Emissions to Exposure: Applications of Impact Functions for Global Human Health

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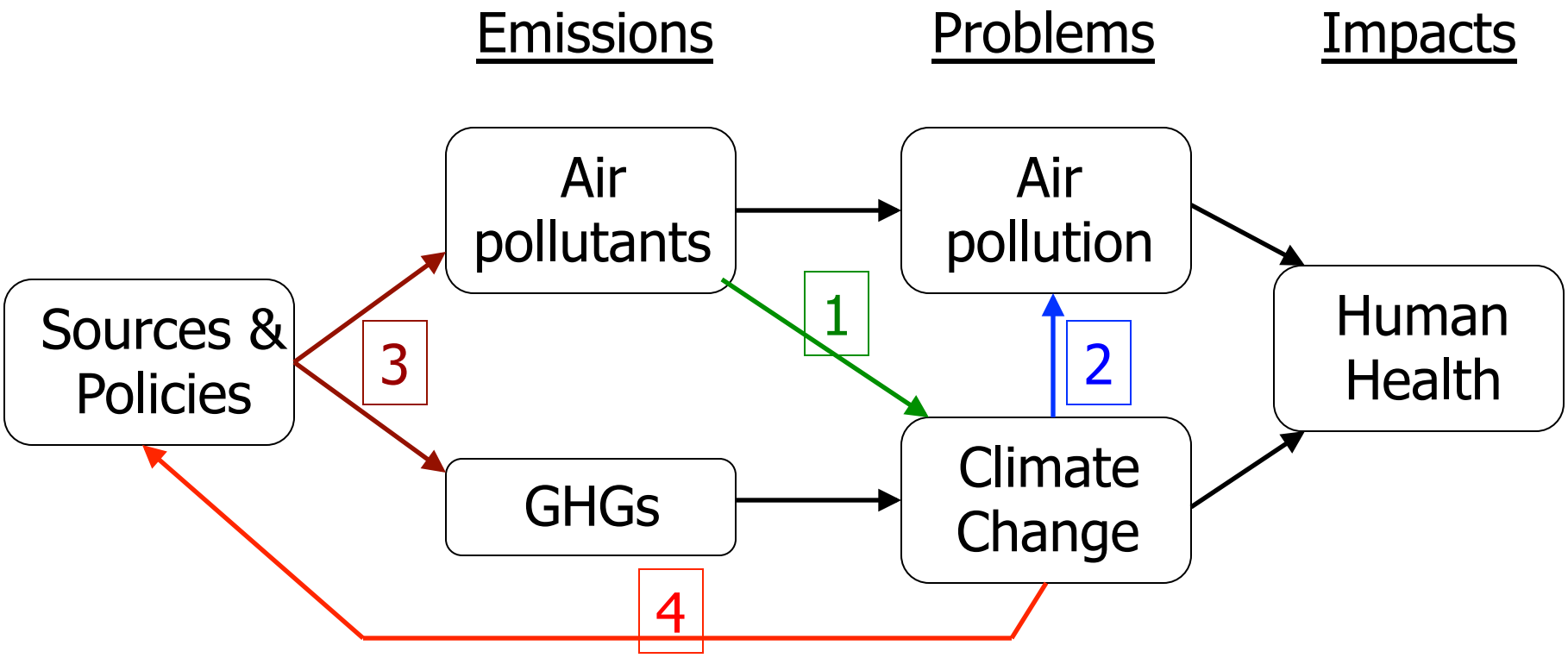
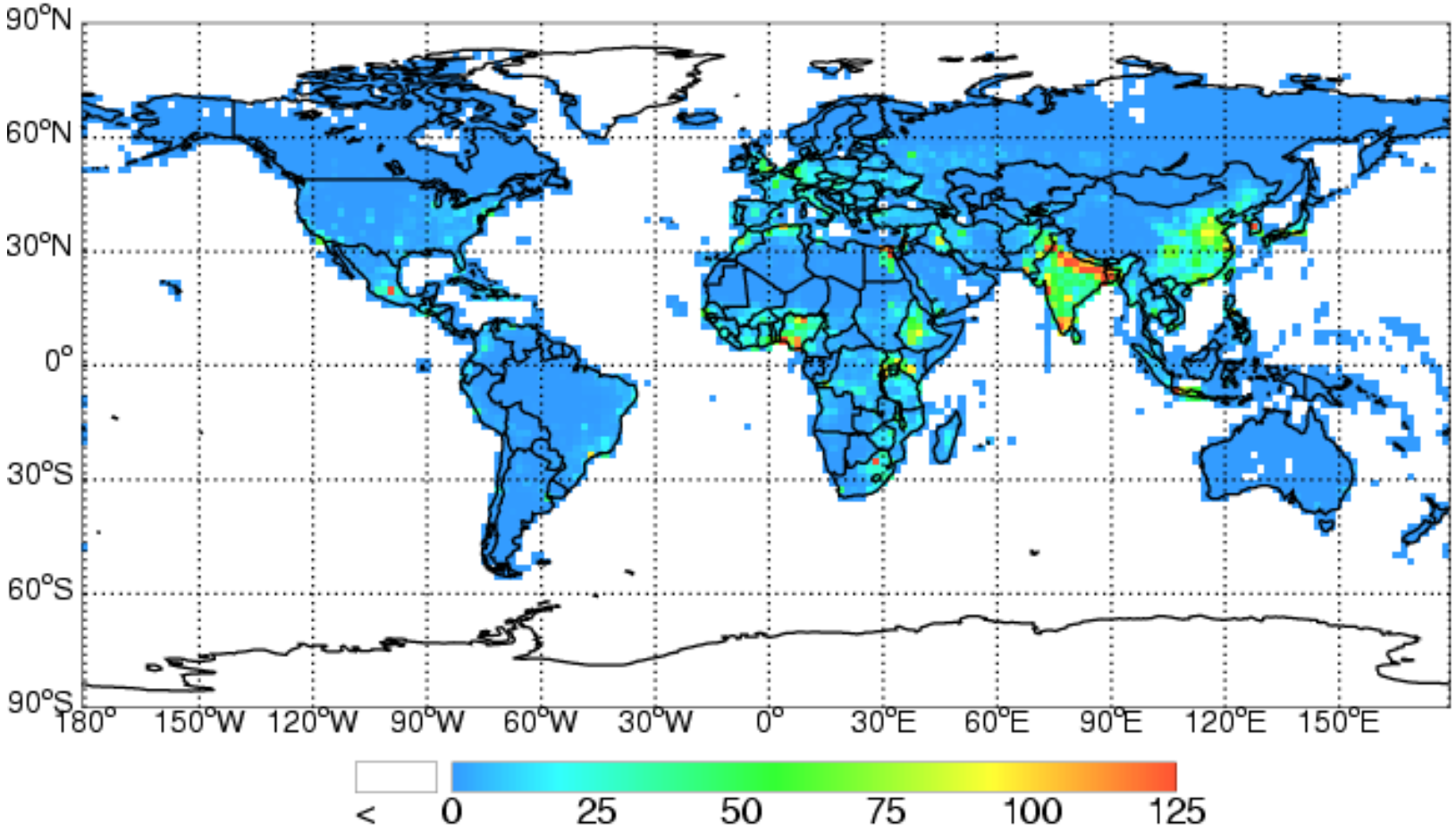
Connections Between Air Pollution and Climate Change



Big Question: How can we plan to address air pollution and climate change in a coordinated way?

-20% Global Anthrop. Methane Emissions: 30,200 avoided premature deaths in 2030 due to reduced ozone



West et al., *PNAS*, 2006

Health impact function

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

$$\Delta Mort = y_0 \times (1 - exp^{-\beta \Delta X}) \times Pop$$

Baseline mortality rate

(≈ CPD)

- **Respiratory diseases** (RESP)
  (inc. COPD – chronic obstructive pulmonary disease)
- **Cardiovascular diseases**
  (inc. IHD – ischemic heart disease, STROKE – cerebrovascular disease)
- **Lung Cancer** (LC)

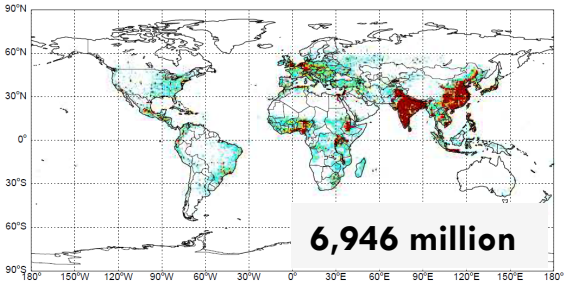
Exposed Population

ΔX = Change in concentration

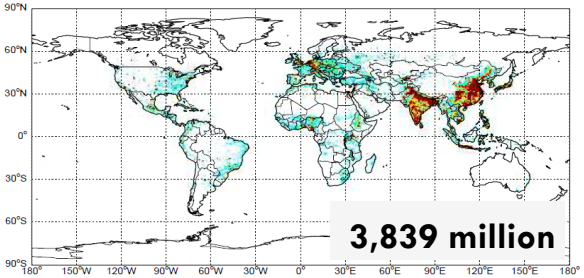
β = Concentration-response factor

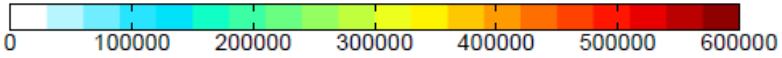
Population and Baseline Mortality Rates

Total Population, persons
(Landscan 2011 at 30"x30" gridded to 0.67°x0.5°)



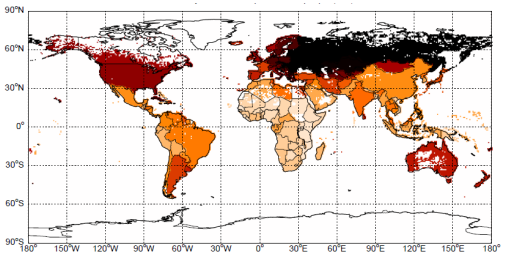
Population 25+, persons
(Landscan 2011 at 30"x30" gridded to 0.67°x0.5°)



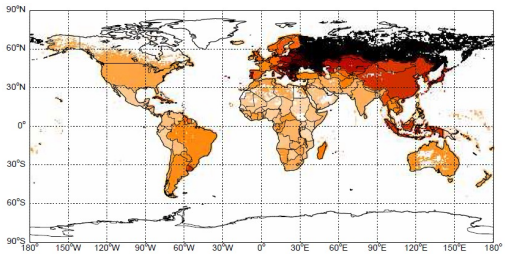


Baseline Mortality Rates, deaths per year per 100,000
(GBD 2010, country level, AllAges > gridded to 0.67°x0.5°)

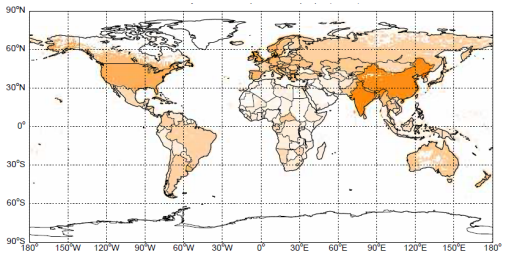
IHD



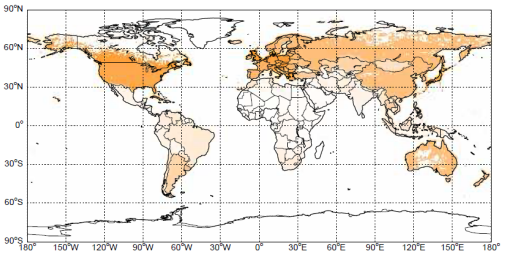
Stroke

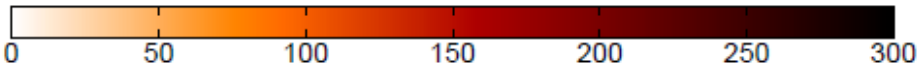


COPD

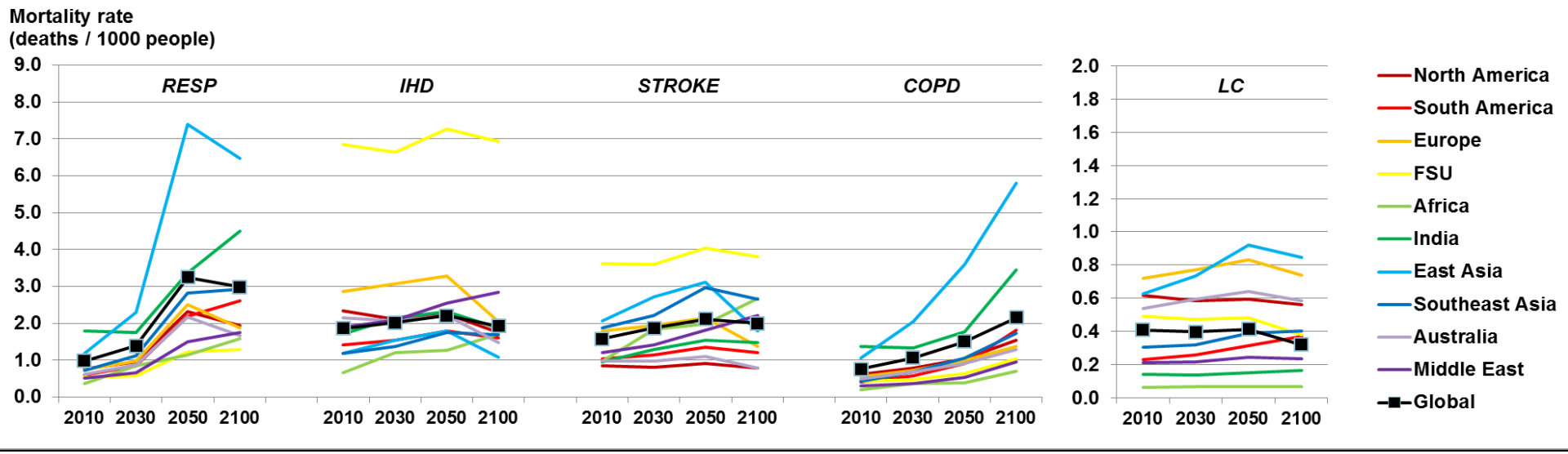


LC





Projecting Baseline Health



2010 from WHO GBD
Future from International Futures

(mortality rates are at country level)

Chemical Transport Models (Eulerian)

Chemical Mechanism

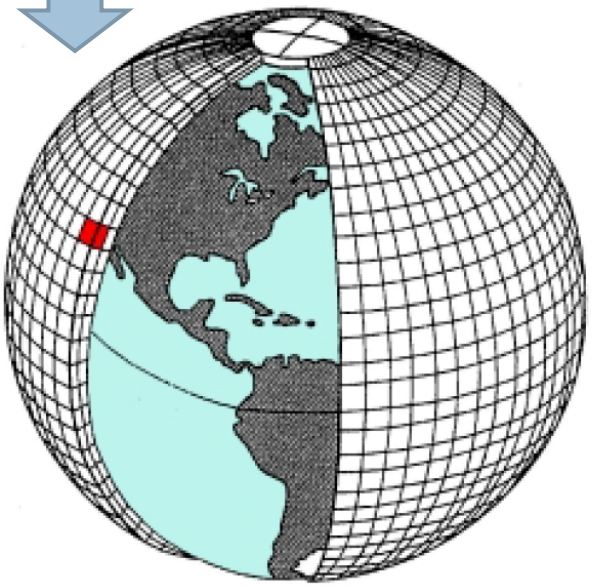
~150 gas-phase & photolysis reactions, aerosol processes, deposition

Meteorology

Input fields are hourly to every 6 hours

Emissions

Inputs vary hourly (regional models) to monthly (global models)



