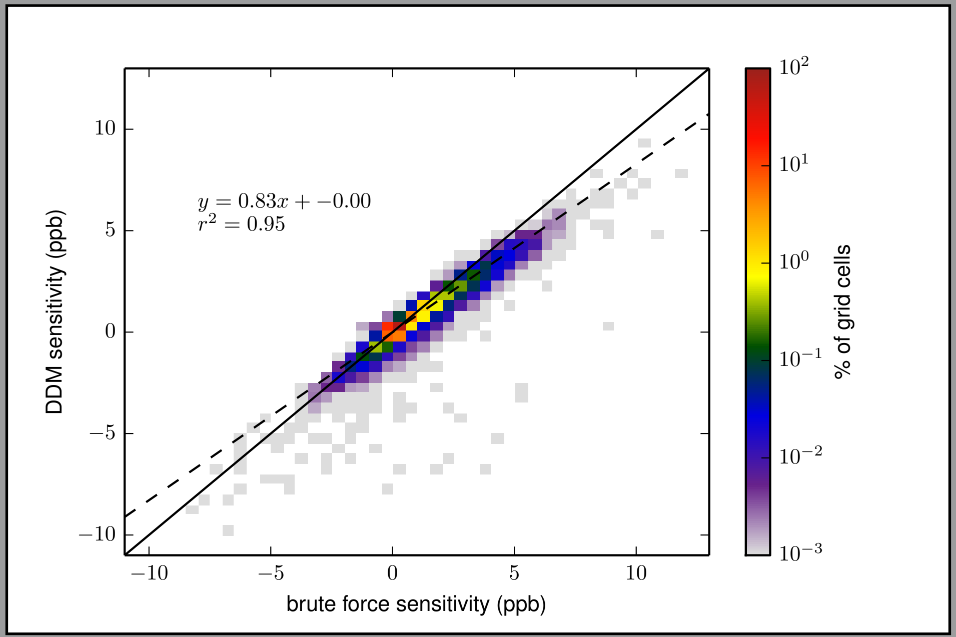
The "brute force" method vs the direct decoupled method

Want to quantify how NOx from 80 EGUs influences ozone production, i.e., want ozone "sensitivity" or "contribution."

domain-wide max 1-hr ozone sensitivity = 19.3 ppb	domain-wide max 1-hr ozone sensitivity = 14.2 and18.8 ppb
brute force	**DDM**
• Select EGUs in the model and zero-out all NOx emissions. • Run the zero-out scenario in CAMx. • The difference between the base case and the zero-out model runs gives the ozone contributions from EGU NOx at the selected facilities. • Provides maximum effect with all non-linearities.	• DDM expresses $\partial(O_3)/\partial(NOx)$ as a first-order Taylor series. • HDDM incorporates the second-order term. • DDM/HDDM is an *approximation*. • Need to tag the EGUs in the model and turn on DDM option.

DDM saves time over the brute force method.

- Brute force requires a base case and a perturbation case with 80 EGU NOx sources removed.
- To obtain individual sensitivities from each of the 80 EGUs, a total of 81 model runs are needed.
- DDM can track individual point source sensitivities.
- Thus, the 81 model runs required using the "brute force" method can be condensed to a single DDM run.



