Health co-benefits of mitigating near-term climate change through black carbon and methane emission controls

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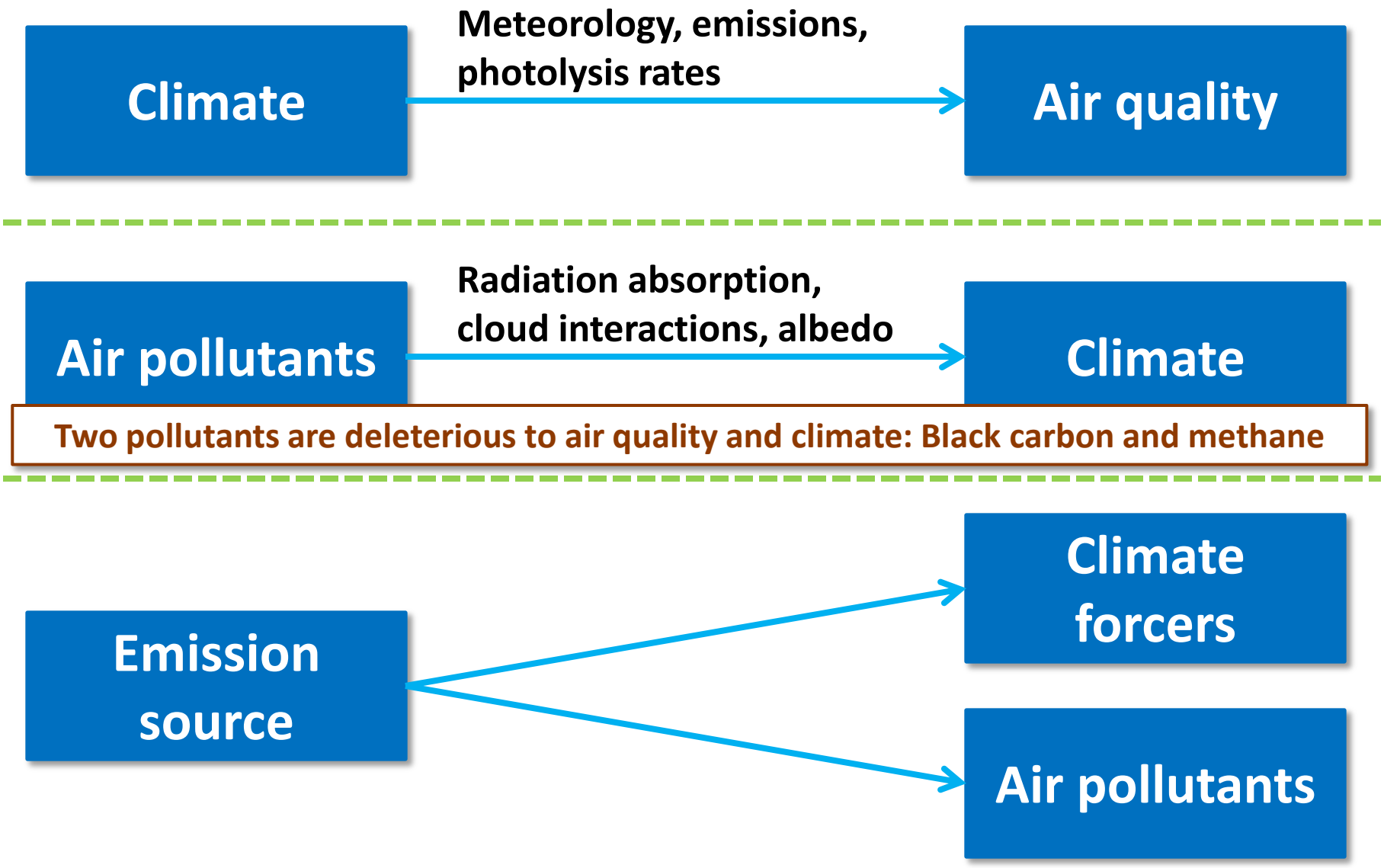
With contributions from Jason West, Drew Shindell, Joel Schwartz, and the UNEP/WMO Methane and Black Carbon Assessment Team

Air quality-climate interactions



Black carbon (BC)

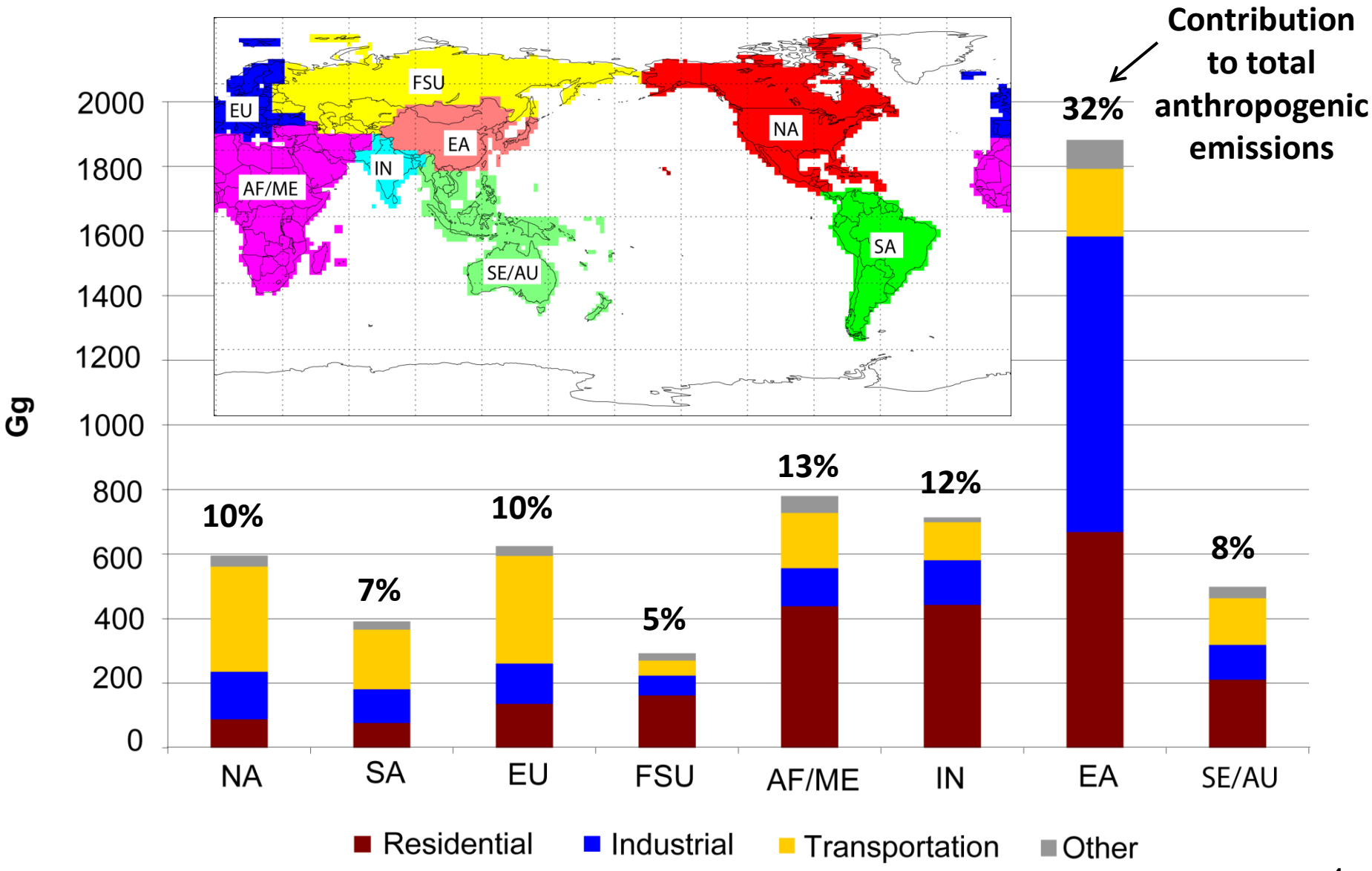
- As a part of $PM_{2.5}$, BC is associated with premature mortality
- BC is a climate warmer - absorbs sunlight in atmosphere and deposits on snow and ice, reducing reflected sunlight
- Most other $PM_{2.5}$ components reflect radiation
- >90% of global anthropogenic BC emissions from three sectors

Industrial:
Brick kilns
Coke ovens

Residential:
Solid fuel burning cookstoves

Transportation:
On-road diesels
Off-road diesels

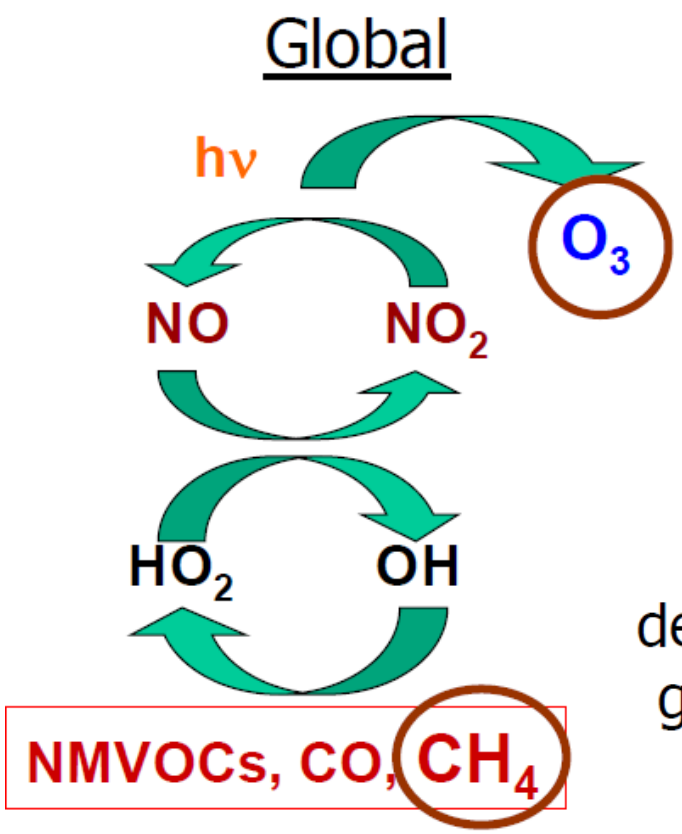
Anthropogenic BC emissions



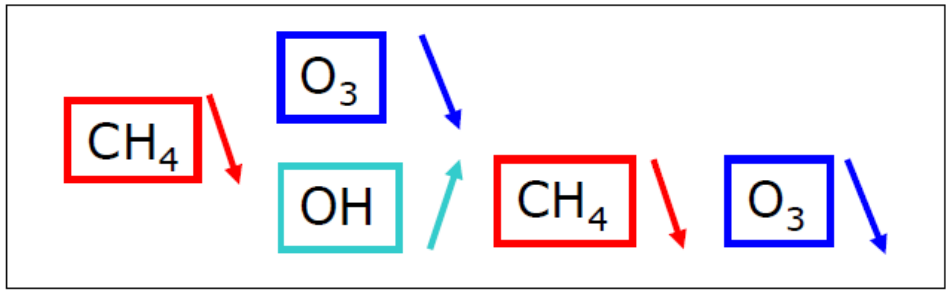
Anenberg et al. *ACP*, 2011; Emissions from Lamarque et al. *ACP*, 2010