Concentrations

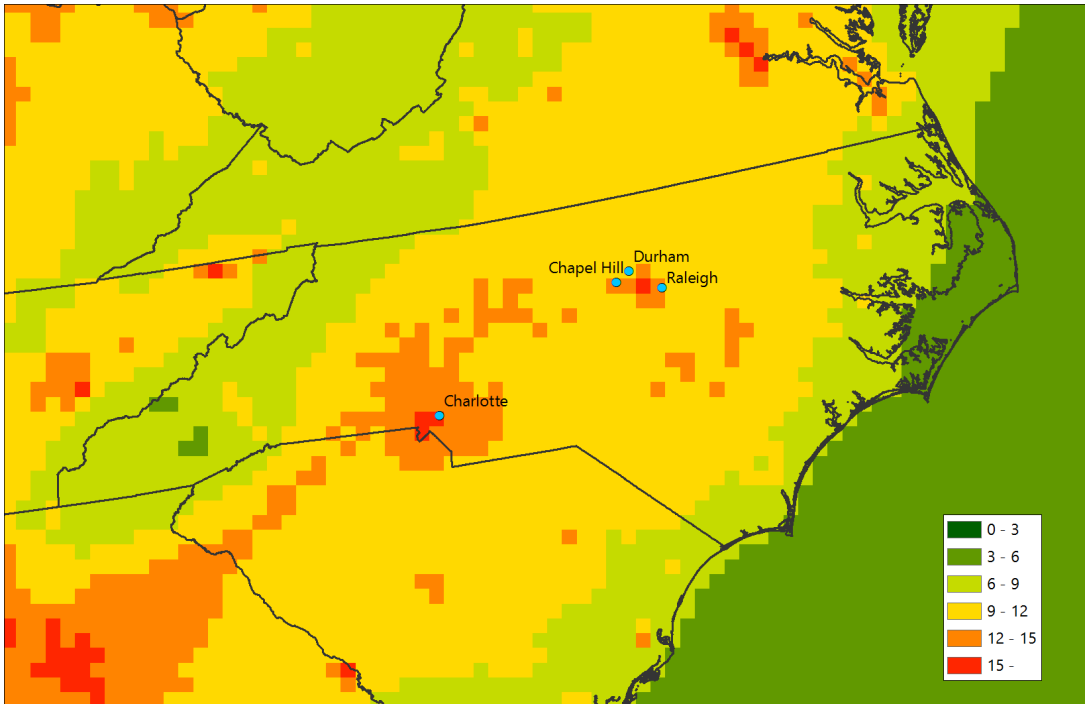
~100 species including Ozone and $PM_{2.5}$ species, can be output hourly

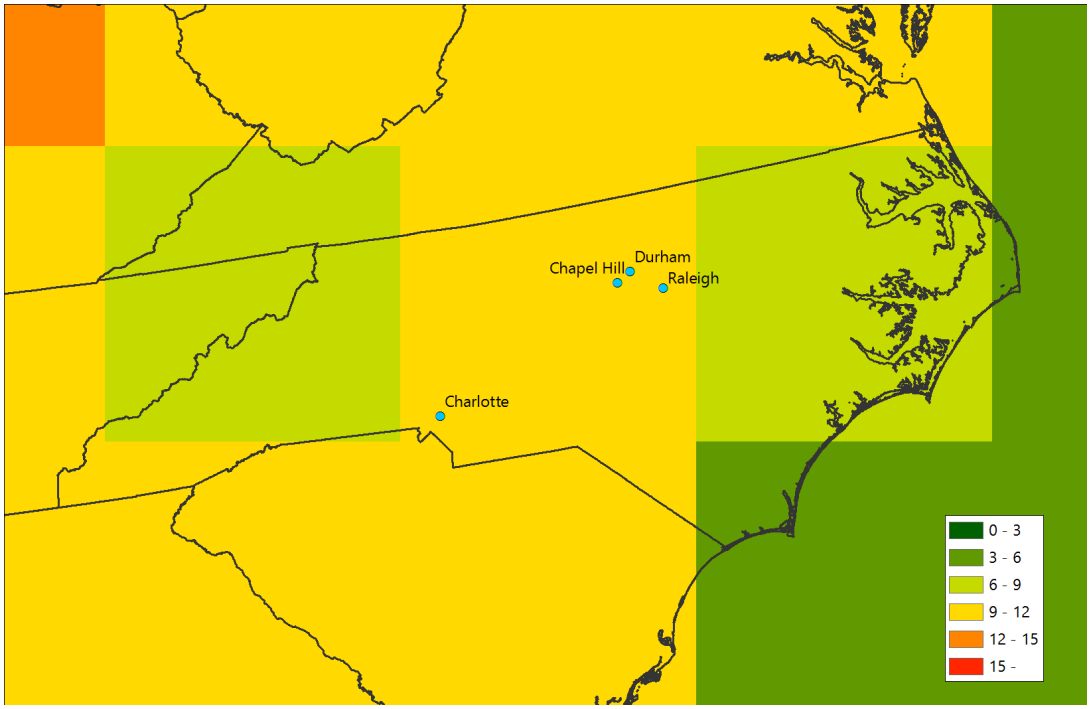
Typical horizontal resolutions:

Global model – 5 to 0.5 degrees

Regional model (continental) – 50 to 10 km

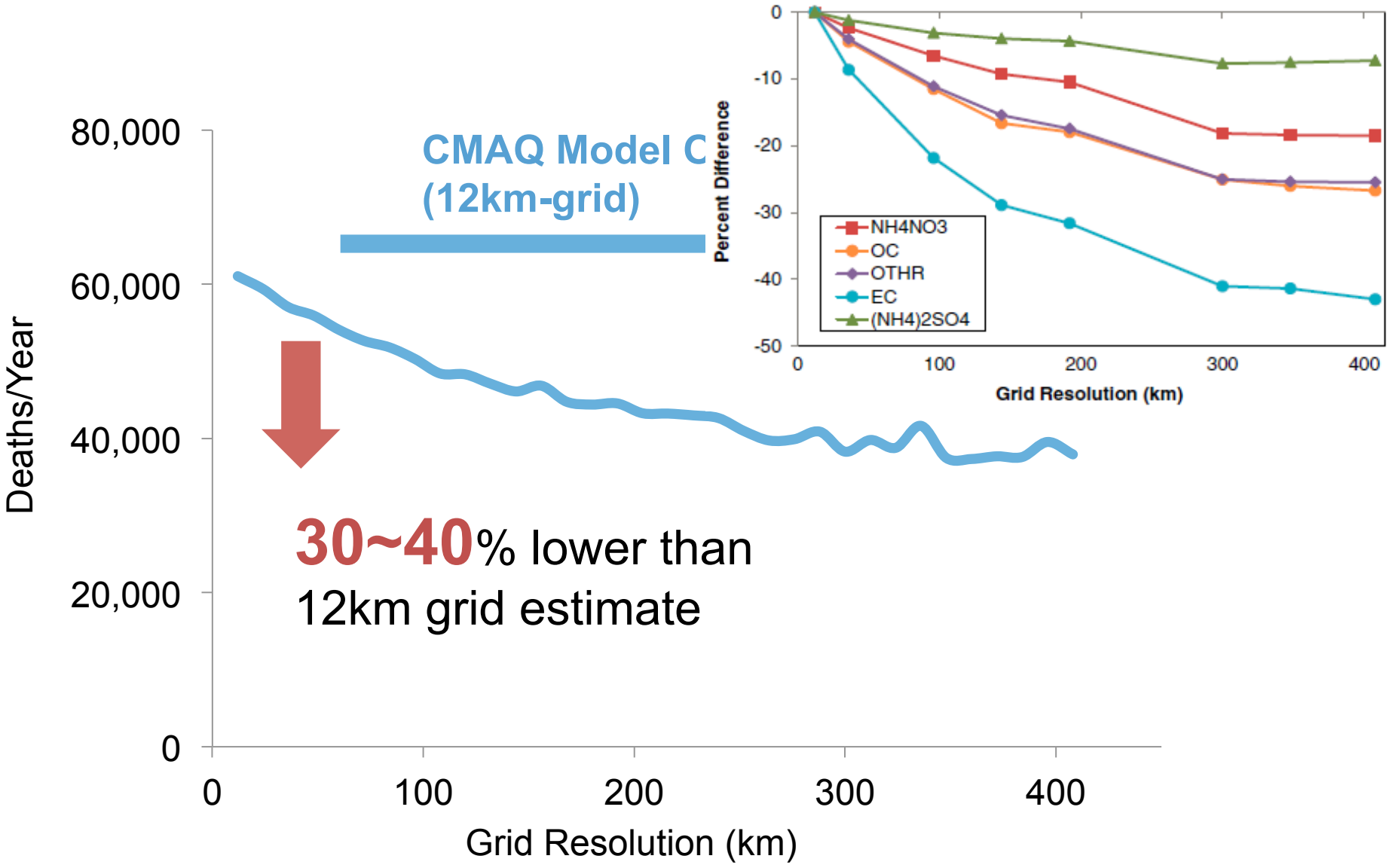
12-km CMAQ





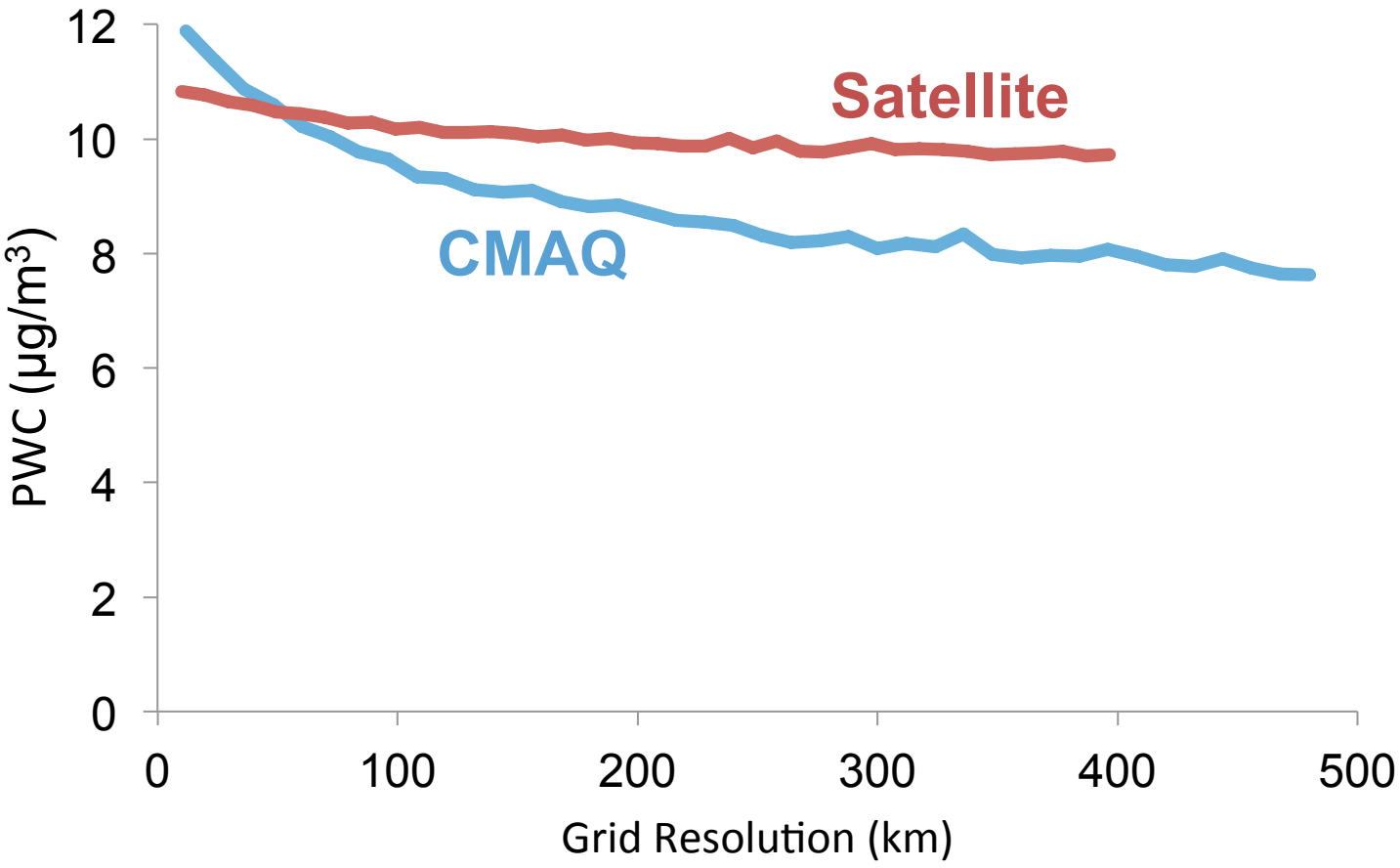
Global model
2.8º resolution

Bias in US Deaths from $PM_{2.5}$



Punger and West (2013) The effect of grid resolution on estimates of the burden of ozone and fine particulate matter on premature mortality in the USA

US Bias is different for Satellite $PM_{2.5}$!



Akita et al. *in prep.*

Limitations of Health Assessments

- Evidence for chronic impacts stronger for $PM_{2.5}$ than for ozone.
- Long-term studies in US and Europe. We assume that the CRFs apply globally and in the future despite differences in:
  - Population health status
  - $PM_{2.5}$ composition, air pollutant mixtures
  - Climate-air pollution interrelationships?
- Relationships of indoor & ambient air, importance of time activity.
- Morbidity internationally?

Ozone from European Emissions Causes More Deaths Outside of Europe than Within

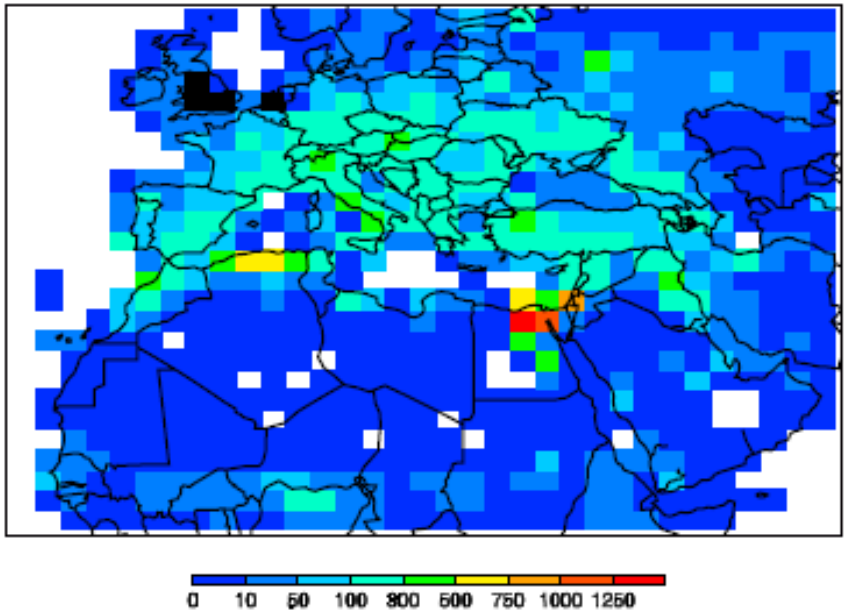


Fig. 8. Premature mortalities (per year) due to emission reductions in Europe. Black boxes represent regions with increased premature mortalities (i.e. fewer mortalities in the simulation with European pollution than without it).