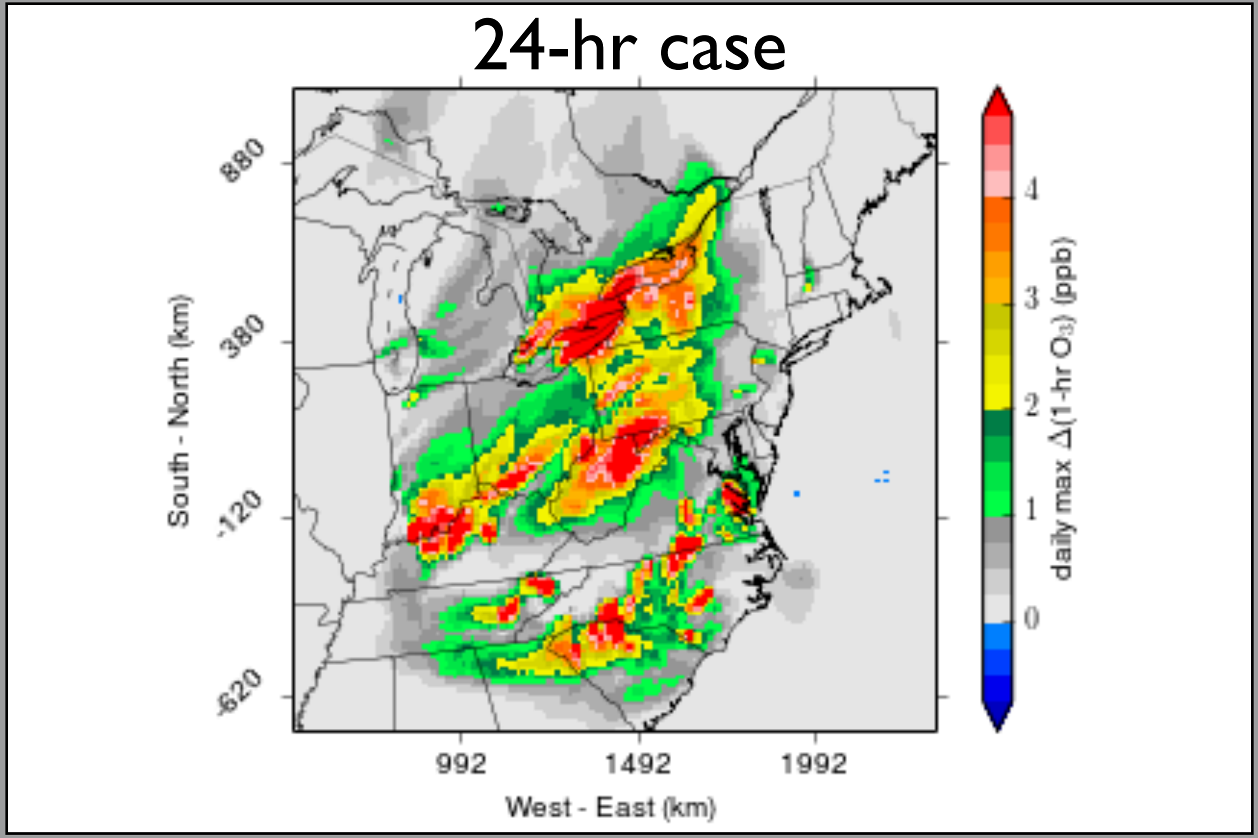
	NMB	NME	r
DDM	-0.195	0.219	0.948
HDDM	-0.102	0.142	0.979

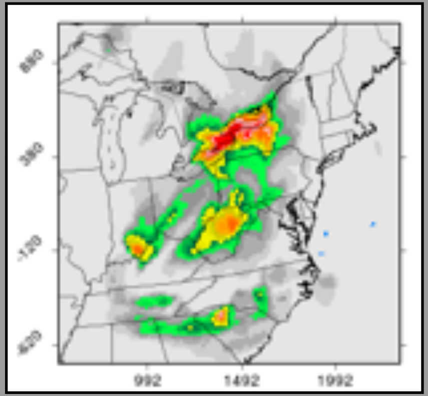
Diminishing returns for longer EGU down time

We simulated full EGU shut down for three time intervals:

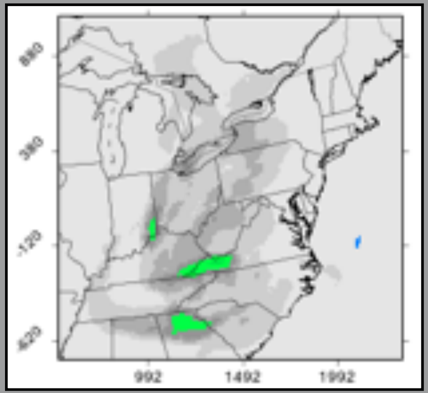
- 12:00 August 3 (**12 hours before** 00:00 August 4)
- 00:00 August 3 (**24 hours before** 00:00 August 4)
- 12:00 August 2 (**36 hours before** 00:00 August 4)

Substantial ozone "benefits" of 24-hr case over 12-hr case not seen when moving to 36-hr case.