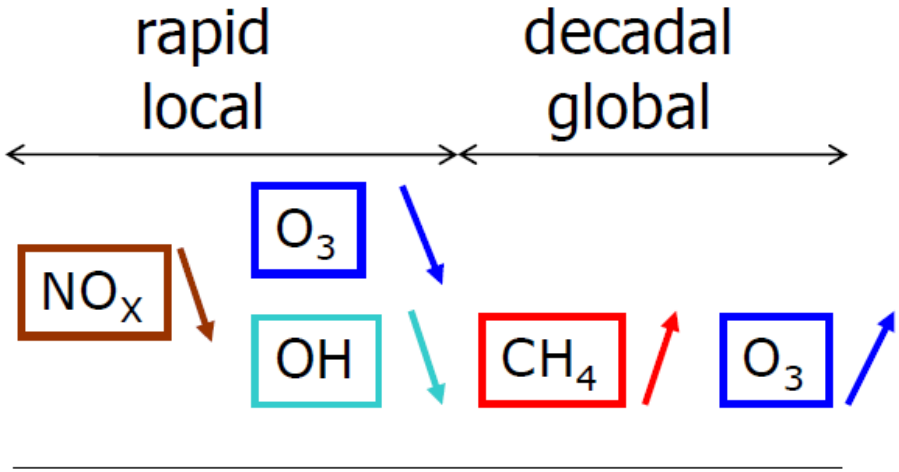
Methane (CH_4)

- 2nd most important greenhouse gas (GHG)
- Precursor to ground-level ozone, a GHG and air pollutant



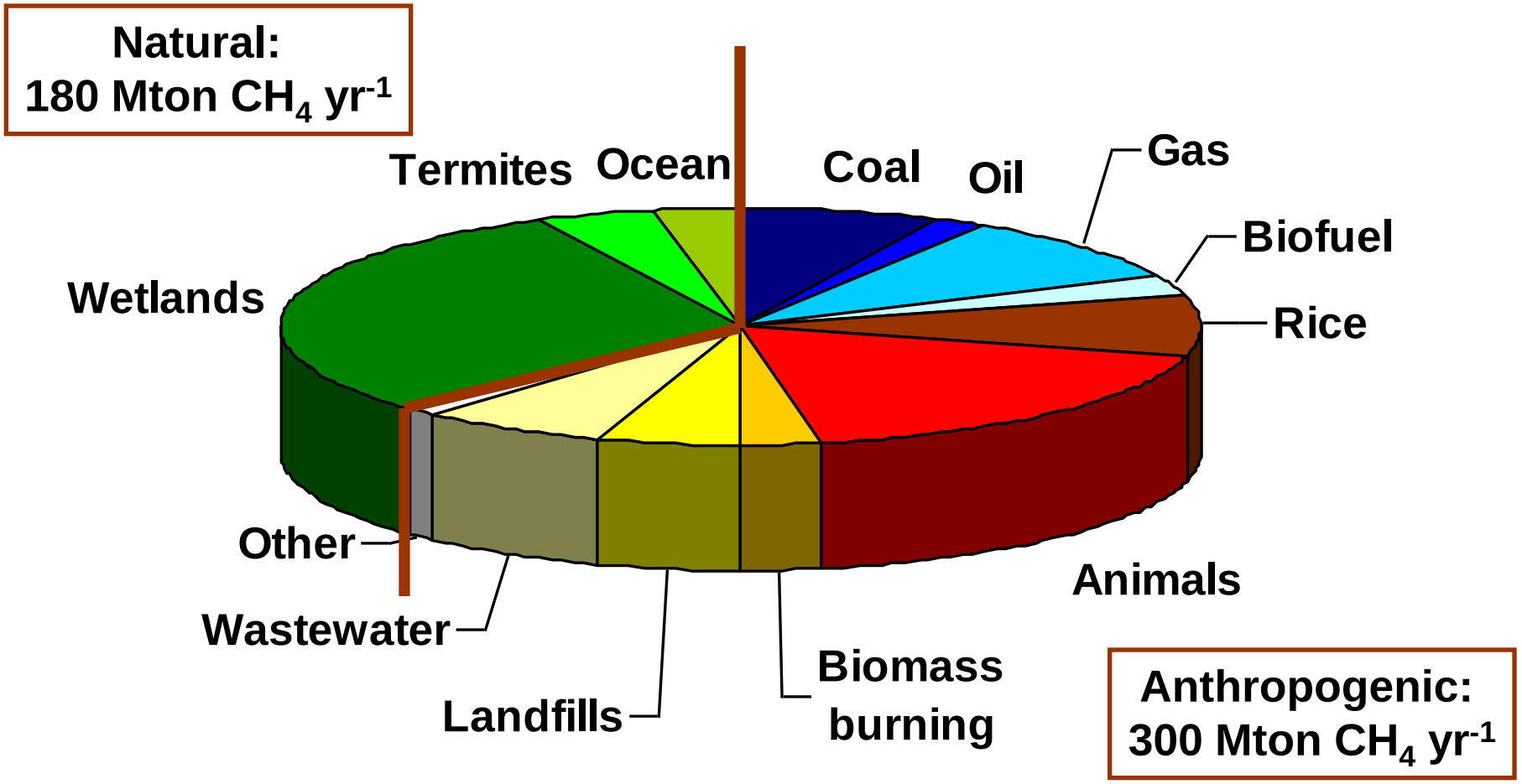
decadal
global





Courtesy Jason West, UNC

Global Methane Emissions

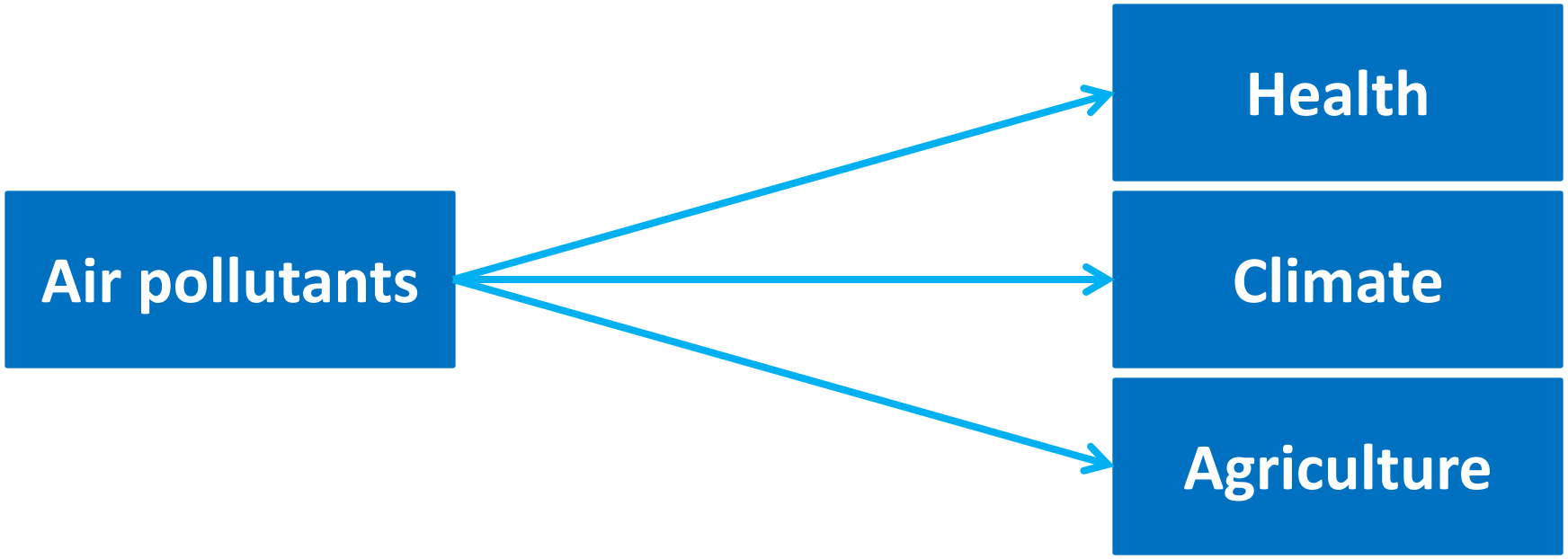


EDGAR3.2 & Houweling *et al.*, 1999

Courtesy Jason West, UNC

Simultaneously mitigating air pollution and near-term climate change

- Mitigation measures targeting $PM_{2.5}$ and ozone are employed around the world
- Those that target black carbon (BC) and methane may have climate co-benefits

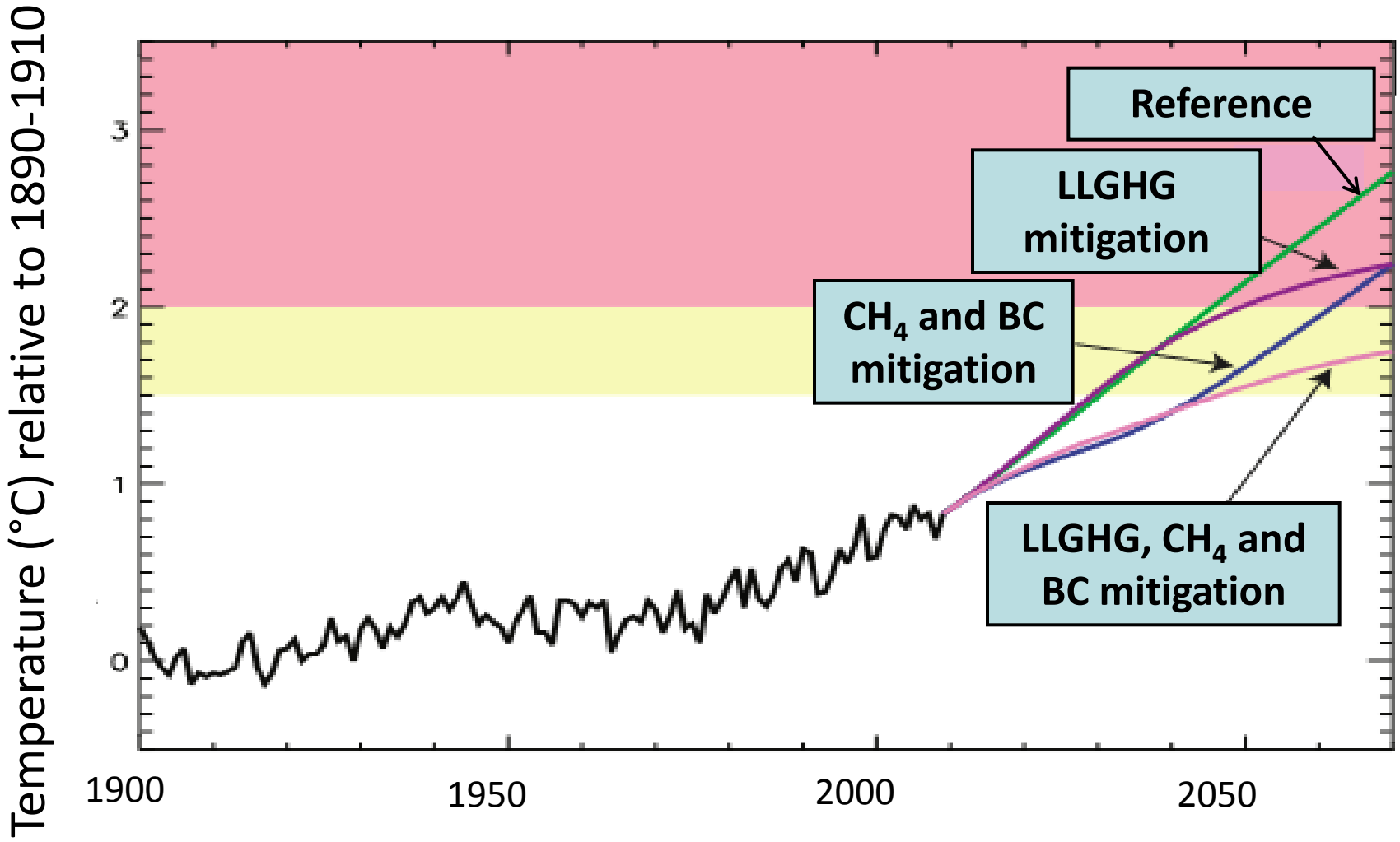


What are the climate, health, and agricultural benefits of further implementing climate-friendly air pollution mitigation measures that have already been employed around the world?

UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone

- Screened ~2000 emission control measures in GAINS database
- Identified 14 specific BC and methane emission control measures based on potential benefits for near-term climate
- Examined 5 emission scenarios:
  - Present-day (2005)
  - 2030 reference (World Energy Outlook, IEA 2009)
  - **Methane** measures
  - Methane + **BC Group 1** measures (technological – i.e. diesel particulate filters, improving biomass cook stoves)
  - Methane + BC Group 1 + **BC Group 2** measures (policy – i.e. elimination of high-emitting vehicles and biomass cook stoves)
- Calculated climate, health, agricultural, and economic benefits of the 3 groups of measures

Near-term climate benefits



UNEP/WMO Integrated Assessment of BC and Ozone, 2011; Shindell et al. *Science*, 2012

Δ global pop.-weighted avg. $PM_{2.5}$ conc. relative to 2030 reference

(annual avg.)

Methane measures

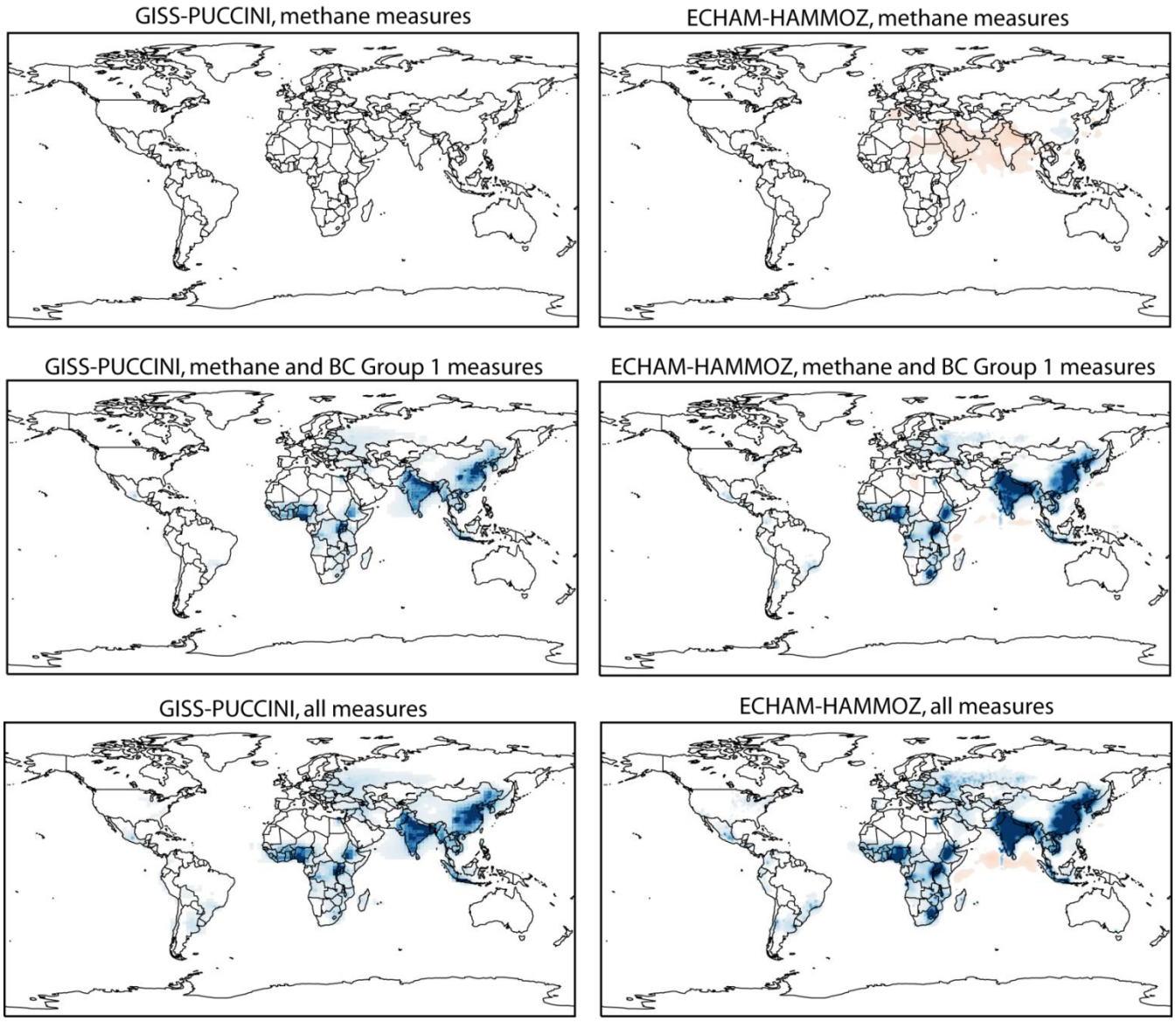
↓0 µg/m³

+ BC Group 1 measures

↓ 2.9 – 3.6 µg/m³

+ BC Group 2 measures

↓ 4.0 – 4.9 µg/m³



Anenberg et al. *EHP*, 2012

Δ global pop.-weighted avg. ozone conc. relative to 2030 reference

(6-mo. avg. of 1-hr. daily max.)