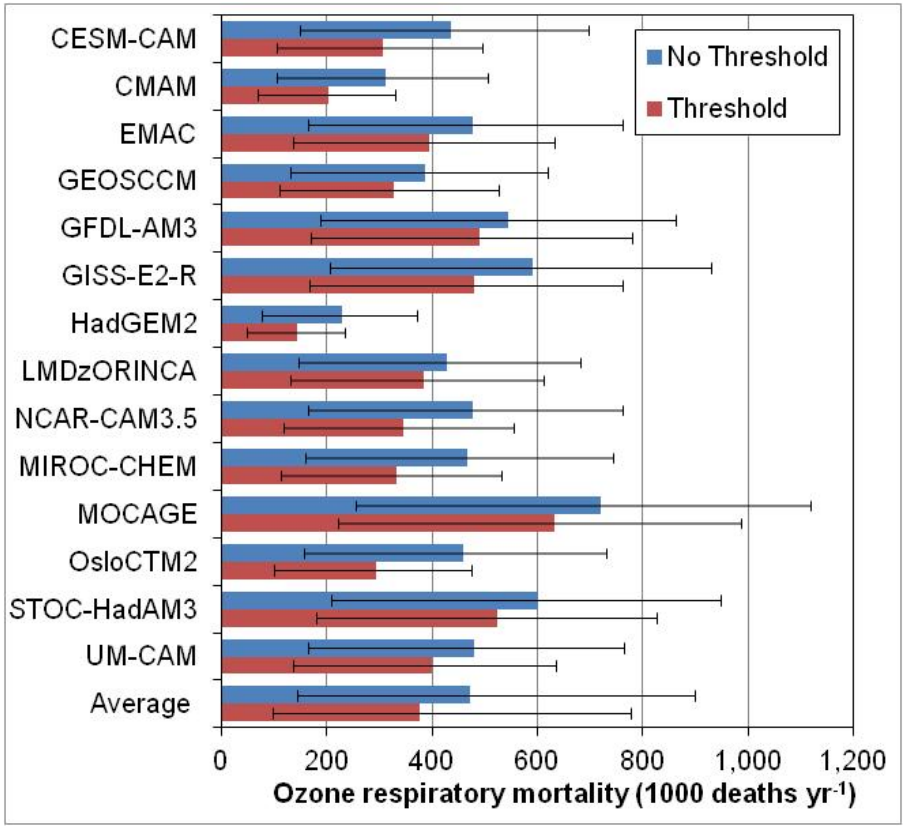
Region[a]	Pop. (millions)	ΔO_3 (ppbv)	Premature mortalities (/yr)	Premature mortalities (/million/yr)
Europe	688.9	6.0	18,800	27.3
Northern Africa	626.4	4.1	10 700	17.1
Near/Middle East[b]	408.6	7.0	8400	20.5
Former Soviet Union[c]	98.7	4.5	1700	17.7
South Asia[d]	1267.1	0.8	3800	3.0
East Asia[e]	1518.5	1.4	5800	3.8
Southeast Asia[f]	361.9	0.4	300	1.0
America	578.7	0.9	1400	2.4
Total Northern Hemisphere	5548.8	2.5	51 000	9.2

Duncan et al., ACP, 2008

Global mortality burden – ACCMIP ensemble

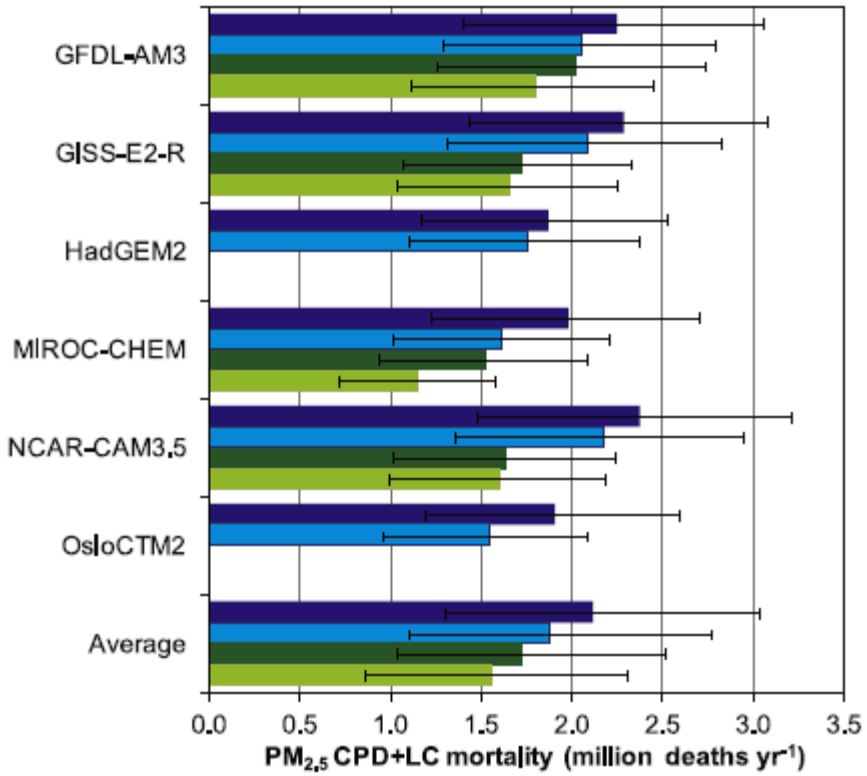
Ozone-related mortality

470,000 (95% CI: 140,000 - 900,000)



$PM_{2.5}$-related mortality(*)

2.1 million (95% CI: 1.3 - 3.0 million)



(*) $PM_{2.5}$ calculated as a sum of species (dark blue)
$PM_{2.5}$ as reported by 4 models (dark green)
Light-colored bars - low-concentration threshold (5.8 μg m^{-3})

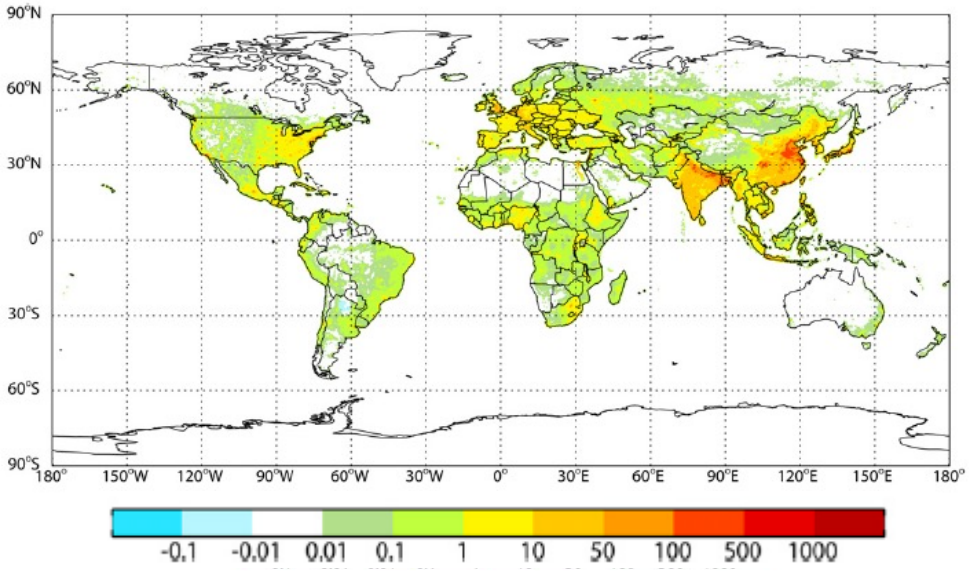
Silva et al. (2013)

Global Burden: Ozone-related mortality

Global and regional mortality per year

Regions	Total deaths	Deaths per million people (*)
North America	34,400	121
Europe	32,800	96
Former Soviet Union	10,600	66
Middle East	16,200	68
India	118,000	212
East Asia	203,000	230
Southeast Asia	33,300	119
South America	6,970	38
Africa	17,300	73
Australia	469	29
Global	472,000	149

(*) Exposed population (age 30 and older)



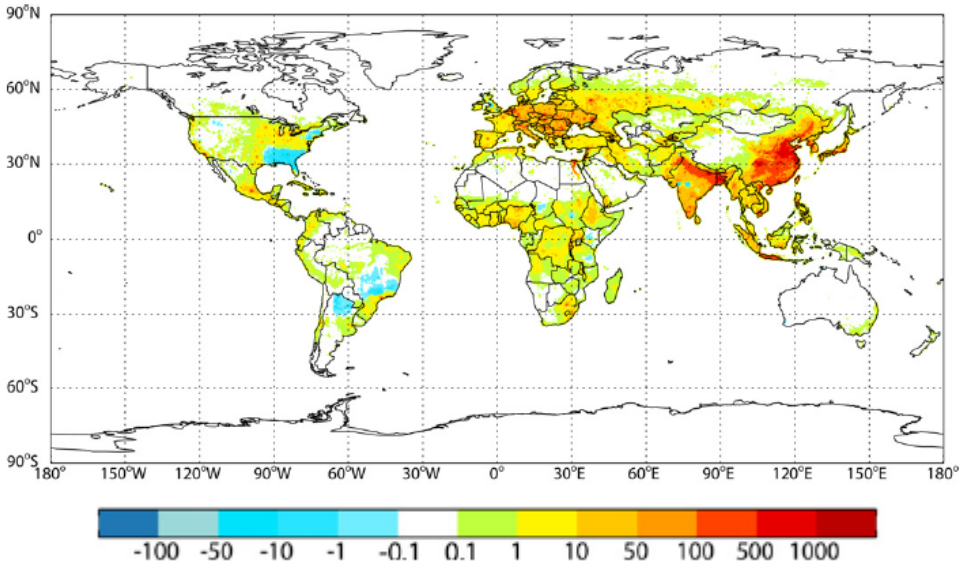
Respiratory mortality , deaths yr^{-1} $(1000\ km^2)^{-1}$,
multi-model mean in each grid cell , 14 models

Global Burden: $PM_{2.5}$-related mortality

Global and regional mortality per year

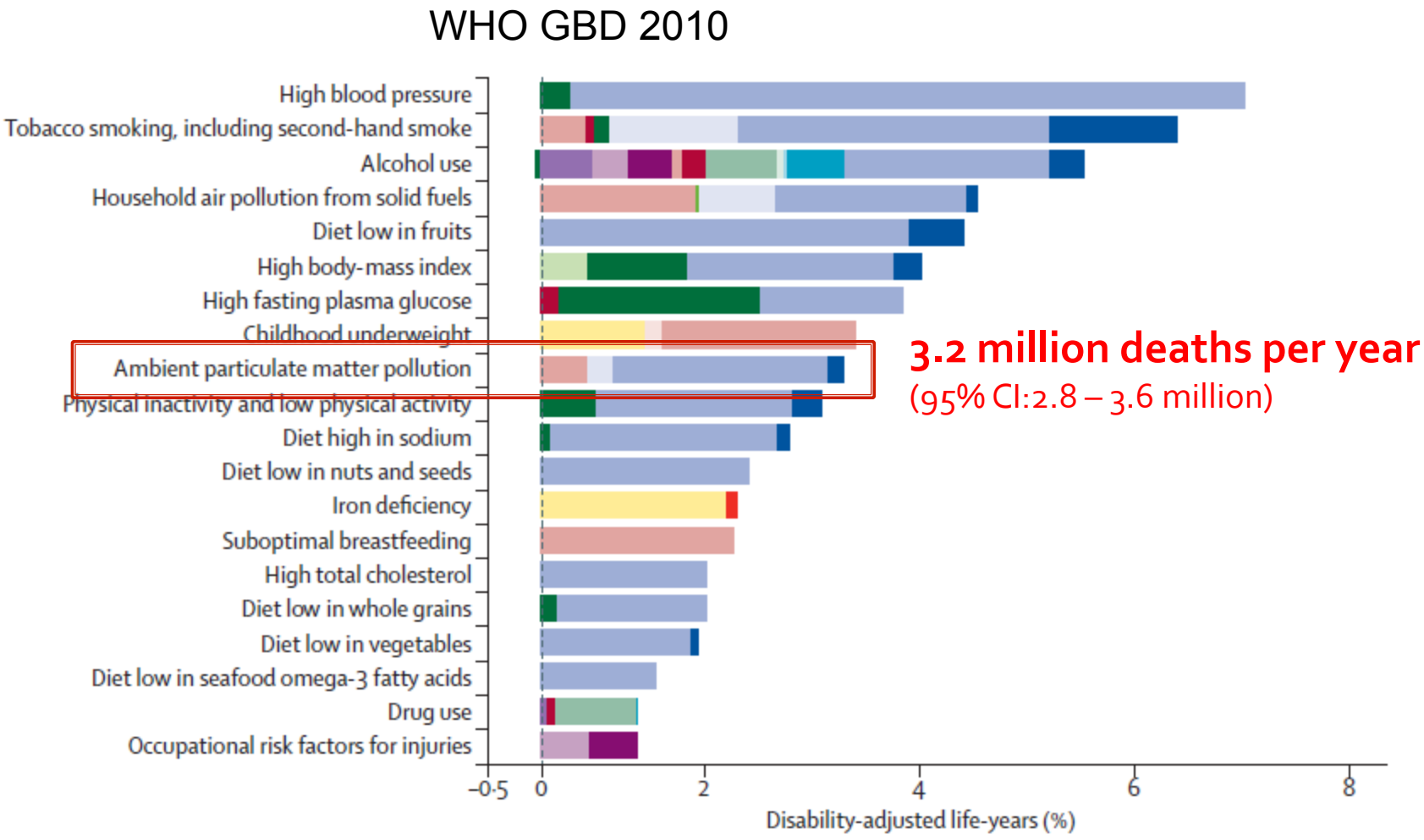
Regions	Total deaths	Deaths per million people (*)
North America	43,000	152
Europe	154,000	448
Former Soviet Union	128,000	793
Middle East	88,700	371
India	397,000	715
East Asia	1,049,000	1,191
Southeast Asia	158,000	564
South America	16,800	92
Africa	77,500	327
Australia	1,250	78
Global	2,110,000	665

(*) Exposed population (age 30 and older)



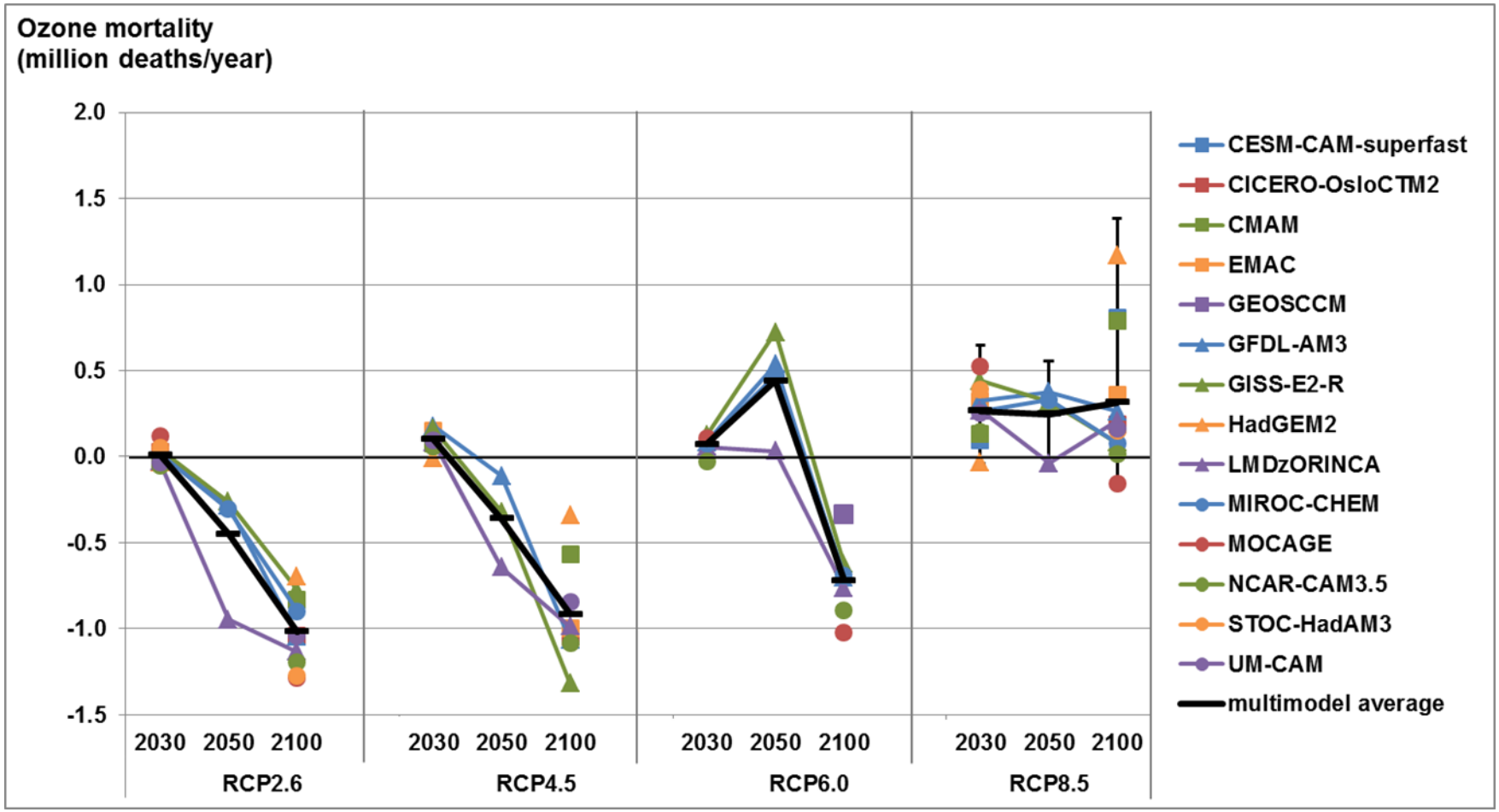
CPD+LC mortality , deaths yr^{-1} $(1000\ km^2)^{-1}$,
multi-model mean in each grid cell , 6 models

