The Community Multiscale Air Quality (CMAQ) Modeling System

EPA United States Environmental Protection Agency

Atmospheric Modeling and Analysis Division, National Exposure Research Laboratory
Office of Research and Development

Background

Drivers for Air Quality Models

Regulatory & Assessment Needs

Model Development & Application
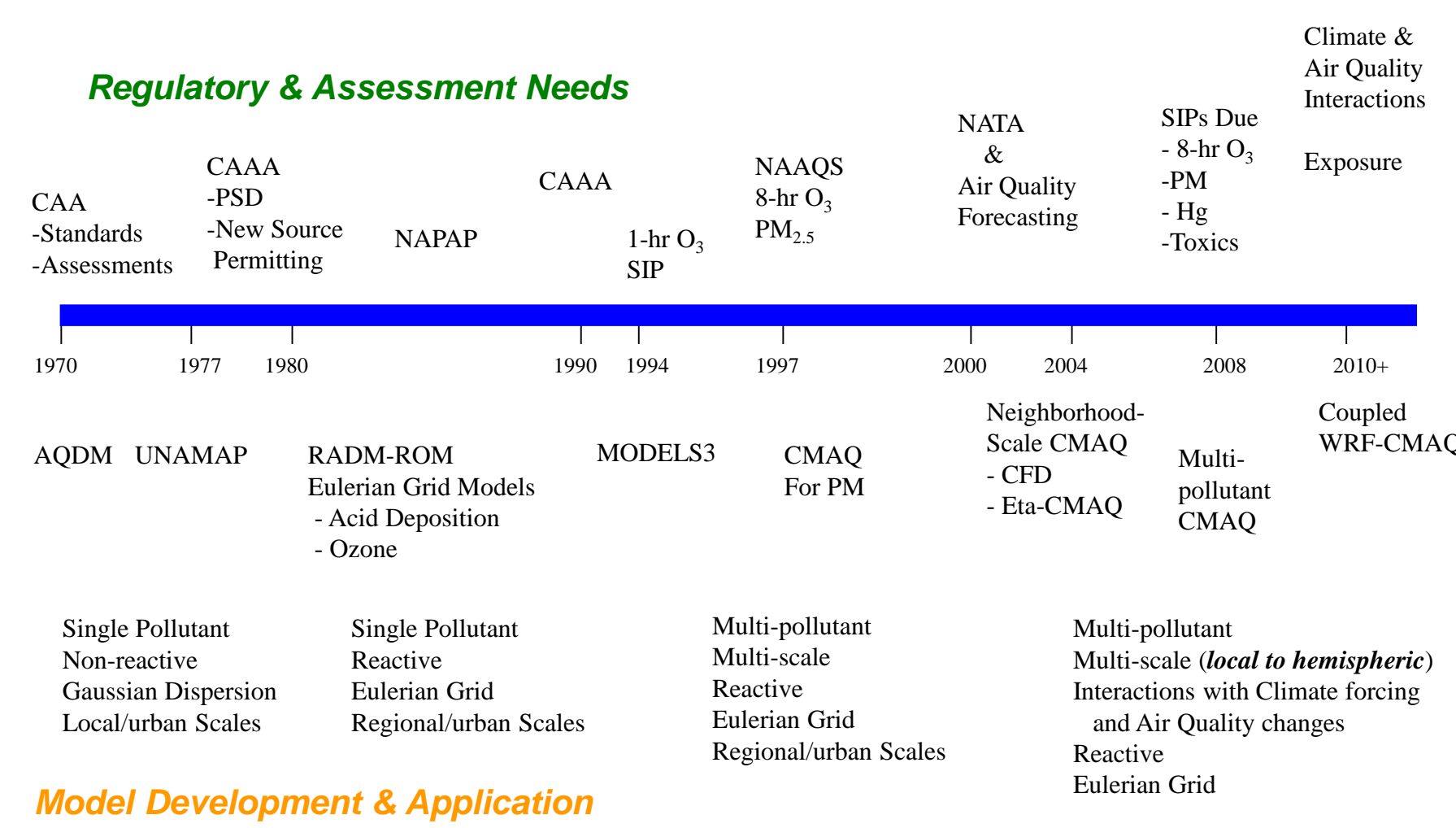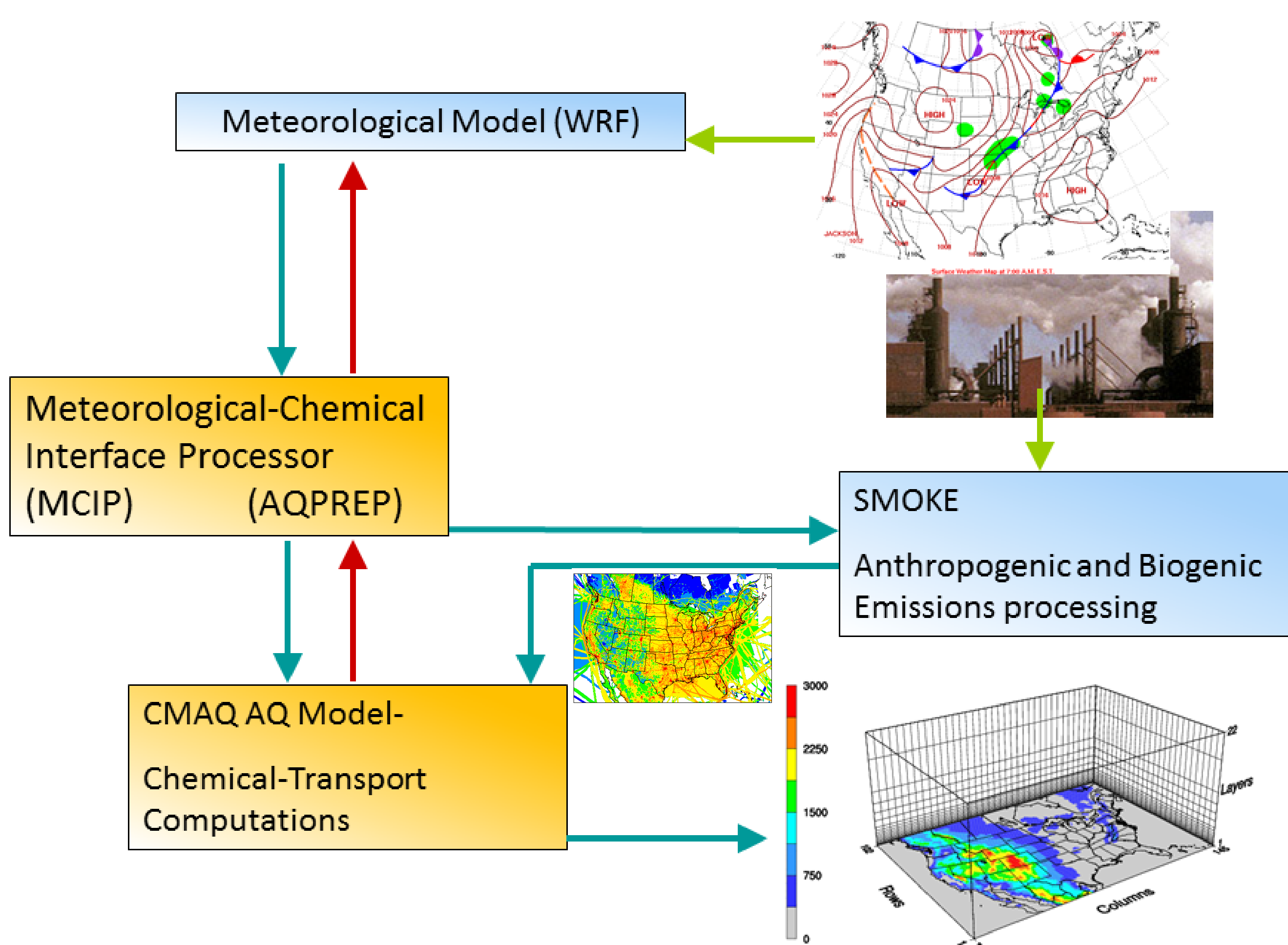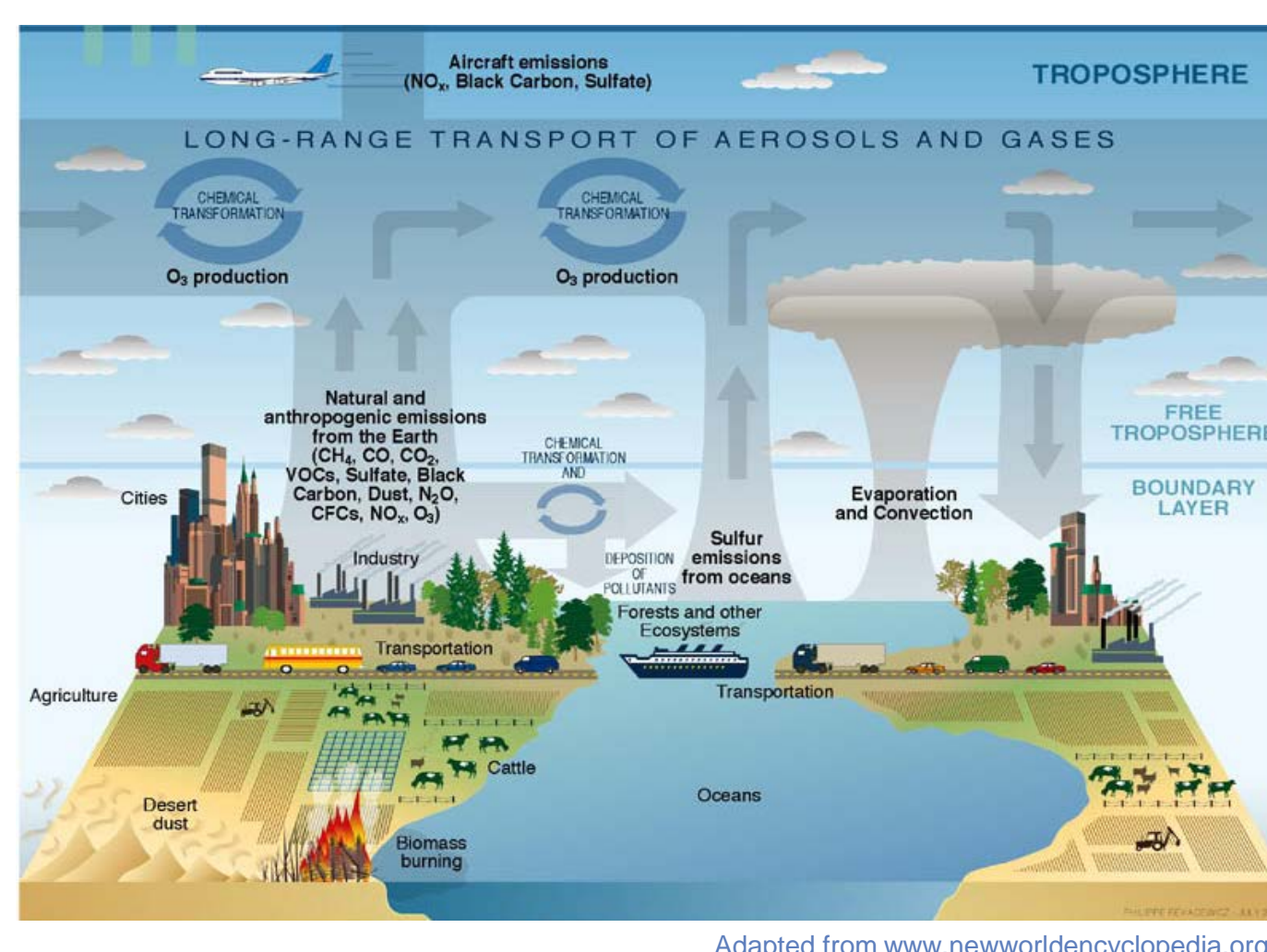
Air quality models have evolved over the past several decades to address increasingly complex application and assessment needs.

