EPA United States Environmental Protection Agency

Challenges in Atmospheric Science and Air Pollution: Directions and Questions for Modelers

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18th Annual CMAS Conference, Chapel Hill, NC
October 21-23, 2019

United States Environmental Protection Agency

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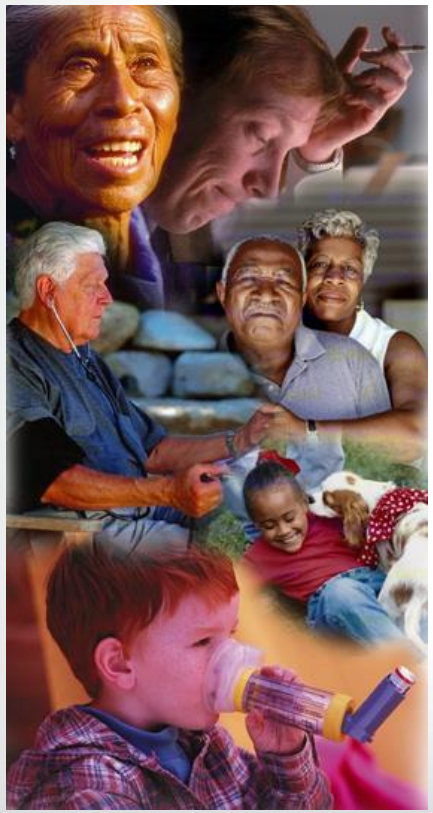
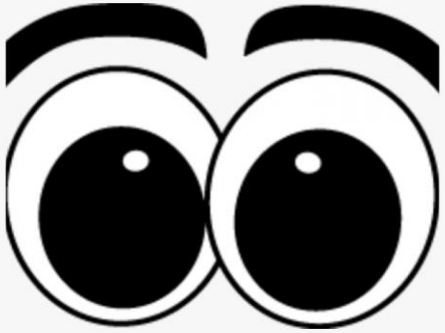
Why do we have air quality models?

- To better understand air quality
- To identify sources of pollution
- To develop strategies to reduce exposure to harmful pollutants
- To inform policy and develop plans for compliance



A Little History

Before we had computer models, we had our senses.



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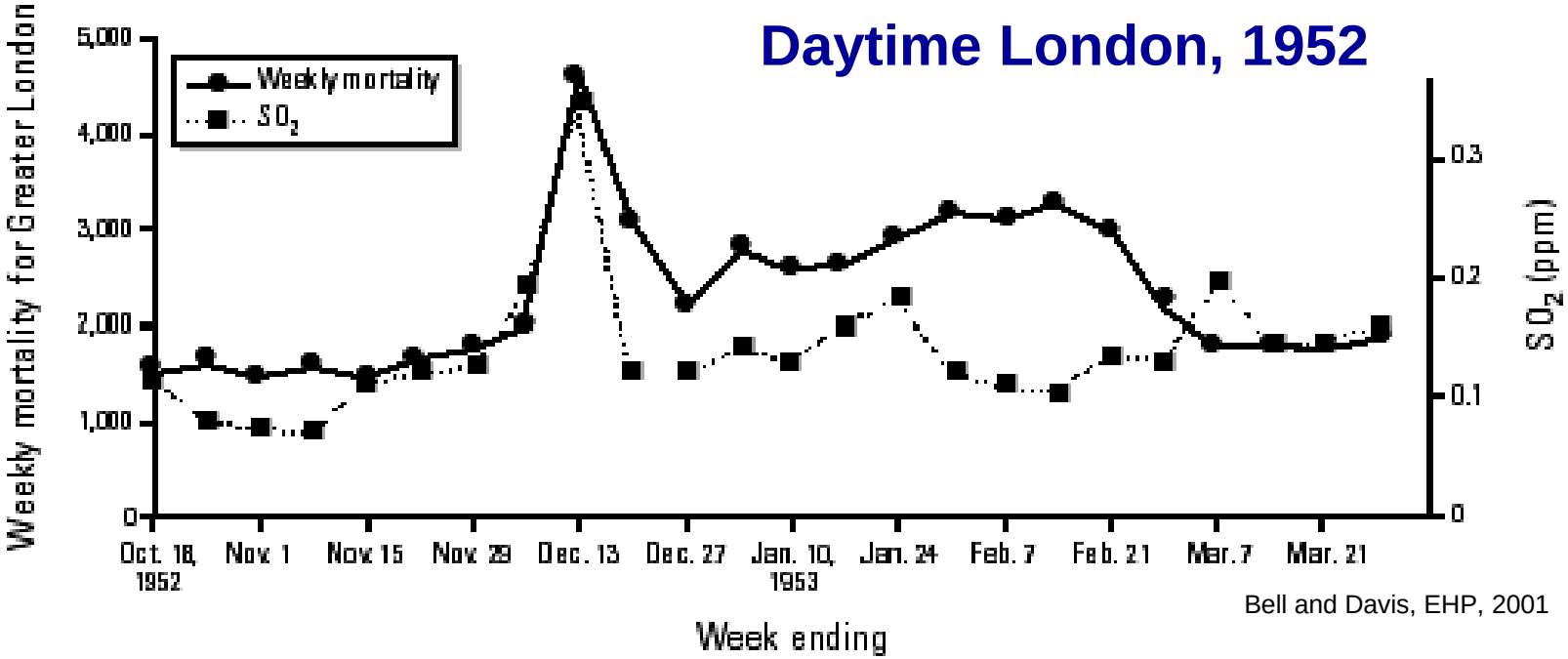
Daytime London, 1952



Bell and Davis, EHP, 2001

- Total Suspended Material reached 1500 $\mu g/m^3$
- 12,000 Excess Deaths Attributed to Event

