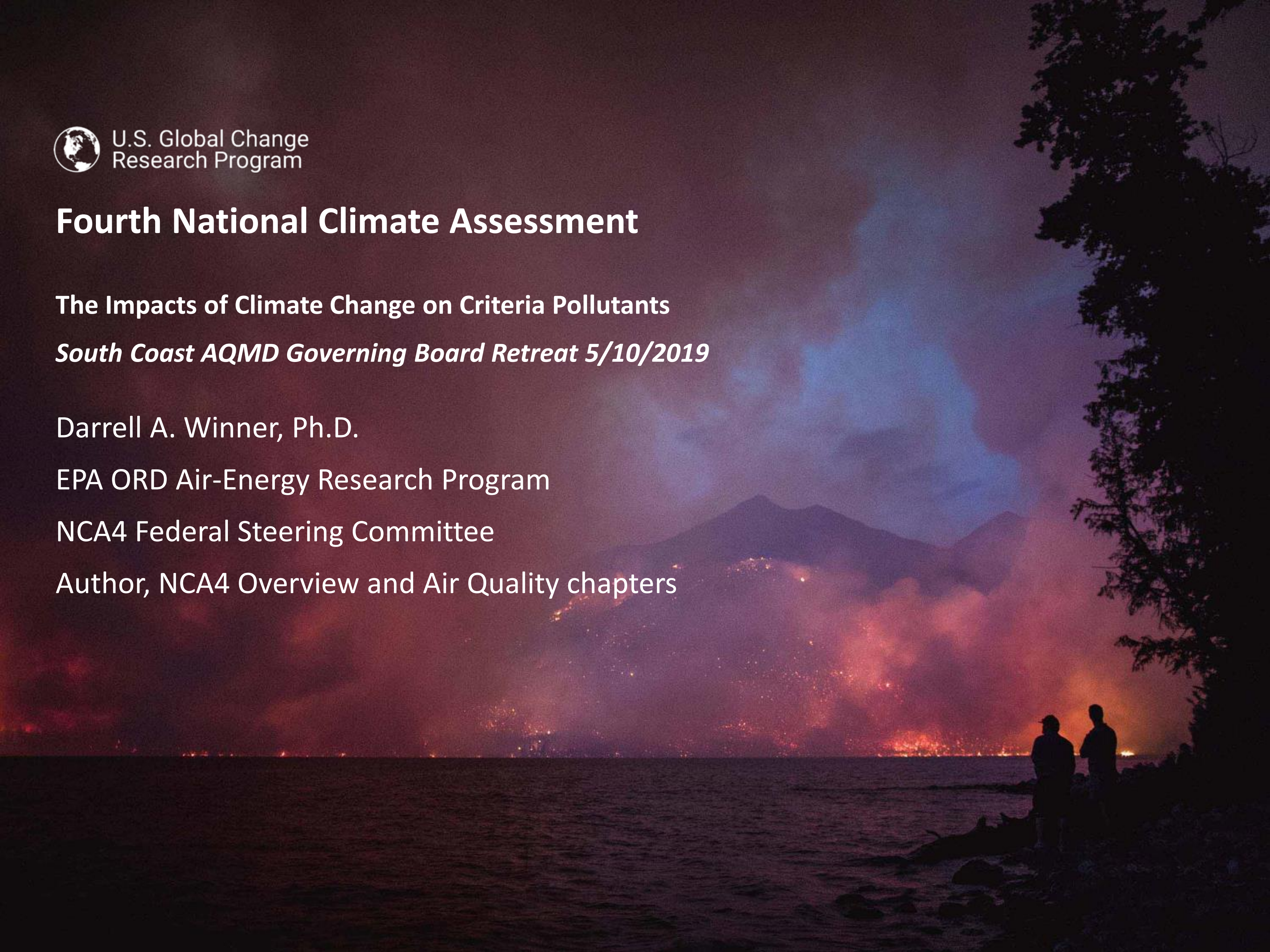

U.S. Global Change Research Program

Fourth National Climate Assessment

The Impacts of Climate Change on Criteria Pollutants

South Coast AQMD Governing Board Retreat 5/10/2019

Darrell A. Winner, Ph.D.

EPA ORD Air-Energy Research Program

NCA4 Federal Steering Committee

Author, NCA4 Overview and Air Quality chapters

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U.S. Global Change Research Program

- USGCRP began as a Presidential initiative in 1989
- Mandated by Congress in the U.S. Global Change Research Act (GCRA) of 1990 “to assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change”
- Overseen by Principals representing the 13 member agencies of the Subcommittee on Global Change Research (SGCR)

National Climate Assessment (NCA) in the Global Change Research Act (GCRA)

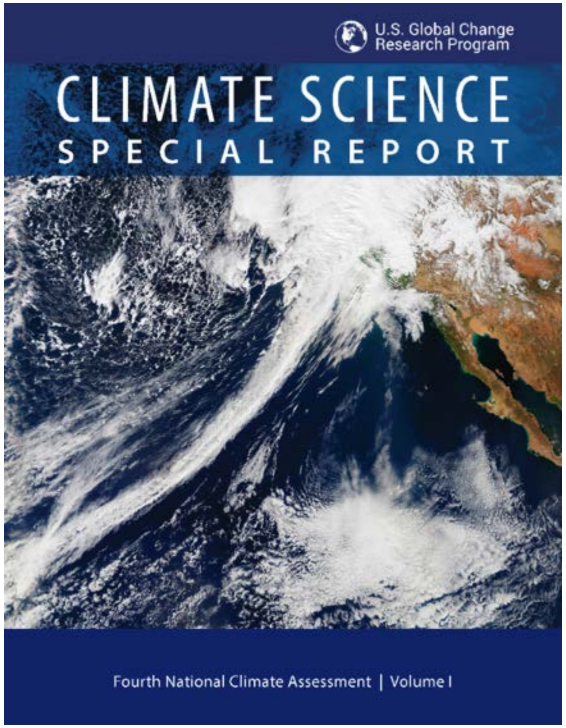
GCRA (1990), Section 106:

Not less frequently than every 4 years [USGCRP] shall prepare and submit to the President and Congress an assessment which:

- Integrates, evaluates, and interprets the findings of [USGCRP] and discusses the scientific uncertainties associated with such findings
- Analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity
- Analyzes current trends in global change, both human- induced and natural, and projects major trends for the subsequent 25 to 100 years.