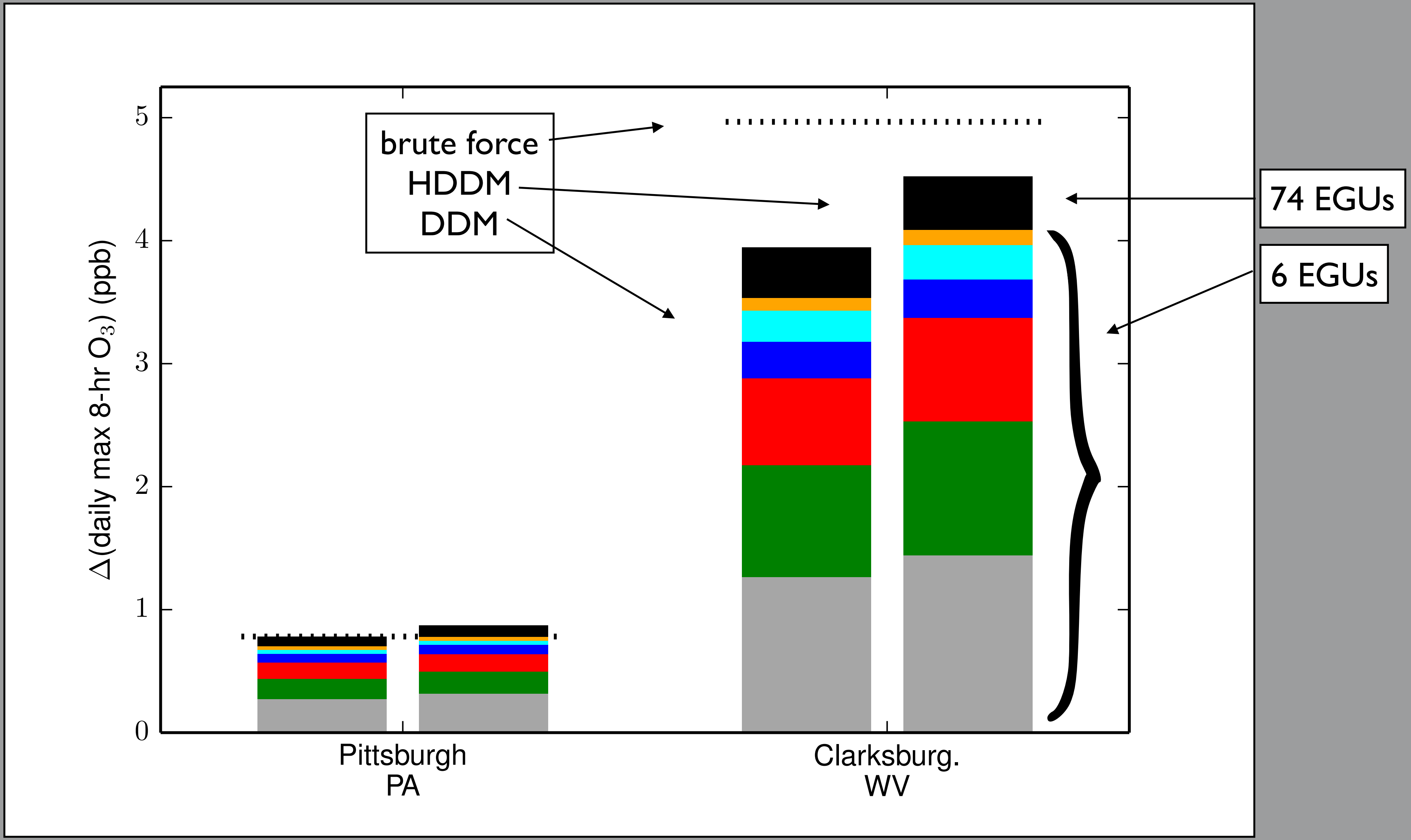


24 hour - 12 hour



36 hour - 24 hour