Photos: Erwin Hampe

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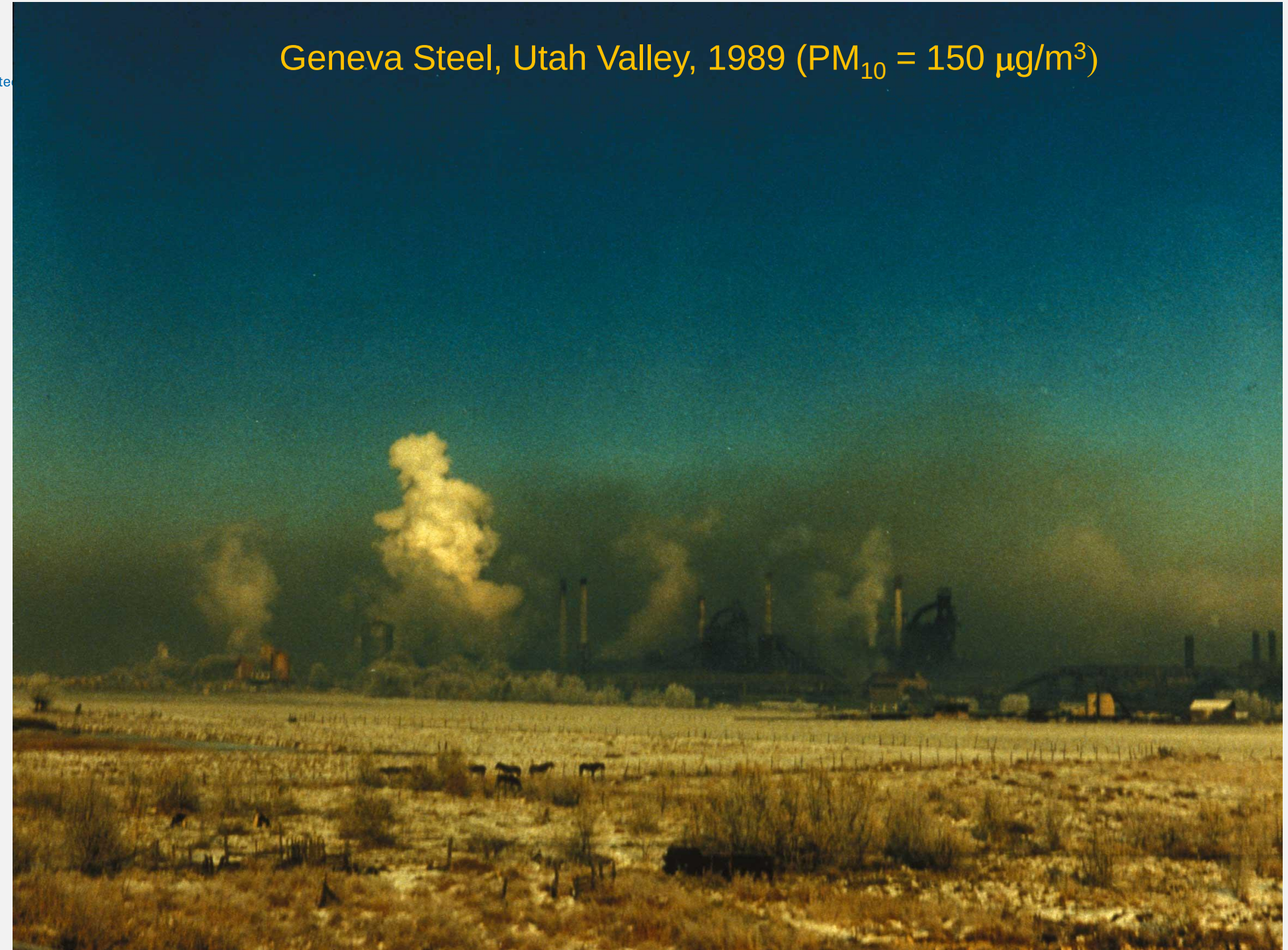
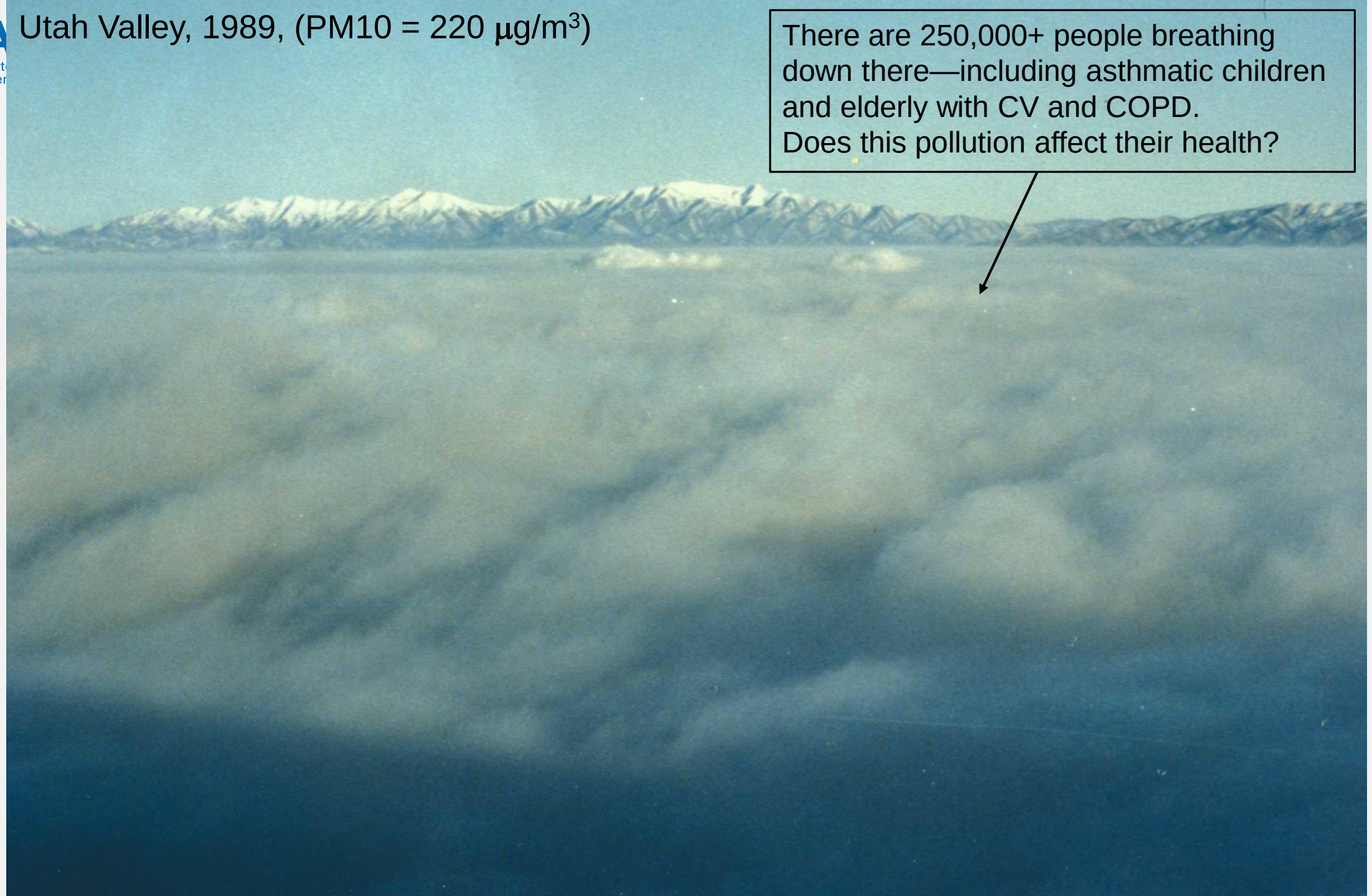
Geneva Steel, Utah Valley, 1989 (PM_{10} = 150 μg/m^3)

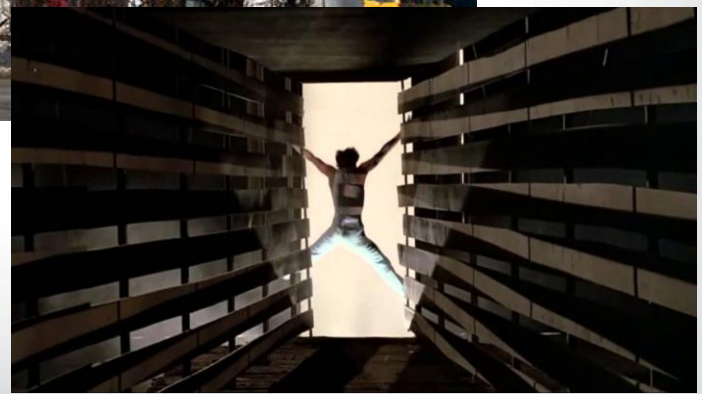


Utah Valley, 1989, (PM10 = 220 μg/m^3)



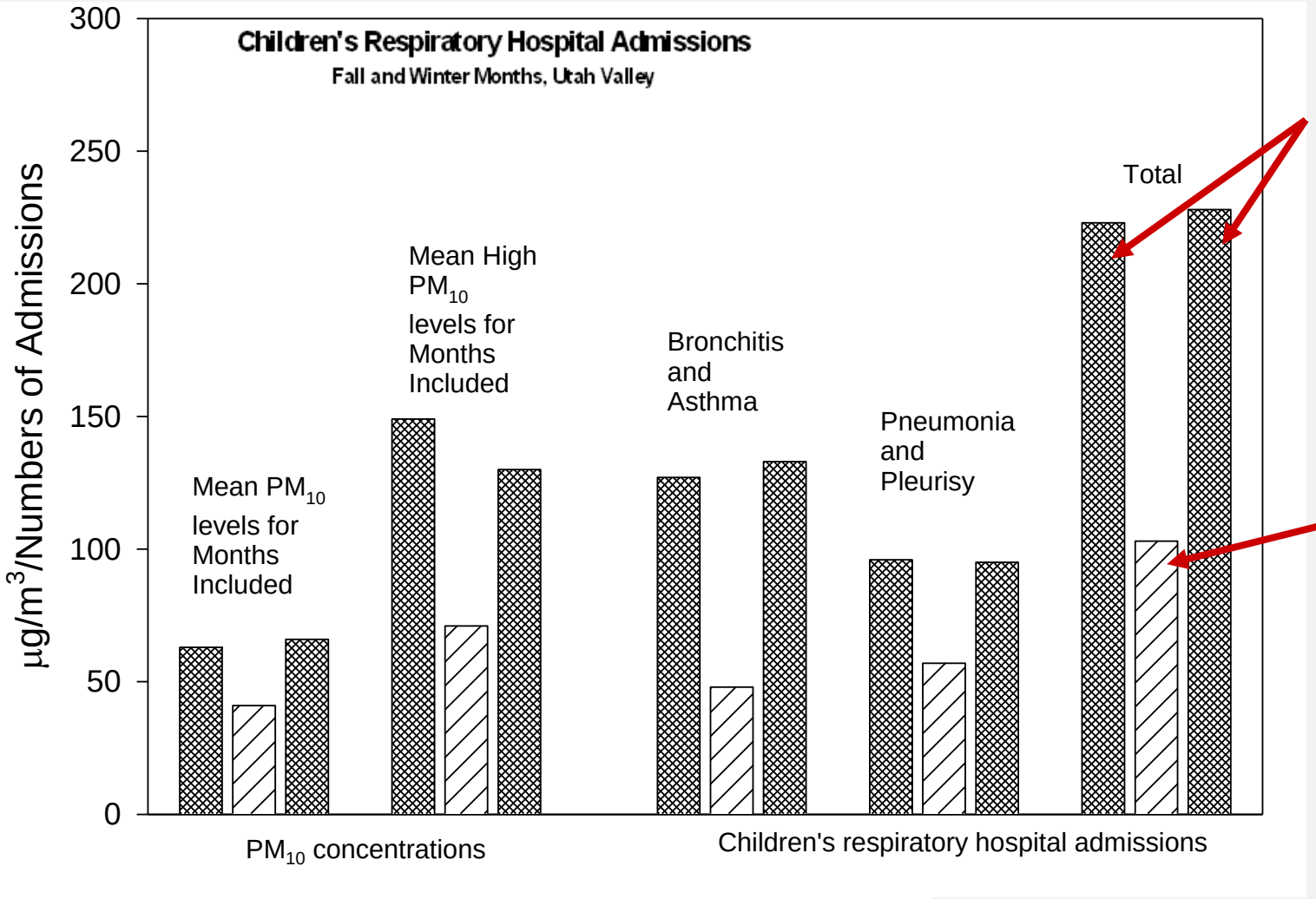
Very Simple Air Quality Model

Steel Mill Open **or** **Steel Mill Closed**



When the steel mill was open, total children's hospital admissions for respiratory conditions **approx. doubled.**

Arden Pope



Sources: Pope. Am J Pub Health.1989; Pope. Arch Environ Health. 1991

Early Air Quality Model

The first urban air quality model with spatial and temporal resolution was developed for the Los Angeles basin in California, USA