NCA4 Vol I:
Climate Science Special Report

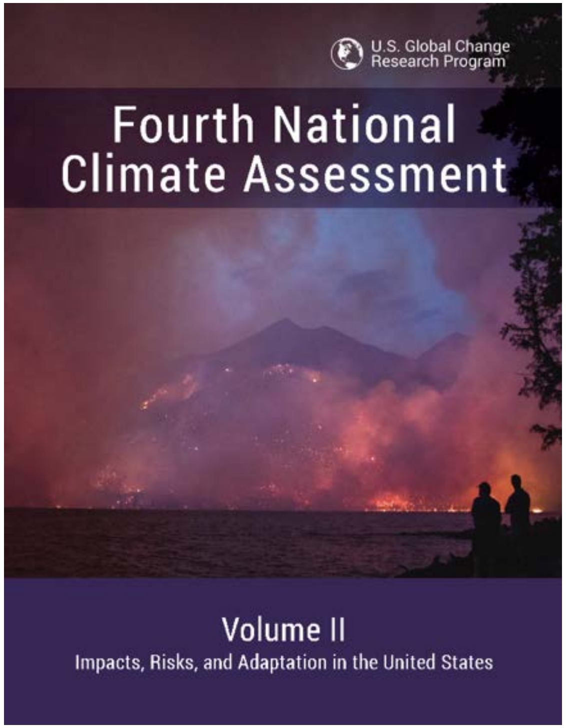
- Released Nov 3, 2017
- Key advances:
  - Detection and attribution
  - Extreme events (tropical cyclones, tornadoes, atmospheric rivers)
  - Downscaled information (including sea level rise)
  - Potential surprises
  - Climate model weighting
- Summarized in Our Changing Climate chapter of NCA4 Vol II



Read and download the report at
science2017.globalchange.gov

NCA4 Vol II:
Impacts, Risks, and Adaptation in the U.S.

- Released Nov 23, 2018
- Policy relevant, but not policy prescriptive
- Places a strong emphasis on regional information
- Assesses a range of potential impacts, helping decision makers better identify risks that could be avoided or reduced
- Uses case studies to provide additional context and opportunities to showcase community success stories



Read and download the report at
nca2018.globalchange.gov

Table of Contents

1 Our Changing Climate: *Observations, Causes, and Future Change*

- Observations collected around the world provide significant, clear, and compelling evidence that global average temperature is much higher, and is rising more rapidly, than anything modern civilization has experienced
- The warming trend observed over the past century can only be explained by the effects that human activities, especially emissions of greenhouse gases, have had on the climate
- Earth's climate will continue to change over this century and beyond. After mid-century, how much the climate changes will depend primarily on global emissions of greenhouse gases and on the response of Earth's climate system to human-induced warming

Fig. 2.1: Human and Natural Influences on Global Temperature

Both human and natural factors influence Earth's climate, but the long-term global warming trend observed over the past century can only be explained by the effect that human activities have had on the climate.

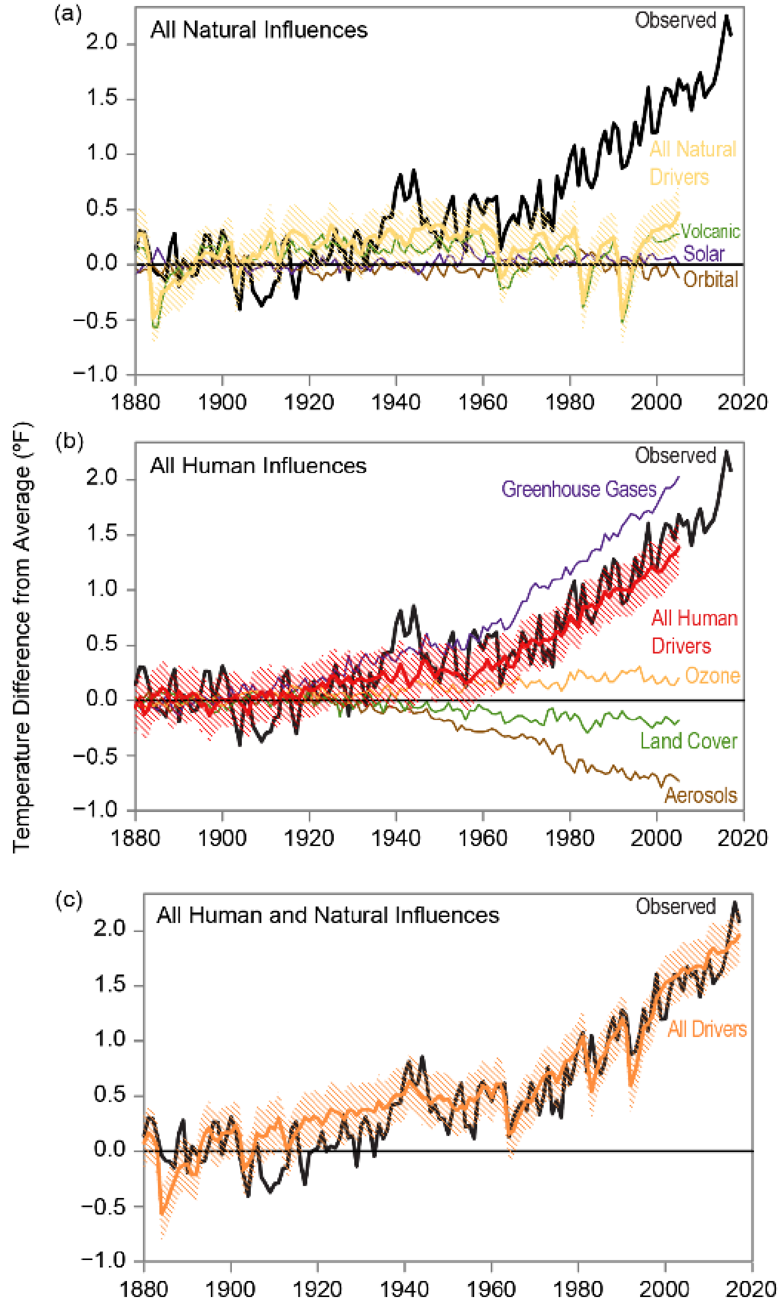
Sophisticated computer models of Earth's climate system allow scientists to explore the effects of both natural and human factors. In all three panels of this figure, the black line shows the observed annual average global surface temperature for 1880–2017 as a difference from the average value for 1880–1910.

