Dynamic Electricity Generation for Addressing Daily Air Quality Exceedances in the US

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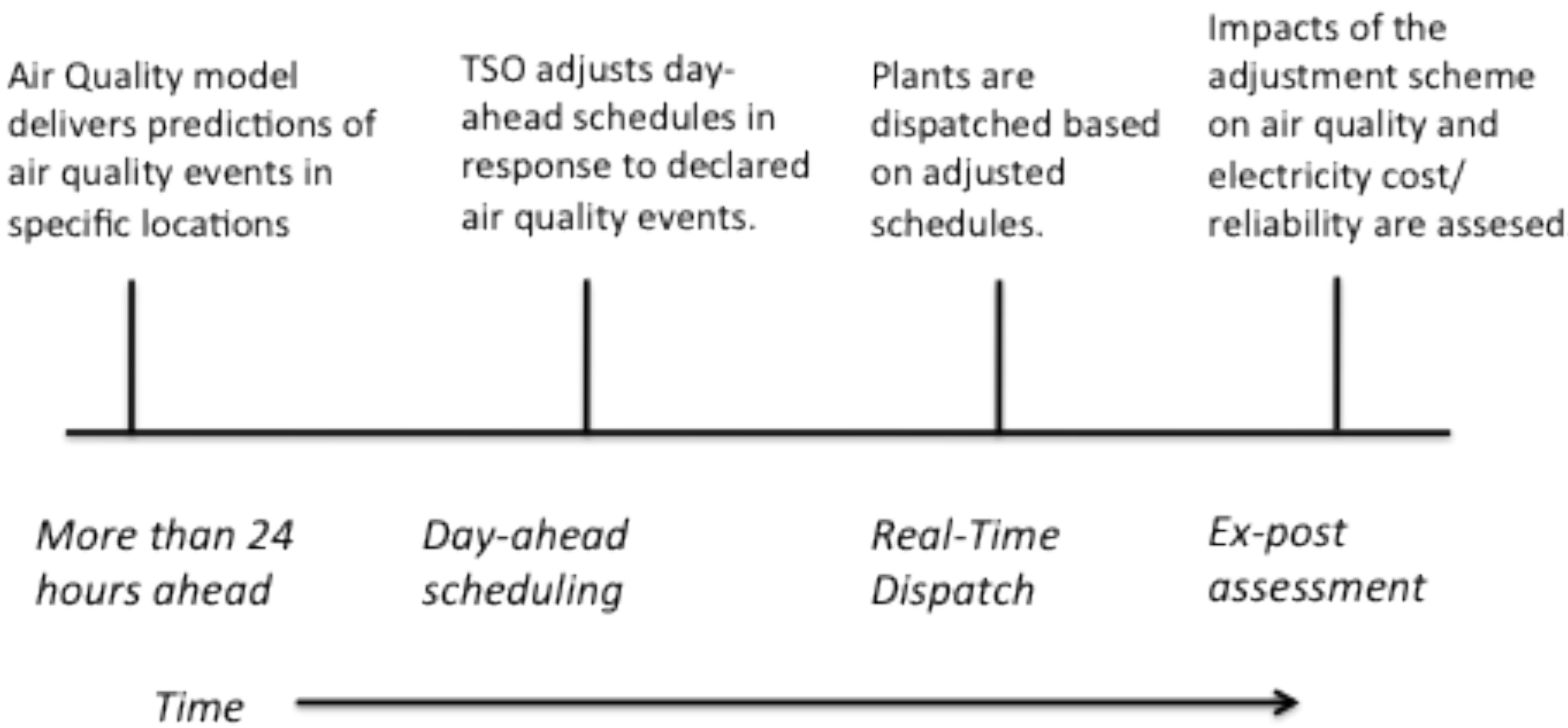
Motivation

1) Air quality is forecast daily in the US.
   - Forecasts are used to alert the public, but not generally to change polluting activities.
2) Many urban areas violate the 8-hr. daily maximum ozone standard.
   - Violations of the standard are damaging to public health and the environment.
   - Meeting the standard is costly and challenging.
3) Electric power plants contribute significantly to air pollution:
   - 18% of total US anthropogenic NO_x and 66% of SO_2 in 2008.
4) Electric power plants are managed daily to meet electrical grid demands at least cost.