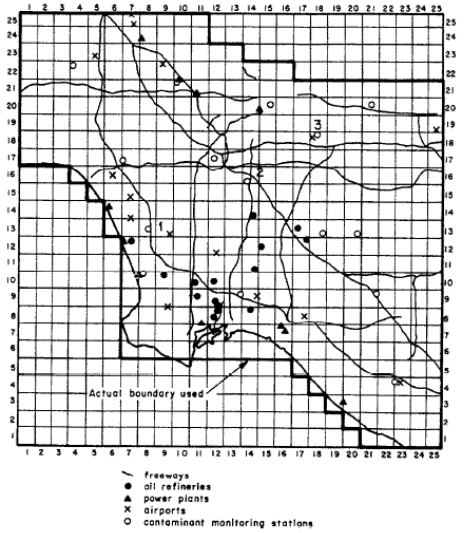
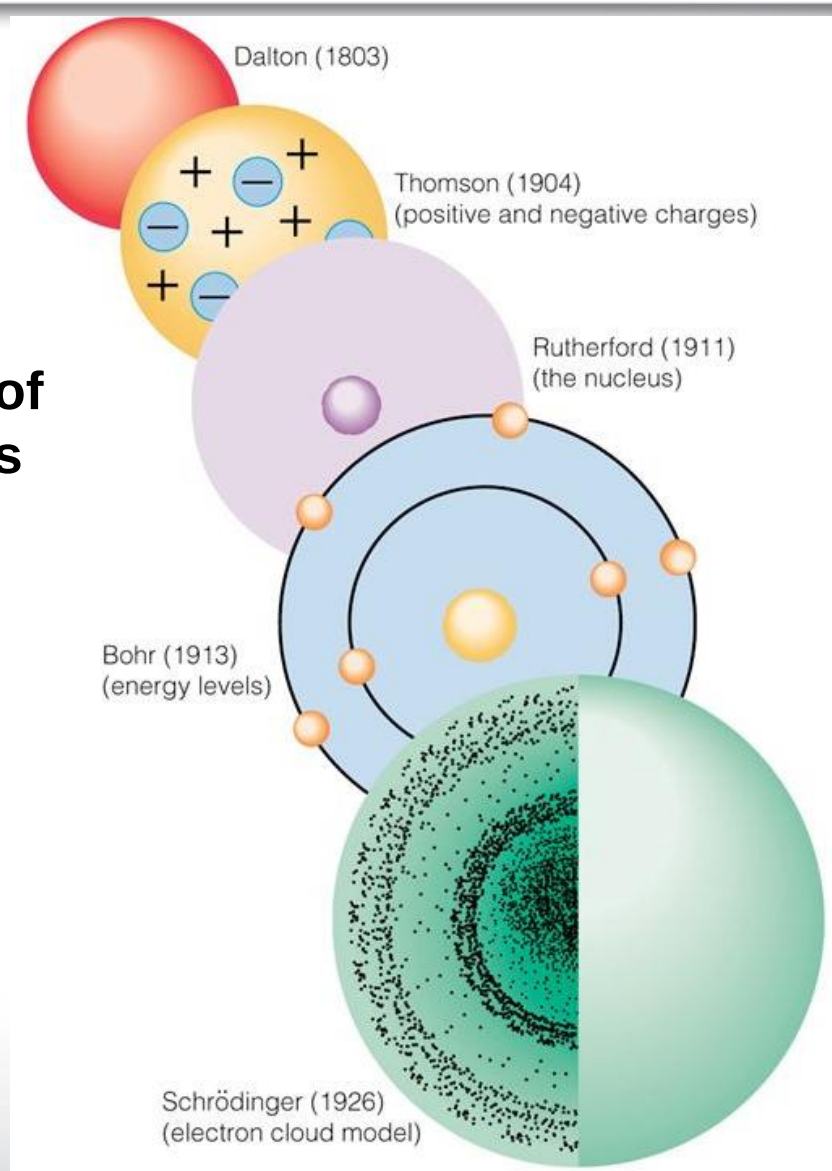


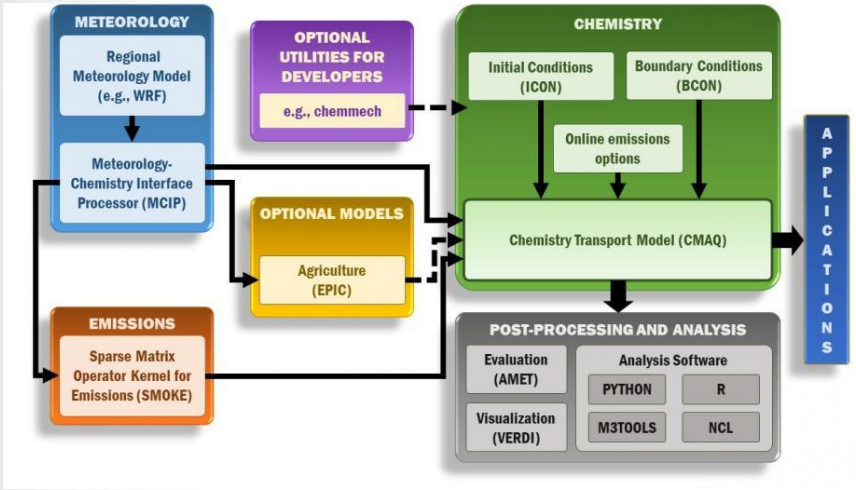
FIG. 1. The modeling region. Locations of monitoring stations and major contaminant sources in the Los Angeles Basin.

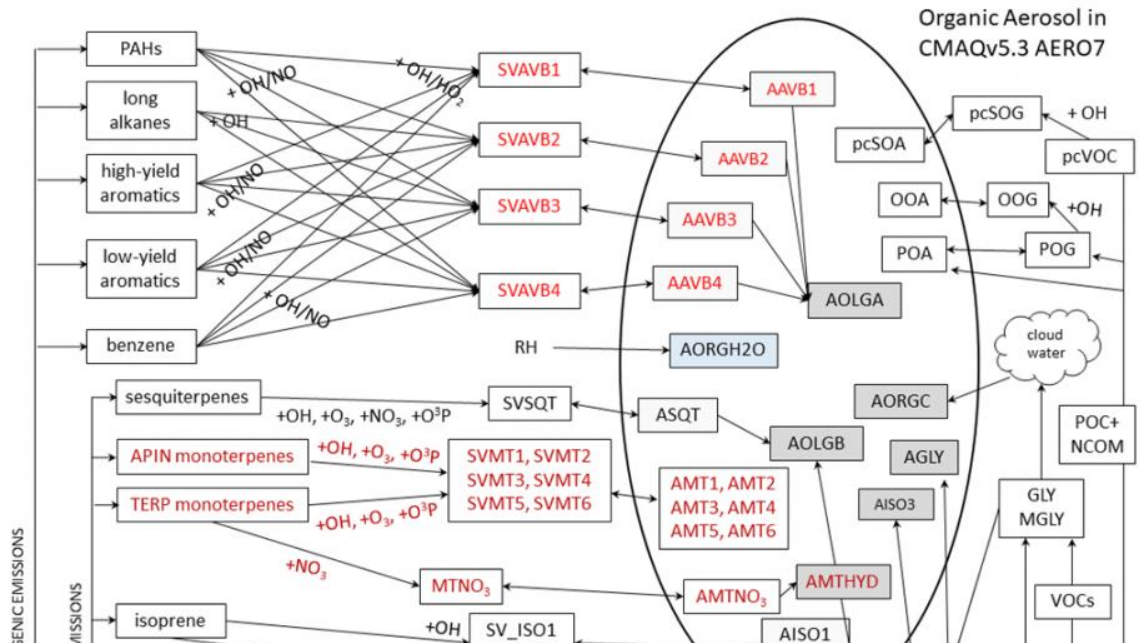
S. Reynolds, P. Roth, J. Seinfeld, *Mathematical modeling of photochemical air Pollution,* Atmos. Environ., 7 (1973), pp. 1033-1061

