Significant reduced health burdens from ambient air pollution in U.S. under emission reductions from 1990 to 2010

Yuqiang Zhang, ORISE Postdoc; zhang.yuqiang@epa.gov

Motivation

- Domestic ozone precursor emissions decreased strongly during 1990–2010: total U.S. anthropogenic emissions declined by 49%, 58% and 44% for the ozone precursors NOx (=NO + NO_2), CO and VOC, respectively (Cooper et al., 2012);
- Meanwhile, between 1990 and 2015, the U.S. average concentration of $PM_{2.5}$ decreased by 37% and ozone decreased by 22% (EPA, 2016).
- Recent estimates suggest that roughly 100,000 Americans die prematurely each year due to exposure to ambient air pollution (HEI/IHME, 2017), which is about 1 in 26 US deaths;
- Epidemiological studies have inferred how health effects have changed through time in the US (Pope et al., 2009), but previous studies have not focused on burden of disease calculations in the US for several years in succession.
- In the US, such changes in the health burden of air pollution can support decision making on air pollution policies. For the public, analyzing trends can illustrate very effectively the benefits of past air pollution controls, as well as the challenges for future policy efforts.

Objectives

- Use long-term historical air quality modelling results to quantify how air pollution-related mortality has changed in the U.S., including both O_3 and $PM_{2.5}$ each year since 1990.
- Quantify the health benefits from the emission reductions for the past 2 decades.

Methodology

- Model configuration for the coupled WRF-CMAQ two-way model
  - ➢ Horizontal resolution of 36 × 36 km covering the Continental U.S. (CONUS).
  - ➢ Comprehensive consistent U.S. emission inventory from 1990 to 2010 developed by Xing et al., 2013.
  - ➢ Boundary conditions are obtained from 108 × 108 km WRF-CMAQ hemisphere simulation (Xing et al., 2015).
  - ➢ Simulation period covering 1990 to 2010.
- Health impact function

$$\Delta Mort = y_0 \times AF \times Pop$$

  - ➢ **ΔMort**: Health burden for O_3 or $PM_{2.5}$;
  - ➢ **Y_0** : baseline mortality rates;
  - ➢ **AF** : attributable fraction = (**RR** – 1)/**RR**;
  - ➢ **Pop** : Exposed population, ages > 25 yrs

➢ The baseline mortality rates (Y_0) and the population (Pop) data are downloaded from the U.S. Centers for Disease Control and Prevention (CDC) at county level from 1990 to 2010, and processed into the CMAQ grid cells at 36 × 36km.

➢ For attributable fraction (AF):

For O_3	For $PM_{2.5}$
Use Log -linear model: **RR** = $\exp^{\beta\Delta X}$ (1) RR = 1.040 (1.1013-1.067) per 10 ppbv O_3 increases (Jerrett et al., 2009) (2) β: Concentration response factor (3) ΔX = X_2(1990-2010) – X_1 (1850)	Use Integrated Exposure–Response (IER) model (Burnett et al., 2014): **RR** equals to $RR_{IER}(z) = \begin{cases} 1, & z < z_{cf} \\ 1 + \alpha(1 - e^{-\gamma(z-z_{cf})^{\delta}}) & z \geq z_{cf} \end{cases}$ z = ambient $PM_{2.5}$ concentration; z_{cf} = counterfactual conc. = Uniform(5.8,8.8)

Results

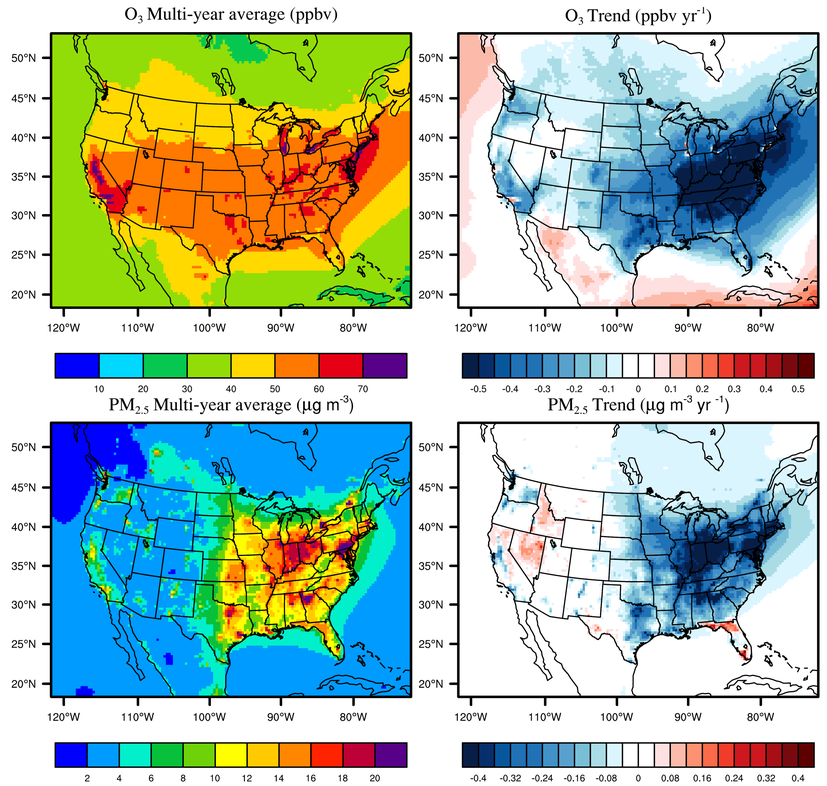

Fig. 1 21-year average of 6-month average of 1hr daily maximum O_3 (April-September, top) and annual mean $PM_{2.5}$ (bottom) concentration on the left, and the trends on the right

➢ The 6-month average of 1hr daily maximum O_3 (April-September) decreases significantly in the eastern U.S., > 0.5 ppbv yr^{-1}. It also decreases in the western U.S., not as significant as in the east, with > 0.2 ppbv yr^{-1}.