The CMAQ Modeling System: A "Numerical Laboratory"

CMAQ is a comprehensive *state-of-the-science* atmospheric modeling system that integrates and synthesizes our evolving knowledge of the various atmospheric processes regulating the fate of atmospheric pollutants.
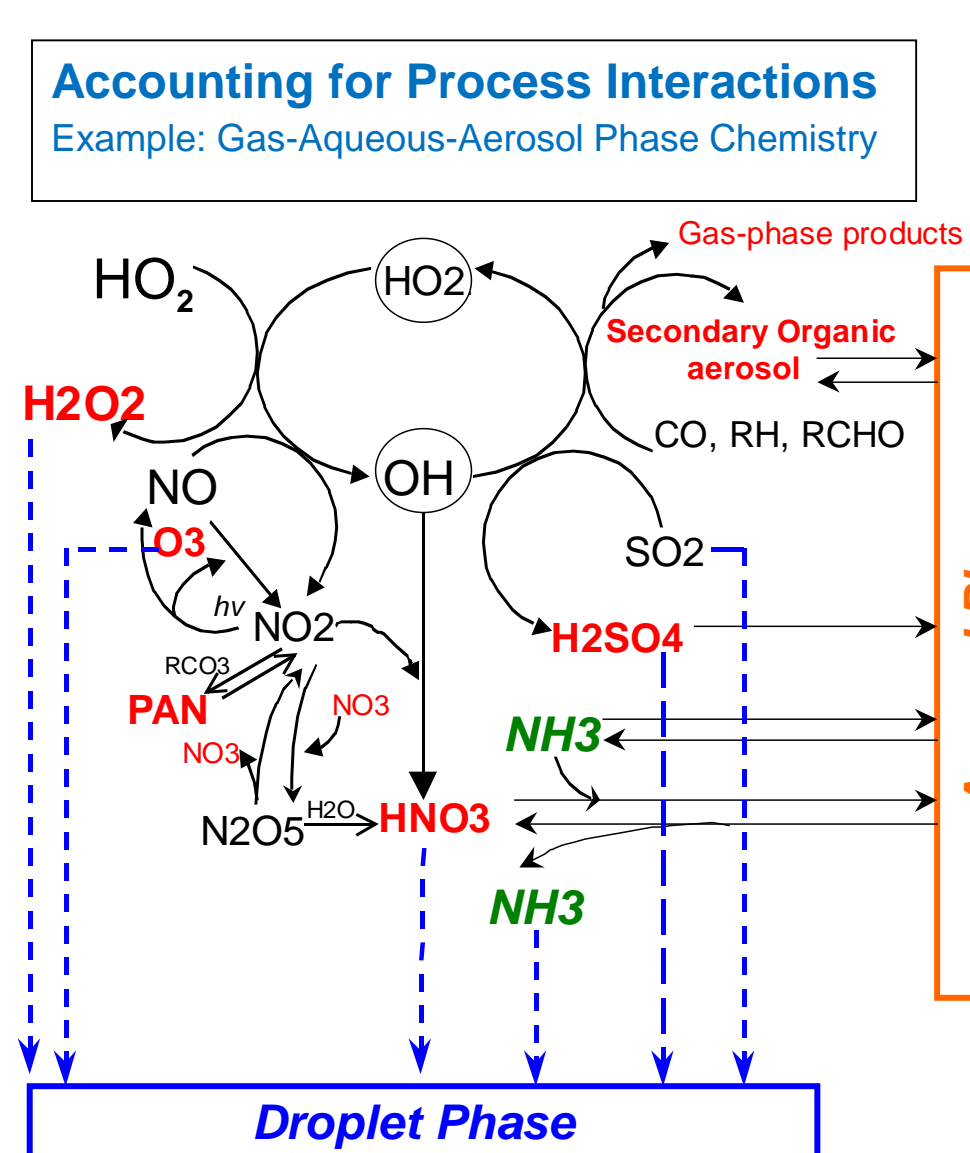
Adapted from www.newworldencyclopedia.org

Meteorological Model (WRF)

Meteorological-Chemical Interface Processor (MCIP)   (AQPREP)

SMOKE
Anthropogenic and Biogenic Emissions processing

CMAQ AQ Model-
Chemical-Transport Computations

- Eulerian grid-based **Multi-pollutant** model:
  - Gas-phase chemistry (e.g., O_3 and precursors); aerosols ($PM_{2.5}$ and PM_{10}); air toxics (e.g., Hg)

- **Multi-scale**: simulates processes from urban (few km) to regional (hundreds of km) to inter-continental (thousands of km) scales of transport

- **Community** model:
  - First version publicly released in ~2000
  - CMAQv5.1 to be released in October 2015

CMAQ Formulation

The theoretical basis for model formulation is the **conservation of mass** for atmospheric trace species transport, chemistry, and deposition:

$$\frac{\partial \varphi_i^*}{\partial t} + \hat{v}_\xi \bullet \left[\varphi_i^* \overline{\hat{v}}_\xi \right] + \frac{\partial (\varphi_i^* \overline{\hat{v}^3})}{\partial \hat{x}^3} + \hat{v}_\xi \bullet \left[\overline{\rho} \sqrt{\hat{\gamma}} \hat{r}_{\xi_i} \right] + \frac{\partial (\overline{\rho} \sqrt{\hat{\gamma}} \hat{F}_{q_i}^3)}{\partial \hat{x}^3}$$

$$= \sqrt{\hat{\gamma}} R_{\varphi_i}(\overline{\varphi}_1, ..., \overline{\varphi}_N) + \sqrt{\hat{\gamma}} S_{\varphi_i} + \left. \frac{\partial (\varphi_i^*)}{\partial t} \right|_{cld} + \left. \frac{\partial (\varphi_i^*)}{\partial t} \right|_{aero}$$