Global burden of disease of outdoor air pollution



Lim et al., 2012

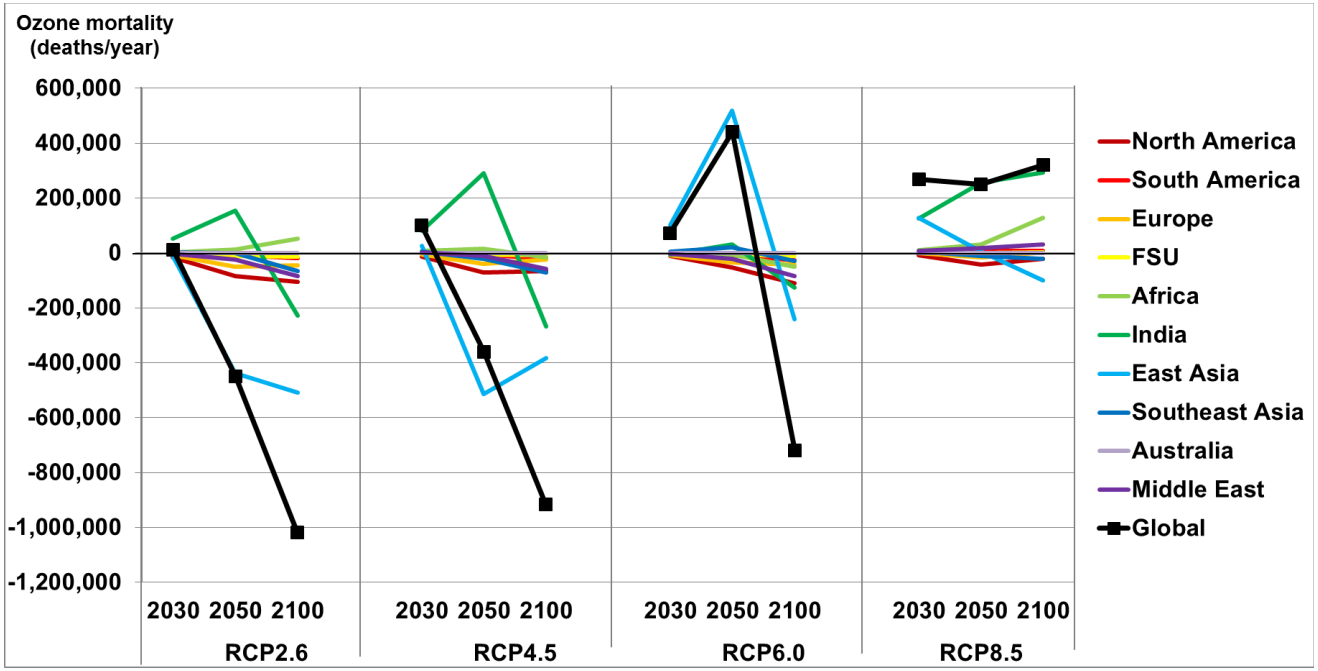
Future ozone-related mortality



Global Respiratory Premature Ozone Mortality: 2030, 2050 and 2100 vs. 2000 conc.

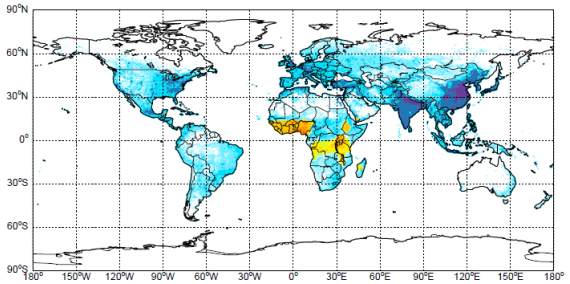
- Uncertainty for the ensemble mean is a 95% CI including uncertainty in RR and across models. -

Future ozone-related mortality

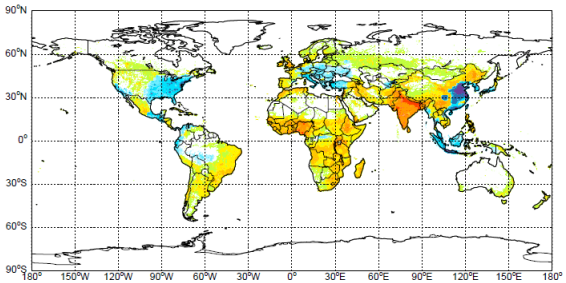


Respiratory premature ozone mortality - 2030, 2050, 2100 vs. 2000

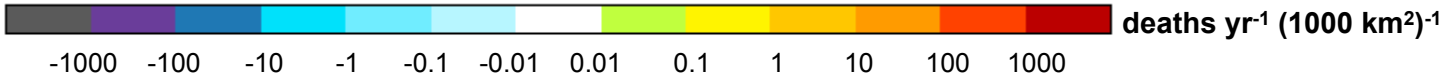
RCP2.6 **11 models**



RCP8.5 **13 models**

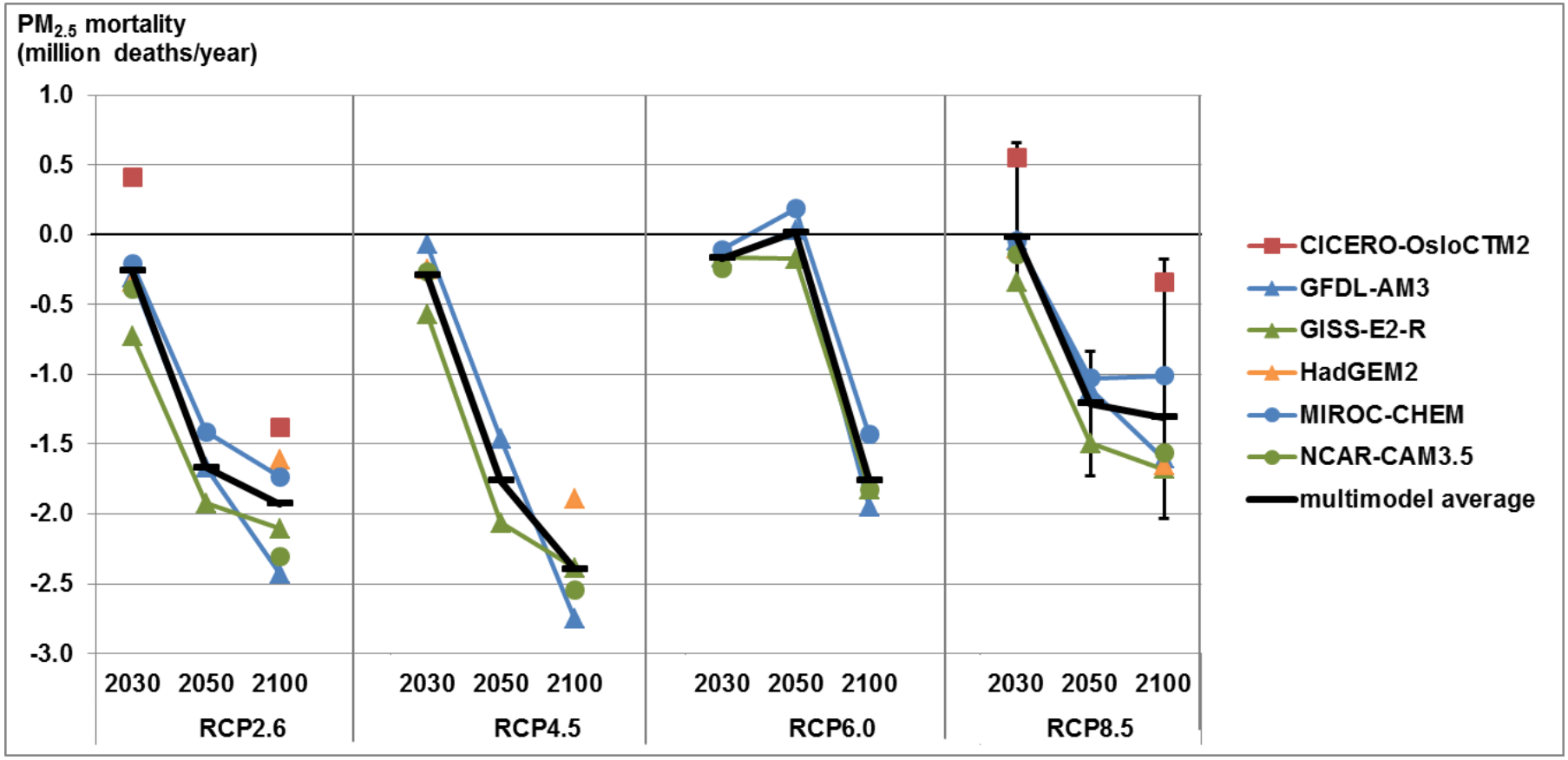


Respiratory premature ozone mortality - 2100 (two scenarios)



Silva et al. (in prep.)

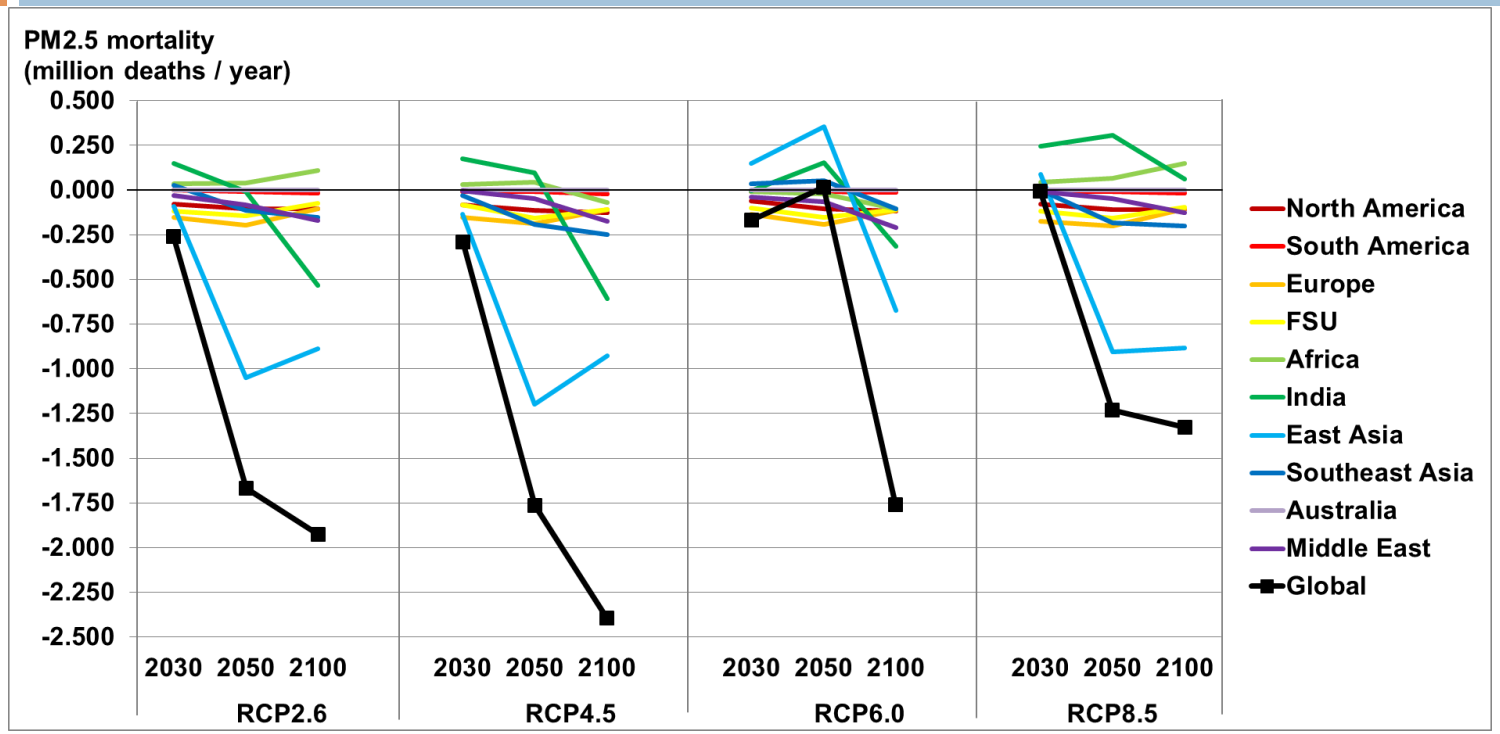
Future $PM_{2.5}$-related mortality



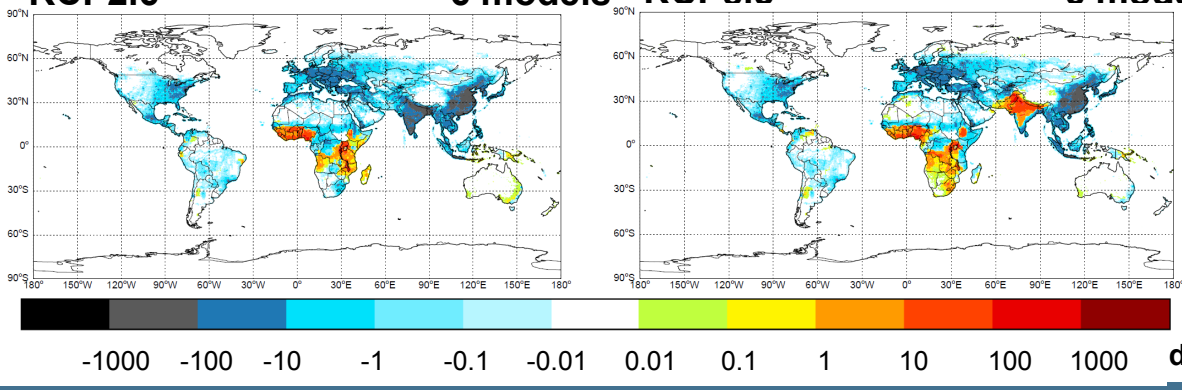
Global CPD+LC Premature $PM_{2.5}$ Mortality: 2030, 2050 and 2100 vs. 2000 conc.

Uncertainty for the ensemble mean is a 95% CI including uncertainty in the RR and across models.