A dynamic electricity system to avoid daily ozone exceedances



Objectives

1) Design a dynamic electricity management system that incorporates air quality forecasts, with a goal of avoiding daily ozone exceedances in the eastern US

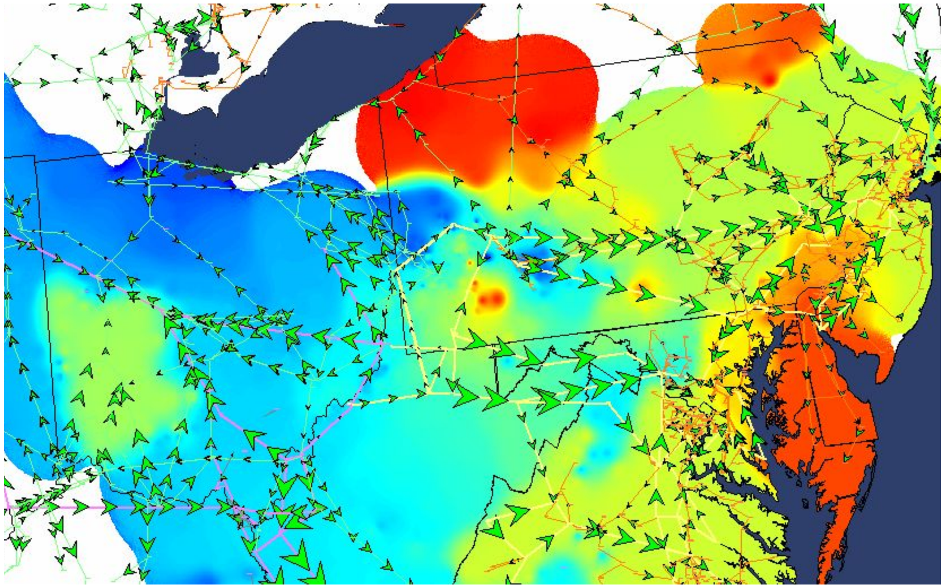
2) Demonstrate this dynamic electric system for selected episodes from the recent past, evaluating operation choices.

3) Demonstrate this system over an entire summer season, where we assume air quality forecasts are perfect, and where forecast uncertainties are incorporated.

Questions for system design and evaluation

1) What decision rules should grid operators use to try to avoid ozone exceedances? Hard constraints vs. cost functions? How stringent?
2) How sensitive is peak ozone to NO_x emissions from power plants? How effective would controls on local plants be? What time and spatial scales of controls would be best?
3) How can air quality forecast models use online sensitivity techniques to best forecast sensitivities to power plant NO_x?
4) How would the costs of a dynamic system compare with the costs of selective catalytic reduction units, for comparable improvements in ozone metrics?
5) How would ozone and $PM_{2.5}$ change over the whole eastern US, and would there be effects on system-wide GHG emissions and reliability?