Accounting for Process Interactions
Example: Gas-Aqueous-Aerosol Phase Chemistry

CMAQ Applications

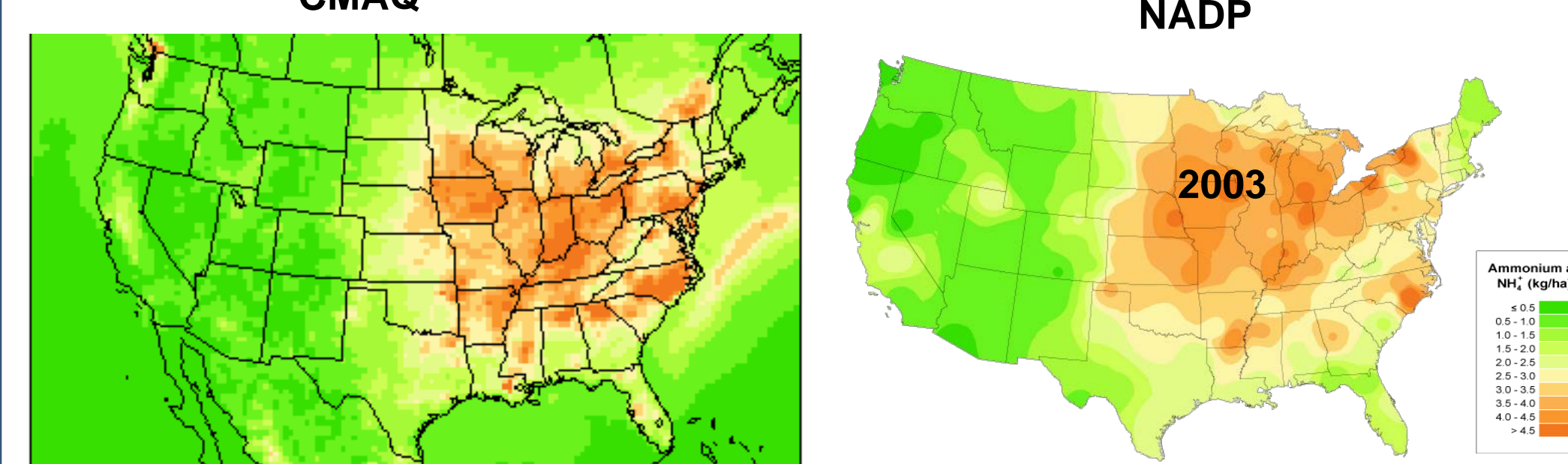### Policy Analysis
Assessing effectiveness of emission control strategies for National Rules, State Implementation Plans

July Base Year Sulfate   **July Future Control Case Sulfate**
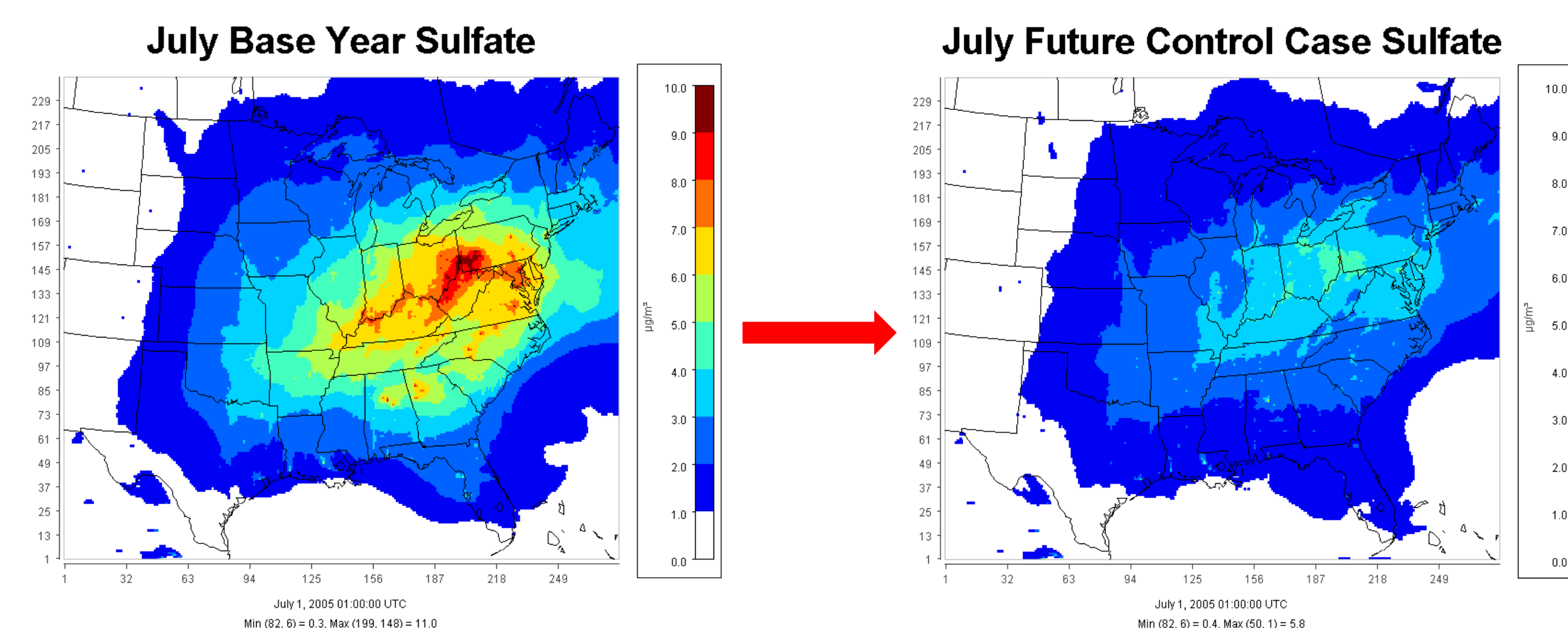
Nutrient Loading to Sensitive Ecosystems
Ammonium Ion Wet Deposition

