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Contribution of individual anthropogenic emissions sectors to global human mortality due to outdoor air pollution

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INTRODUCTION

- Outdoor air pollution has increased significantly due to anthropogenic emissions of air pollutants and their precursors.
- Exposure to air pollution from ozone and fine particulate matter ($PM_{2.5}$) can cause adverse health effects, particularly cardiovascular and respiratory morbidity and mortality.
- We previously estimated 2.1 million $PM_{2.5}$- related deaths annually from cardiopulmonary diseases and lung cancer, and 470,000 ozone-related deaths annually from respiratory diseases, at a global scale (Silva et al. 2013).
- This and other recent studies have quantified global air pollution mortality but they do not estimate the contribution of different emission sectors (Anenberg et al. 2010, Lim et al. 2012, Evans et al. 2013) or they focus on a specific emissions sector - shipping (Corbett et al. 2007) and aircraft (Barrett et al. 2010).

Objectives

- Use a **global chemical-transport model (CTM) at a fine horizontal resolution** to estimate:
  - ✓ **Total global burden** of present-day anthropogenic ozone and $PM_{2.5}$ on human mortality;
  - ✓ **The contributions of five anthropogenic emissions sectors** (energy, residential & commercial, industry, land transportation, all transportation) to current ozone and $PM_{2.5}$ concentrations and premature human mortality.

MATERIALS AND METHODS

- **Modeling ozone and $PM_{2.5}$ concentrations**

Meteorology

GEOS-5 meteorological fields, 2005
at 0.67°x0.5° horizontal resolution and 72 vertical hybrid levels

Emissions

IPCC's AR5 RCP8.5 global emissions inventory, 2005
at 0.5°x0.5° horizontal resolution

Riahi *et al.* 2007, Lamarque *et al.* 2010

MOZART-4
(Emmons *et al.* 2010)

Chemistry, Transport and Deposition

Offline **global 3-D Chemical Transport Model** for the troposphere

https://www2.acd.ucar.edu/gcm/mozart

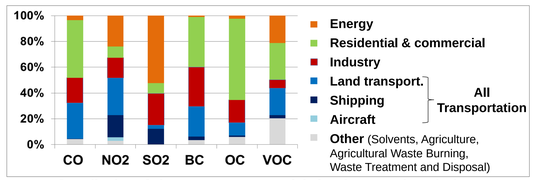
Concentrations

Ozone
(hourly output)
+
$PM_{2.5}$ species
(monthly output)

0.67°x0.5° horizontal resolution and 72 vertical hybrid levels; surface concentration: lowest vertical level (992.5 hPa)

Emissions processing:

- Add **seasonality**, **speciation of NMVOCs** and **regrid to 0.67°x0.5° resolution**;
- Prepare emissions files for control simulations by **zeroing-out each source sector**: Energy, Residential & Commercial, Industry, Land Transportation, All Transportation.



Contribution of six source sectors to global anthropogenic emissions of major ozone precursors and components of $PM_{2.5}$
Source: RCPs Database, www.iiasa.ac.at

- **Applying a health impact function** to estimate air pollution-related premature mortality (ΔMort):

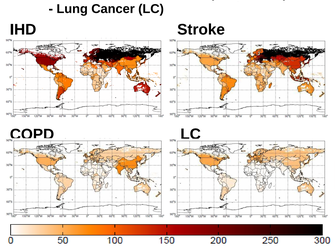
Baseline mortality rate
- Respiratory diseases (inc. COPD)
- Cardiovascular diseases (IHD, Stroke)
- Lung Cancer (LC)

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

Exposed Population

Population 25+
Source: ORNL, 2012 - Landscan 2011
- total population (30"x30") and percent of population per age-group (country-level), gridded to 0.67°x0.5°