Approach

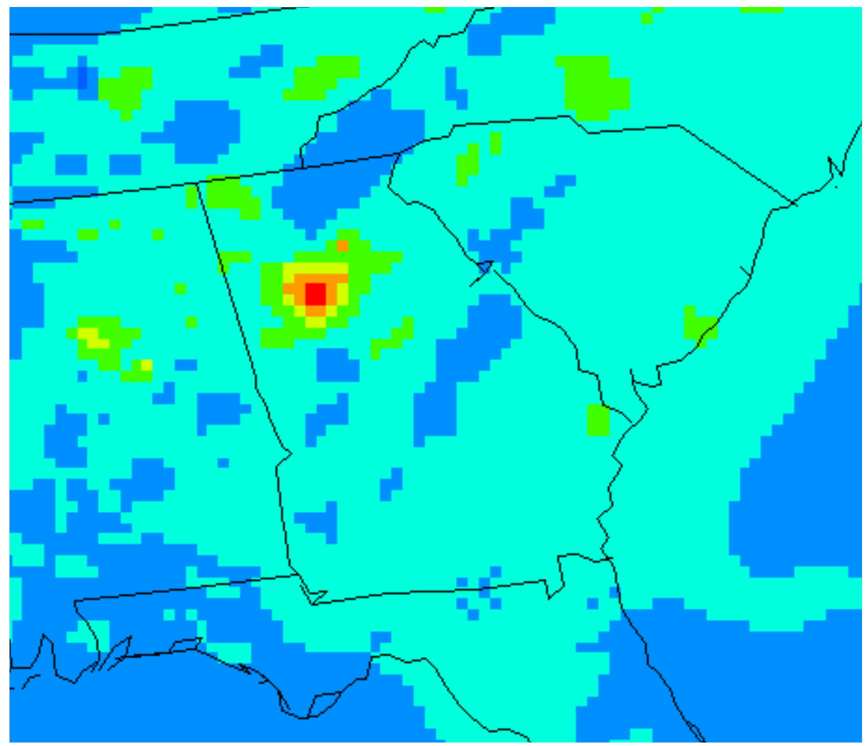


Electrical grid model

least-cost plant dispatch to meet grid demand

CAMx air quality model

emissions → concentrations



Use of air quality online sensitivity

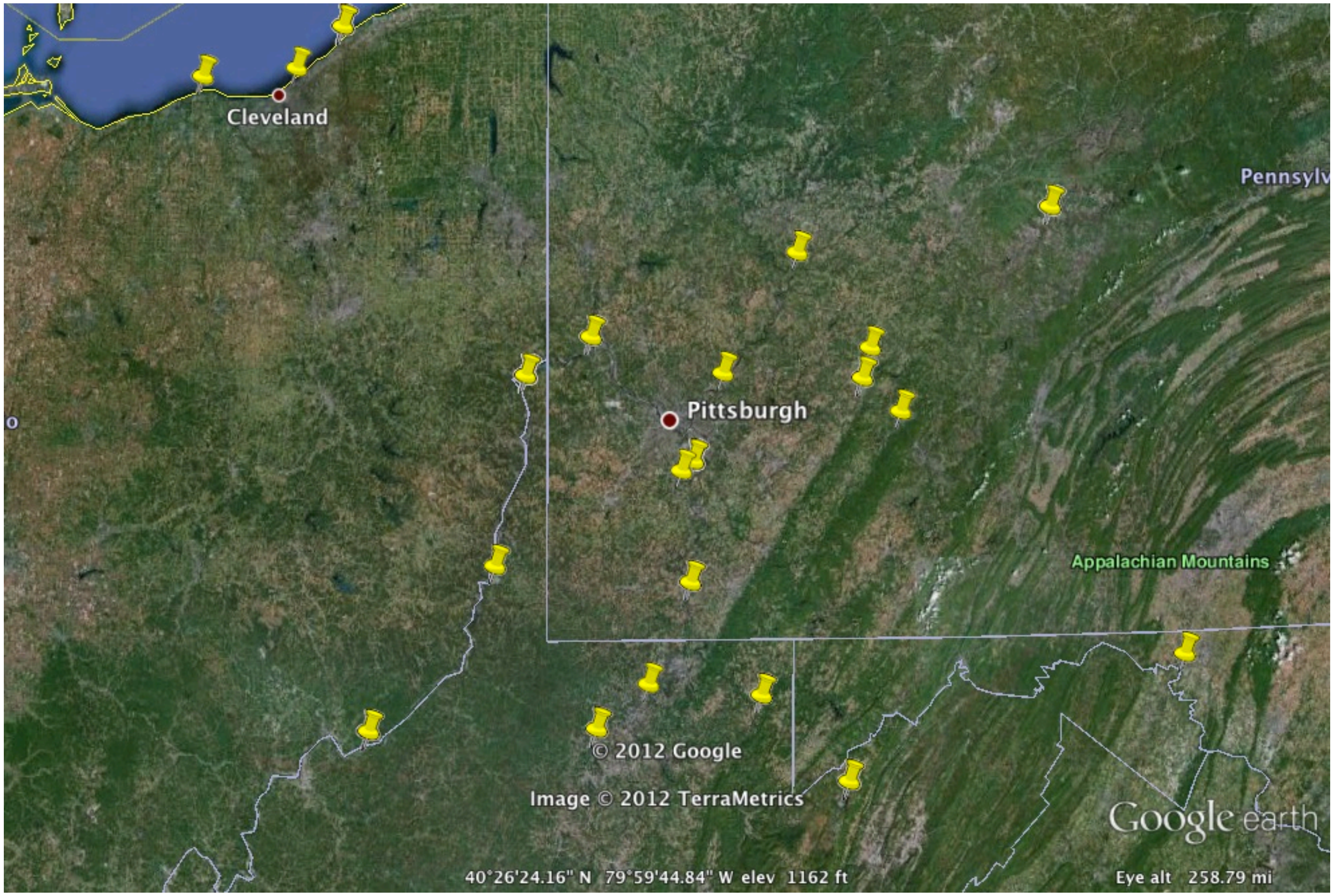
- We are using online sensitivity tools to indicate the sensitivity of ozone to NO_x from individual power plants.