Development of Atomic Models

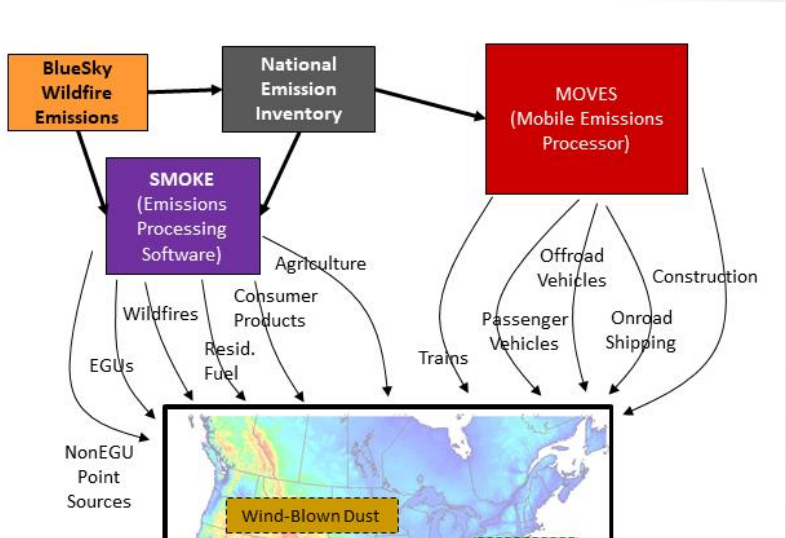


Many, Many Model Improvements

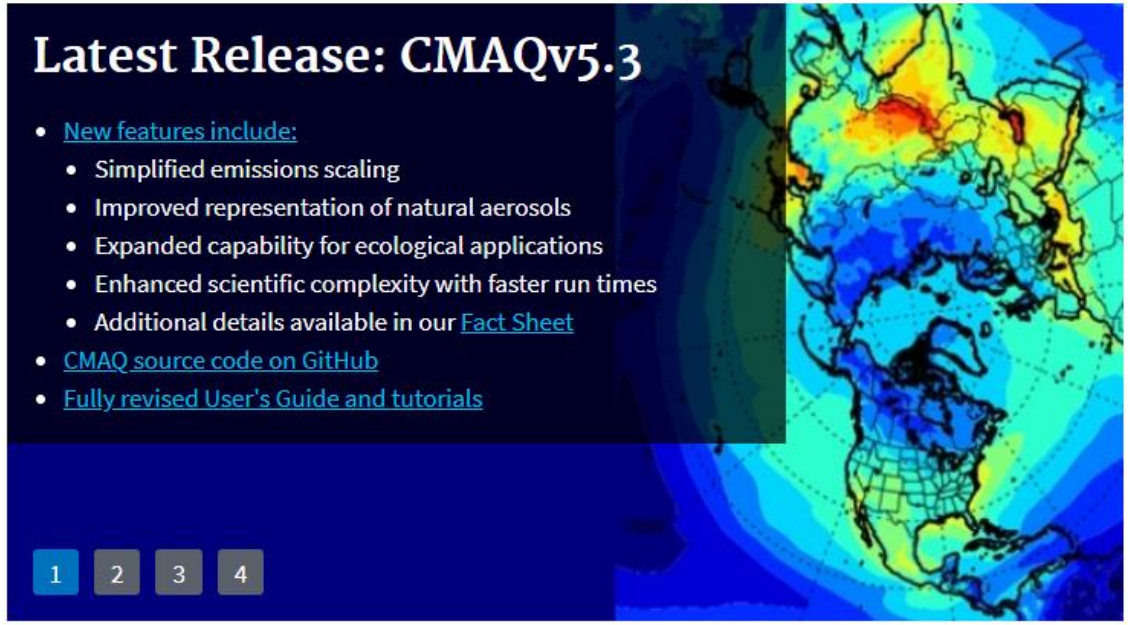




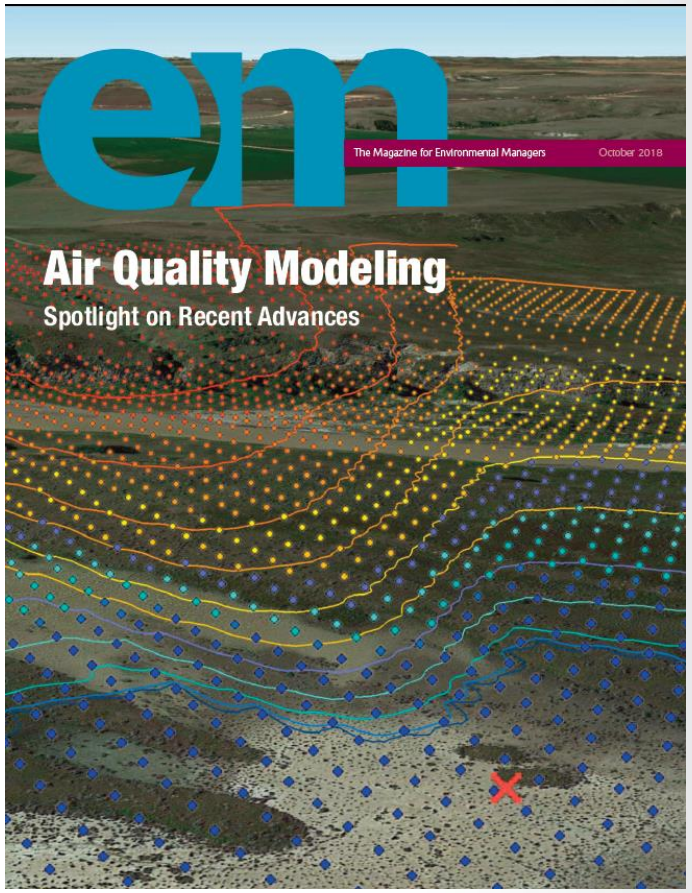
- Finer scale resolution
- More complete chemical mechanism
- Inclusion of aerosols
- Clouds and radiation
- Linking global and regional models for better treatment of long range transport and climate impacts
- More complex land/atmosphere interactions
- Updates to emissions inventories
- Data fusion for meteorology and measurements from the ground or above
- and more…



Current Air Quality Model



CMAQ ***(see-mak):*** an active open-source development project of the U.S. EPA that consists of a suite of programs for conducting air quality model simulations. CMAQ combines current knowledge in atmospheric science and air quality modeling, multi-processor computing techniques, and an open-source framework to deliver fast, technically sound estimates of ozone, particulates, toxics and acid deposition.



Many many hard working EPA scientists

But Models Still Have Limitations

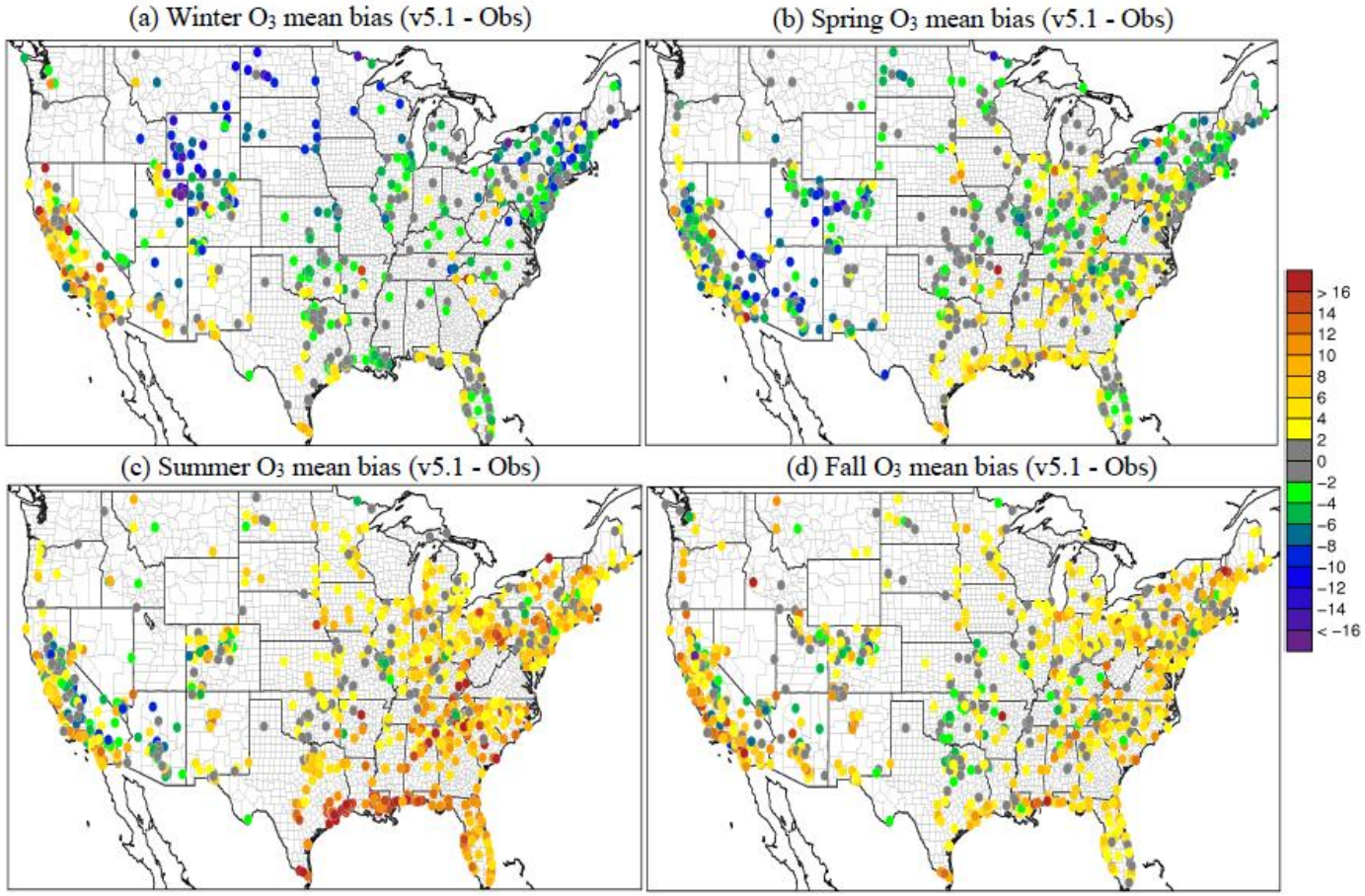


Figure 12. Seasonal average hourly O_3 (ppbv) mean bias at AQS sites for (**a**) winter (DJF), (**b**) spring (MAM), (**c**) summer (JJA) and (**d**) fall (SON) for the CMAQv5.1_Base_NEIv1 simulation.

- For example, O_3 bias persists and varies with season
- When O_3 concentration matches measurements, we lack information to assess whether it's correct for the right reasons

Appel, K. W., et al., Description and evaluation of the Community Multiscale Air Quality (CMAQ) modeling system version 5.1, Geoscientific Model Development 10, 1703-1732, doi:10.5194/gmd-10-1703-2017 (2017).