CMAQ   **NADP**   2003
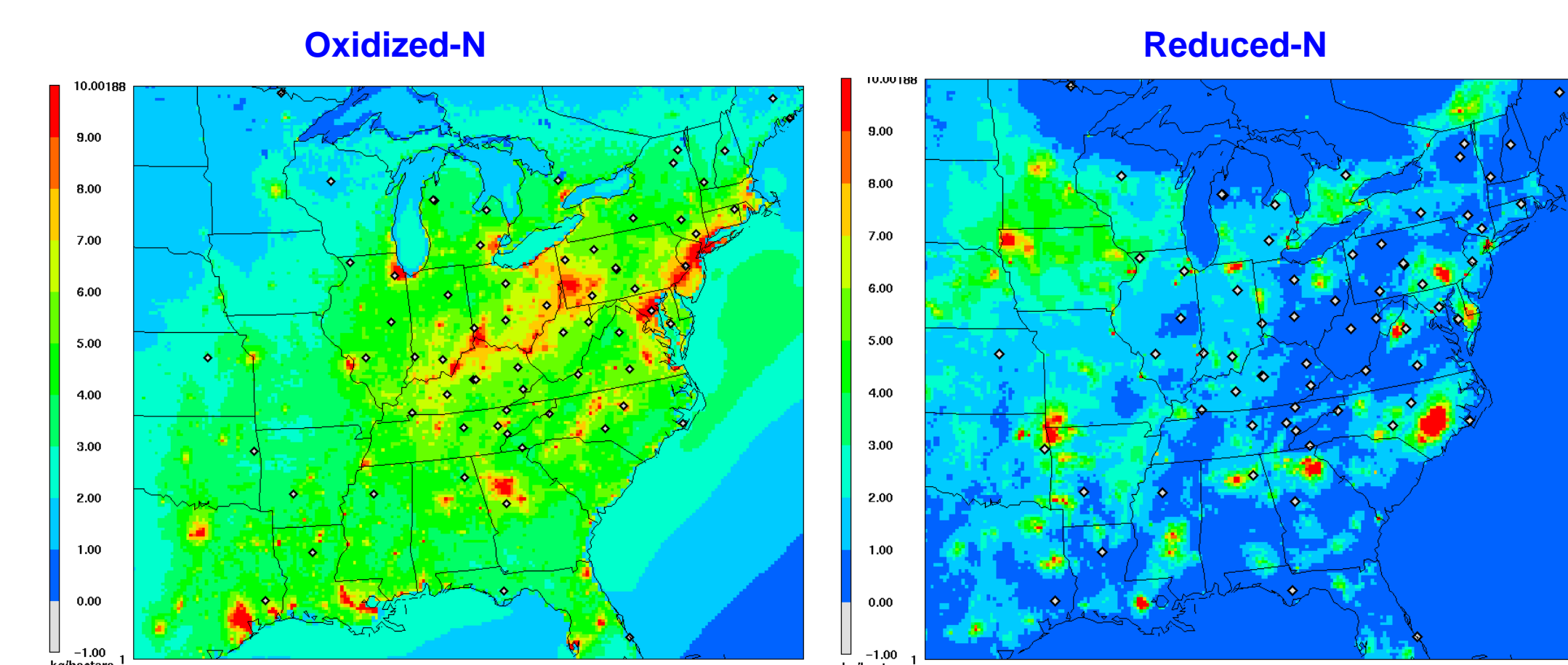
Wet and dry deposition are key removal processes for airborne pollutants, but also the pathway for atmospheric input to terrestrial and aquatic ecosystems
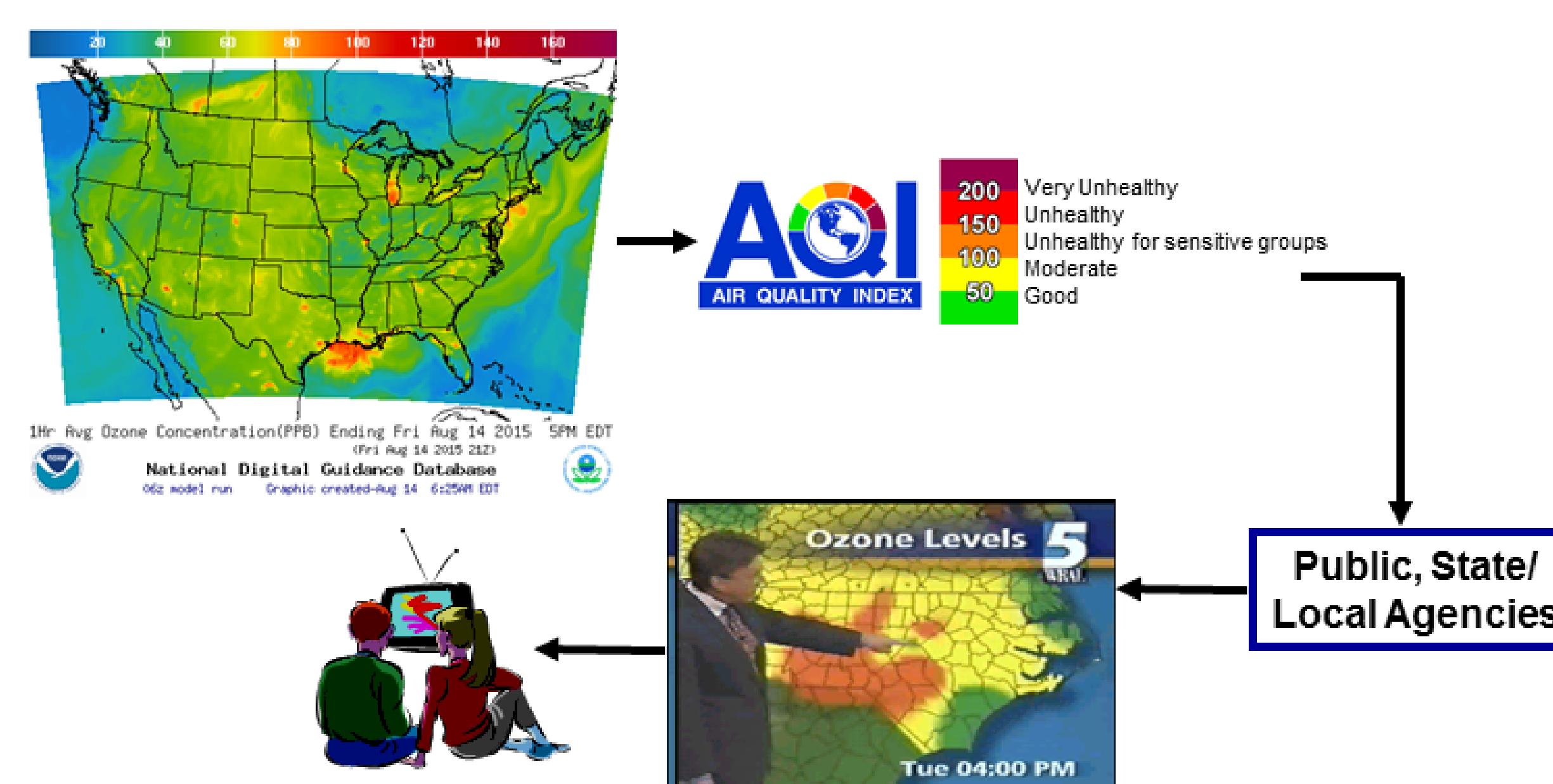
Help Design Monitoring Network
Modeled spatial trends vs. CASTNET locations

Oxidized-N   **Reduced-N**

Current coverage of sites may not be sufficient to capture hot-spots. Thus budgets based solely on observations will be misleading

### Improving Public Health: Air Quality Forecast Guidance
CMAQ deployed at NOAA-NWS to develop next day air quality forecast

AQI AIR QUALITY INDEX
200 Very Unhealthy
150 Unhealthy
100 Unhealthy for sensitive groups
50 Moderate
0 Good

Public, State/ Local Agencies

Developing accurate short-term air quality forecasts enables state and local agencies to alert the public of the onset, severity and duration of unhealthy air, and to encourage public and industry to reduce emission producing activities.