The top panel (a) shows the temperature changes simulated by a climate model when only natural factors (yellow line) are considered. The other lines show the individual contributions to the overall effect from observed changes in Earth's orbit (brown line), the amount of incoming energy from the sun (purple line), and changes in emissions from volcanic eruptions (green line). Note that no long-term trend in globally-averaged surface temperature over this time period would be expected from natural factors alone.[10]

The middle panel (b) shows the simulated changes in global temperature when considering only human influences (dark red line), including the contributions from emissions of greenhouse gases (purple line) and small particles (referred to as aerosols, brown line) as well as changes in ozone levels (orange line) and changes in land cover, including deforestation (green line). Changes in aerosols and land cover have had a net cooling effect in recent decades, while changes in near-surface ozone levels have had a small warming effect.[18] These smaller effects are dominated by the large warming influence of greenhouse gases such as carbon dioxide and methane. Note that the net effect of human factors (dark red line) explains most of the long-term warming trend.

The bottom panel (c) shows the temperature change (orange line) simulated by a climate model when both human and natural influences are included. The result matches the observed temperature record closely, particularly since 1950, making the dominant role of human drivers plainly visible.

Researchers do not expect climate models to exactly reproduce the specific timing of actual weather events or short-term climate variations, but they do expect the models to capture how the whole climate system behaves over long periods of time. The simulated temperature lines represent the average values from a large number of simulation runs. The orange hatching represents uncertainty bands based on those simulations. For any given year, 95% of the simulations will lie inside the orange bands. *Source: NASA GISS.*



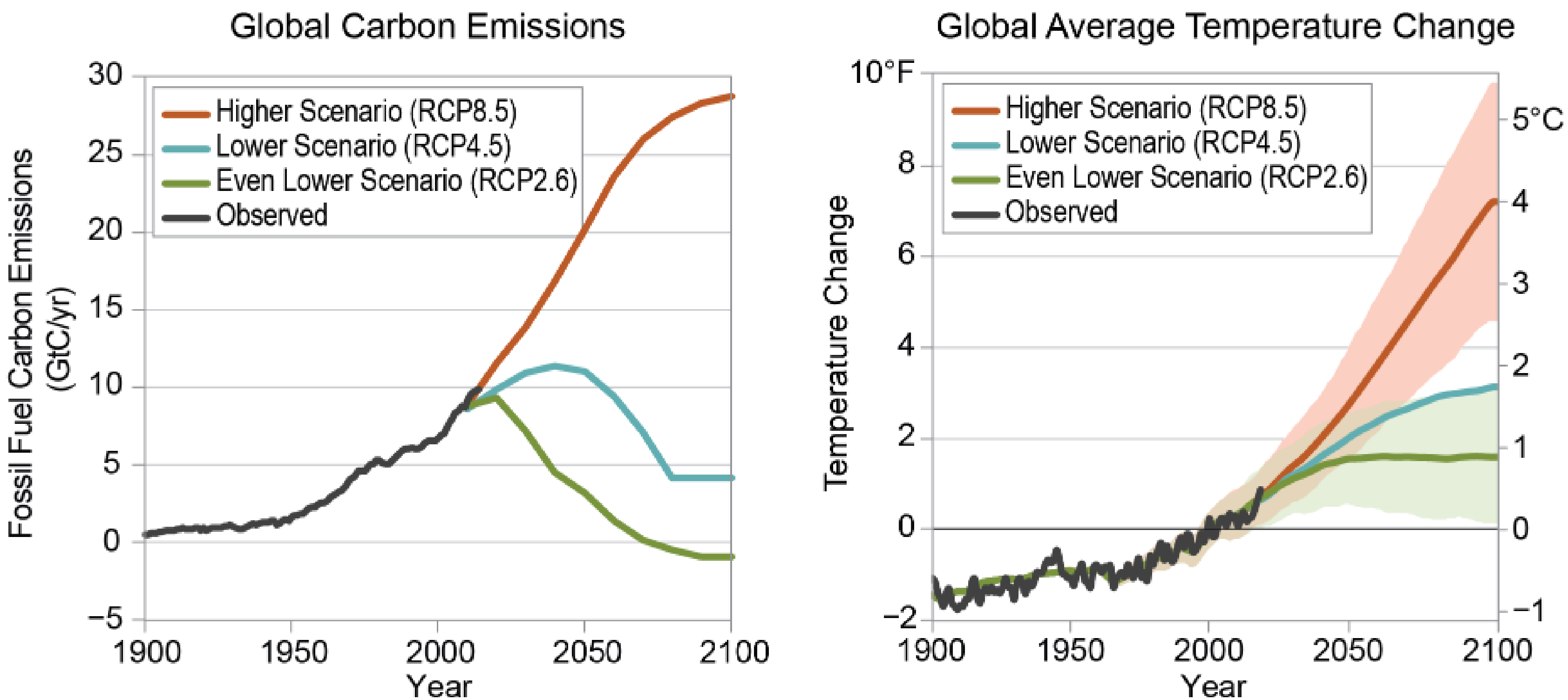
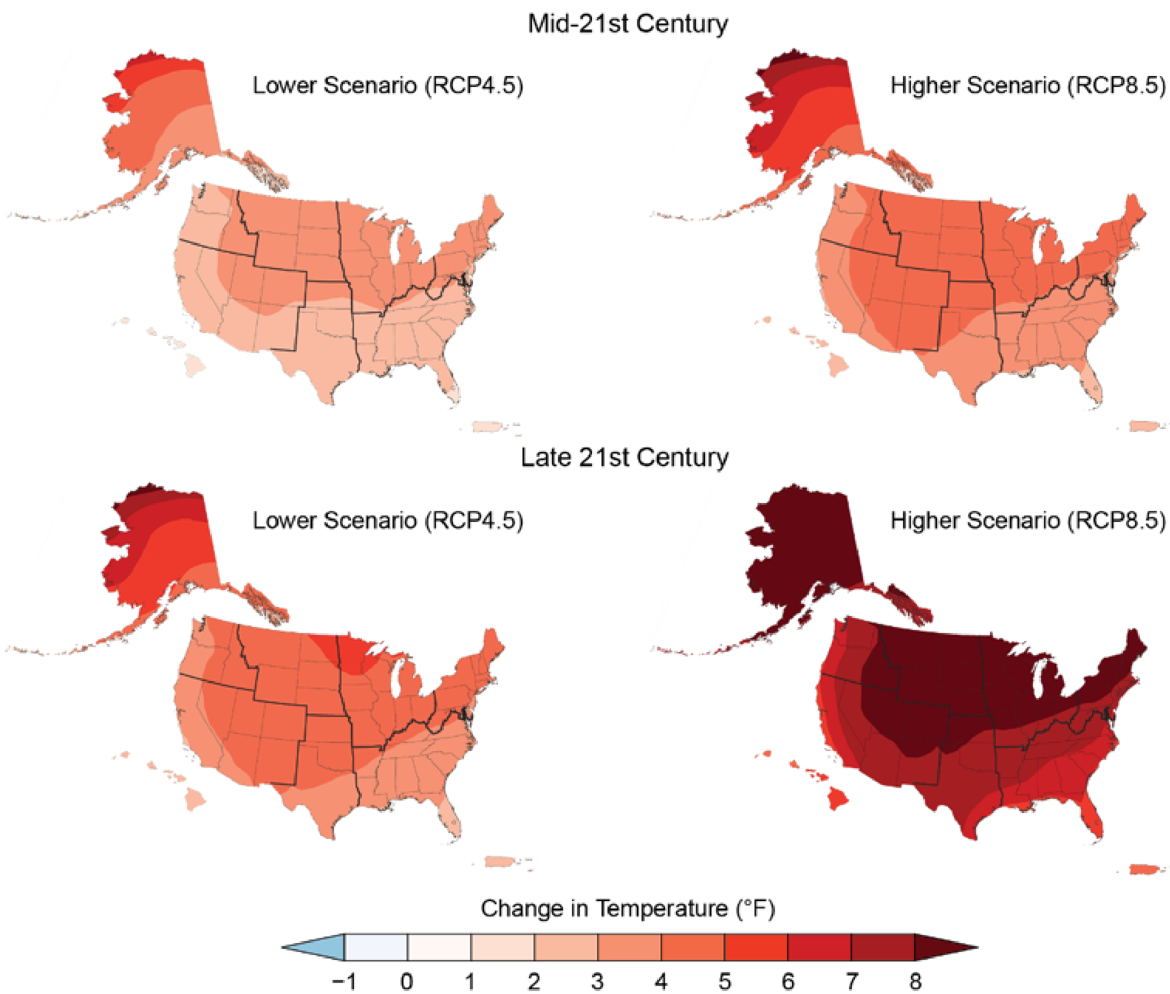