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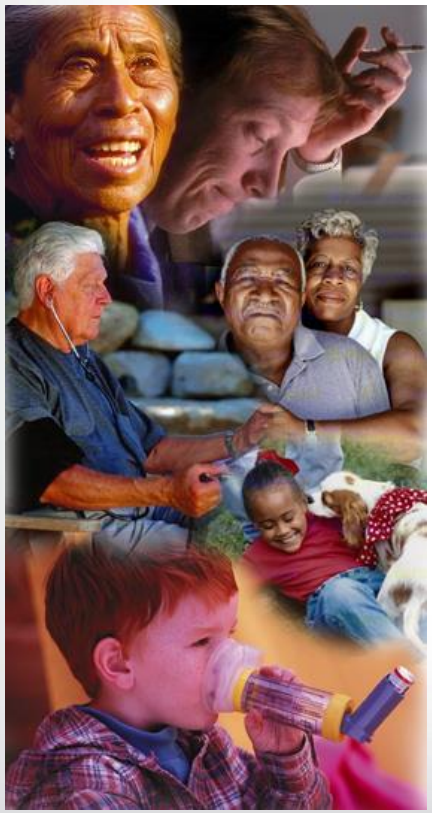
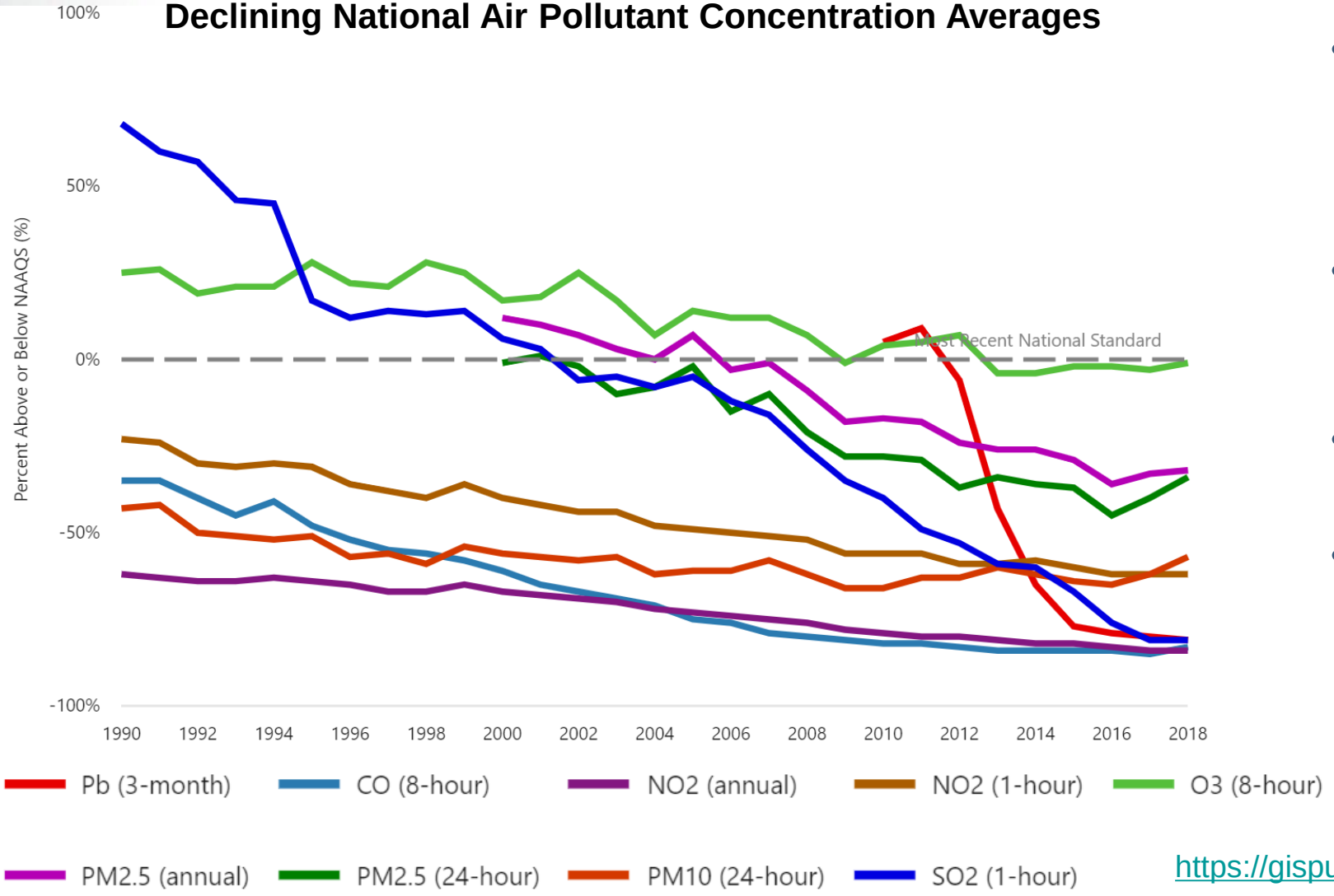


Cleaner Air Leads to New Questions



- Decreased emissions from many large regional sources means other sources are now important
- Long-range transport and background may be increasing in importance
- Improvements in air quality are not uniform
- Lower concentrations require different models

https://gispub.epa.gov/air/trendsreport/2019/#home

How Do We Improve AQ Models?

- Adding heterogenous chemistry
- Improving chemical mechanism
- Including phase state of aerosols
- Improvements to emissions inventories
- Using more observations for data assimilation and evaluation
- Adding dynamic boundary conditions
- Improving representation of physics and dynamics (boundary layer schemes, convection,…)
- ….

EPA's Modeling Efforts

MPAS
Model for Prediction Across Scales

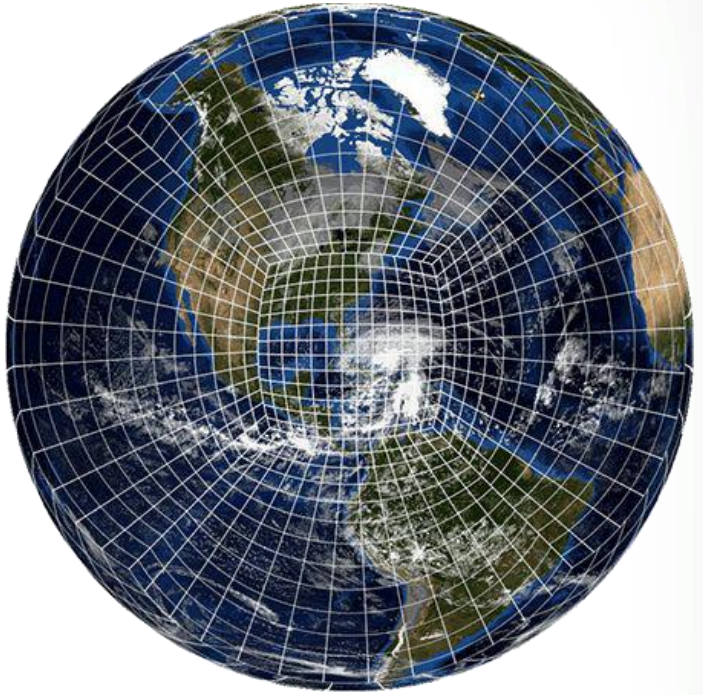
CMAQ

- EPA's focus is to protect human health and the environment
- Allows *global-to-local* environmental influences to be holistically considered within same modeling system
- Combines a version of Model for Prediction Across Scales (MPAS) with components of Community Multiscale Air Quality (CMAQ) model
- EPA-funded Air Climate and Energy Centers are developing reduced form models and considering potential changes in energy production
- New STAR grants will support projects on Chemical Mechanisms To Address New Challenges In Air Quality Modeling

NOAA's Modeling Efforts

NOAA Office of Weather and Air Quality

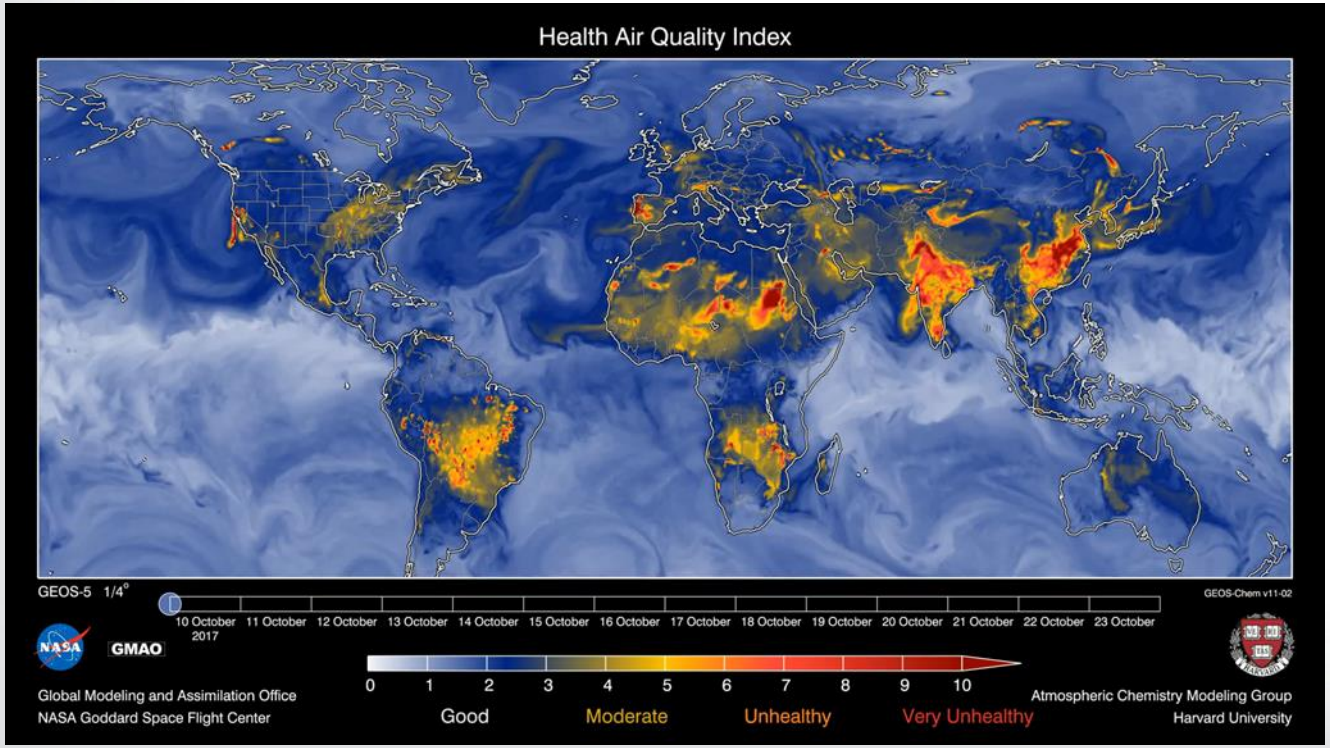
Supporting world-class research to advance timely and accurate weather information