- DDM in CAMx – we can now run DDM on 100s of individual power plants, running CAMx in parallel on multiple processors.

- We will recommend that online sensitivity tools be used in air quality forecast models, to support dynamic management.
  - We will investigate options to make online sensitivity practical.

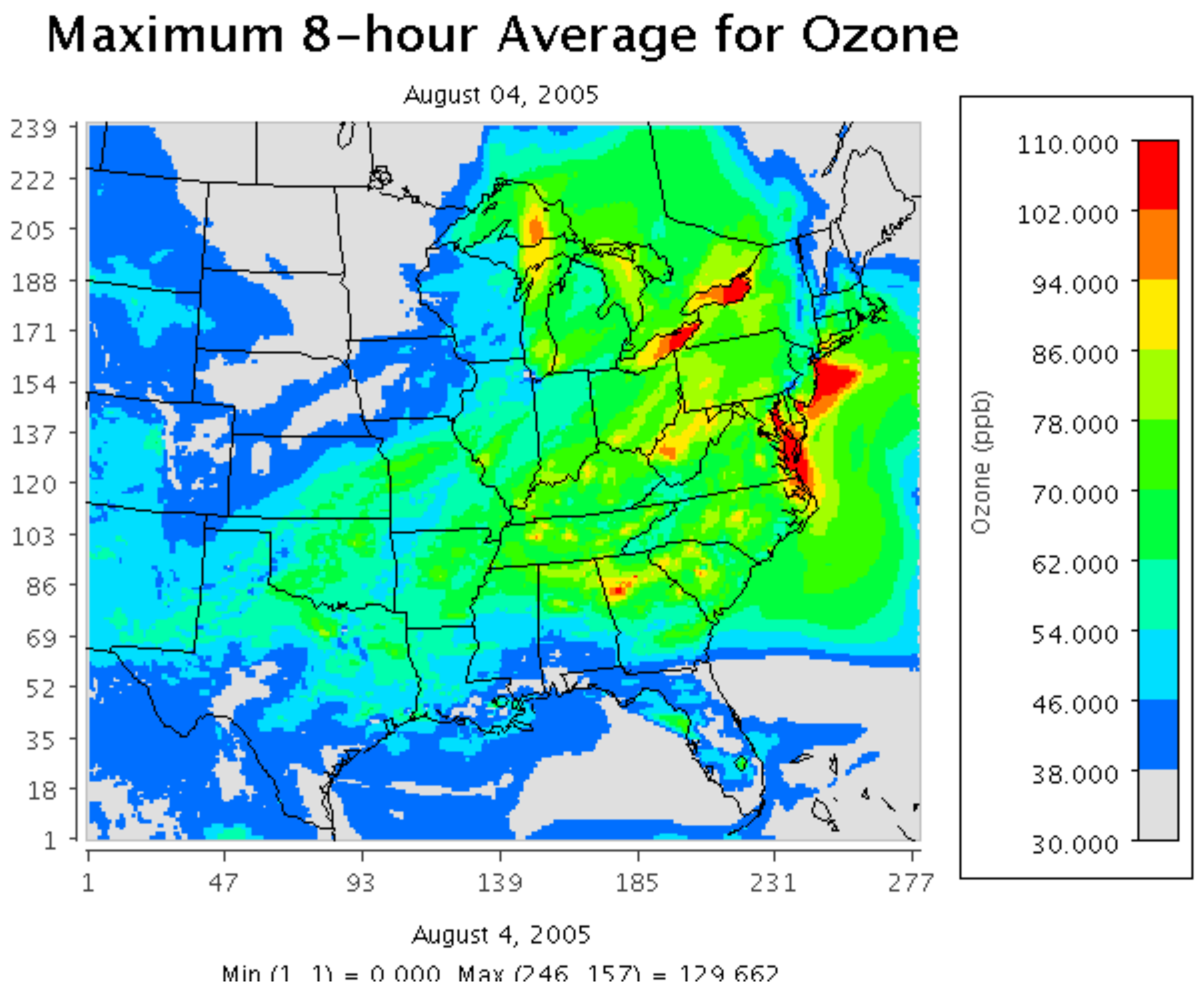
- Side Project: Evaluate DDM estimates of sensitivity versus ex-post analysis with model runs.