Methane measures

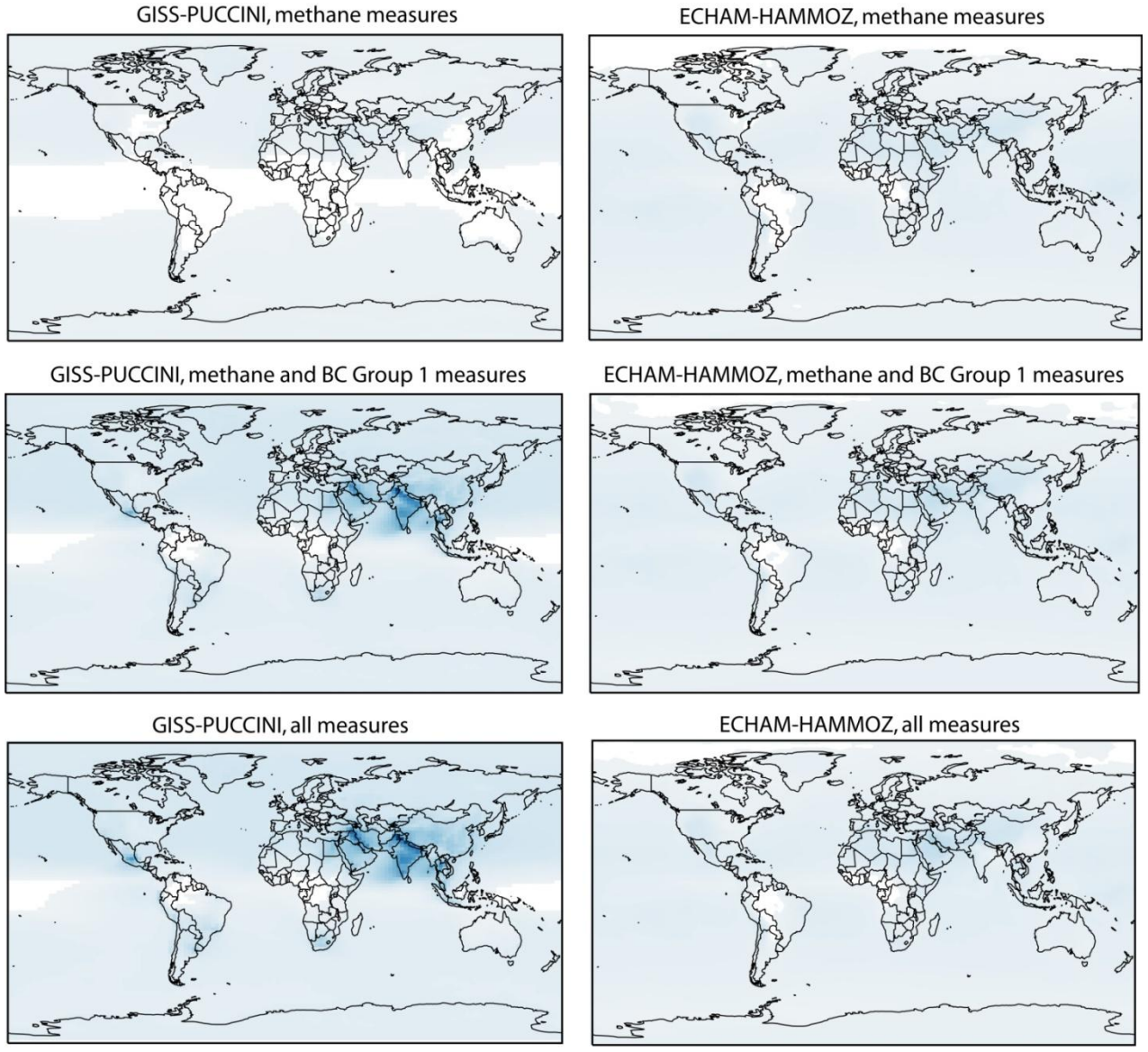
↓ 2.8 - 4.1 ppb

+ BC Group 1 measures

↓ 5.0 – 10.0 ppb

+ BC Group 2 measures

↓ 4.7 – 11.0 ppb



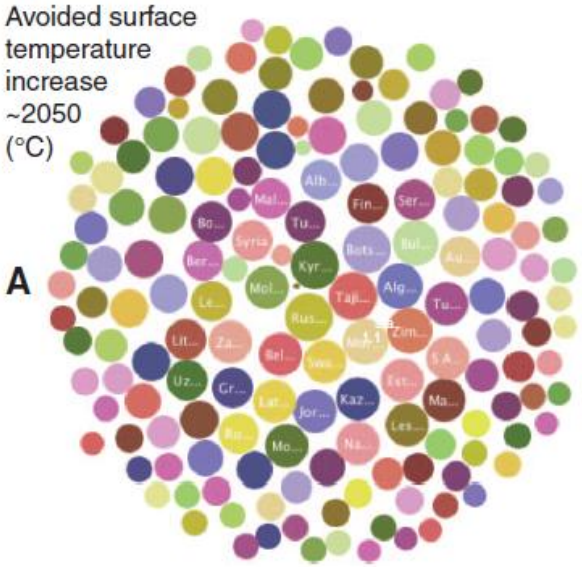
Anenberg et al. *EHP*, 2012

Benefits of BC and methane mitigation

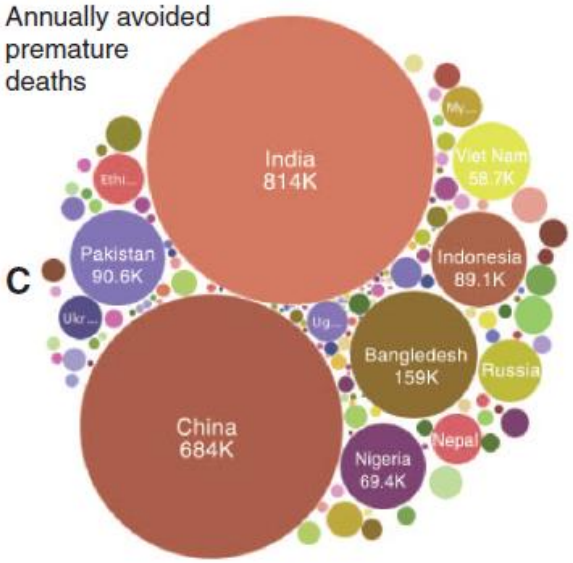
- The methane and BC measures are estimated to reduce:
  - Global pop.-wt. avg. $PM_{2.5}$ and ozone by 23-34% and 7-17%
  - Annual air-pollution related deaths by 1-5 million globally
- Approximately 30% of the health benefits are estimated to occur in China (driven both by large emission reductions and exposed population)

Benefits of the methane and BC mitigation measures by country:

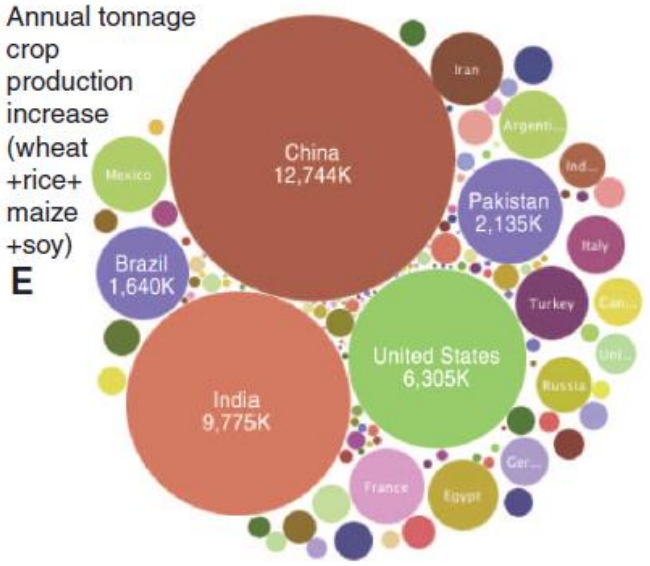
Climate



Health

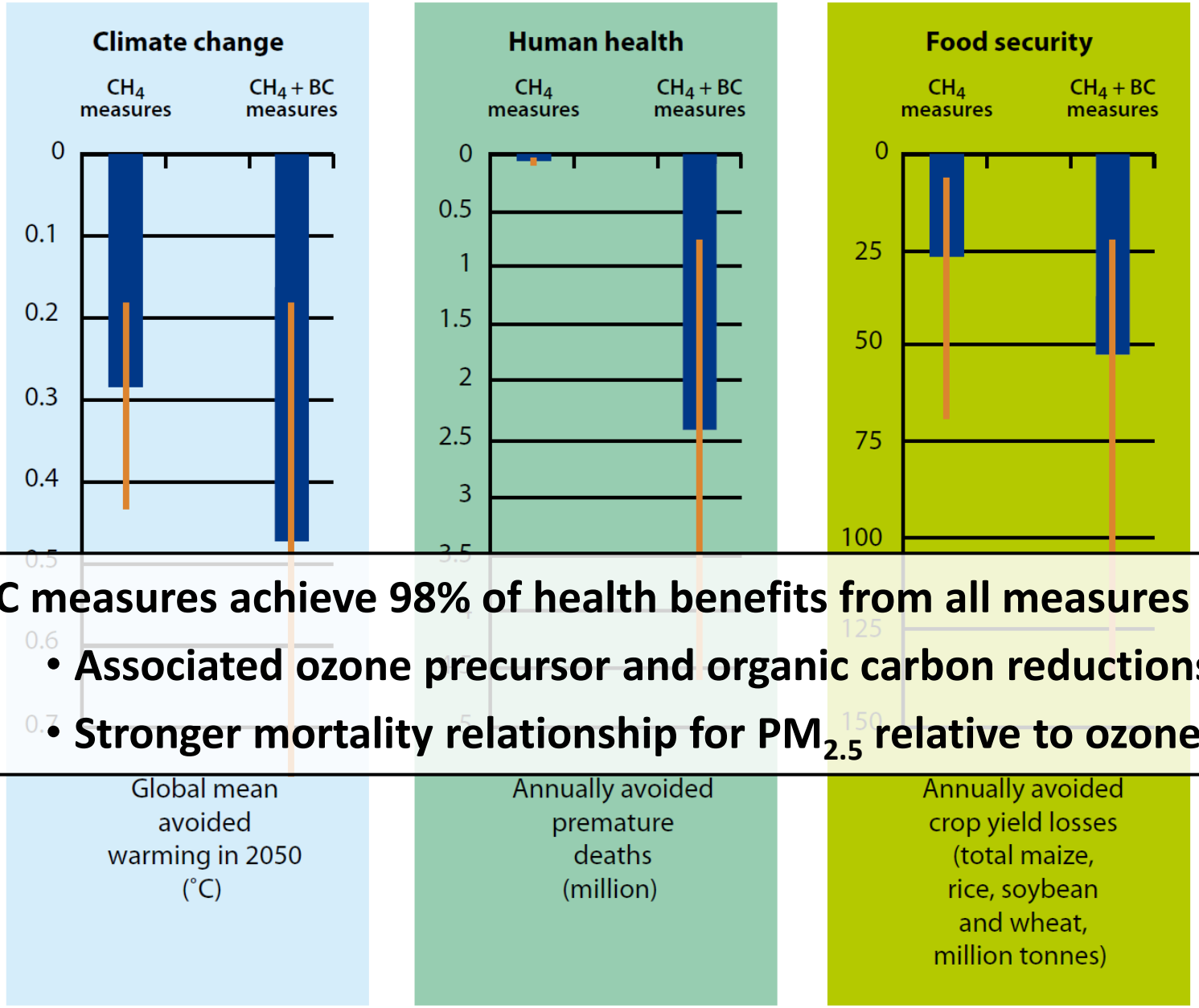


Crops



Shindell et al. *Science*, 2012

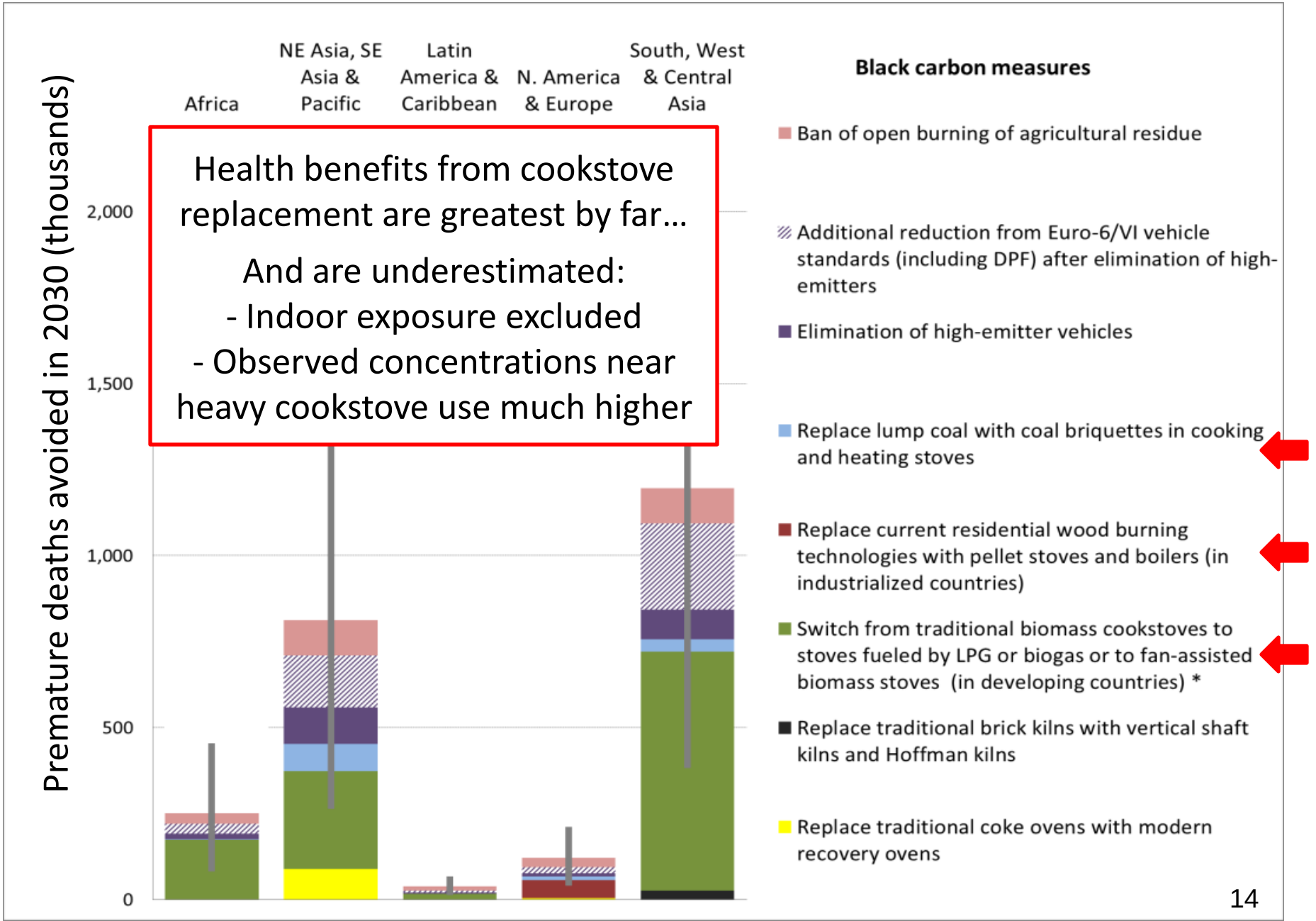
Benefits of mitigating BC and methane



BC measures achieve 98% of health benefits from all measures

- **Associated ozone precursor and organic carbon reductions**
- **Stronger mortality relationship for $PM_{2.5}$ relative to ozone**