- NOAA's focus is on weather and air quality forecasting
- The Earth Prediction Innovation Center (EPIC) will accelerate community-developed scientific and technological advancements into the operational applications for Numerical Weather Prediction (NWP) by supporting a Unified Forecast System (UFS) community model.
- NOAA works closely with entities in the weather enterprise (public, private, and academic) to inform the planning, development, and strategy for EPIC.

NASA's Modeling Efforts

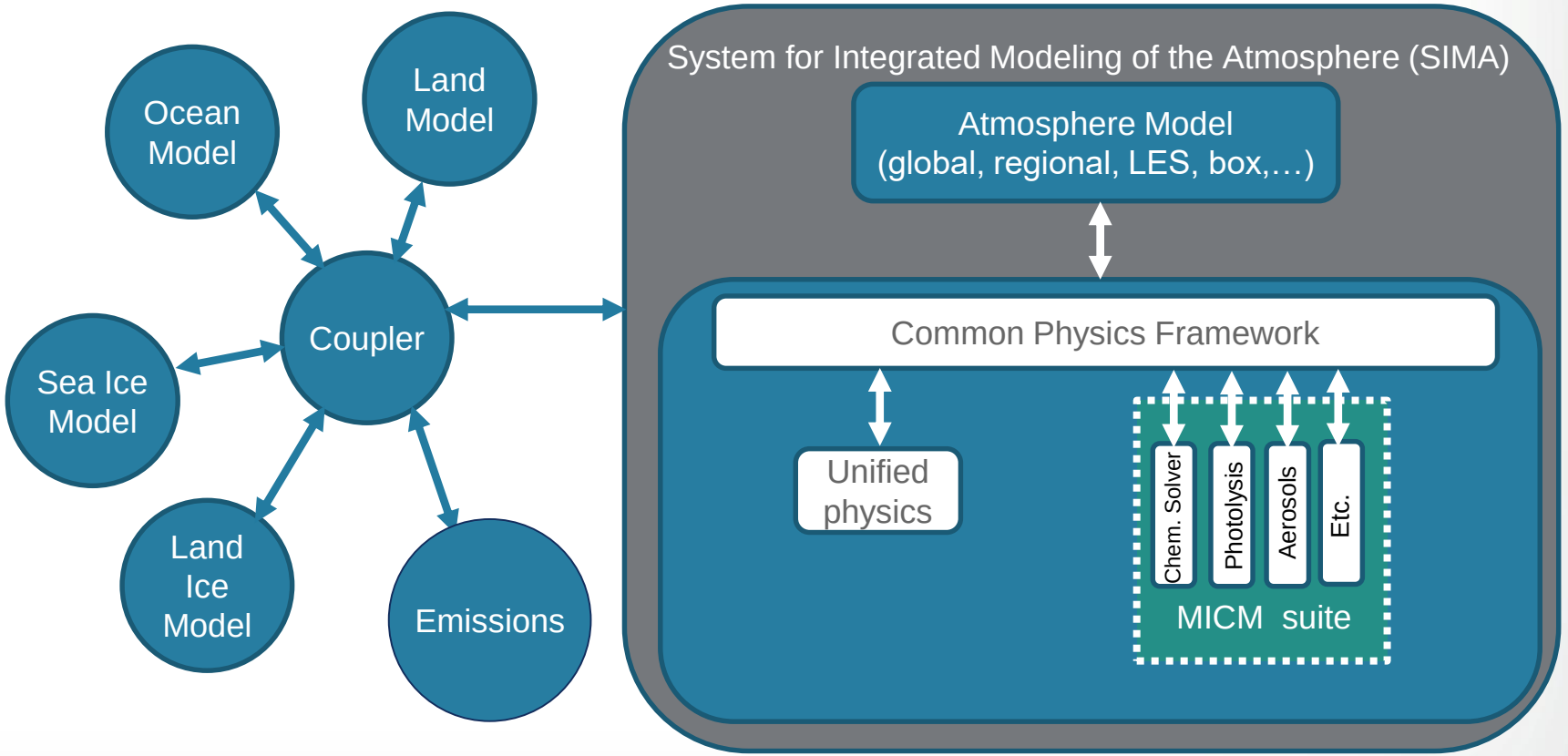
- NASA's focus is on a more complete understanding of the earth's atmosphere and ways to understand and use satellite data
- Support model development for air quality forecasting and applications



NSF's Modeling Efforts

- NSF's focus is fundamental science research
- NCAR is a focal point for research in the field of atmospheric sciences

Multi-Scale Infrastructure for Chemistry and Aerosols (MUSICA)

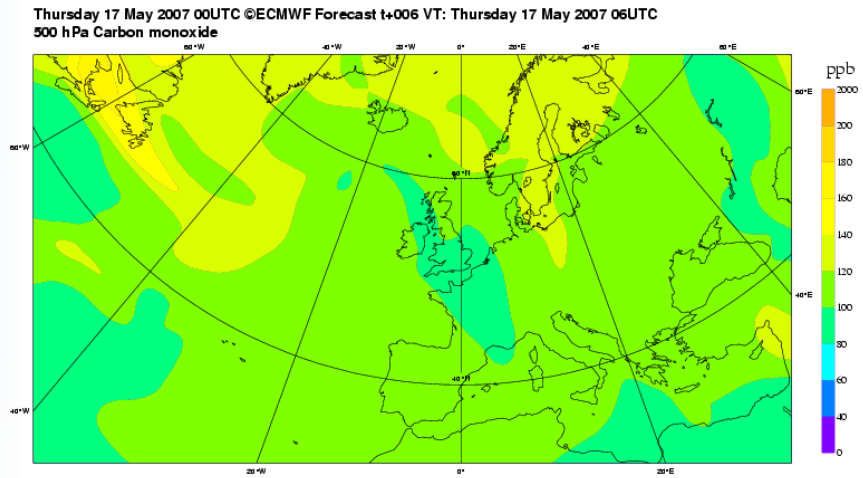


Atmosphere Monitoring

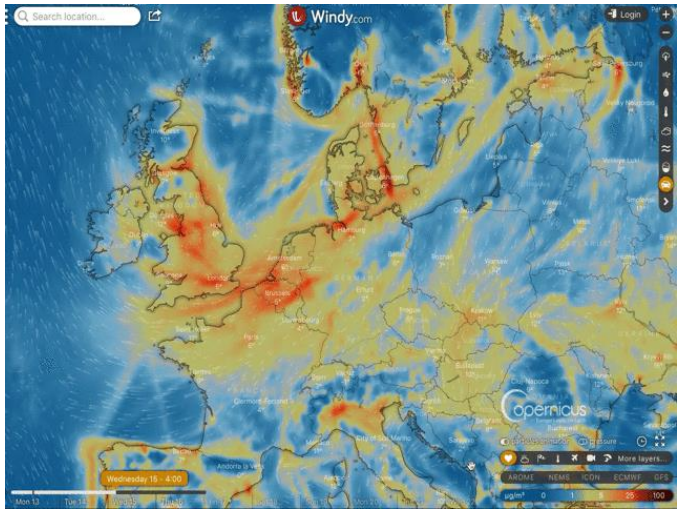
European Modeling Efforts

C o p e r n i c u s A t m o s p h e r e M o n i t o r i n g S e r v i c e

ECMWF manages the Copernicus Atmosphere Monitoring Service (**CAMS**), one of 6 thematic Services of the EU Space flagship programme **Copernicus**