Example Episode: Pittsburgh, Aug. 4, 2005



Locations of large coal-fired power plants near Pittsburgh.

Example Episode: Pittsburgh, Aug. 4, 2005



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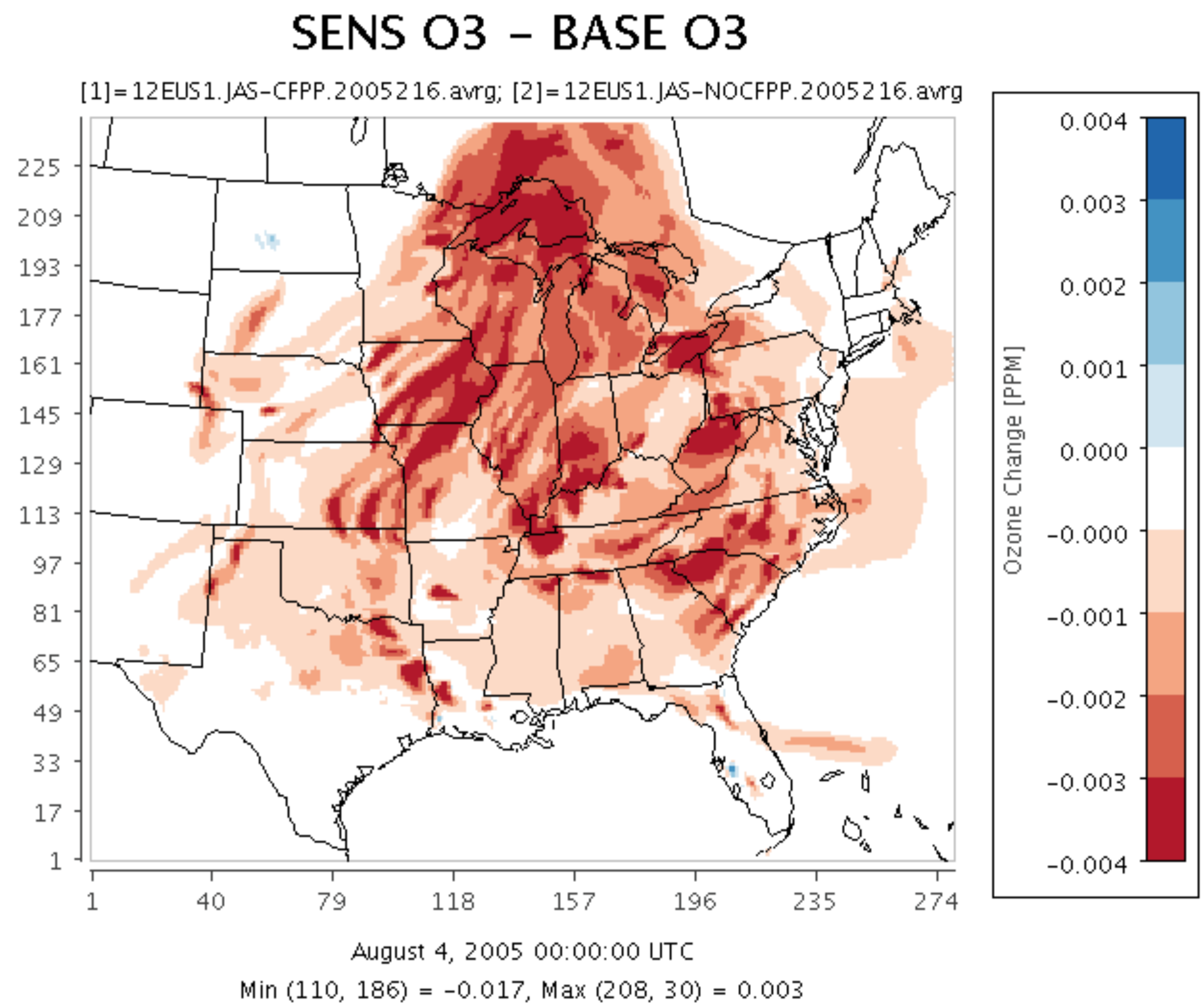
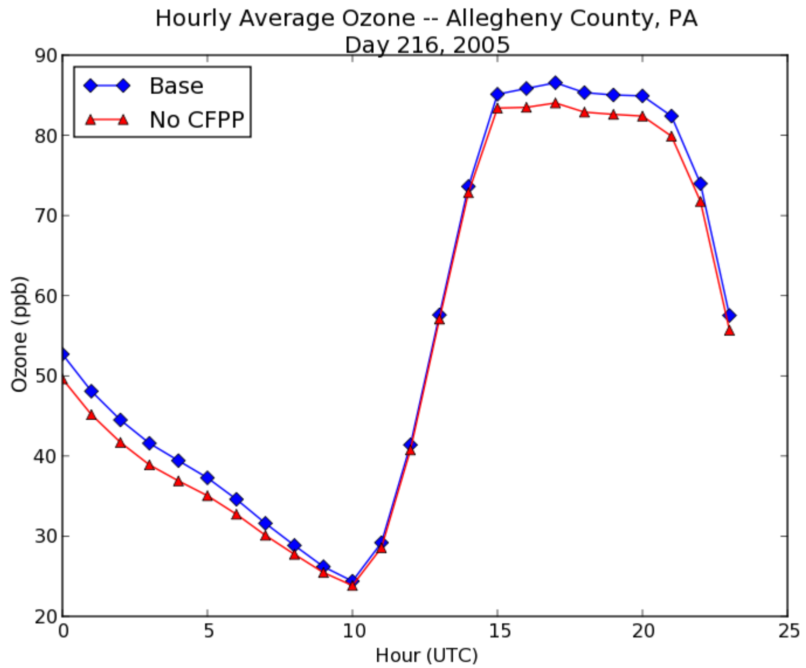
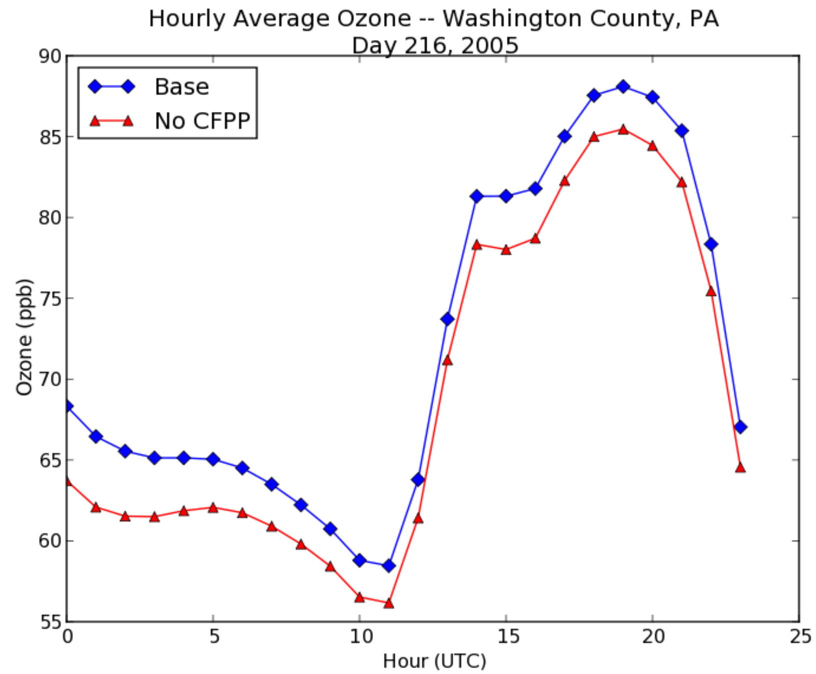