Fig. 2.2: Observed and Projected Changes in Carbon Emissions and Temperature

Observed and projected changes in global average temperature (right) depend on observed and projected emissions of carbon dioxide from fossil fuel combustion (left) and emissions of carbon dioxide and other heat-trapping gases from other human activities, including land use and land-use change. Under a pathway consistent with a higher scenario (RCP8.5), fossil fuel carbon emissions continue to increase throughout the century and by 2081–2100, global average temperature is projected to increase by 4.2°–8.5°F (2.4°–4.7°C; shown by the burnt orange shaded area) relative to the 1986–2015 average. Under a lower scenario (RCP4.5), fossil fuel carbon emissions peak mid-century then decrease, and global average temperature is projected to increase by 1.7°–4.4°F (0.9°–2.4°C; range not shown on graph) relative to 1986–2015. Under an even lower scenario (RCP2.6), assuming carbon emissions from fossil fuels have already peaked, temperature increases could be limited to 0.4°–2.7°F (0.2°–1.5°C; shown by green shaded area) relative to 1986–2015. Thick lines within shaded areas represent the average of multiple climate models. The shaded ranges illustrate the 5% to 95% confidence intervals for the respective projections. In all RCP scenarios, carbon emissions from land use and land-use change amount to less than 1 GtC by 2020 and fall thereafter. Limiting the rise in global average temperature to less than 2.2°F (1.2°C) relative to 1986–2015 is approximately equivalent to 3.6°F (2°C) or less relative to preindustrial temperatures, consistent with the aim of the Paris Agreement (see Box 2.4). *Source: adapted from Wuebbles et al. 2017.*[10]

Fig. 1.3: Projected Changes in U.S. Annual Average Temperature

Annual average temperatures across the United States are projected to increase over this century, with greater changes at higher latitudes as compared to lower latitudes, and under a higher scenario (RCP8.5; right) than under a lower one (RCP4.5; left). This figure shows projected differences in annual average temperatures for mid-century (2036–2065; top) and end of century (2071–2100; bottom) relative to the near present (1986–2015). *From Figure 2.4, Ch. 2: Climate (Source: adapted from [Vose et al. 2017](#)).*



1 Climate Change in the United States: *Current and Future Risks*

- Climate change presents growing challenges to: (1) the economy and our Nation’s infrastructure, (2) the natural environment and the services ecosystems provide to society, and (3) human health and quality of life
- Risks posed by climate variability and change vary by region and sector and by the vulnerability of people experiencing impacts
- This report characterizes specific risks across regions and sectors in an effort to help people assess the risks they face, create and implement a response plan, and monitor and evaluate the efficacy of a given action