12 years of continuous daily global atmospheric composition forecasts

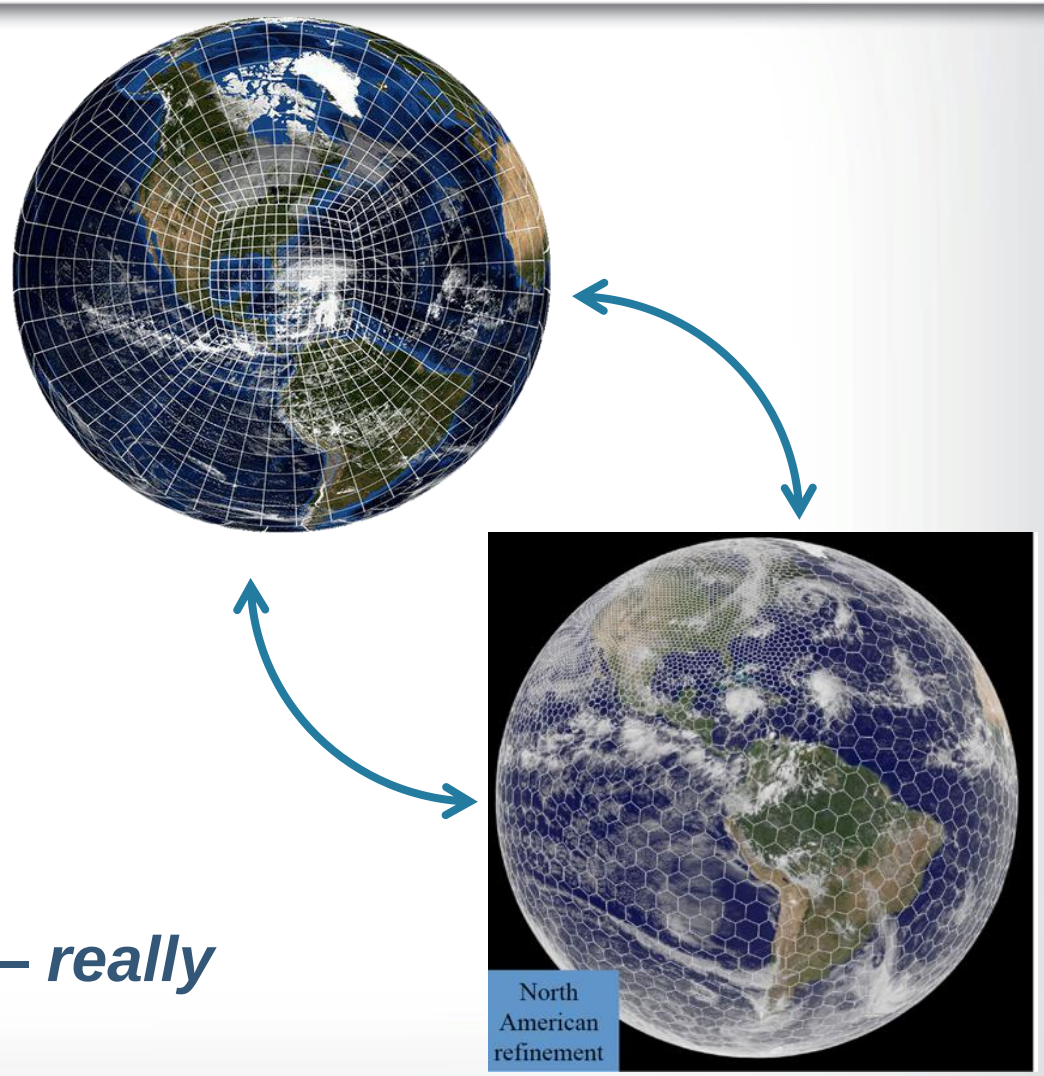


CAMS regional forecasts seen in the Windy app and website

How Do We Improve AQ Models?

- Many big modeling activities currently (and previously)
- We need to leverage resources across organizations
- We don't need one single modeling system

- We do need **interoperability** across modeling systems so new knowledge can be shared



Sherri's Thoughts:
We have to work together – really

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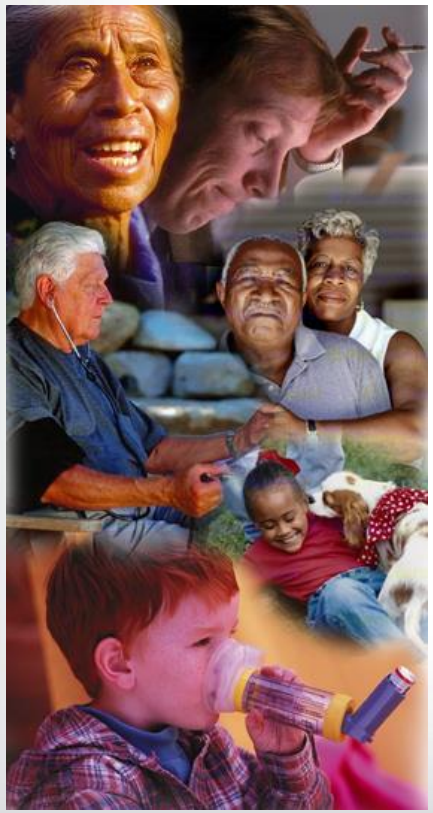
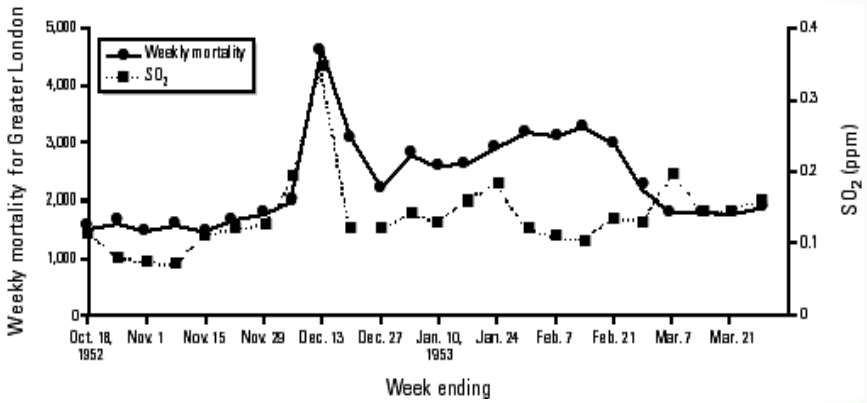


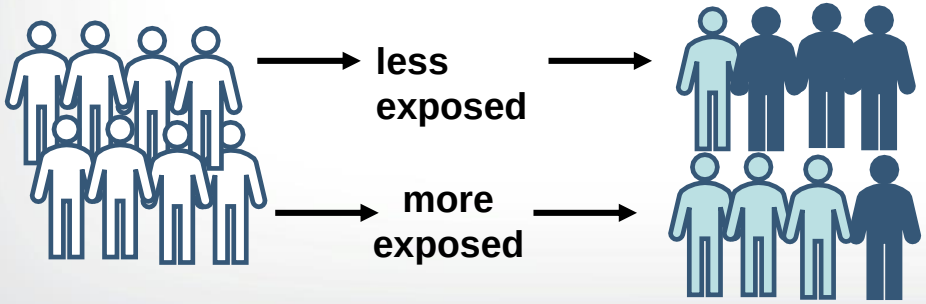
A Little Bit of Epidemiology

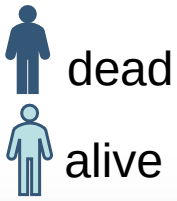
- Epidemiology examines relationships between exposure and health effects (e.g., heart/lung function, hospital admissions, mortality)
- AQ models can improve exposure estimates
- Kinds of observational epidemiology studies:
  - Short-term exposure: time-series, case-crossover, panel studies
  - Long-term exposure: cohort studies