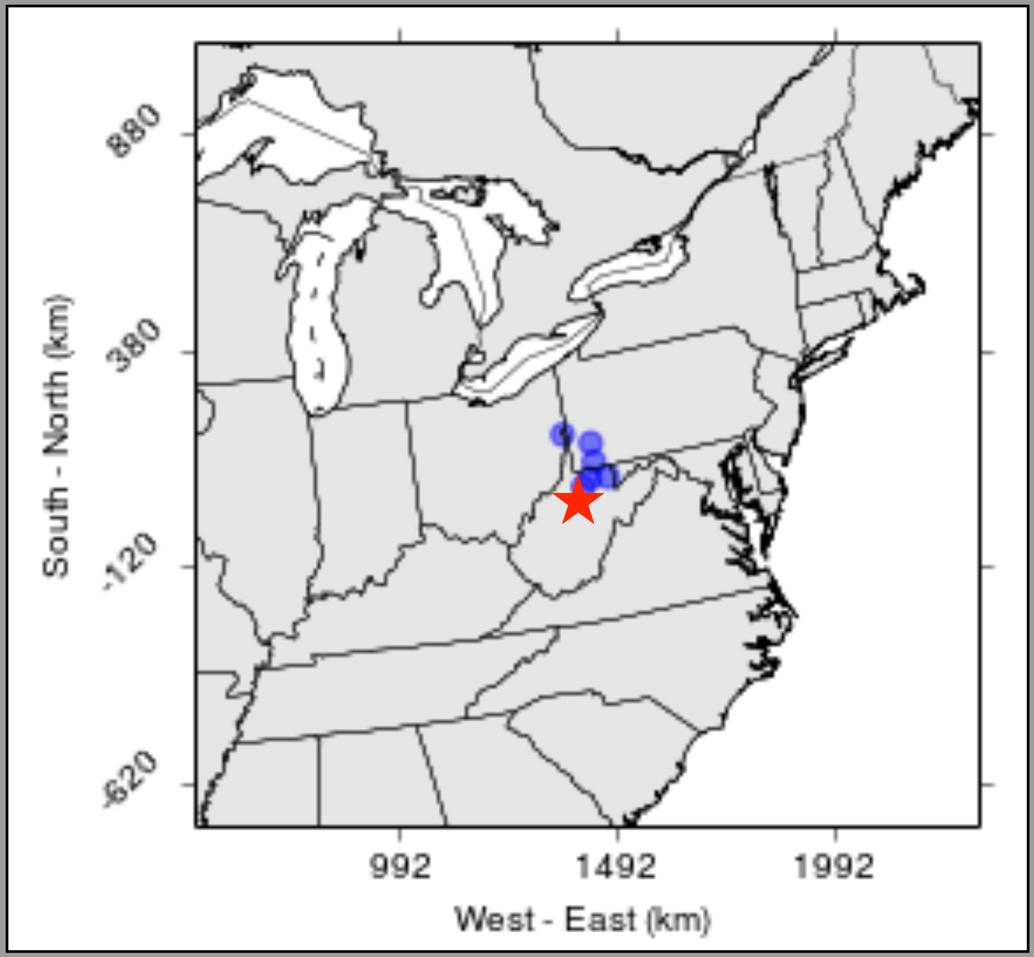
We can identify the contributions of individual EGUs