1 Economy & Infrastructure

- Many extreme weather and climate-related events are expected to become more frequent and more intense in a warmer world, creating greater risks of infrastructure disruption and failure that can cascade across economic sectors
- Regional economies and industries that depend on natural resources and favorable climate conditions, such as agriculture, tourism, and fisheries, are increasingly vulnerable to impacts driven by climate change
- Some aspects of our economy may see slight improvements in a modestly warmer world. However, the continued warming that is projected to occur without significant reductions in global greenhouse gas emissions is expected to cause substantial net damage to the U.S. economy, especially in the absence of increased adaptation efforts

1 Human Health & Well-Being

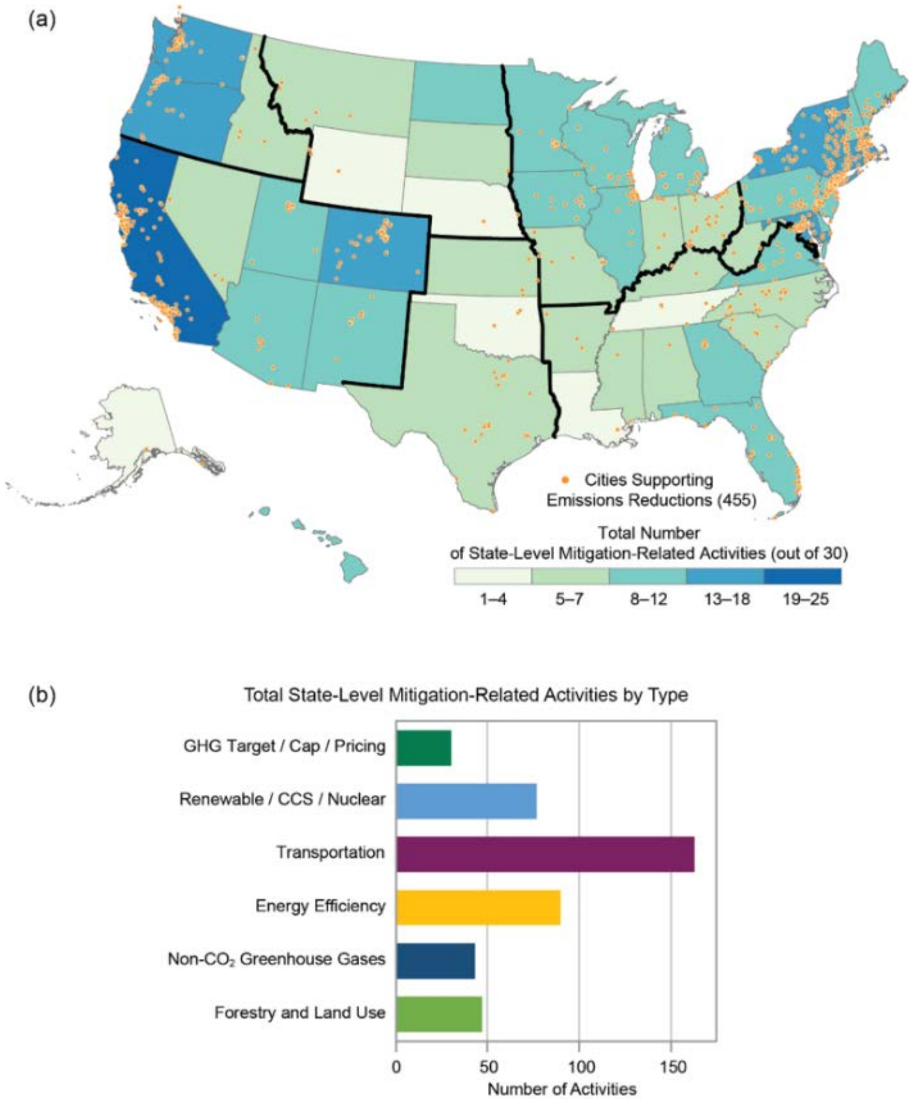
- Higher temperatures, increasing air quality risks, more frequent and intense extreme weather and climate-related events, increases in coastal flooding, disruption of ecosystem services, and other changes increasingly threaten the health and well-being of the American people
- Risks are often highest for those that are already vulnerable, including low-income communities, some communities of color, children, and the elderly
- Future climate change is expected to further disrupt many areas of life, exacerbating existing challenges and revealing new risks to health (including mental health) and prosperity

1 Reducing the Risks of Climate Change

- Many climate change impacts and economic damages in the United States can be substantially reduced through global-scale reductions in greenhouse gas emissions complemented by regional and local adaptation efforts
- Since the Third National Climate Assessment (NCA3) in 2014, a growing number of states, cities, and businesses have pursued or expanded upon initiatives aimed at reducing greenhouse gas emissions, and the scale of adaptation implementation across the country has increased
- However, these efforts do not yet approach the scale needed to avoid substantial damages to the economy, environment, and human health expected over the coming decades

Fig. 1.19: Mitigation-Related Activities at State and Local Levels

(top) The map shows the number of mitigation-related activities at the state level (out of 30 illustrative activities) as well as cities supporting emissions reductions; **(bottom)** the chart depicts the type and number of activities by state. Several territories also have a variety of mitigation-related activities, including American Sāmoa, the Federated States of Micronesia, Guam, Northern Mariana Islands, Puerto Rico, and the U.S. Virgin Islands. *From Figure 29.1, Ch. 29: Mitigation (Sources: [top] EPA and ERT, [bottom] adapted from America's Pledge 2017).*



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Recommended chapter citation

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U.S. Global Change Research Program