Attributable fraction
AF=(RR – 1)/RR

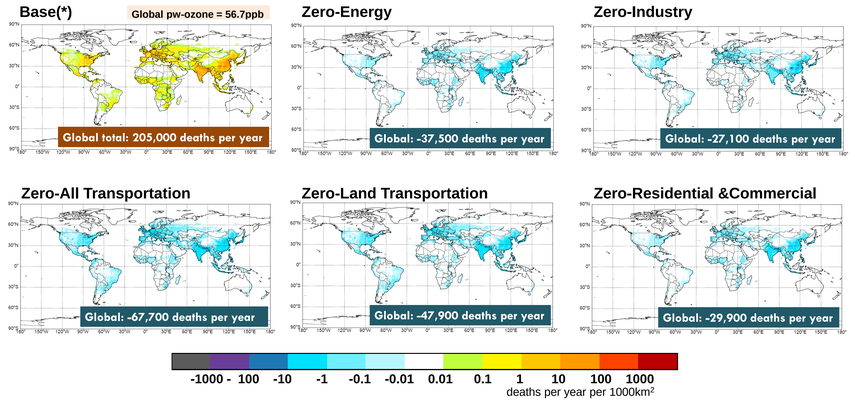


Baseline Mortality Rates, deaths per 100,000
Source: IHME, 2013, country level, AllAges > gridded to 0.67°x0.5°

RR = Relative Risk of death attributable to changes in pollutant concentration, from long-term epidemiological studies:

Log-linear model	IER model (Burnett *et al.* 2014)
OZONE	$PM_{2.5}$
$AF = 1\text{-}exp^{-\beta\Delta X}$	$AF = AF_{Control} - AF_{Base}$
β = ln(RR)/10, where **RR = 1.040** (95% CI: 1.013-1.067) (Respiratory diseases, Jerrett *et al.* 2009)	$AF_i = 1\text{-}1/RR_{IER}(z_i)$ where $RR_{IER}(z_i)$ - estimated by linear interpolation of concentration-response curve values (given for 1μg/m³ increments of $z_i = PM_{2.5}$ concentration) for IHD, Stroke, COPD, LC.
$\Delta X = X_2 - X_1$, where X_1, X_2 – ozone concentrations (baseline and control, respectively)	

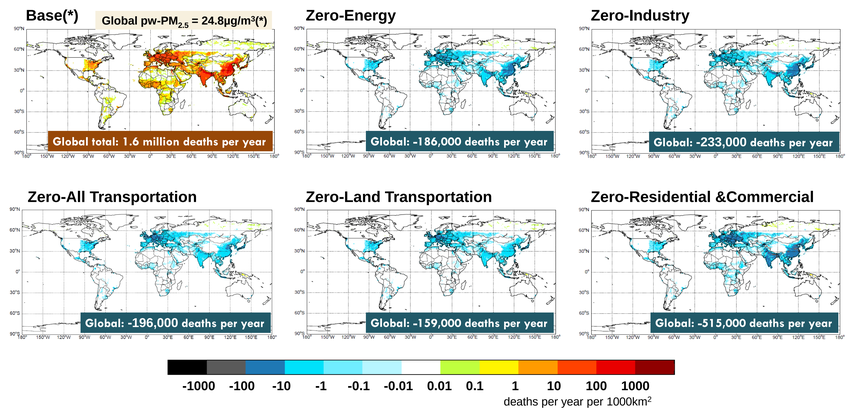
PRELIMINARY RESULTS: Ozone-related premature mortality



Premature Ozone Mortality (Resp.),
(*) considering a counterfactual = 33.3ppb

- **Ozone-related mortality**: **205,000 deaths/year** globally, most in East Asia (41%) and India (30%);
- **The Transportation sector has the greatest impact globally (33% of total premature mortality)**, but Energy and Residential & Commercial have strong impact in India and East Asia and Industry has strong impact in East Asia;
- Globally, these sectors contribute about 80% of total ozone respiratory mortality.