Time Series Study

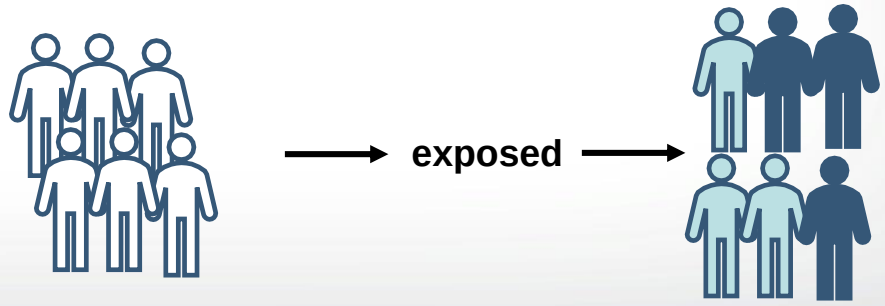


Cohort Study

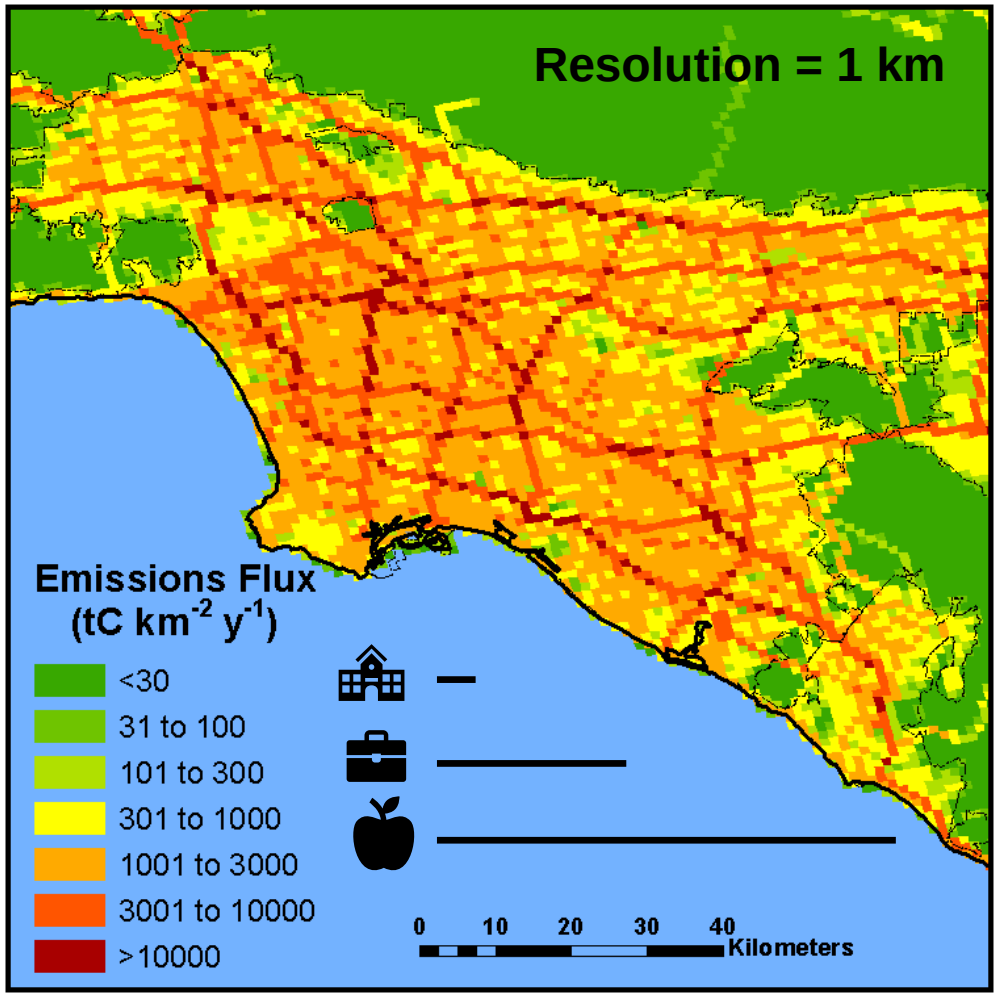




Panel Study



What About Spatial Resolution?



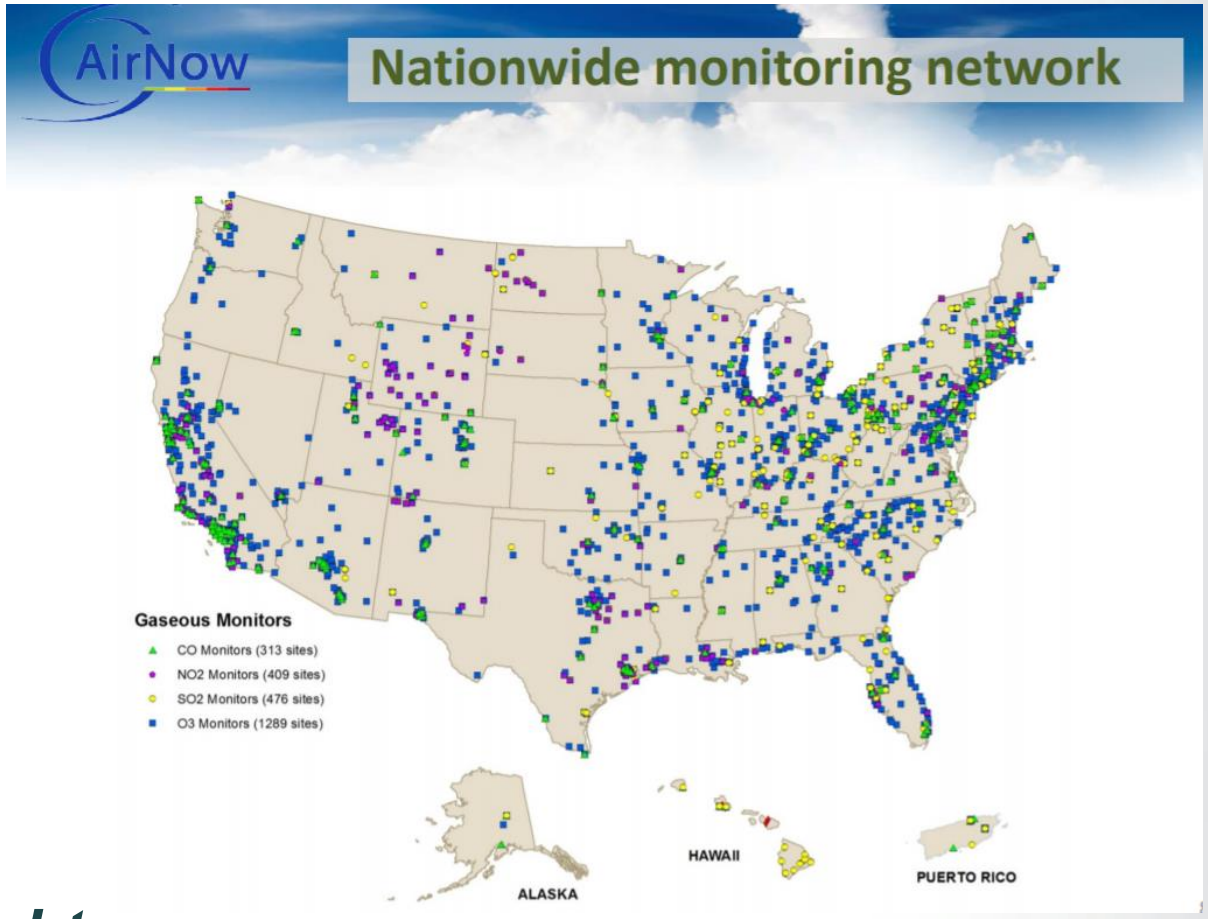
- Finer resolution does not mean better exposure information
- Most people don't stay within 1 km (except elderly)
- For population level studies (e.g. time-series), health data is often only available at the county or census track level

CO_2 emissions inventory

McDonald et al. (*J. Geophys. Res.* 2014)

Model-Data Fusion Is Useful

- A major advancement in the Draft PM Integrated Science Assessment (ISA) is the inclusion of model-data fusion methods to estimate exposure in epidemiologic studies
- Helpful for estimating exposure in places without monitors, especially rural areas
- Evaluation is challenging, because these models fit their datasets to the network measurements and then make predictions in places and at scales that are poorly sampled by the network (e.g. rural areas or 1-km scale)

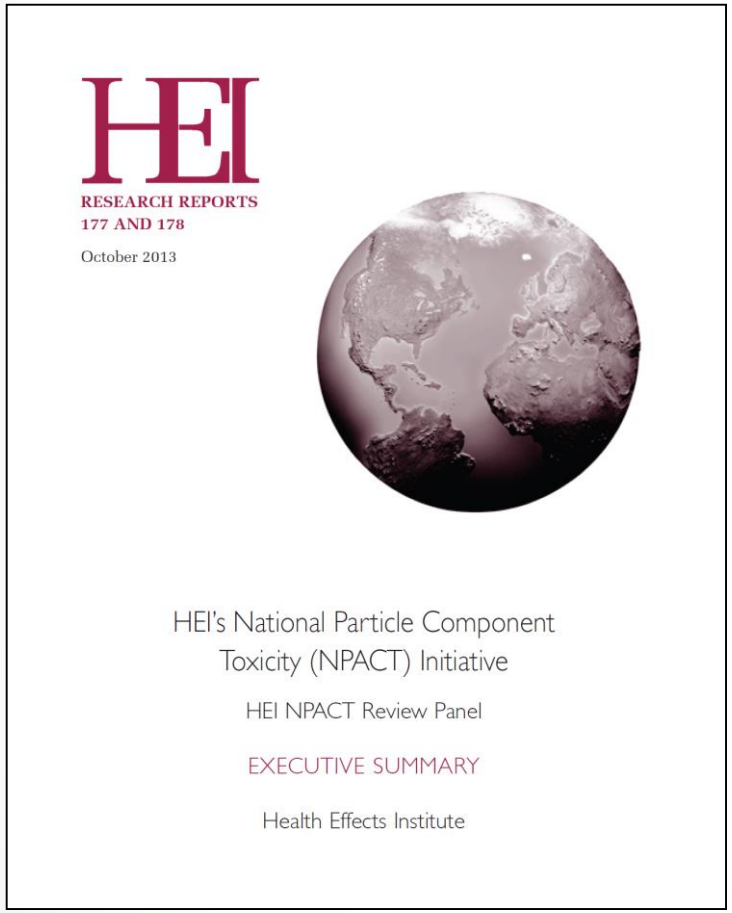


Sherri's Thoughts:

Model-data fusion is useful but still needs evaluation

Finer resolution might not provide an improved exposure estimate

Health Effects and PM Components



National Particle Component Toxicity Initiative

- The NPACT studies are the most systematic effort to combine epidemiologic and toxicologic analyses of the health effects of PM components to date

- The studies found associations between health effects and sulfate particles (primarily from coal combustion) and, to a somewhat lesser extent, traffic sources

… but the NPACT Panel concluded that the studies do not provide compelling evidence that any specific source, component, or size class of PM may be excluded as a possible contributor to PM toxicity.

Health Effects and PM Components

What we know:

- PM mass has been a good indicator for health impacts for 40 years
- Each component only contributes a small percentage to the total mass

Better questions:

- Can PM composition be used to make a connection to a particular pollution source?
- Are there combinations of certain components that change the toxicity and health effects of PM exposure?

Sherri's Thoughts:
Some kinds of errors may be okay.
Changes in concentration may be more important that absolute.
Talk to the health researchers more than once.

Thoughts on Funding

- EPA funding is limited, but scientists like to collaborate
- Talk to program directors
- Consider how to characterize your idea
- Investigate cross-directorate programs at the National Science Foundation

Sherri's Final Thoughts

- Remember why we are here – to help people breathe clean air
- We need to work towards interoperability across models
- Work on data fusion methods should continue
- Review past work in other disciplines
- Consider attending conferences for other disciplines
- Interdisciplinary research requires multiple interactions across disciplines to understand needs
- Models don't always need all the details (e.g. reduced form models) but you should consider the application of model information