➢ The annual average $PM_{2.5}$ also decreases significantly in the east, but increases in the west and in Florida due to the smoke burning.

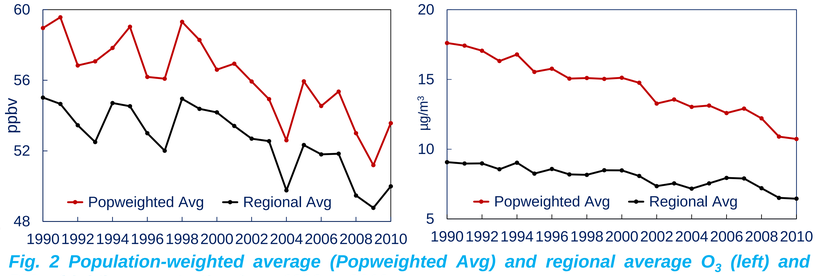

Fig. 2 Population-weighted average (Popweighted Avg) and regional average O_3 (left) and $PM_{2.5}$ (right) concentration from 1990 to 2010.

➢ Both the regional average and population-weighted average O_3 are generally decreasing from 1990 to 2010, but with a larger interannual variability because of the interface of the meteorological effects, like the hot temperatures in year 1994 and 1998, and large precipitation in year 2004.

➢ Compared with O_3, the domain average of annual $PM_{2.5}$ has a smoother decreasing trends: U.S. domain average has decreased from 9.07 μg m^{-3} in 1990 to 6.45 μg m^{-3} in 2010; population-weighted average has also decreased from 17.61 μg m^{-3} to 10.73 μg m^{-3}, with a 39% decreases even though the population has increased by 29%.

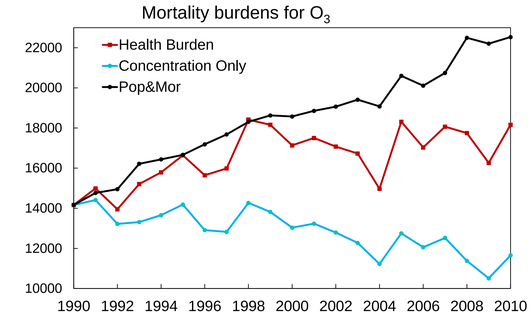

Fig. 3 Total mortality burdens of $PM_{2.5}$ (red), and separated the contribution from air pollution changes (blue), and population plus baseline mortality rates changes (black). Units are deaths yr^{-1}.

➢ The premature health burden associated with O_3 has **increased** by 28% for the past 2 decades, from 14200 (95% confidence intervals (CI), 4900-22500) deaths yr^{-1} in 1990 to 18200 (95% CI, 6200-29000) deaths yr^{-1} in 2010.

➢ However, the health burdens could be **decreased** by 18% in 2010, compared with that in 1990, if only the O_3 changes are considered (blue lines).

➢ The O_3 related health burden could have **increased** by 59%, from 14200 deaths yr^{-1} in 1990 to 22500 deaths yr^{-1} in 2010, if the O_3 concentration are kept constant at 1990 levels, due to the increase of the exposed Pop and Y_0. That increase ratio could be even higher if no Clean Air Act plan was implemented because the O_3 concentration would continue to increase when the precursors emissions are increasing.

➢ On average, the O_3 changes from 1991 to 2010 could reduce the O_3 health burden by 2000 deaths yr^{-1} compared with the health burden in 1990.

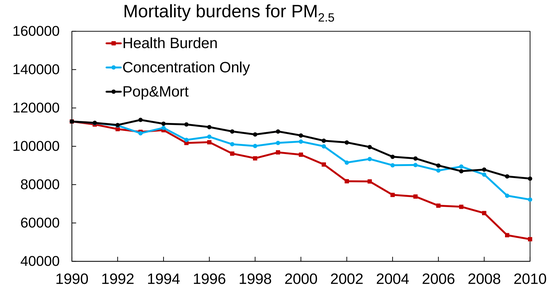

Fig. 4 Total mortality burdens (red) $PM_{2.5}$, and separated the contribution from air pollution changes (blue), and population plus baseline mortality rates changes (black). Units are deaths yr^{-1}.

➢ The $PM_{2.5}$ related health burdens are seen steadily decreasing. The health burden has decreased by 54%, from 113000 deaths yr^{-1} (95%CI, 65000-162200) in 1990, to 51500 deaths yr^{-1} (95%CI, 22000-86500) in 2010.

➢ The $PM_{2.5}$-related health burdens could decrease only by 26% if the $PM_{2.5}$ concentrations changes were not considered. So the $PM_{2.5}$ changes have significantly reduced the health burdens, even though the exposed population are increasing.

➢ On average, the $PM_{2.5}$ changes from 1991 to 2010 could reduce the $PM_{2.5}$ health burden by 14500 deaths yr^{-1} compared with the health burden in 1990.