Modeled sensitivity of ozone to all power plants in Eastern US

Example Episode: Pittsburgh, Aug. 4, 2005





Modeled sensitivity of ozone to all power plants in Eastern US

Grid Modeling: Optimal Power Flow

$$\min_{P_{Gi}} \sum_i C_i(P_{Gi})$$

Minimize total production costs

$$s.t.$$

$$\sum_i P_{Gi} = \sum_i P_{Li}$$

Energy balance (supply = demand)

$$g(x) = 0$$

Kirchhoff's Laws

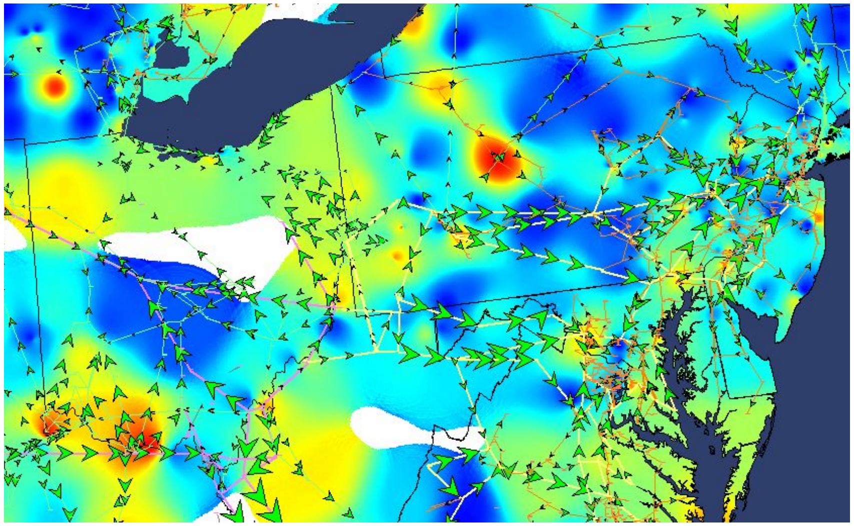
$$h(x) \leq 0$$

Operational constraints

Grid Modeling: Data Sources

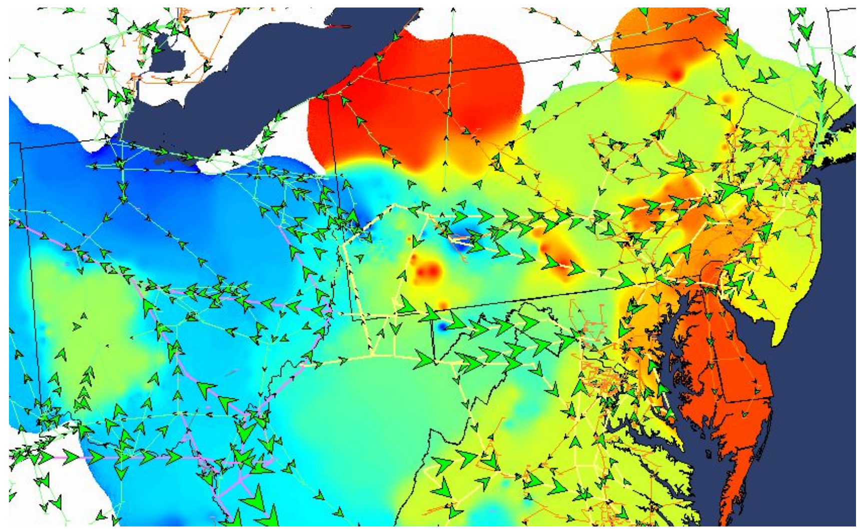
- FERC Form 715 contains information on grid topology and locational demand profiles for peak/off-peak cases
- Commercial simulators (e.g. Powerworld) include some production cost models for generators
- Average emission factors (units NOx per MWh)

Grid Modeling: Outputs



Least-cost generation dispatch and network loadings

Location-based electricity prices



Operator decision rules

1) Command-and-control policy limiting output from specific generation plants (based on DDM sensitivities, geographic proximity or some other criterion).

2) O_3 sensitivities (dO_3/dNO_x) from DDM can be converted to marginal concentration reduction costs (d\$/dO_3); costs can be used to rank-order plants for curtailment.

3) Adjustment from day-ahead generation schedules represents the minimum-cost redispatch that achieves O_3 concentrations below a threshold.

These rules can vary based on stringency.

Avoid increasing emissions within other regions with high ozone.

Progress & Next Steps

Underway:

- Comparing and reconciling power plant NO_x emissions from the electric grid model and CAMx inputs.
- Rerun base case simulation with reconciled emissions, and with DDM for many power plants.
- Sorting through choices of decision rules.

Next steps:

- Electric grid model and air quality simulations for Pittsburgh, Aug. 4, under multiple decision rules.
- Analyze DDM sensitivities against ex-post simulations.

Longer term goals

- Evaluate an entire summer period with a single decision rule to see:
  - Effectiveness in avoiding air quality exceedances.
  - Changes in O_3 and $PM_{2.5}$ over the whole domain.
  - Changes in GHG emissions.
  - Changes in electrical system reliability.
  - Costs.
  - Compare costs with NO_x reductions by selective catalytic reduction (SCRs) for comparable improvement in metrics.

- Represent air quality forecast uncertainty in the electrical grid optimization.
  - Consider uncertainty in the magnitude of ozone (whether an exceedance) and in the sensitivity to power plants.
  - Consider costs of false positives and of false negatives.