Future $PM_{2.5}$-related mortality



IHD+Stroke+COPD+LC Premature $PM_{2.5}$ Mortality

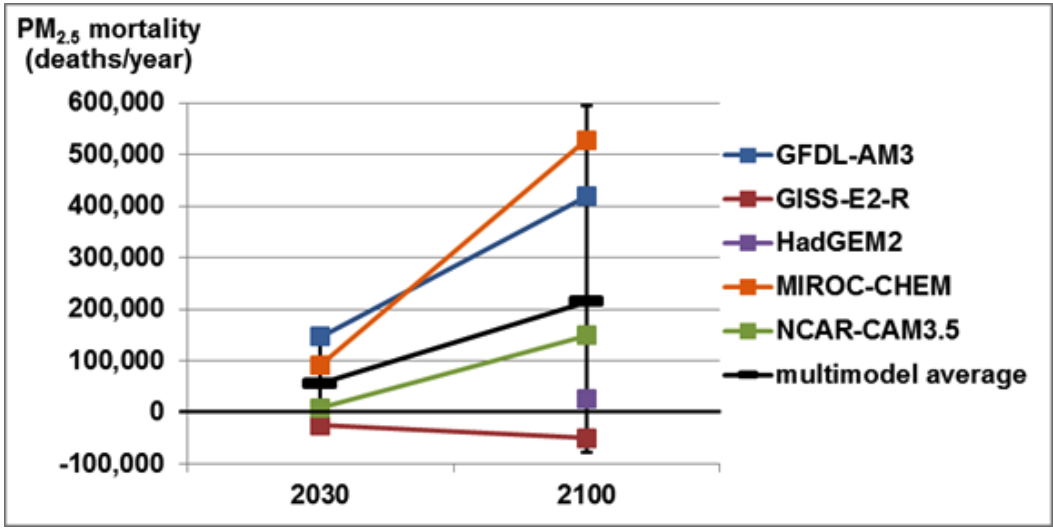


IHD+Stroke+COPD+LC Premature $PM_{2.5}$ Mortality – 2100 (two scenarios)

Silva et al. (*in preparation*)

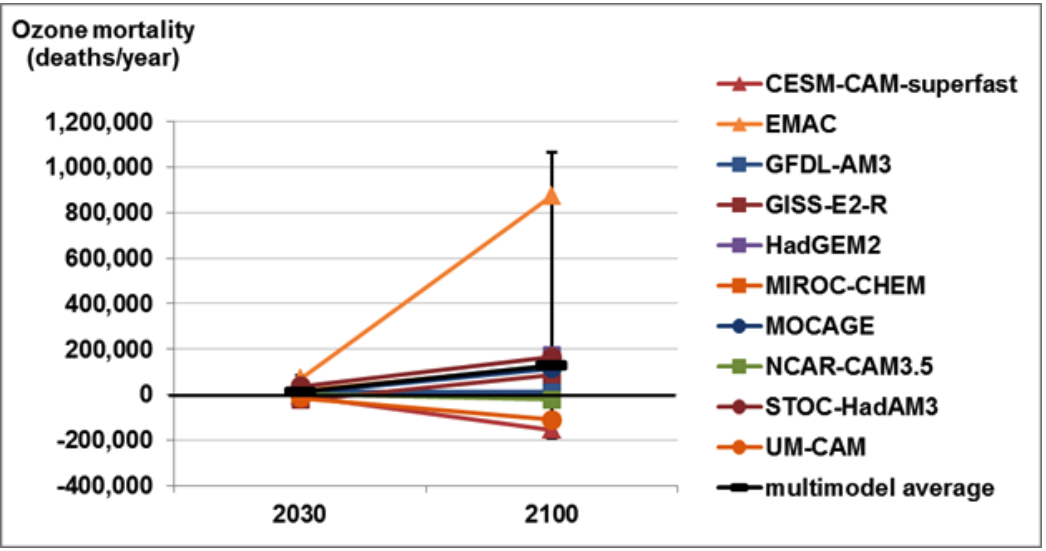
Impact of future climate change on mortality

Climate Change under RCP8.5



Ozone-related mortality

2030: 10,600 (-29,700 to 86,200)
2100: 127,000 (-193,000 to 1.1 mill.)

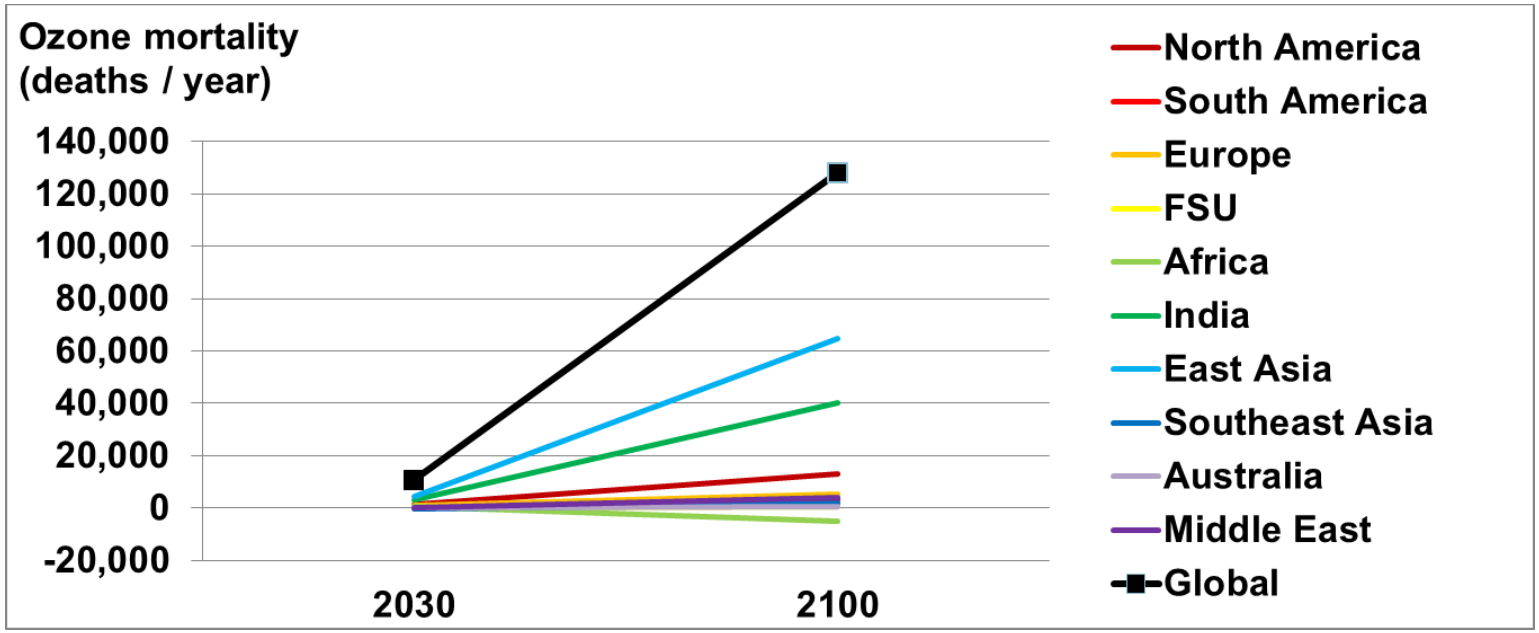


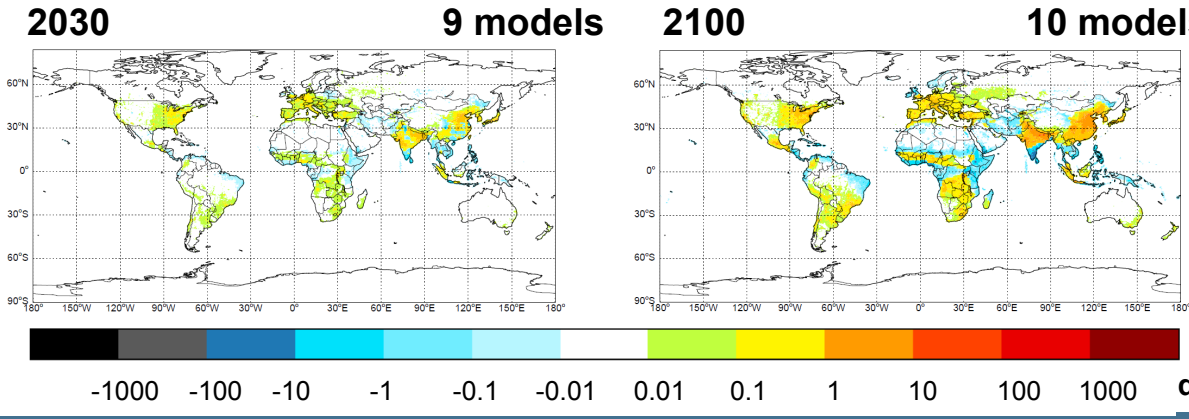
$PM_{2.5}$-related mortality

2030: 55,600 (-34,300 to 164,000)
2100: 215,000 (-76,100 to 595,000)

Silva et al. *in preparation*

Impact of Climate Change: ozone mortality

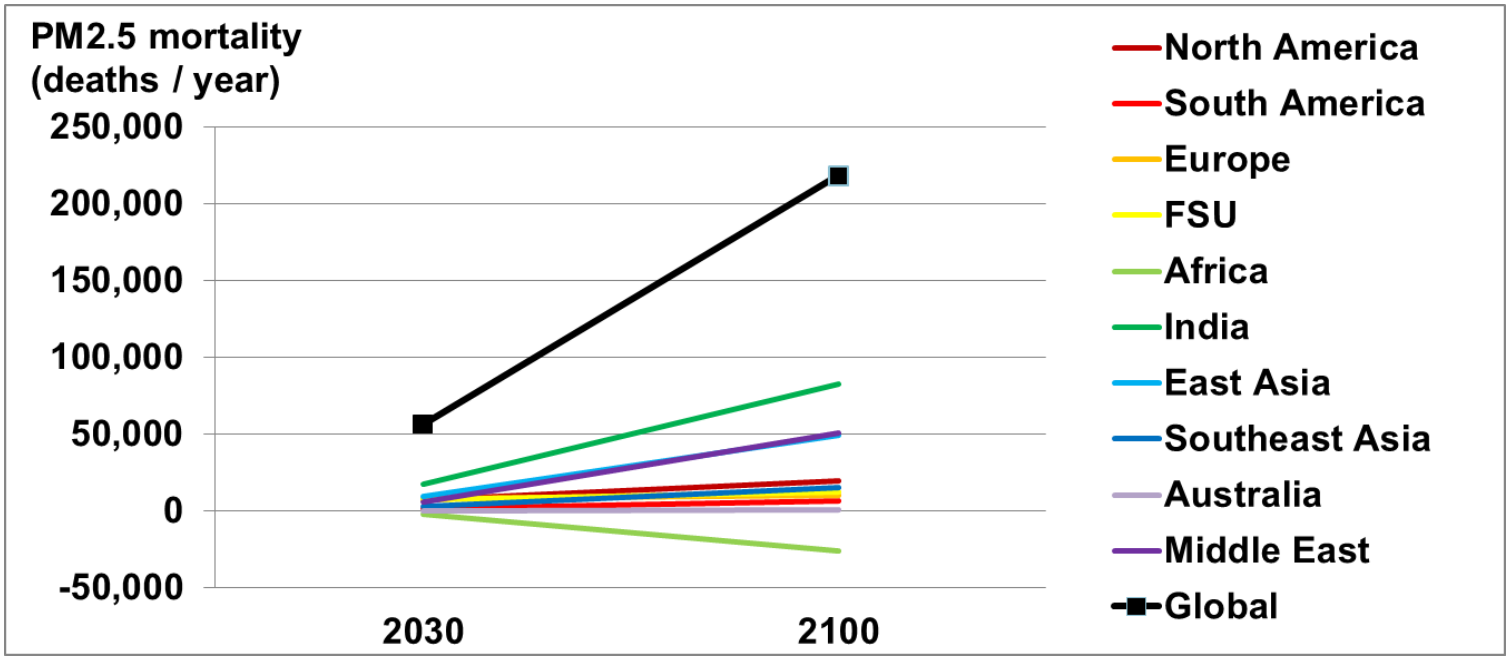


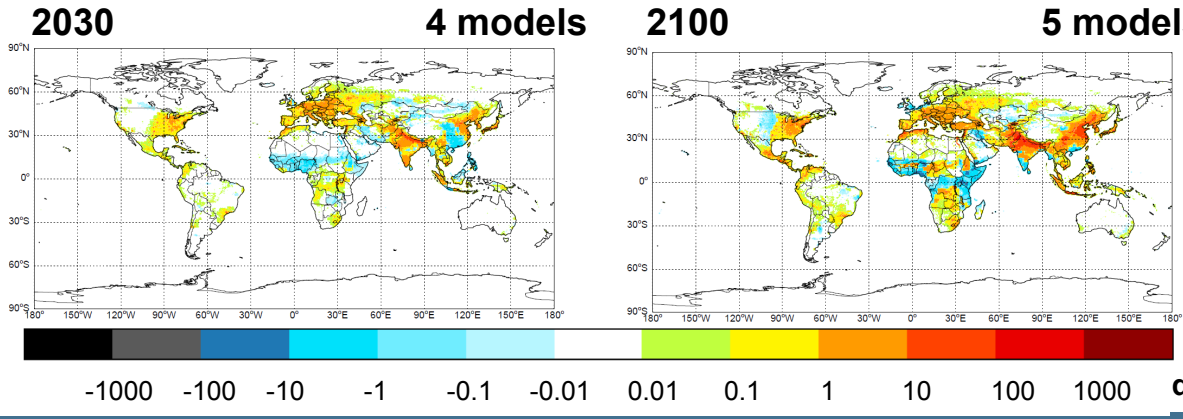


Premature Ozone Mortality – 2030, 2100

Silva et al. *in preparation*

Impact of Climate Change: $PM_{2.5}$ Mortality

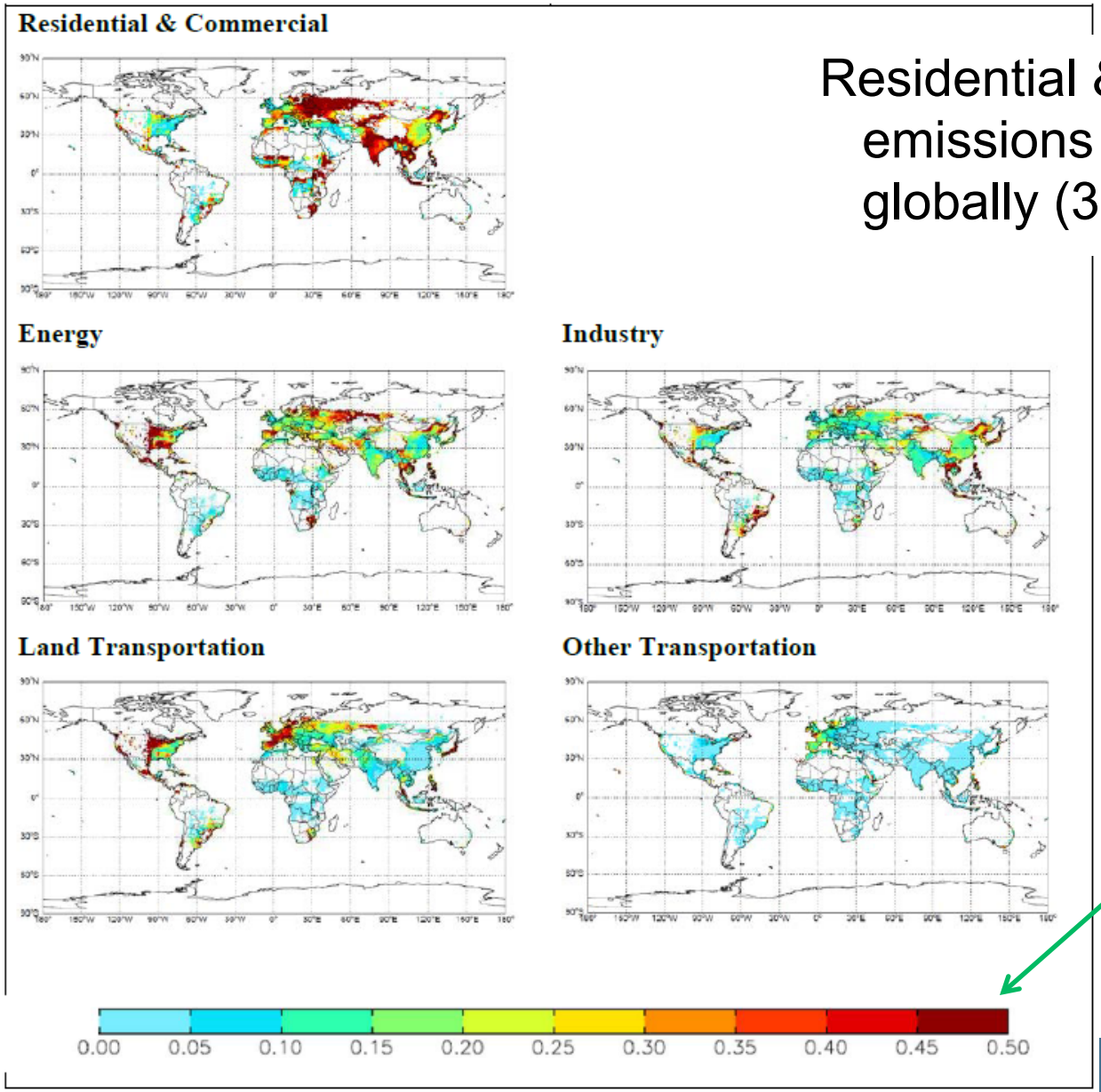




IHD+Stroke+COPD+LC Premature $PM_{2.5}$ Mortality – 2030, 2100

Silva et al. *in preparation*

Contributions of sectors to $PM_{2.5}$ mortality



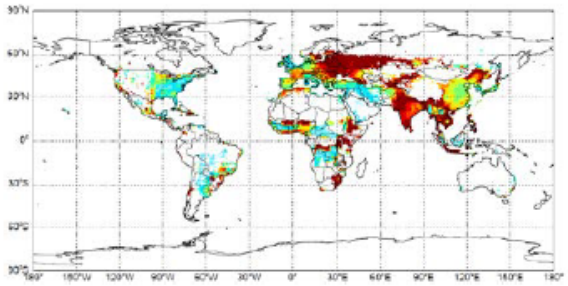
Residential & commercial emissions are most important globally (30% of deaths).