Fourth National Climate Assessment

Chapter 13 | Air Quality

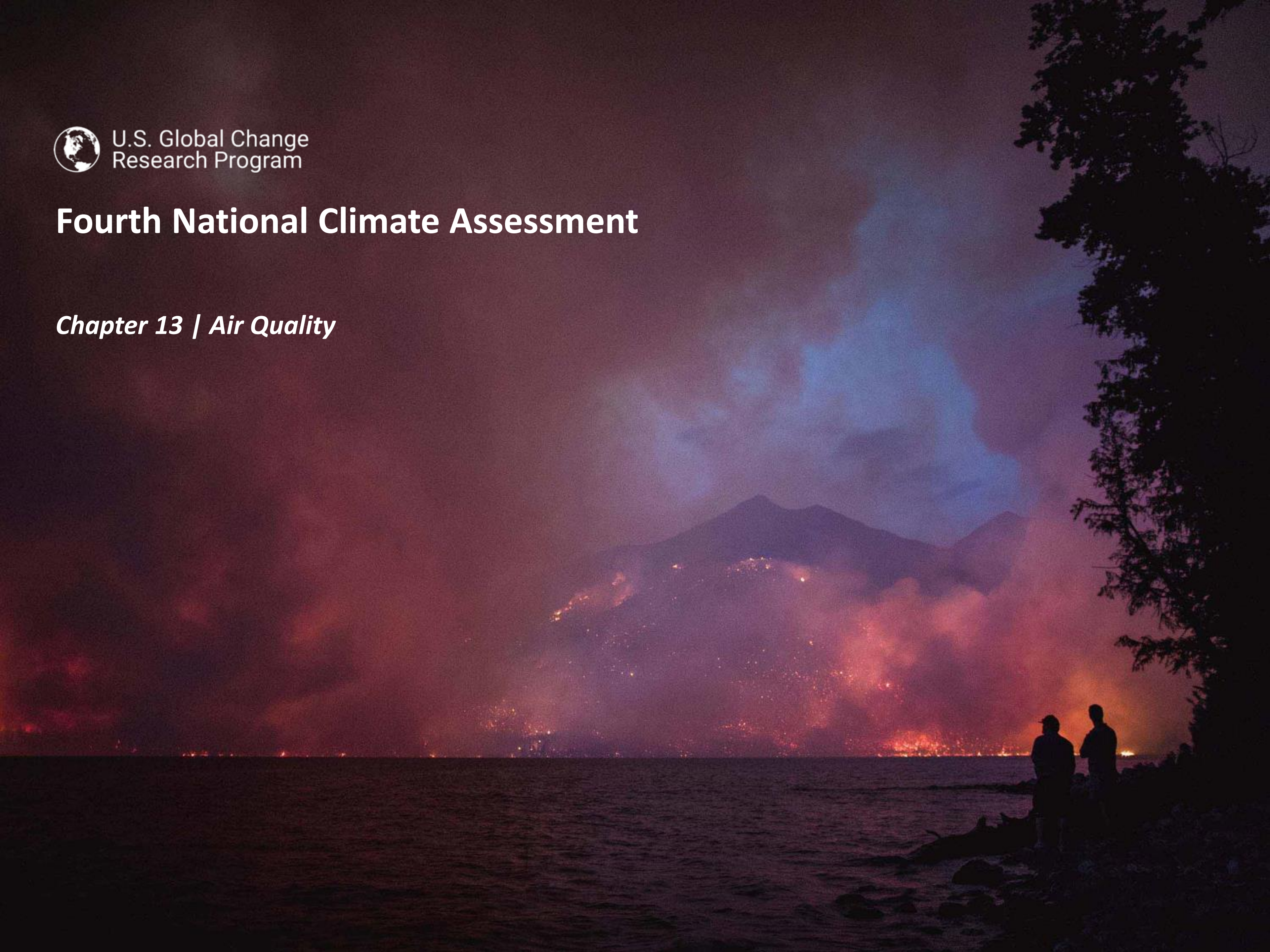
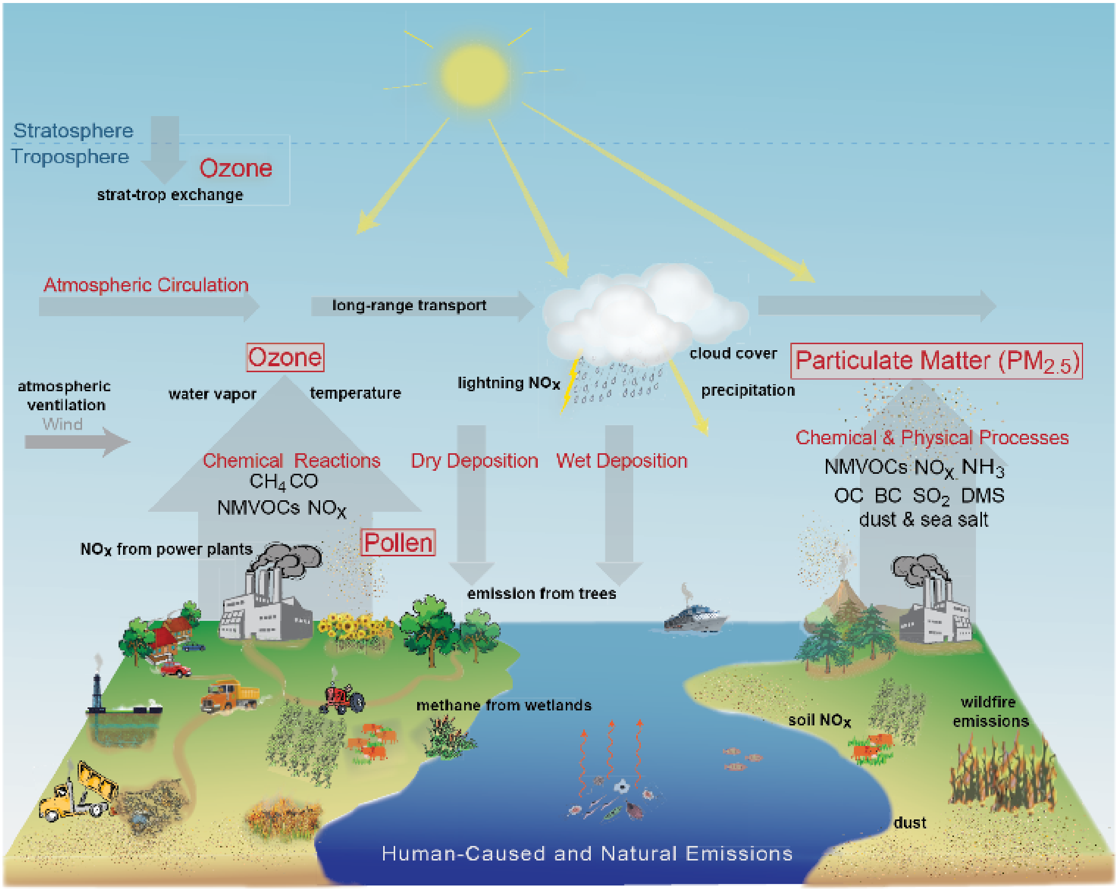