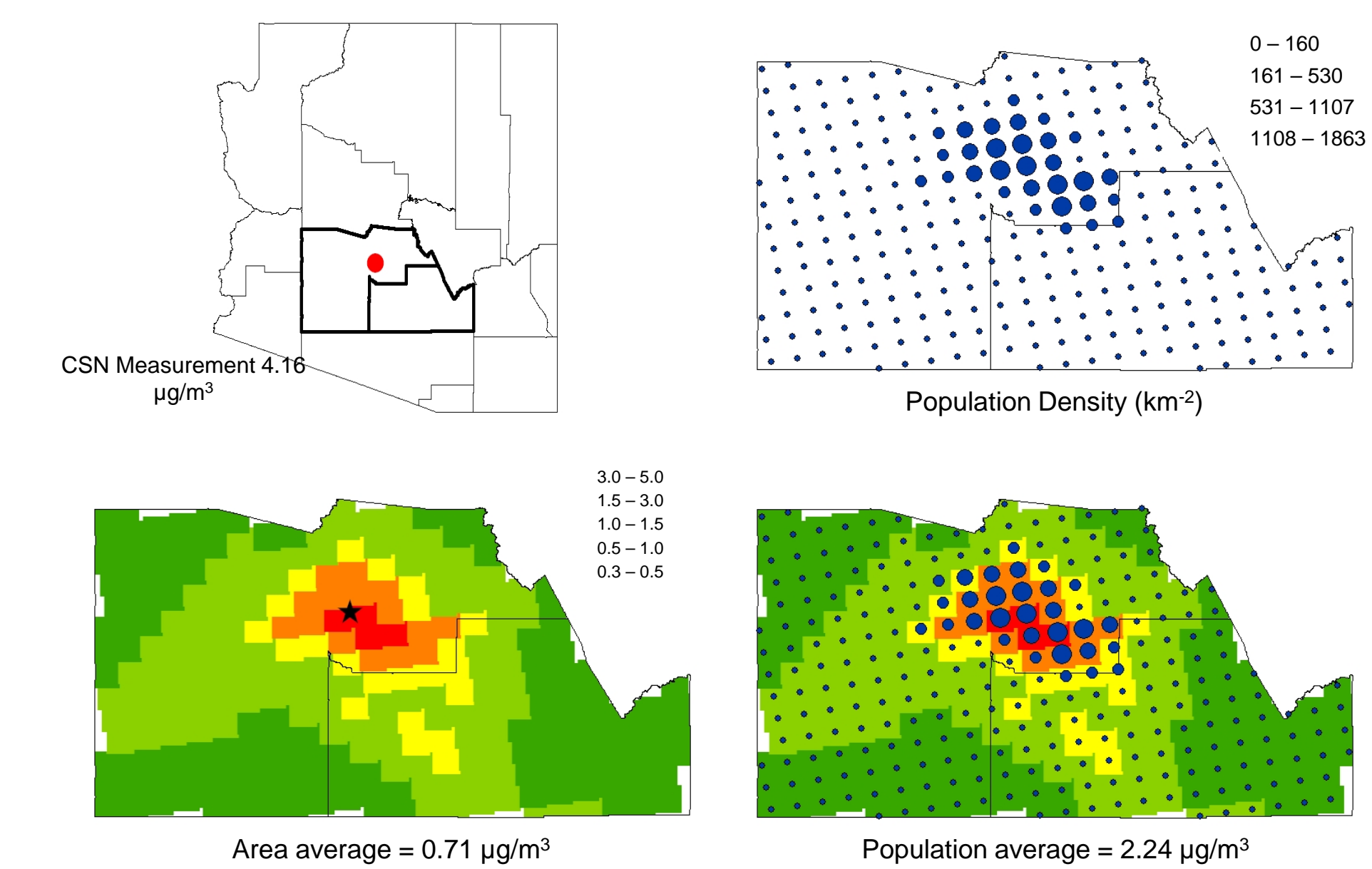### Characterizing Long-term Trends in Air Pollution Exposure
1990-2010 Trends; Impact of the Clean Air Act