Fraction of total $PM_{2.5}$-related deaths attributable to each sector.

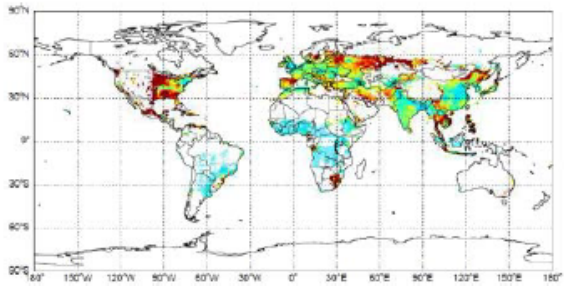
Silva et al. *in prep.*

Contributions of sectors to $PM_{2.5}$ mortality

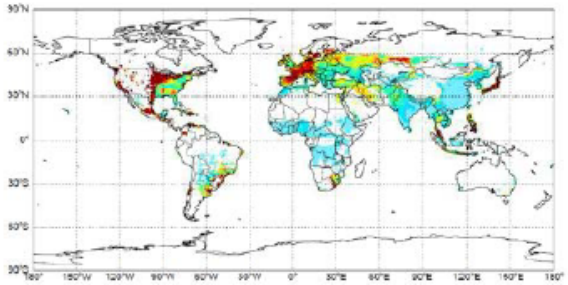
Residential & Commercial



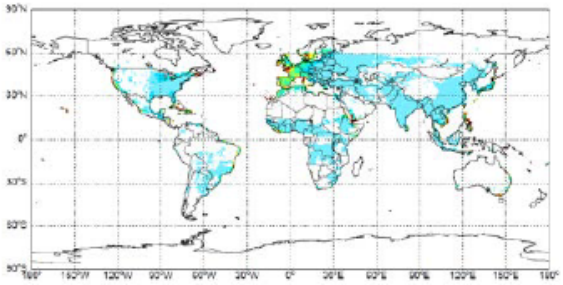
Energy

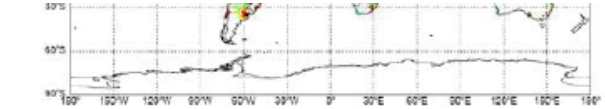


Land Transportation

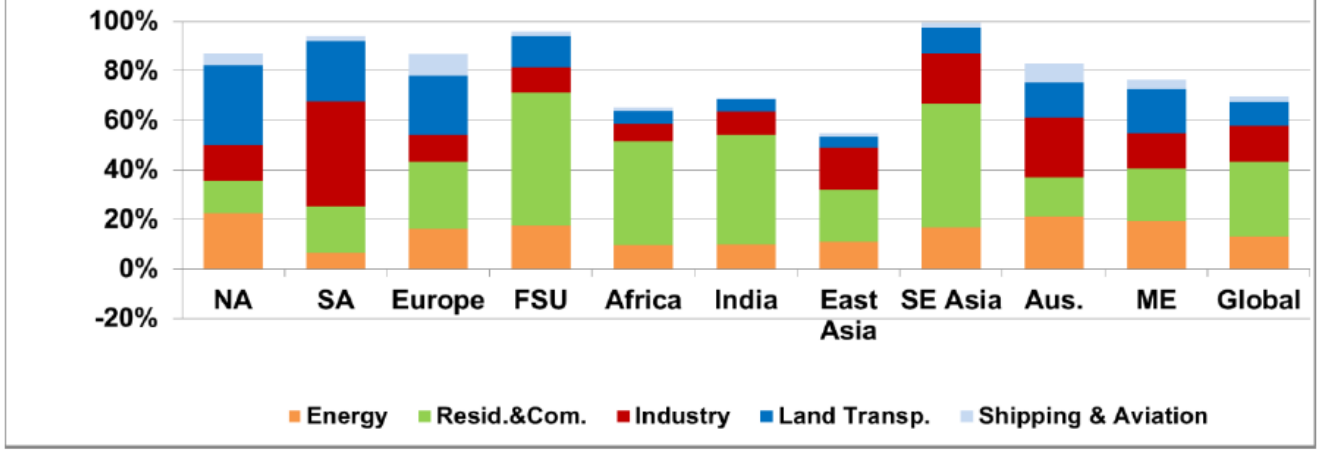


Other Transportation





Total burden	91,100	31,000	236,000	210,000	28,600	392,000	1,060,000	120,000	922	59,700	2,230,000
Five sectors	79,300	29,100	205,000	201,000	18,700	270,000	580,000	119,000	1,160	45,600	1,550,000



Fraction of total $PM_{2.5}$-related deaths attributable to each sector.

Silva et al. *in prep.*

Co-benefits - Two Lines of Research

Co-benefits of GHG Mitigation on Air Quality (immediate and local)

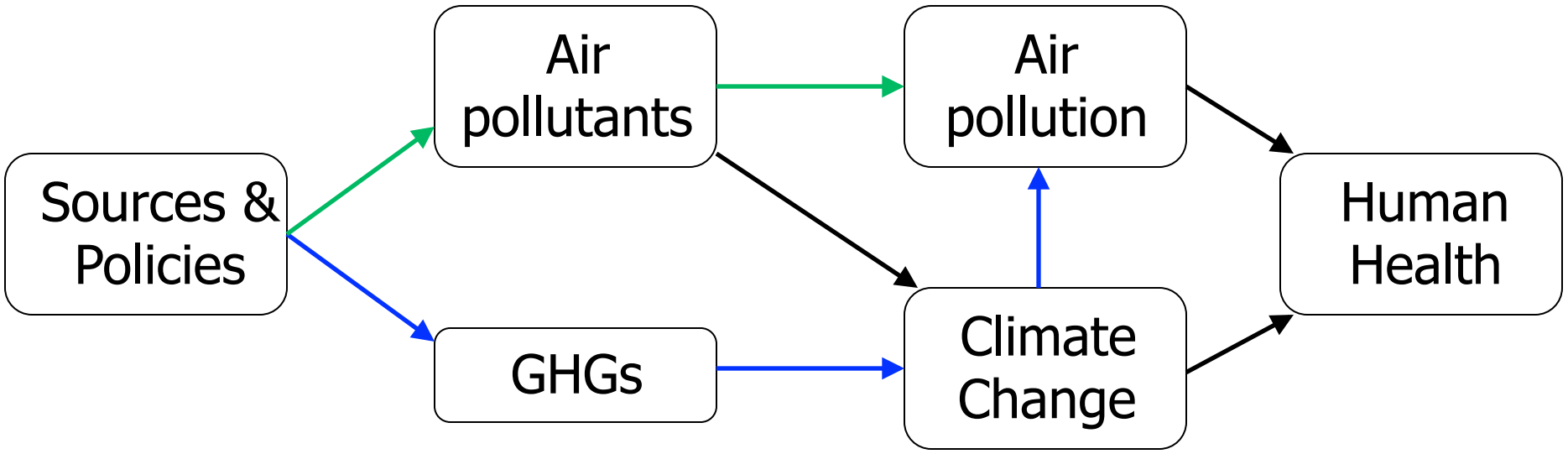
- Air quality and health co-benefits are \$2-196 / ton CO_2, comparable to GHG abatement costs (Nemet et al., 2010)
- Most studies have focused locally or regionally.
- Tend not to analyze future scenarios.
- None has been global using an atmospheric model.

Climate Change Affecting Future Air Quality (long-term and global)

- Climate change shown to increase O_3 in US; effects on PM less clear.
- Emphasis on meteorological downscaling.
- Tend not to analyze future emissions scenarios.
- Few studies present health, economic damages.
- Opportunity to study benefits of GHG reduction.

Co-benefits of GHG Mitigation for Air Quality

1) Immediate and Local



2) Long-Term and Global

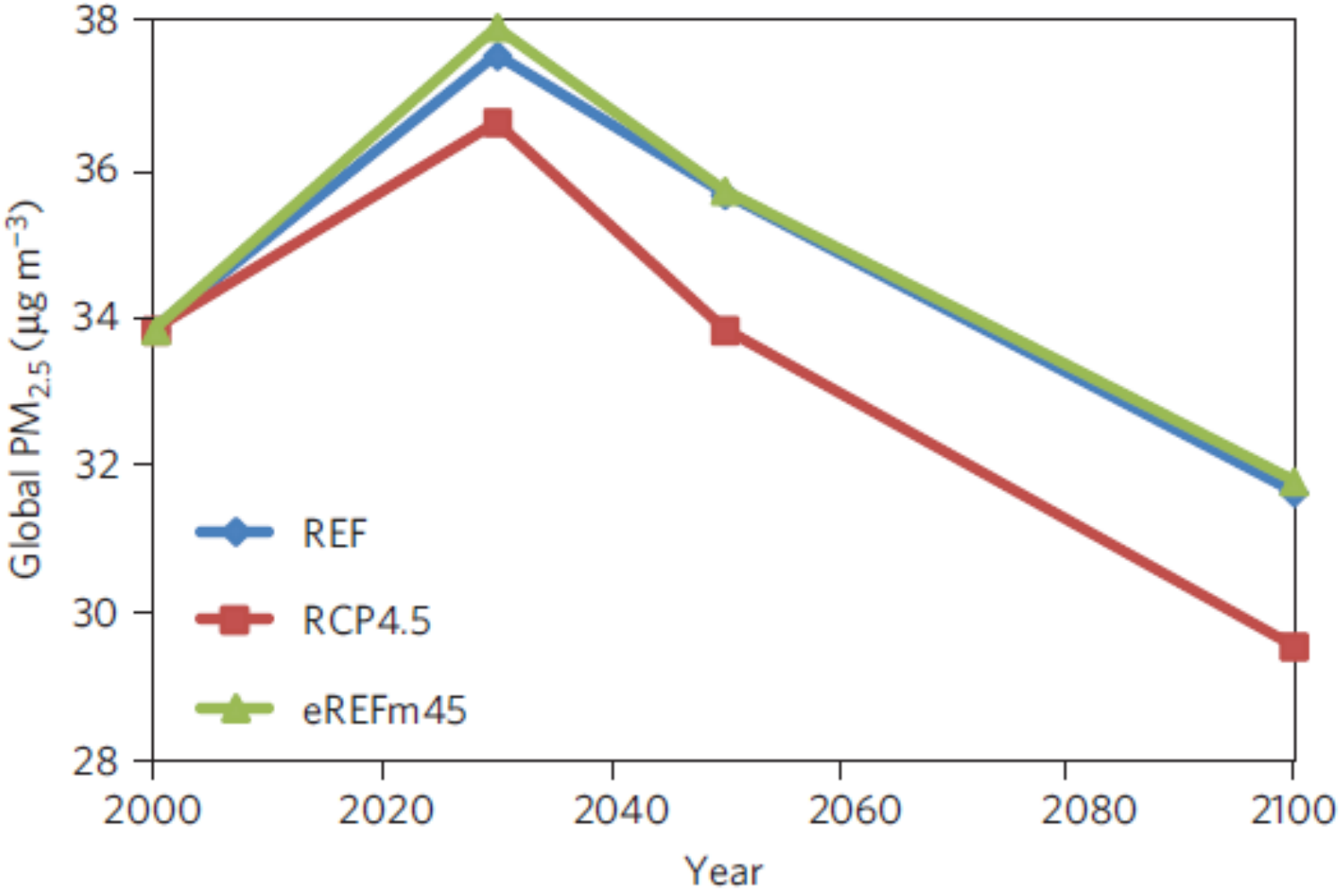
Objective: Analyze global co-benefits for air quality and human health to 2100 via both mechanisms.

Approach

Years	Emissions GCAM	Meteorology GFDL AM3	Name
2000	2000	2000	2000
2030, 2050, 2100	GCAM Reference	RCP8.5	REF
	RCP4.5	RCP4.5	RCP4.5
	GCAM Reference	RCP4.5	eREFm45

- Use the GCAM reference for emissions rather than RCP8.5, for consistency with RCP4.5.
- Simulations conducted in MOZART-4.
  - 2° x 2.5° horizontal resolution.
  - 5 meteorology years for each case.
  - Fixed methane concentrations.
  - Compares well with ACCMIP RCP4.5.

Results – $PM_{2.5}$ Concentration



Global population-weighted, annual average $PM_{2.5}$

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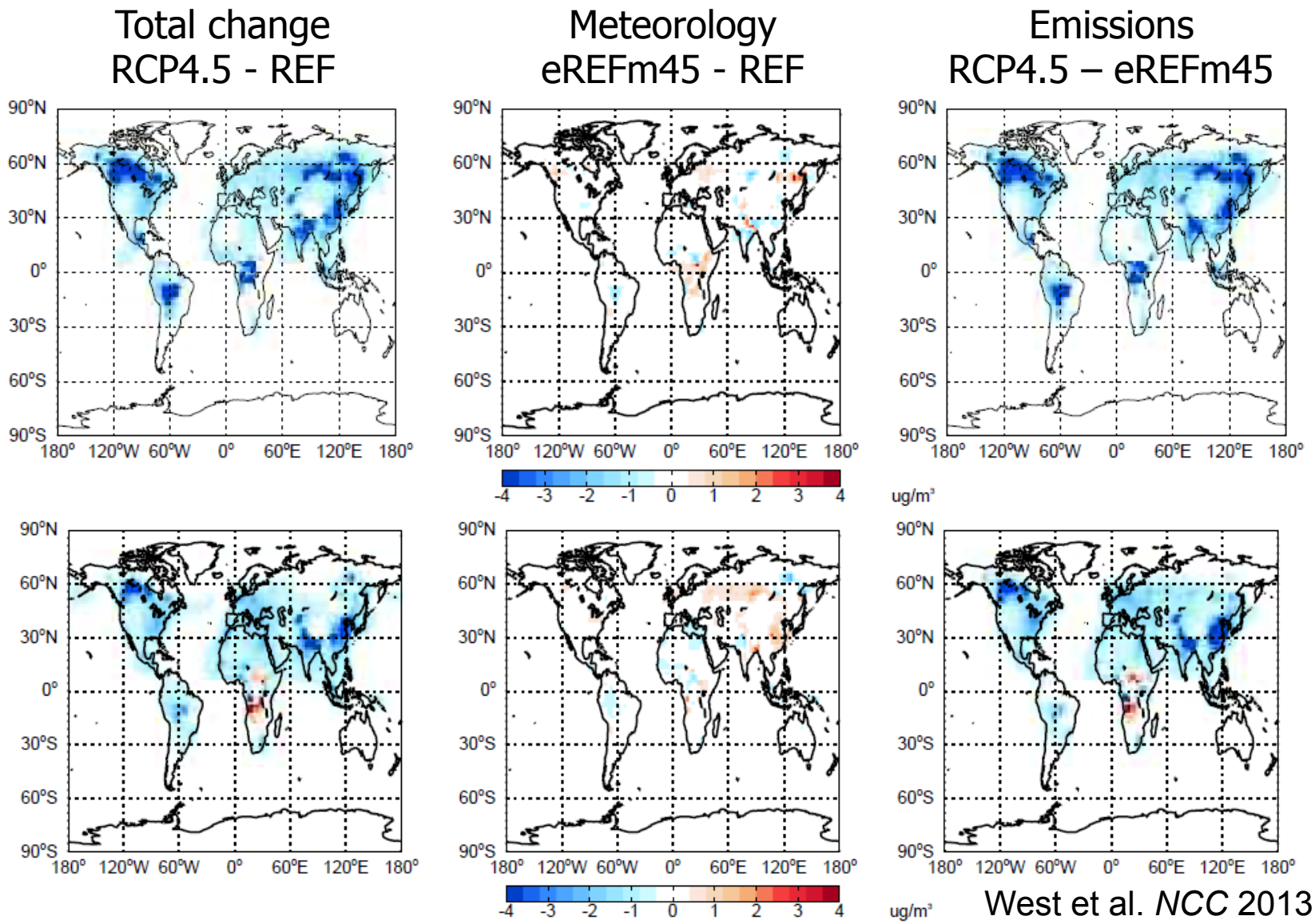
Results – $PM_{2.5}$ Concentration