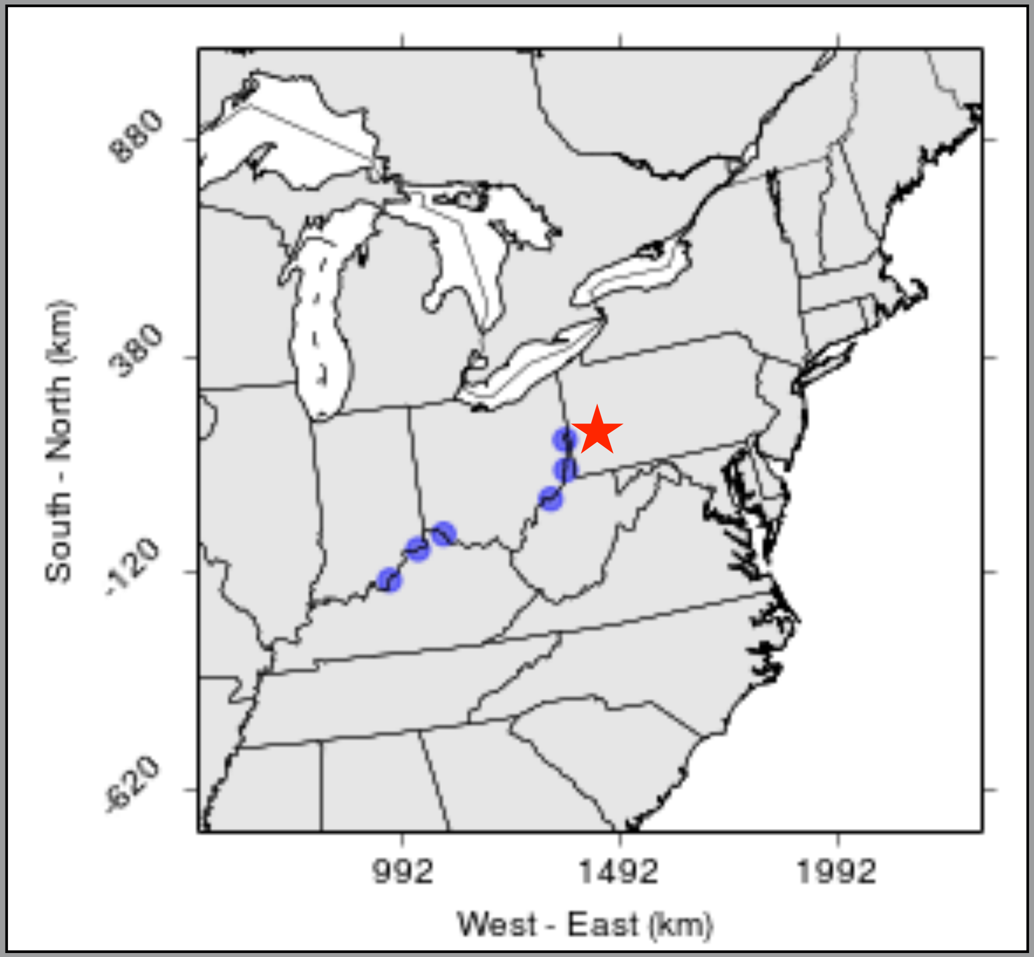
- Results for a 24-hr shut down.
- Sensitivities are dominated by six or fewer EGUs.
- At most, only 27 EGUs (out of 80) contribute more than one ppt to daily maximum 8-hr ozone in any single region.
- In many cases, DDM/HDDM underestimates total sensitivity.

Two clusters of EGUs are most influential on August 4

Clarksburg, WV



Pittsburgh, PA



Shutting down these six plants at 00:00 on Aug. 3 would result in 8-hr ozone reductions (on Aug. 4) of:

	Clarksburg, WV	Pittsburgh, PA
DDM:	3.5 ppb	0.90 ppb
HDDM:	4.1 ppb	0.89 ppb

Decision rules for grid management

We are now modeling different decision rules for selecting power plants to shut down and achieve desired ozone reduction:

- In order of sensitivity to peak ozone, $\partial(O_3)/\partial(NOx)$
- To minimize electrical system costs

$$\partial(\text{cost})/\partial(O_3) = [\partial(\text{cost})/\partial(NOx)] / (\text{ozone sensitivity})$$

Evaluating several impact metrics: total system cost; ozone exceedance reductions; impacts on ozone and $PM_{2.5}$ caused by redispatching; grid system reliability with respect to transmission capacity; and system GHG emissions

Conclusions and future work

- Specific findings
  - 8-hr reductions of up to 4.5 ppb.
  - Few EGUs dominate ozone sensitivity for a given region.
  - Reductions 24-hrs in advance in the "sweet spot."
- Currently using this framework to analyze another high ozone episode and conducting a detailed economic analysis.
- On-going economic analysis will provide system cost of grid management, impacts on air quality, and grid reliability.
- If dynamic management strategy proves cost effective, online sensitivity analysis tools could become a standard feature of air quality forecasts.