Health benefits of BC measures by region



Key messages

- In addition to the climate benefits, fully implementing these 14 measures could:
  - Reduce global population-weighted average surface $PM_{2.5}$ and ozone concentrations by 23-34% and 7-17%
  - Avoid 0.6-4.4 and 0.04-0.52 million $PM_{2.5}$ and ozone-related deaths annually, based on 2030 population
- >80% of health benefits occur in Asia (~30% in China)
- BC measures achieve 98% of health benefits from all measures
  - Associated ozone precursor and organic carbon reductions
  - Stronger mortality relationship for $PM_{2.5}$ relative to ozone
- Health benefits from replacing biomass and coal stoves with cleaner fuels and stoves are greatest and are underestimated

Global action initiatives

Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants

- Announced by Secretary Clinton February 16, 2012
- Administered by UNEP
- Participants: Canada, Sweden, Mexico, Ghana, Bangladesh

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Global Alliance for Clean Cookstoves

- Announced by Secretary Clinton September 2010
- Administered by UN Foundation
- Goal: 100 million clean and efficient stoves by 2020

Global Methane Initiative (formerly Methane to Markets Partnership)

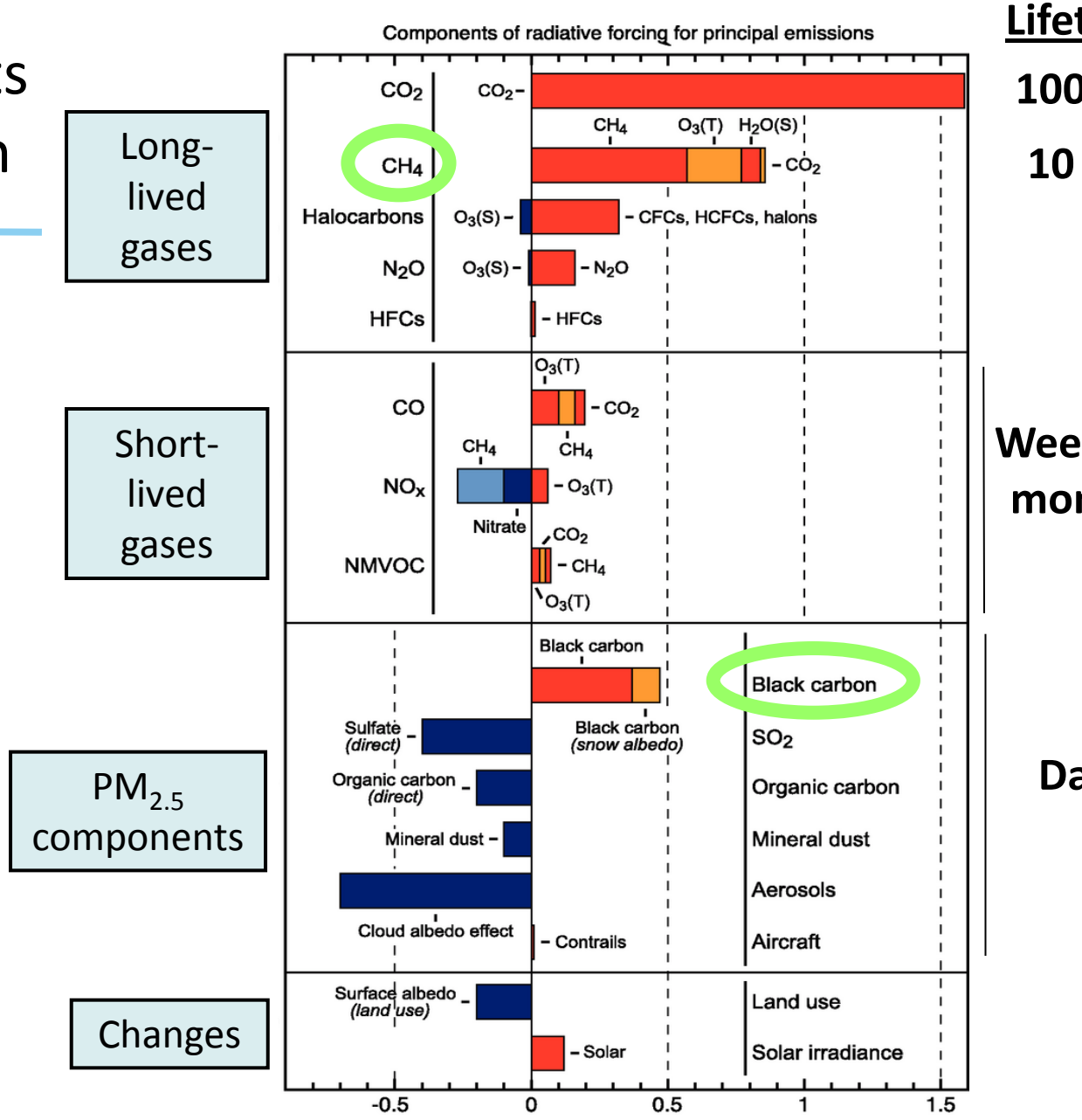
- Launched October 2010 (MMP since 2004)
- Focuses on methane recovery and use
- Administered by US EPA
- Participants: US and ~40 other countries

Global Methane Initiative

Extra slides

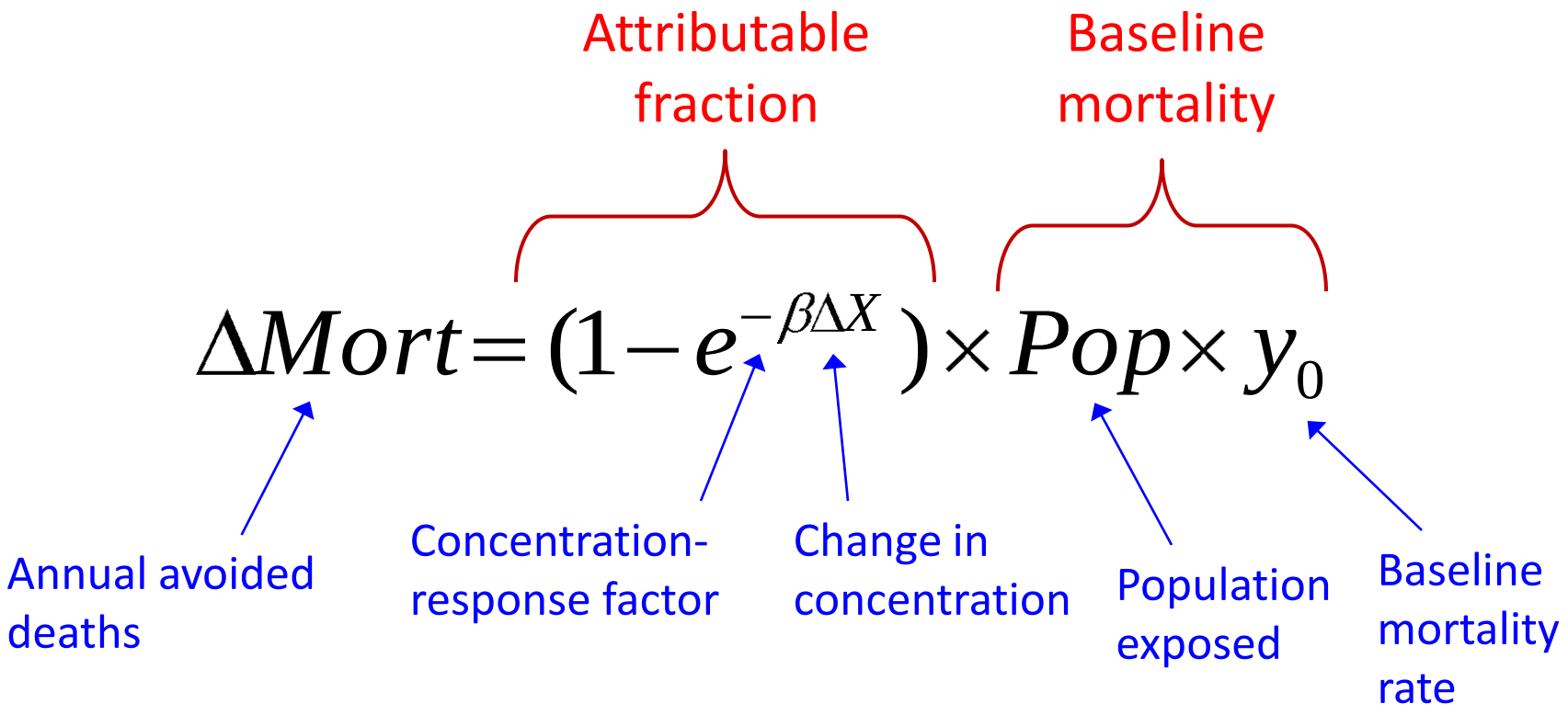
Climate impacts of air pollution

- Long-term climate change is dominated by long-lived greenhouse gases (LLGHGs)
- Ozone and black carbon (BC) are near-term climate warmers
- Of the ozone precursors, methane (CH_4) has the largest climate impact



IPCC AR4 WG1

Quantifying global air pollution health impacts



Health impact function

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

Concentration-response factor

Change in concentration

Exposed population

Baseline mortality rate

Epidemiology studies used to derive concentration-response factors:

	Source	Exposure Type	Metric	Health Endpoint	Relative Risk Estimate
O_3	Jerrett et al. 2009 (American Cancer Society)	Chronic	10 ppb increase in seasonal avg of 1-hr daily max	Respiratory disease	1.04 (1.01-1.07)
$PM_{2.5}$	Krewski et al. 2009 (American Cancer Society)	Chronic	10 µg/m^3 increase in annual avg	Cardiopulmonary disease	1.13 (1.1-1.16)
				Lung cancer	1.14 (1.06-1.23)
$PM_{2.5}$	Laden et al. 2006 (Harvard Six-Cities)	Chronic	10 µg/m^3 increase in annual avg	Cardiopulmonary disease	1.28 (1.13-1.44)
				Lung cancer	1.27 (0.96-1.69)