95th Percentile O_3   **Summer mean $PM_{2.5}$**
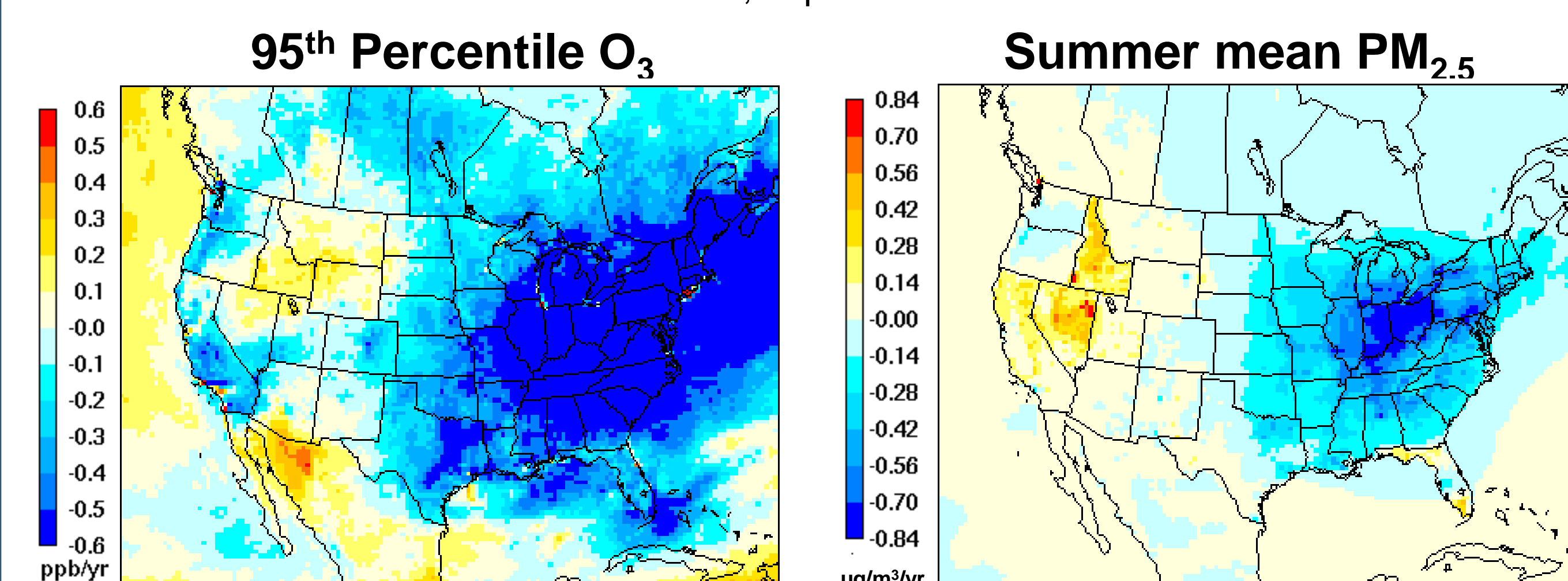
Regulatory actions over the past two decades have resulted in substantial reductions in levels of criteria pollutants across the Nation and in reducing the exposure of sensitive populations to harmful levels of air pollution.
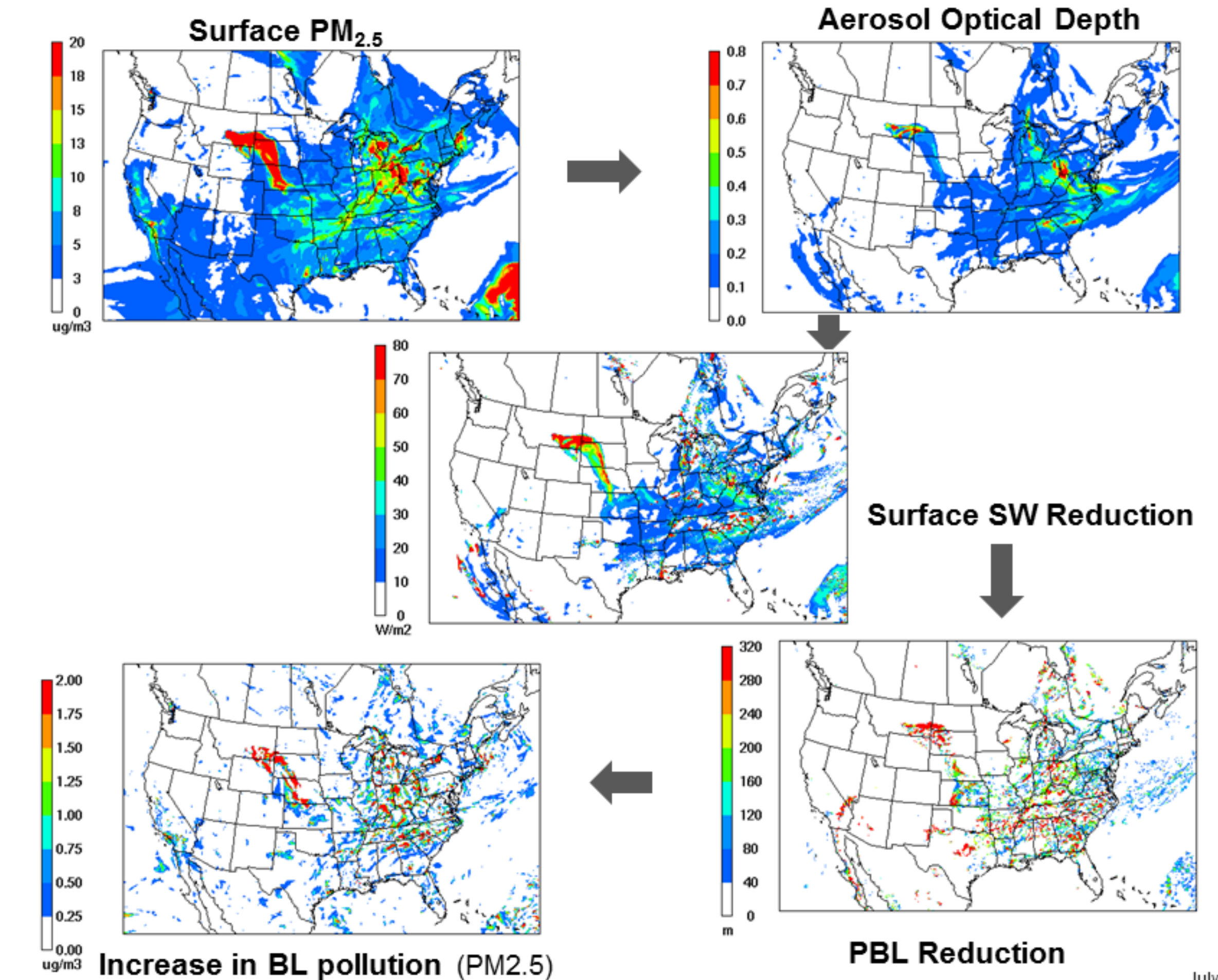

Emerging Application Needs

Informing Human Exposure & Health Studies

CSN Measurement 4.16 $\mu g/m^3$

Population Density (km^2)

Area average = 0.71 $\mu g/m^3$ Population average = 2.24 $\mu g/m^3$

Accounting for spatial variation in air concentrations & population density, enables a more accurate estimate of the average exposure across metropolitan areas

Air Pollution–Meteorology–Climate Interactions

Surface $PM_{2.5}$ **Aerosol Optical Depth**

Surface SW Reduction

Increase in BL pollution ($PM_{2.5}$)   **PBL Reduction**   July 14, 2006 21Z

Many air pollutants ($PM_{2.5}$, O_3) are radiatively active and are also short-lived climate forcers. In regions of high $PM_{2.5}$, feedback effects on atmospheric dynamics can be significant and can impact air pollutant levels. The consideration of such interactions could be important for examining air quality-climate co-benefits of various policy options.