Annual average $PM_{2.5}$



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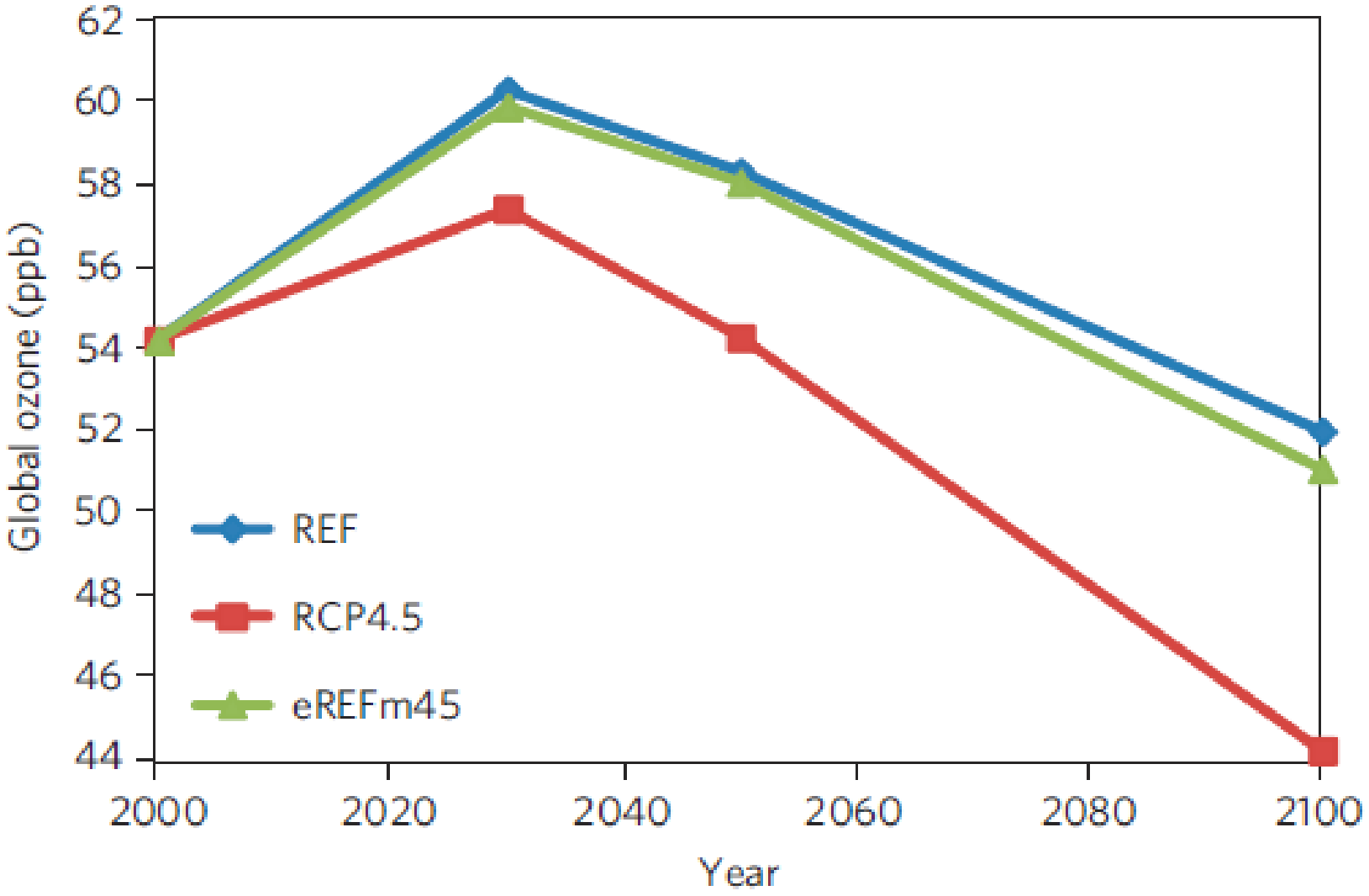
Results – Ozone Concentration



Global population-weighted,
max. 6 month average of 1 hr. daily max ozone

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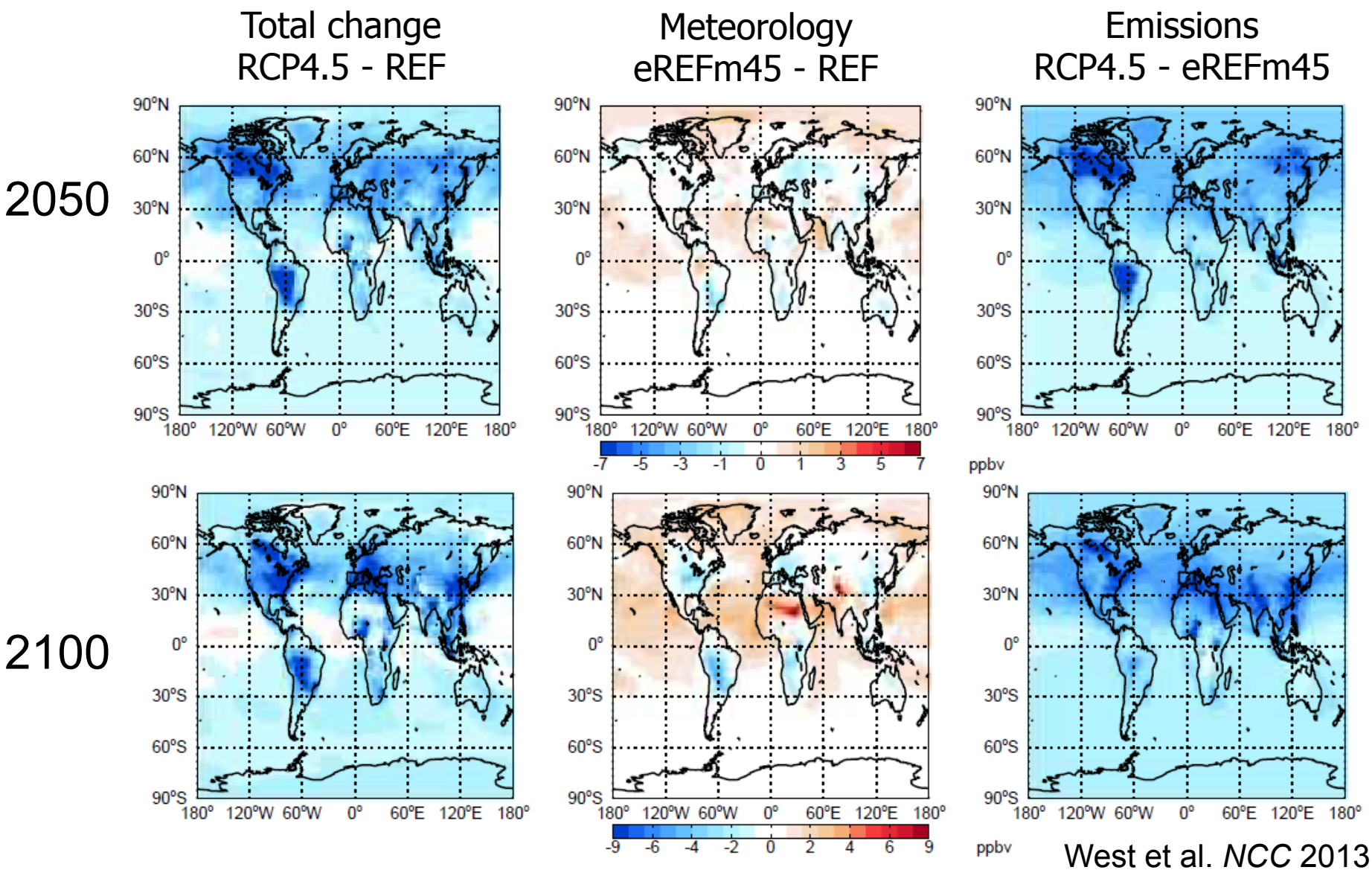
Results – Ozone Concentration

Max. 6 month average of 1 hr. daily max ozone



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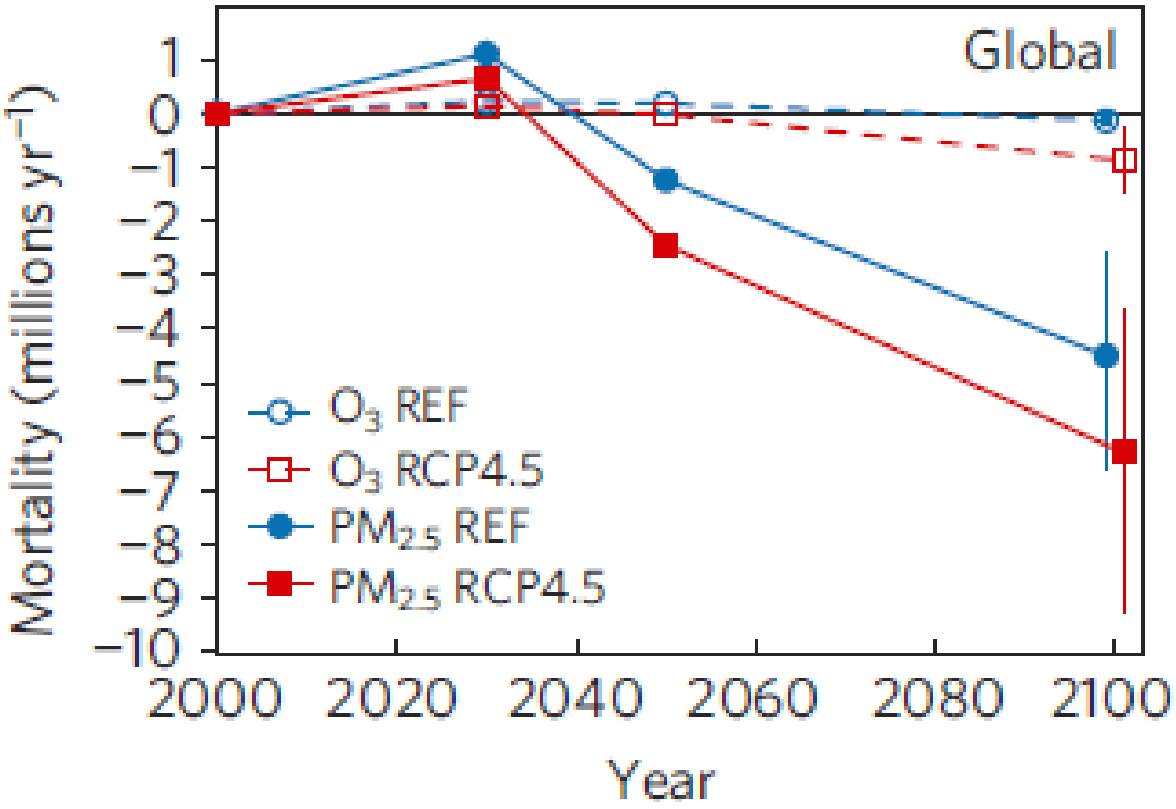
Results – Global Premature Mortality



Projection of global population and baseline mortality rates from International Futures.

$PM_{2.5}$ co-benefits
(CPD + lung cancer mortality)
- 2030: 0.4±0.2 million yr^{-1}
- 2050: 1.1±0.5
- 2100: 1.5±0.6

Ozone co-benefits
(respiratory mortality)
- 2030: 0.09±0.06
- 2050: 0.2±0.1
- 2100: 0.7±0.5

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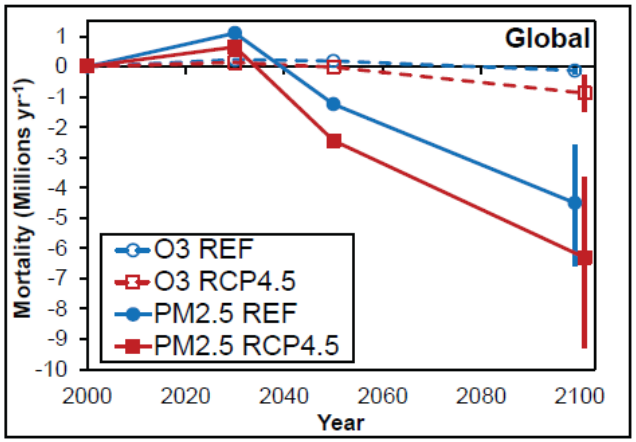
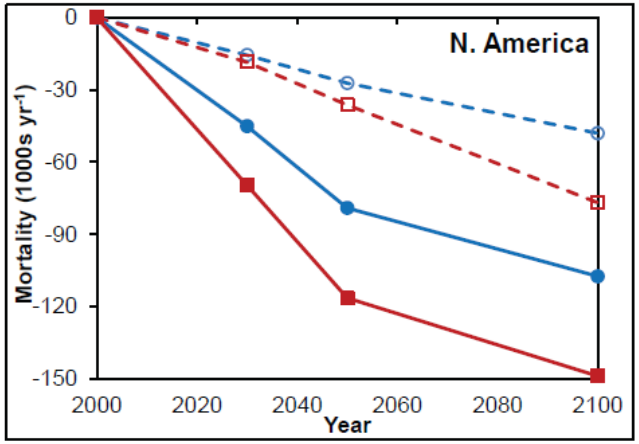
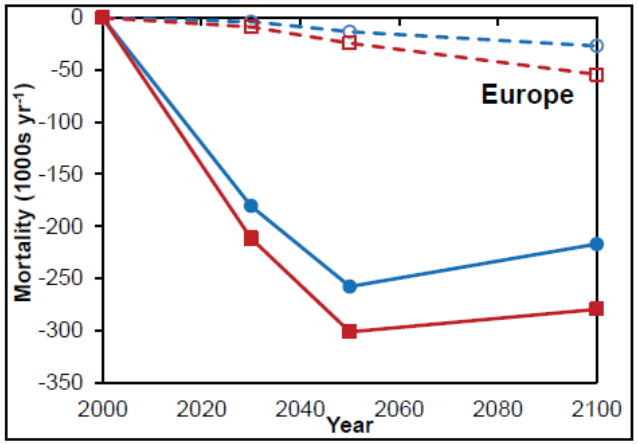
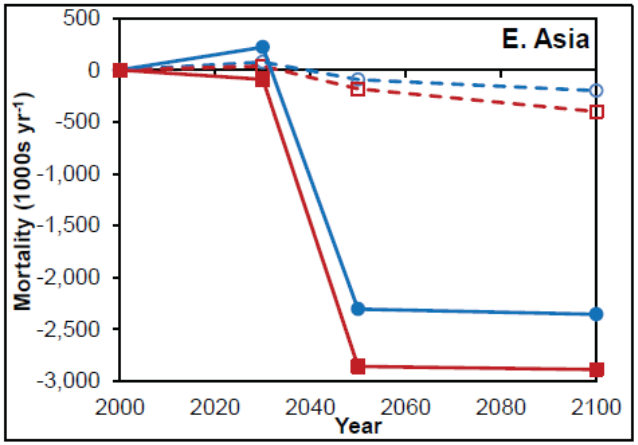
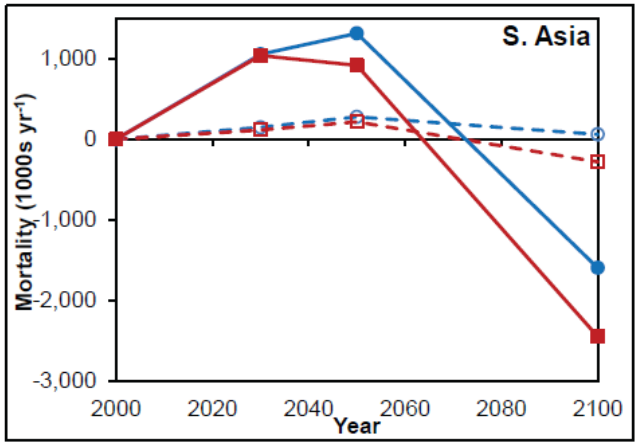
Results – Global Premature Mortality