Health Impact Function

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

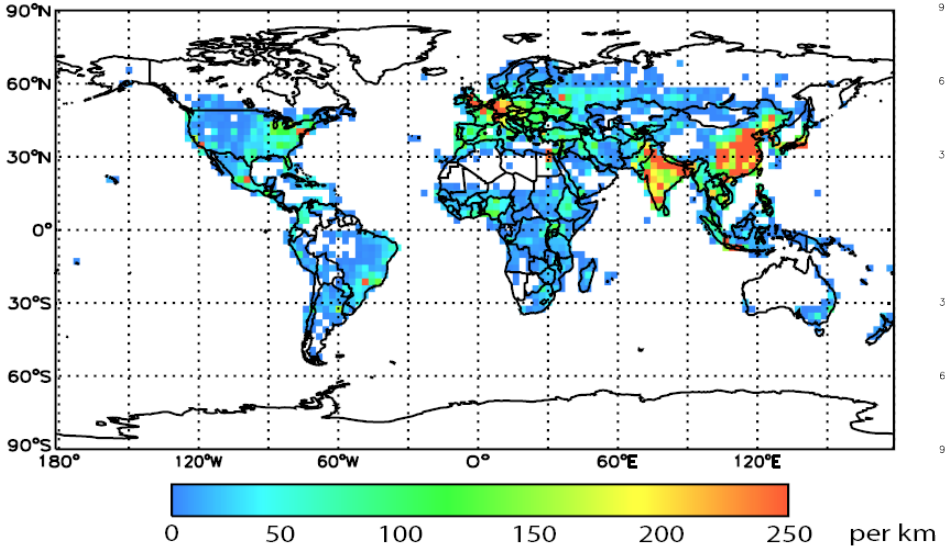
Concentration-response factor

Change in concentration

Exposed population

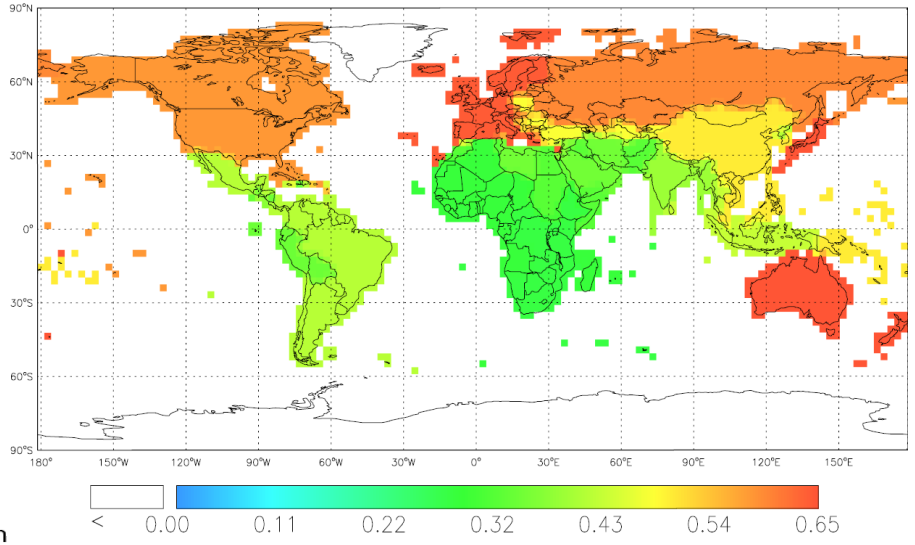
Baseline mortality rate

Total Population



Data from Landscan database (ORNL 2008)

Fraction ≥30



Data from WHO 2004

Health Impact Function

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

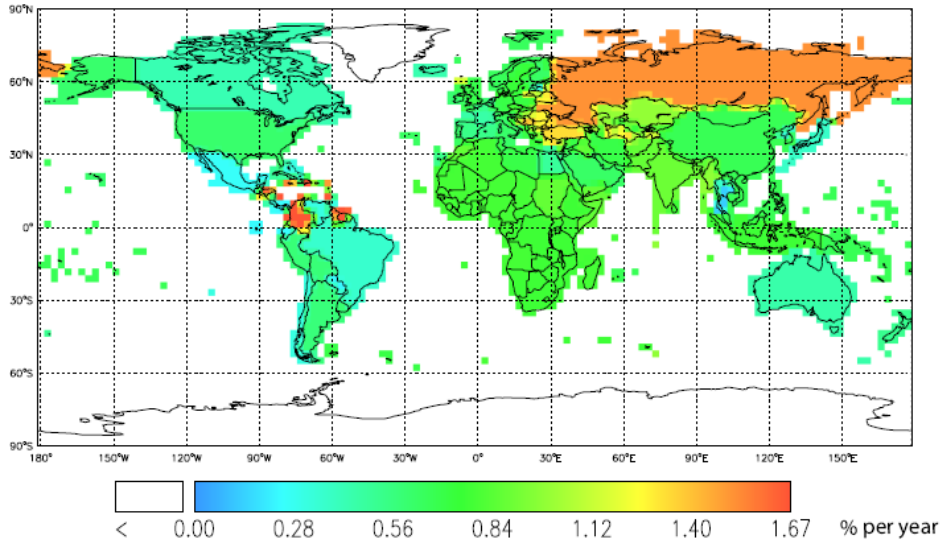
Concentration-response factor

Change in concentration

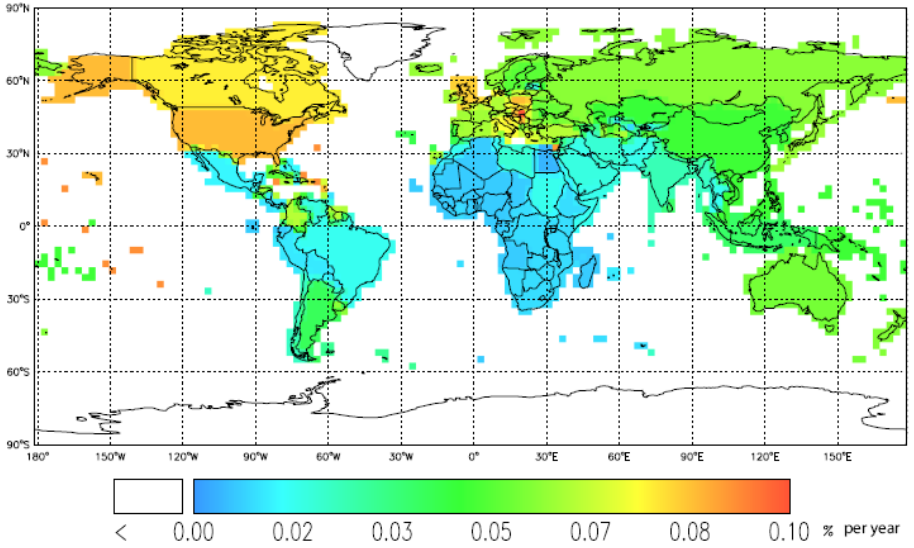
Exposed population

Baseline mortality rate

Cardiopulmonary Disease



Lung Cancer

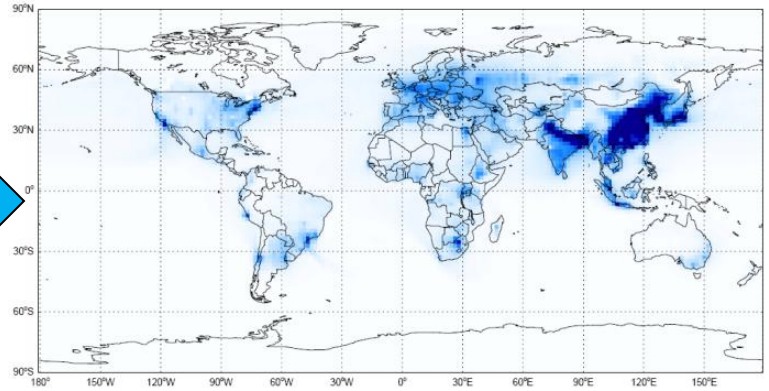


Baseline rates for pop>30
Data from WHO 2004; 2008

Global air quality and health co-benefits of methane and BC emission controls

Methodology for outdoor health impact assessment:

Δ emissions - CH_4, BC, OC, NO_x, VOC, CO, SO_2, CO_2



Δ $PM_{2.5}$ and ozone concentration

Δ $PM_{2.5}$ and ozone-related mortality

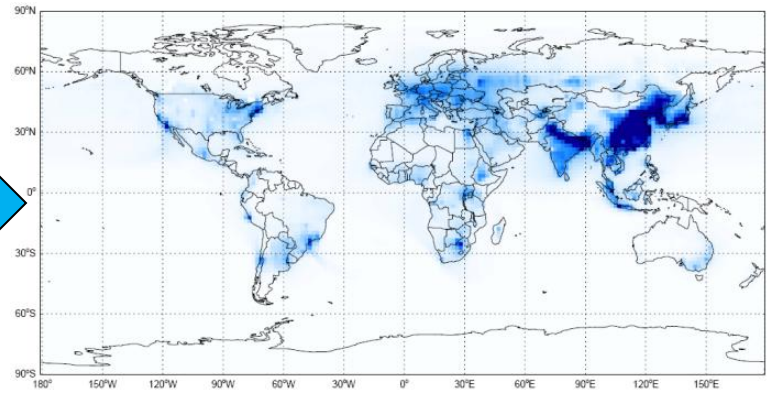
Two global composition-climate models

GISS-PUCCINI (2°x2.5°),
ECHAM-HAMMOZ (2.8°x2.8°)

Global air quality and health co-benefits of methane and BC emission controls

Methodology for outdoor health impact assessment:

Δ emissions - CH_4, BC, OC, NO_x, VOC, CO, SO_2, CO_2



Δ $PM_{2.5}$ and ozone-related mortality

Δ $PM_{2.5}$ and ozone concentration

1. Downscale to 0.5°x0.5° based on population

2. Health impact function

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

β = concentration-response factor

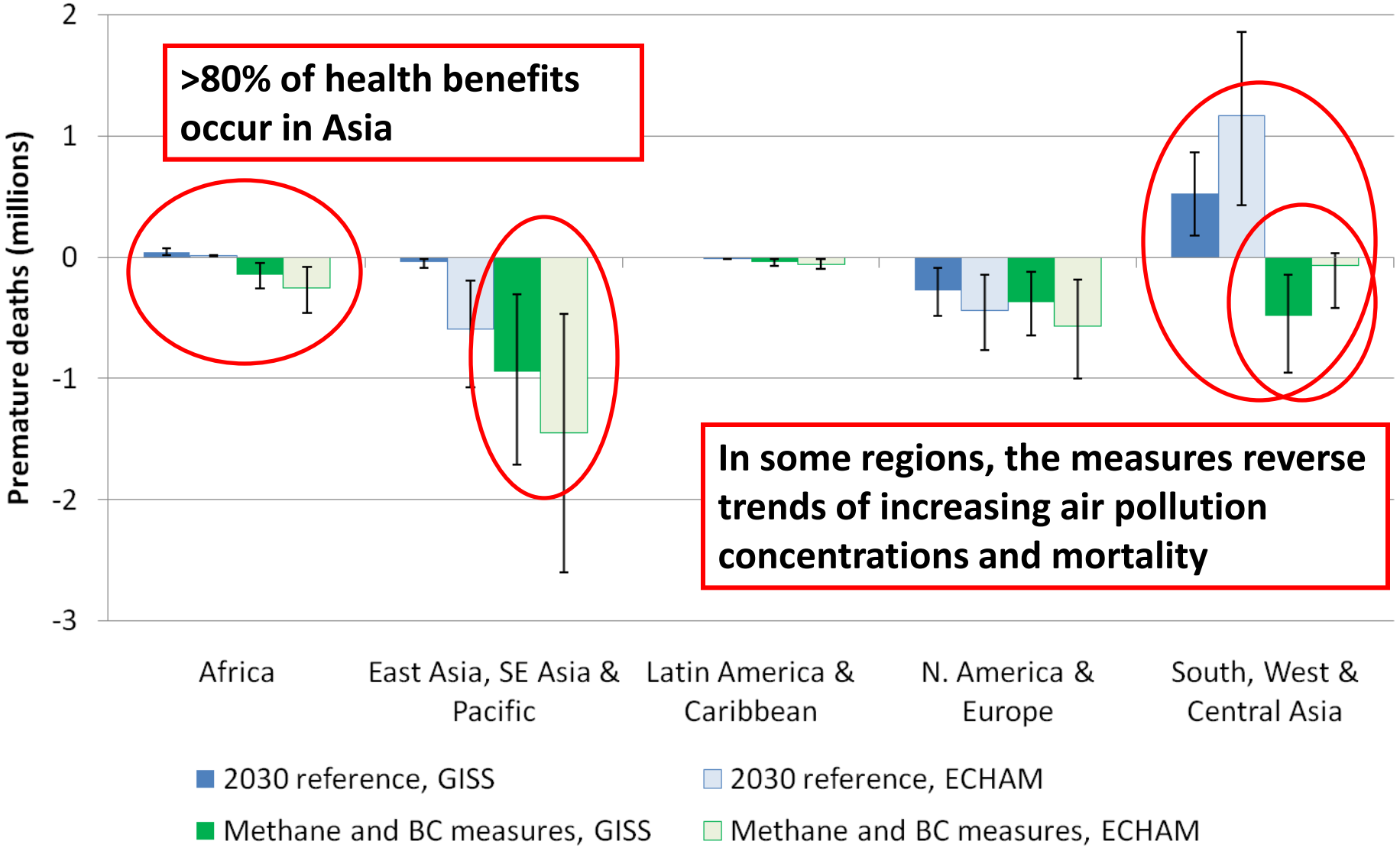
ΔX = change in $PM_{2.5}$ or ozone concentration

y_0 = baseline mortality rate

Concentration-response functions

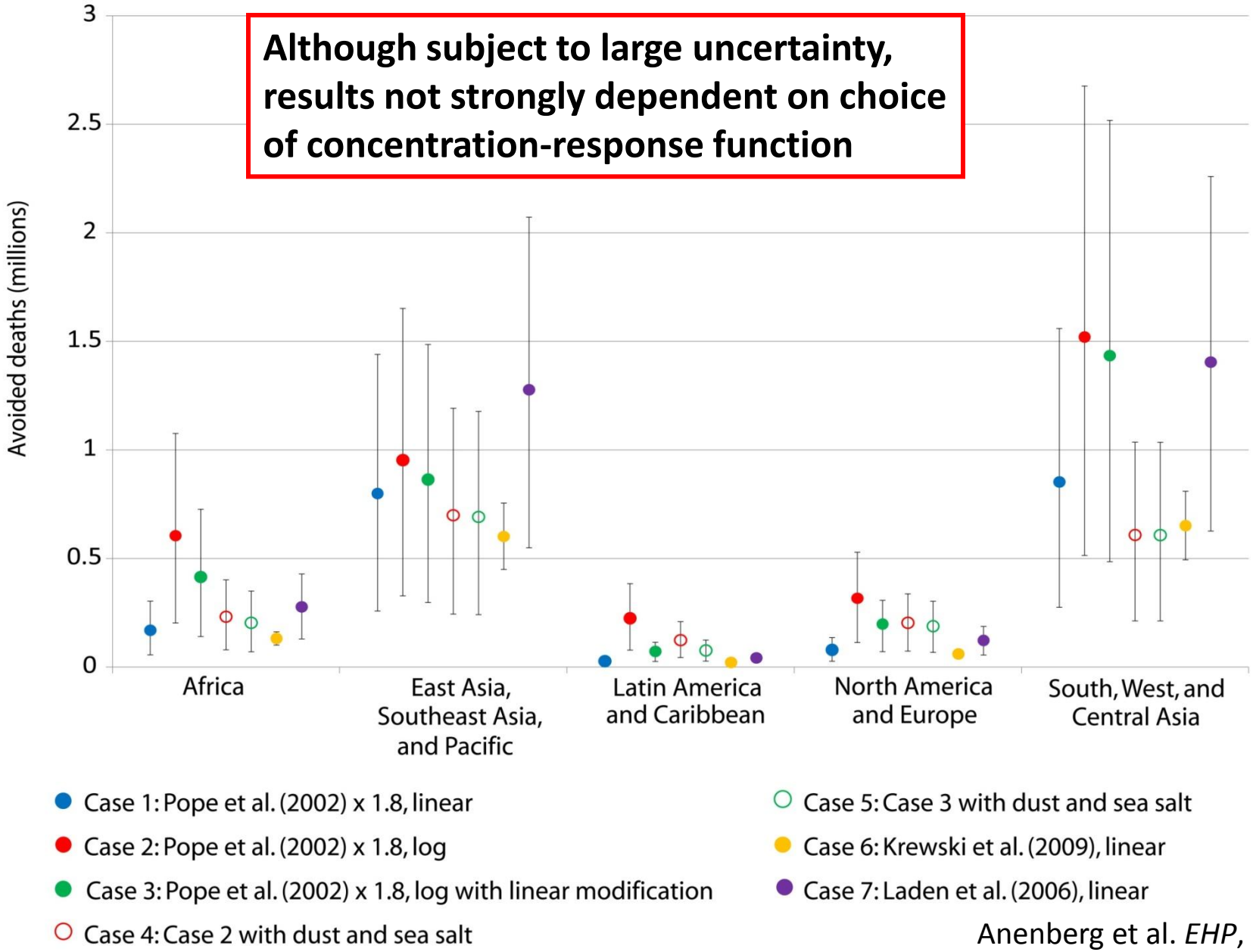
- $PM_{2.5}$ mortality
  - US EPA expert elicitation (Roman et al. 2008) found that long-term relative risk likely to be between estimates from American Cancer Society (ACS) study (Pope et al. 2002; Krewski et al. 2009) and Harvard Six Cities Study (Laden et al. 2006)
  - Cause-specific concentration-response factors scaled up from Pope et al. (2002) by 1.8, the ratio of US EPA expert elicitation estimate for all-cause mortality
  - Examine alternative functions in sensitivity analysis
- Ozone mortality
  - Long-term relative risk estimates for respiratory mortality from ACS study (Jerrett et al. 2009)

Change in $PM_{2.5}$ and ozone-related premature deaths relative to 2005



Anenberg et al. *EHP*, 2012

Sensitivity of avoided deaths to concentration-response function



Anenberg et al. *EHP*, 2012

Benefits of individual mitigation measures

To support policy decisions, need to know the impacts of each measure in each region…

science → **policy**

Integrated Assessment of Black Carbon and Tropospheric Ozone

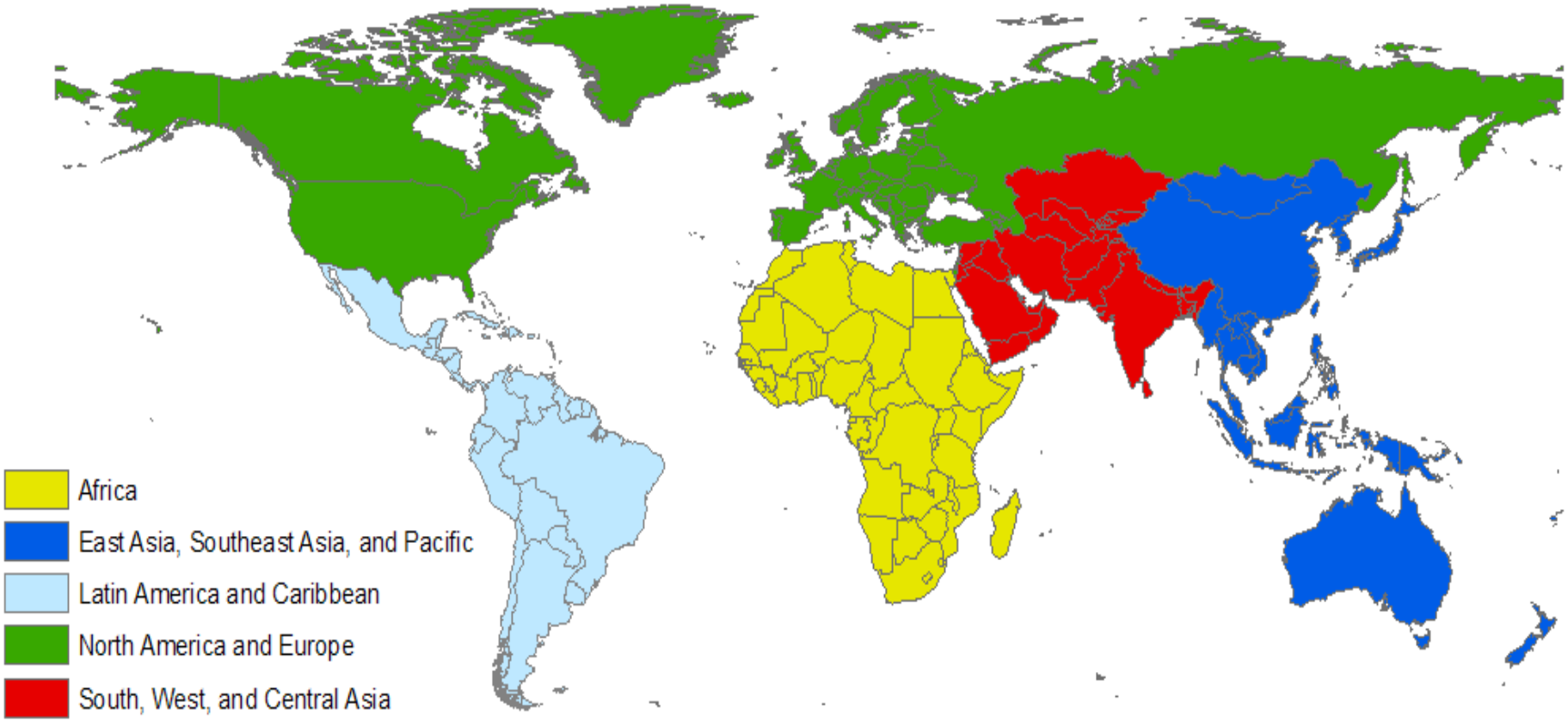
Summary for Decision-Makers released June 2011, rest January 2012

Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers

Report released November 2011

Available: www.unep.org

- Too resource intensive to run full climate-composition models for each measure
- TM5-FAst Scenario Screening Tool (TM5-FASST) used to rapidly assess the impacts of each mitigation measure on concentrations
- Results used to scale avoided deaths due to concentration reductions from all measures simulated by ECHAM model