Integrated Approaches to Address Multiple Problems
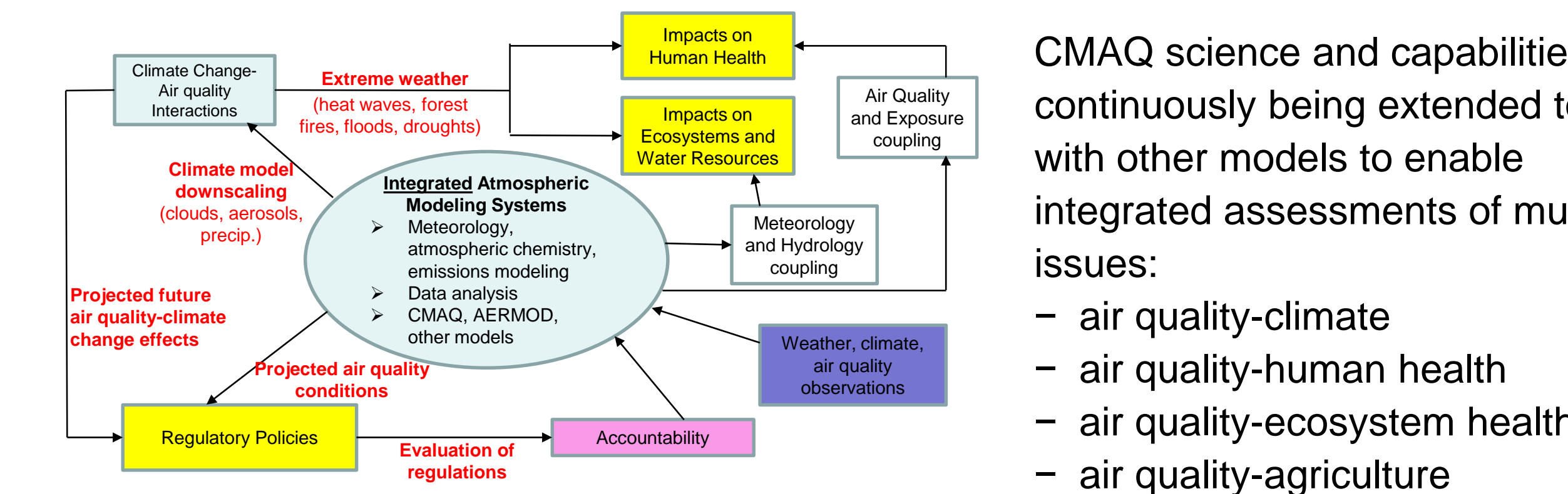
CMAQ science and capabilities are continuously being extended to link with other models to enable integrated assessments of multiple issues:
- air quality-climate
- air quality-human health
- air quality-ecosystem health
- air quality-agriculture

Dissemination and User Community

2014 Conference Registrants   CMAS Users (as of 10-2014)
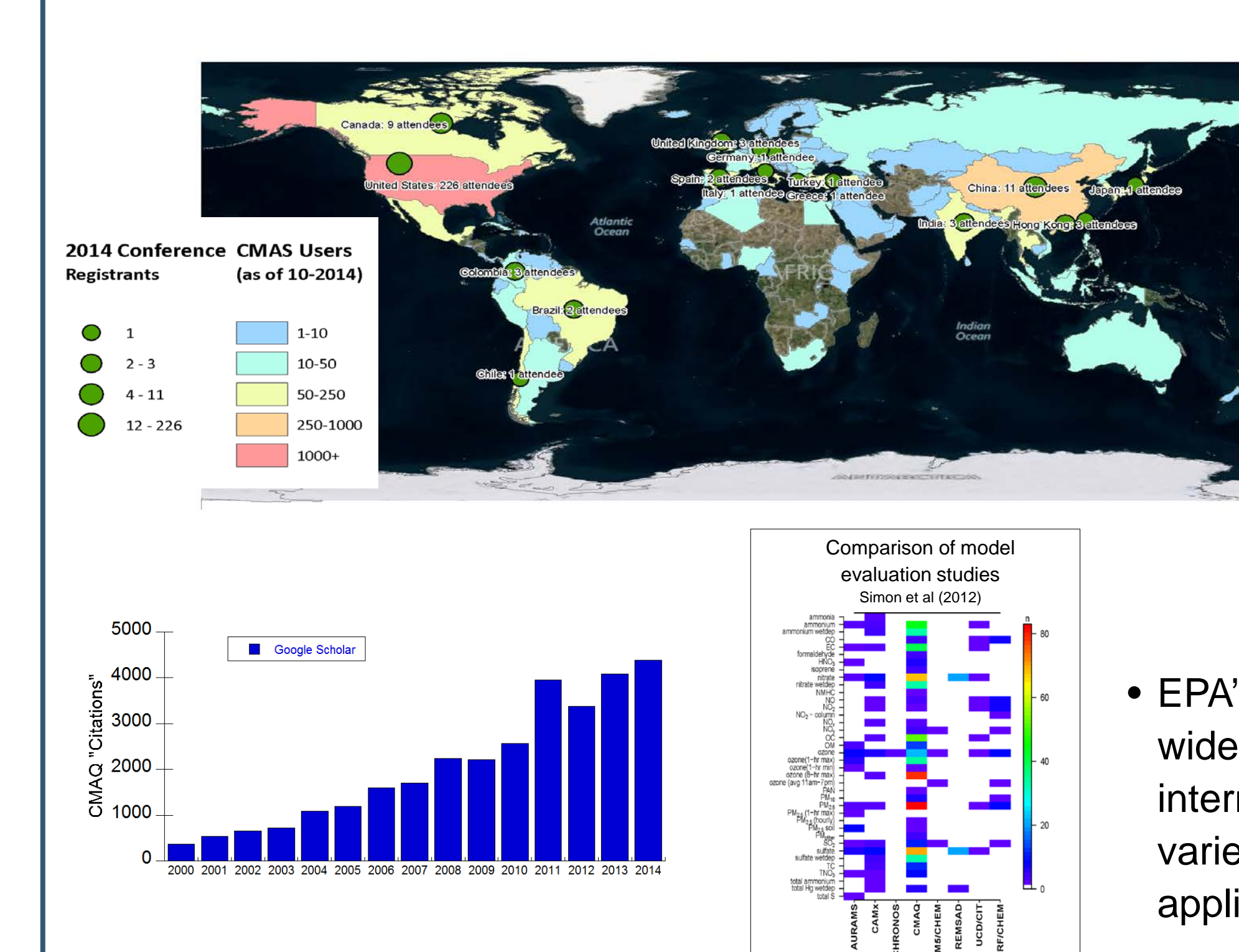
- CMAQ is publicly available through the Community Modeling & Analysis (CMAS) center. www.cmascenter.org

- Periodic scientific updates to CMAQ have led to creation of a dynamic and diverse user community

- Annual Conference and training

- EPA's CMAQ modeling system is widely used by a growing international community for a variety of research and regulatory applications

Comparison of model evaluation studies

Contacts:
Jonathan Pleim (pleim.jon@epa.gov)   **Shawn Roselle** (roselle.shawn@epa.gov)
Rohit Mathur (mathur.rohit@epa.gov)