PRELIMINARY RESULTS: $PM_{2.5}$-related premature mortality

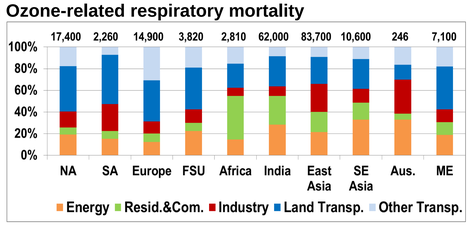


Premature $PM_{2.5}$ Mortality (IHD+Stroke+COPD+LC)
(*) considering a counterfactual = U(5.8-8.8) μg/m³

- **$PM_{2.5}$-related mortality: 1.6 million deaths/year** globally, most in East Asia (45%), India (17%), Europe (12%) and FSU (10%);
- **The Residential & Commercial sector has the greatest impact globally (31% of total excess mortality)**, especially in East Asia, India, Europe and FSU;
- Globally, these sectors contribute about 70% of total $PM_{2.5}$ mortality (IHD+Stroke+COPD+LC), but in Africa and the Middle East they only explain around 30% of total $PM_{2.5}$ mortality.

PRELIMINARY RESULTS: Regional premature mortality

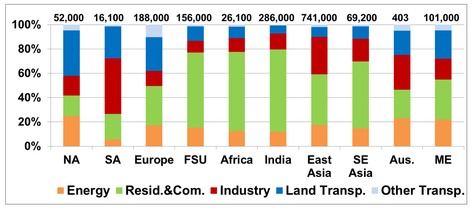
- **Ozone-related respiratory mortality**



Regional Premature Ozone Mortality (Resp.),
relative contribution of each sector
(total ozone-related mortality indicated above each column)

- Sectors with the greatest impact:
(% of total ozone-related mortality)
  - ✓ East Asia: Industry(19%) and Land Transportation (18%);
  - ✓ India: Energy (23%), Land Transportation (22%), Residential & Commercial (21%);
  - ✓ North America: Land Transportation (33%);
  - ✓ Europe: Land Transportation (33%);
  - ✓ Southeast Asia: Energy (31%) and Land Transportation (27%).

- **$PM_{2.5}$-related mortality (IHD+Stroke+COPD+LC)**



Regional Premature $PM_{2.5}$ Mortality (IHD+Stroke+COPD+LC),
relative contribution of each sector
(total $PM_{2.5}$-related mortality indicated above each column)

- Sectors with the greatest impact:
(% of total of $PM_{2.5}$-related mortality)
  - ✓ East Asia: Residential & Commercial (25%);
  - ✓ India: Residential & Commercial (40%);
  - ✓ North America: Land Transportation (52%);
  - ✓ Europe: Residential & Commercial (31%) and Land Transportation (26%);
  - ✓ Southest Asia: Residential & Commercial (54%).

CONCLUSION

- **Contributions to ozone respiratory mortality from different sectors differ among regions but Transportation has the greatest impact globally**: close to 70,000 deaths per year, of which 71% correspond to the impact of **Land Transportation.**
  - In East Asia, **Industry** has the greatest impact (15,700 deaths per year), closely followed by **Land Transportation** (15,200 deaths per year);
  - In India, **Energy** has the greatest impact (14,100 deaths per year), closely followed by **Land Transportation** (13,800 deaths per year) and **Residential & Commercial** (13,100 deaths per year);
  - In North America, **Land Transportation** has the greatest impact (5,800 deaths per year).
- **Globally, the Residential & Commercial sector contributes the most to $PM_{2.5}$-related premature mortality (IHD+Stroke+COPD+LC)**: over 0.5 million deaths per year globally, 36% of which occur in East Asia and 22% in India.
  - In East Asia, Industry also has a great impact (137,000 deaths per year);
  - In North America, Land Transportation has the greatest impact (26,900 deaths per year).
- Research strengths:
  - Results are estimated at a fine enough horizontal resolution to capture both global and regional effects;
  - MOZART-4 improvements over MOZART-2: chemical mechanisms, photolysis scheme, dry deposition mechanism, biogenic emissions, handling of tropospheric aerosols.
- Research limitations:
  - Same RR used worldwide although underlying health conditions and $PM_{2.5}$ composition vary;
  - Zeroed-out simulations vs. non-linear model response;
  - Assumption of uniform spatial distribution of population and baseline mortality rates per age group, at the country level.
- Future work:
  - Estimate uncertainty in premature mortality results;
  - Evaluate these results with coarse resolution simulations.

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