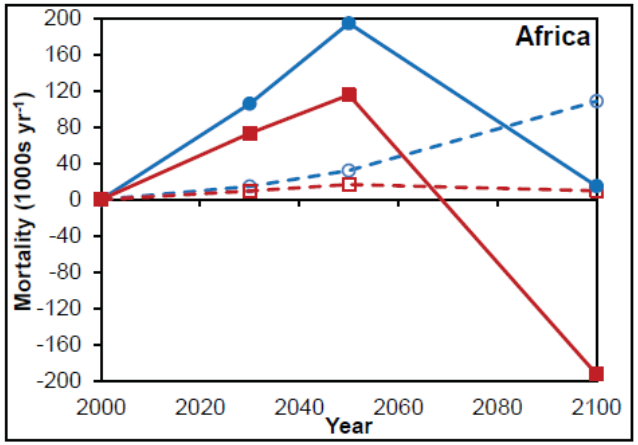












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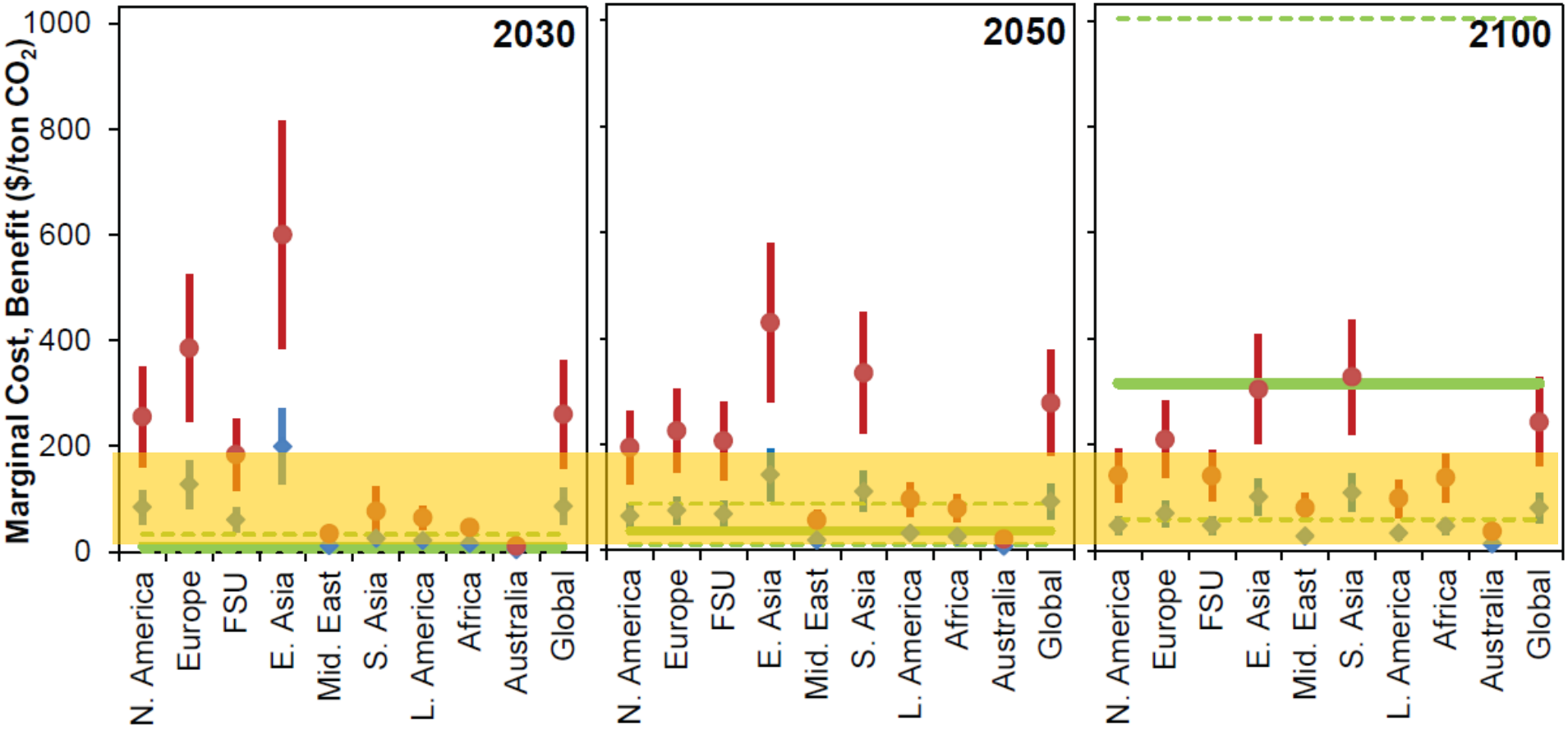
Results – Valuation of Avoided Mortality



Red: High valuation (2030 global mean $3.6 million)
Blue: Low valuation (2030 global mean $1.2 million)
Green: Median and range of global C price (13 models)

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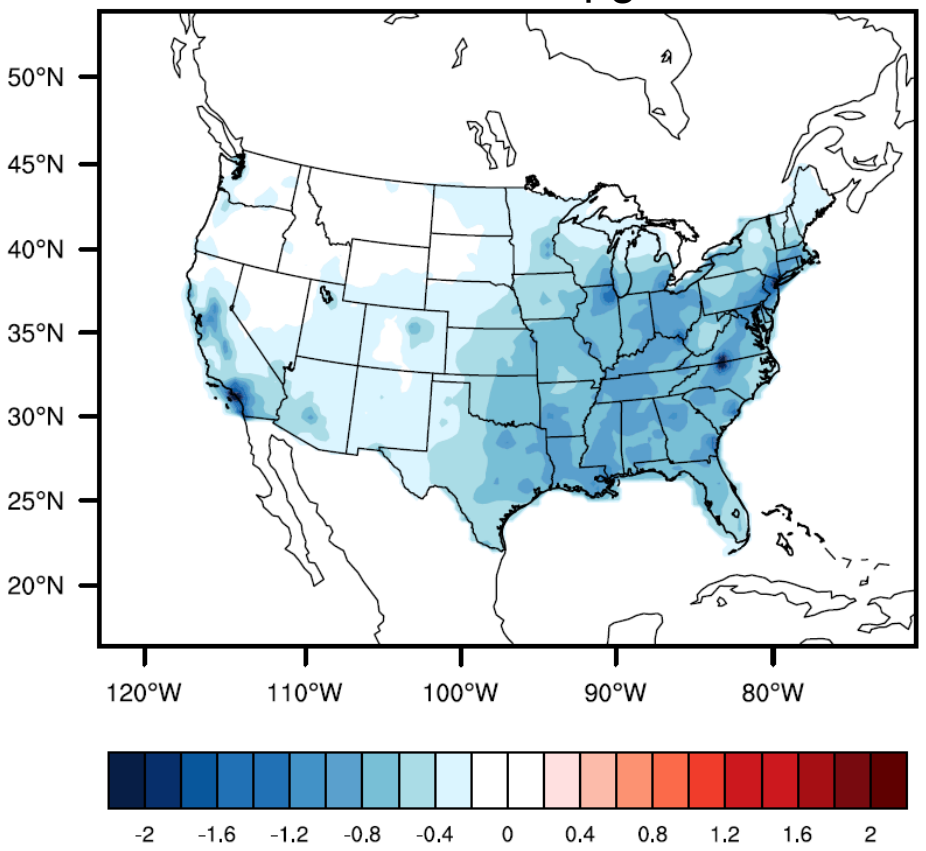
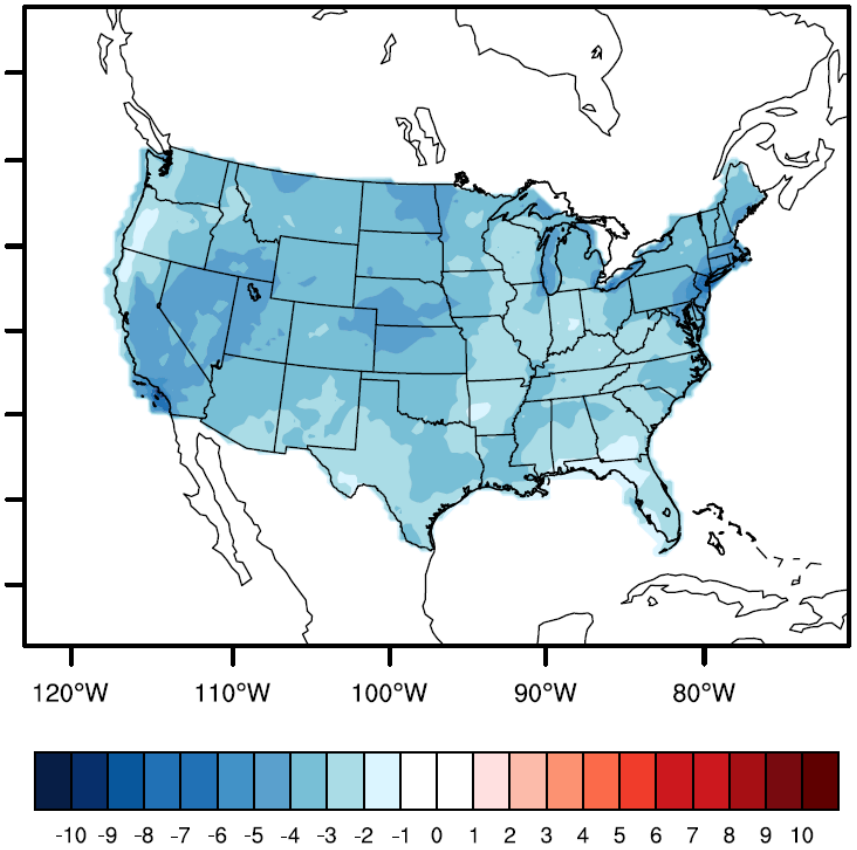
Downscaling Cobenefits to USA (2050)

RCP4.5 - REF

$PM_{2.5}$ (annual avg.)
US mean = 0.47 μg/m^3



Ozone (1hr. 6mo. max.)
US mean = 2.96 ppbv



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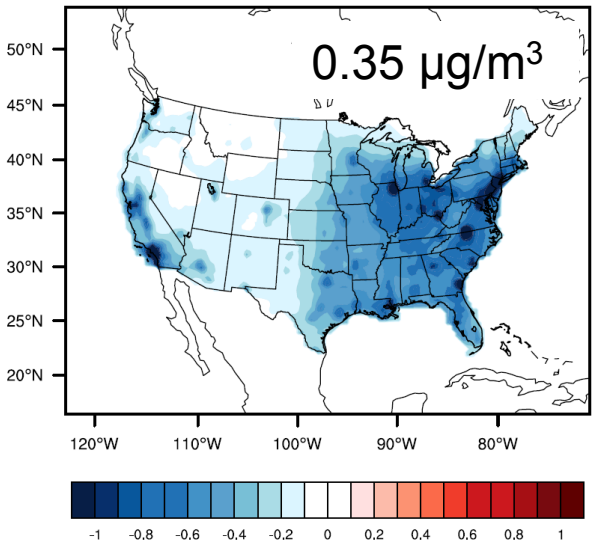
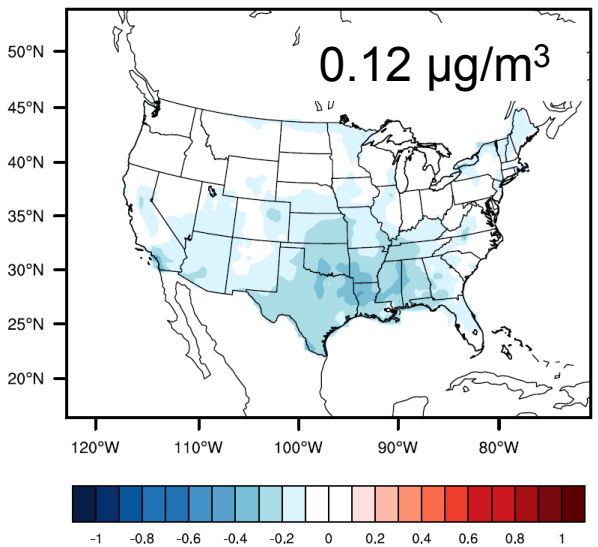
Downscaling Cobenefits to USA (2050)

$PM_{2.5}$

Domestic



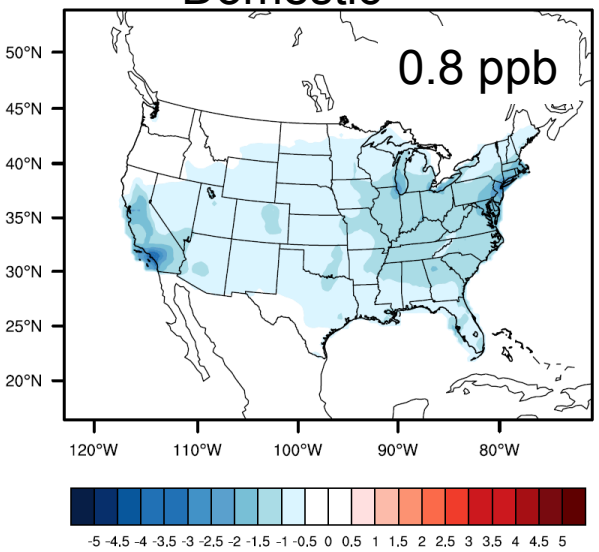
Foreign



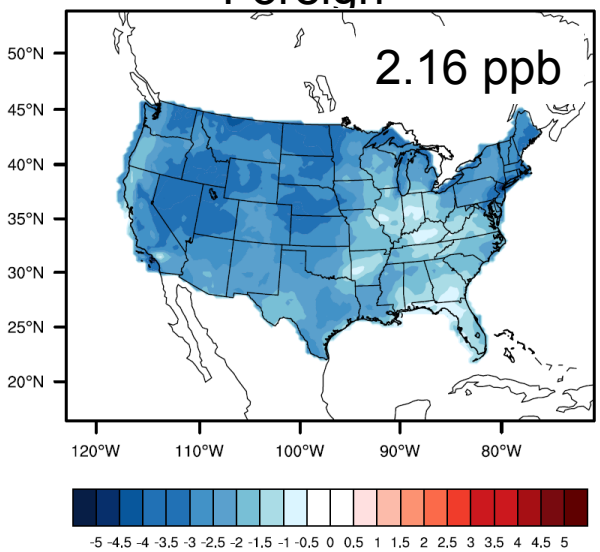
Most $PM_{2.5}$ co-benefits from **domestic** reductions.

Ozone

Domestic



Foreign



Most ozone co-benefits from **foreign** and **methane** reductions.

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Co-benefits: conclusions

- Global abatement of GHG emissions brings substantial air quality and human health co-benefits.
- Global GHG mitigation (RCP4.5 relative to REF) causes 0.5±0.2 million avoided deaths in 2030, 1.3±0.5 in 2050, and 2.2±0.8 in 2100
- Global average monetized co-benefits are $50-380 / ton CO_2
  - Greater than previous estimates
  - Greater than abatement costs in 2030 and 2050.
- The direct co-benefits from air pollutant emission reductions exceed those via slowing climate change.

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Thank you

Contributions from:
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