Fig. 13.1: Pathways by Which Climate Change Will Influence Air Pollution

Climate change will alter (black bold text) chemical and physical interactions that create, remove, and transport air pollution (red text and gray arrows). Human activities and natural processes release precursors for ground-level ozone (O_3) and particulate matter with a diameter less than 2.5 micrometers ($PM_{2.5}$), including methane (CH_4), carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), sulfur dioxide (SO_2), ammonia (NH_3), organic carbon (OC), black carbon (BC), and dimethyl sulfide (DMS); and direct atmospheric pollutants, including mineral dust, sea salt, pollen, spores, and food particles. *Source: adapted from Fiore et al. 2015.[4] Reprinted by permission of the publisher (Taylor & Francis Ltd., http://www.tandfonline.com).*



13 Key Message #1

Increasing Risks from Air Pollution

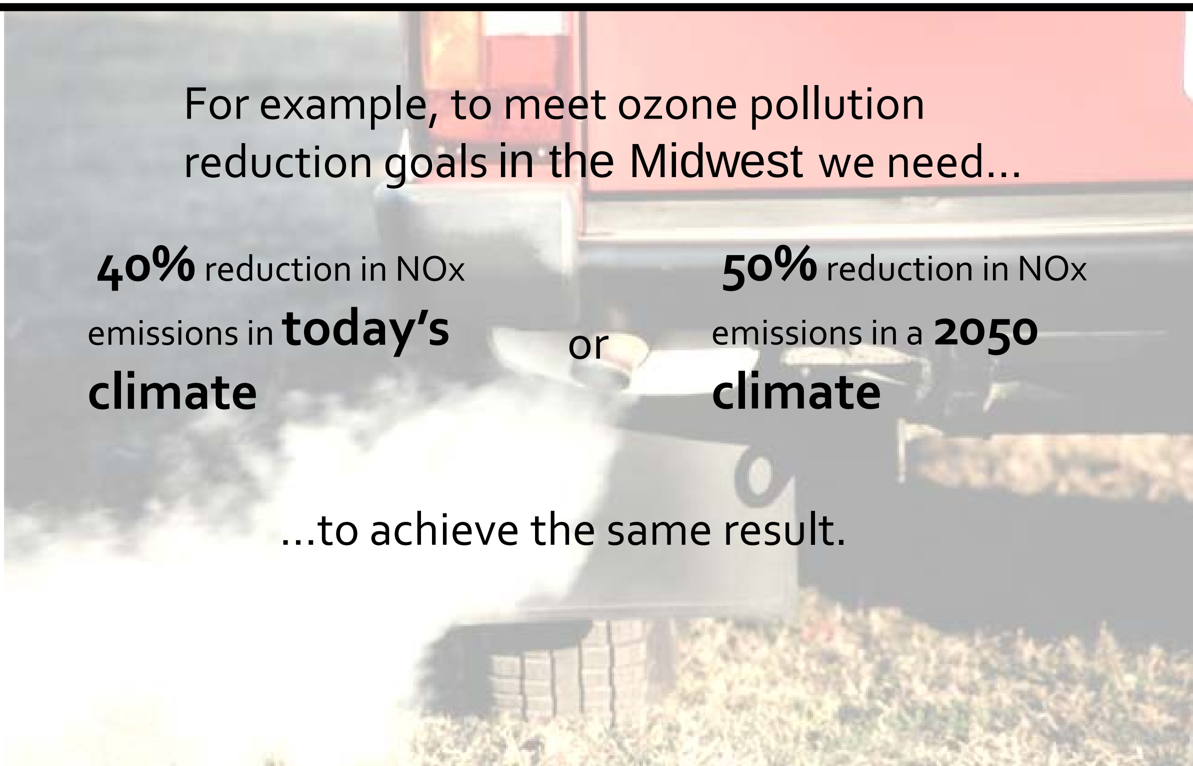
More than 100 million people in the United States live in communities where air pollution exceeds health-based air quality standards. Unless counteracting efforts to improve air quality are implemented, climate change will worsen existing air pollution levels. This worsened air pollution would increase the incidence of adverse respiratory and cardiovascular health effects, including premature death. Increased air pollution would also have other environmental consequences, including reduced visibility and damage to agricultural crops and forests.

United States Environmental Protection Agency

Because climate change will increase ozone concentrations, stronger emissions controls will be needed to achieve air quality standards in the future.