Africa
East Asia, Southeast Asia, and Pacific
Latin America and Caribbean
North America and Europe
South, West, and Central Asia

Technical measures for methane emissions

- Extended pre-mine degasification and recovery and oxidation of methane from ventilation air from coal mines
- Extended recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from the production of oil and natural gas
- Reduced gas leakage from long-distance transmission pipelines
- Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization
- Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control
- Control of methane emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs
- Intermittent aeration of continuously flooded rice paddies

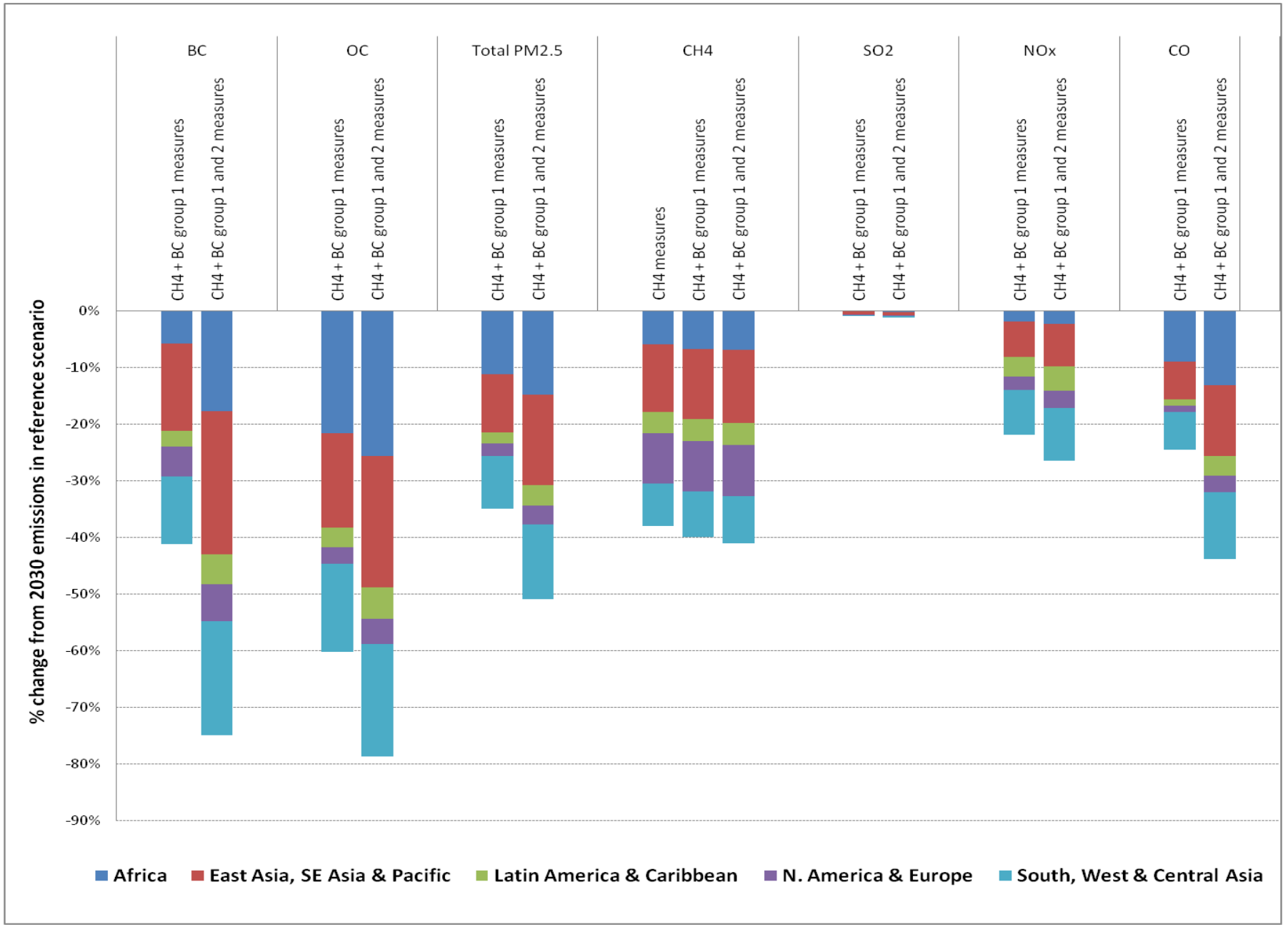
BC Group 1: Technical measures for reducing emissions of incomplete combustion

- Diesel particle filters as part of a Euro VI package for road and off-road diesel vehicles
- Introduction of clean-burning cook stoves for cooking and heating in developing countries
- Replacing traditional brick kilns with vertical shaft kilns and Hoffman kilns
- Replacing traditional coke ovens with modern recovery ovens, including the improvement of end-of-pipe abatement measures in developing countries

BC Group 2: Non-technical measures to eliminate the most polluting activities

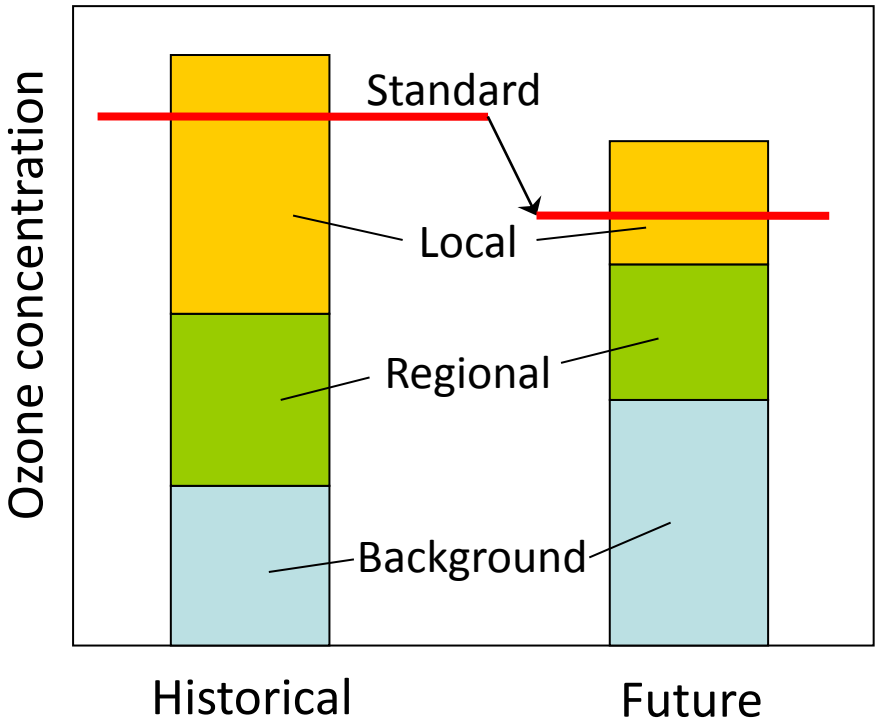
- Elimination of high-emitting vehicles in road and off-road transport (excluding shipping)
- Ban of open field burning of agricultural waste
- Substitution of clean-burning cook stoves using modern fuels for traditional biomass cook stoves in developing countries

Change in emissions relative to 2030 reference



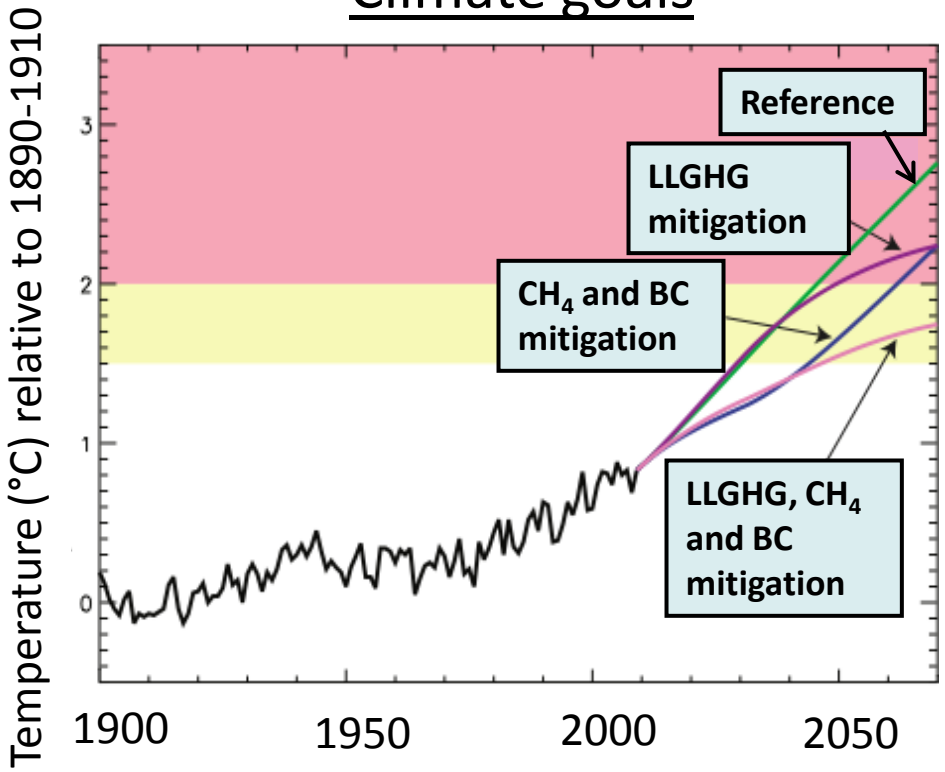
Simultaneously addressing air quality and climate goals

Air quality goals



Keating et al. 2004

Climate goals



UNEP Report on Short-Lived Climate Forcers, 2011; Shindell et al. *Science,* 2012

Reduce methane and black carbon emissions ***in addition to*** **SO_2 and NO_x emissions for air quality and LLGHG emissions for climate**

Relevant papers

Anenberg SC, Horowitz LW, Tong DQ, West JJ (2010) **An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling**. *Environ Health Perspect*, 118:1189-1195.

Anenberg SC, Talgo K, Arunachalam S, Dolwick P, Jang C, West JJ (2011) **Impacts of global, regional, and sectoral black carbon emission reductions on surface air quality and human mortality**. *Atmos Chem Phys*, 11:7253-7267.

Anenberg, S.C., J. Schwartz, D. Shindell, + 16 others (forthcoming) **Global air quality and health co-benefits of mitigating near-term climate change through methane and black carbon emission controls**, *Environ Health Perspect*.

Shindell, D., S.C. Anenberg, + 22 others (2012) **Simultaneously mitigating near-term climate change and improving human health and food security**, *Science*, 335:183-189.

West, J. J., A. M. Fiore, L. W. Horowitz, D. L. Mauzerall (2006) **Mitigating ozone pollution with methane emission controls: global health benefits**, Proceedings of the National Academy of Sciences, 103(11): 3988-3993.

UNEP (2011) **Integrated Assessment of Black Carbon and Tropospheric Ozone**. Nairobi:UNEP. Available at www.unep.org.

UNEP (2011) **Near-Term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers**. Nairobi:UNEP. Available at www.unep.org.