Climate Change's Effect		Ozone	Particulate Matter
↑	**Stagnation**	↑	↑
↑	**Temperature**	↑	↓
?	**Mixing Depth**	=	↑
?	**Precipitation**	=	↑
?	**Cloud Cover**	↓	↓
?	**Humidity**	=	↑

Meteorology → **Air Quality**



For example, to meet ozone pollution reduction goals in the Midwest we need…

40% reduction in NOx emissions in **today's climate**

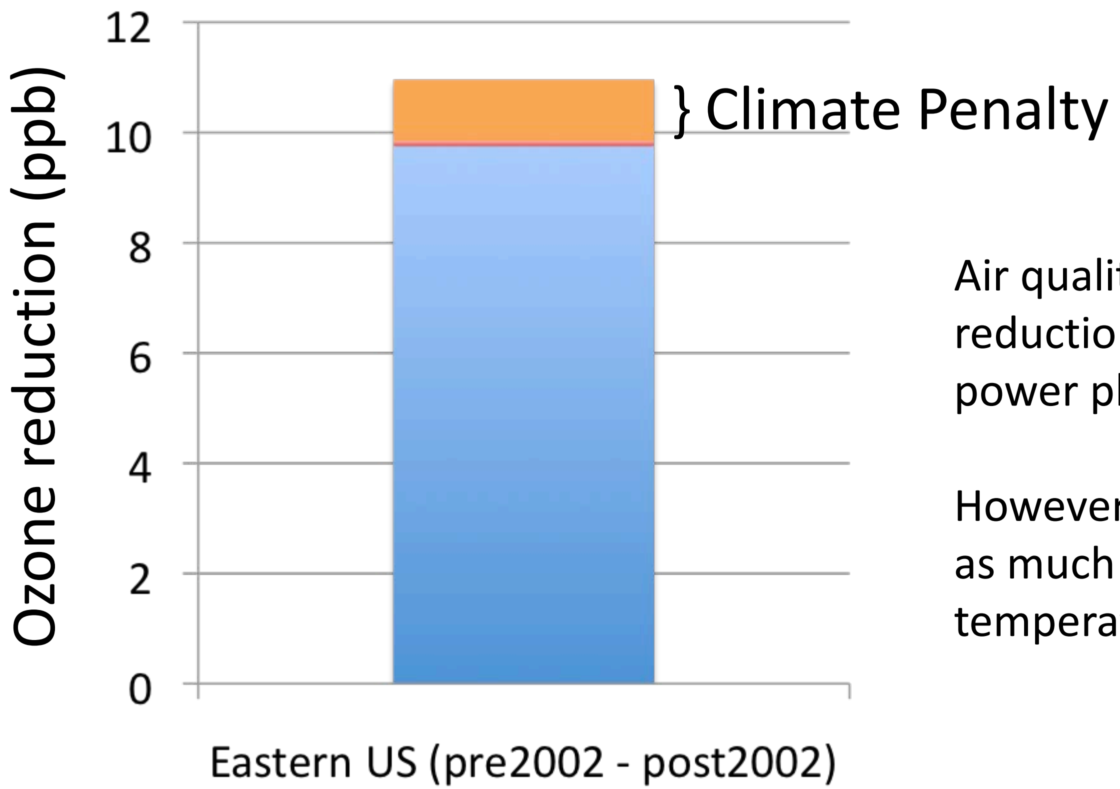
or

50% reduction in NOx emissions in a **2050 climate**

…to achieve the same result.

Jacob and Winner 2009, "Effect of climate change on air quality"

Climate penalty for ozone air quality in the Eastern U.S. based on observations



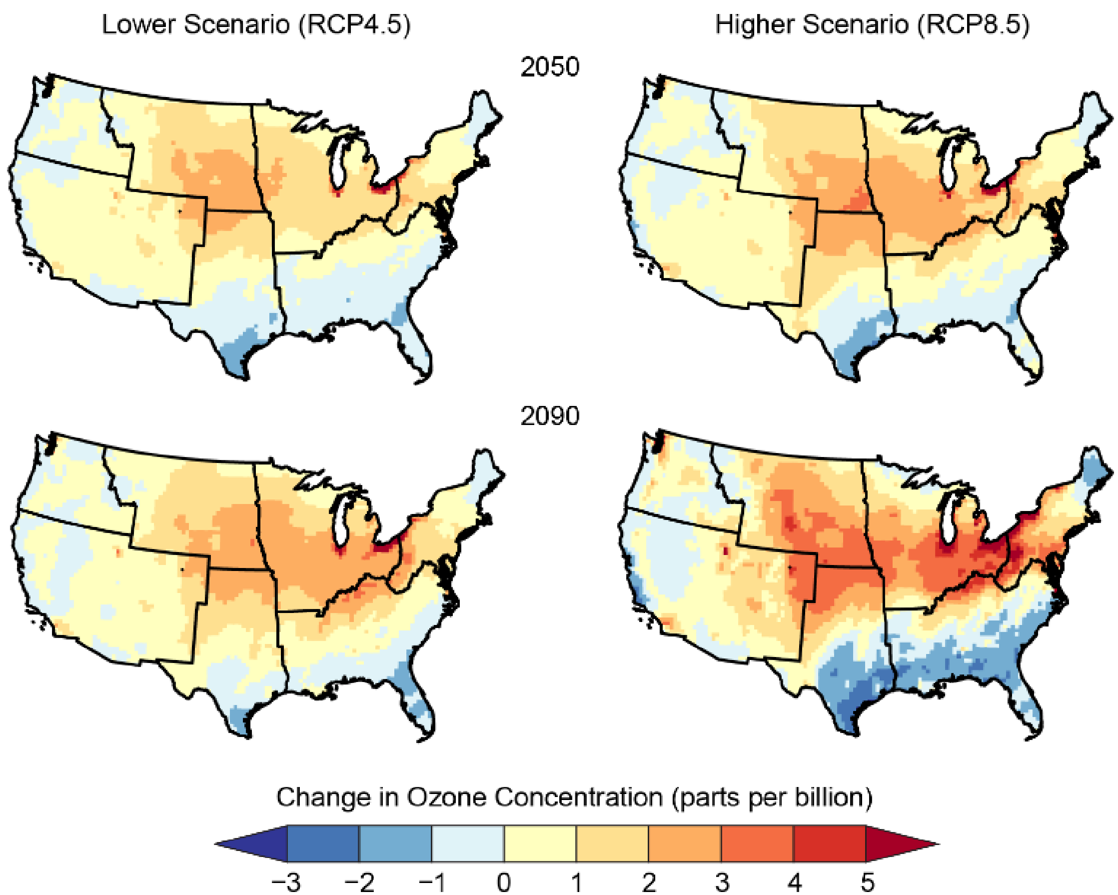
Air quality improved after the 43% reduction in NOx emissions from power plants

However, air quality did not improve as much as it would have had temperatures not increased.

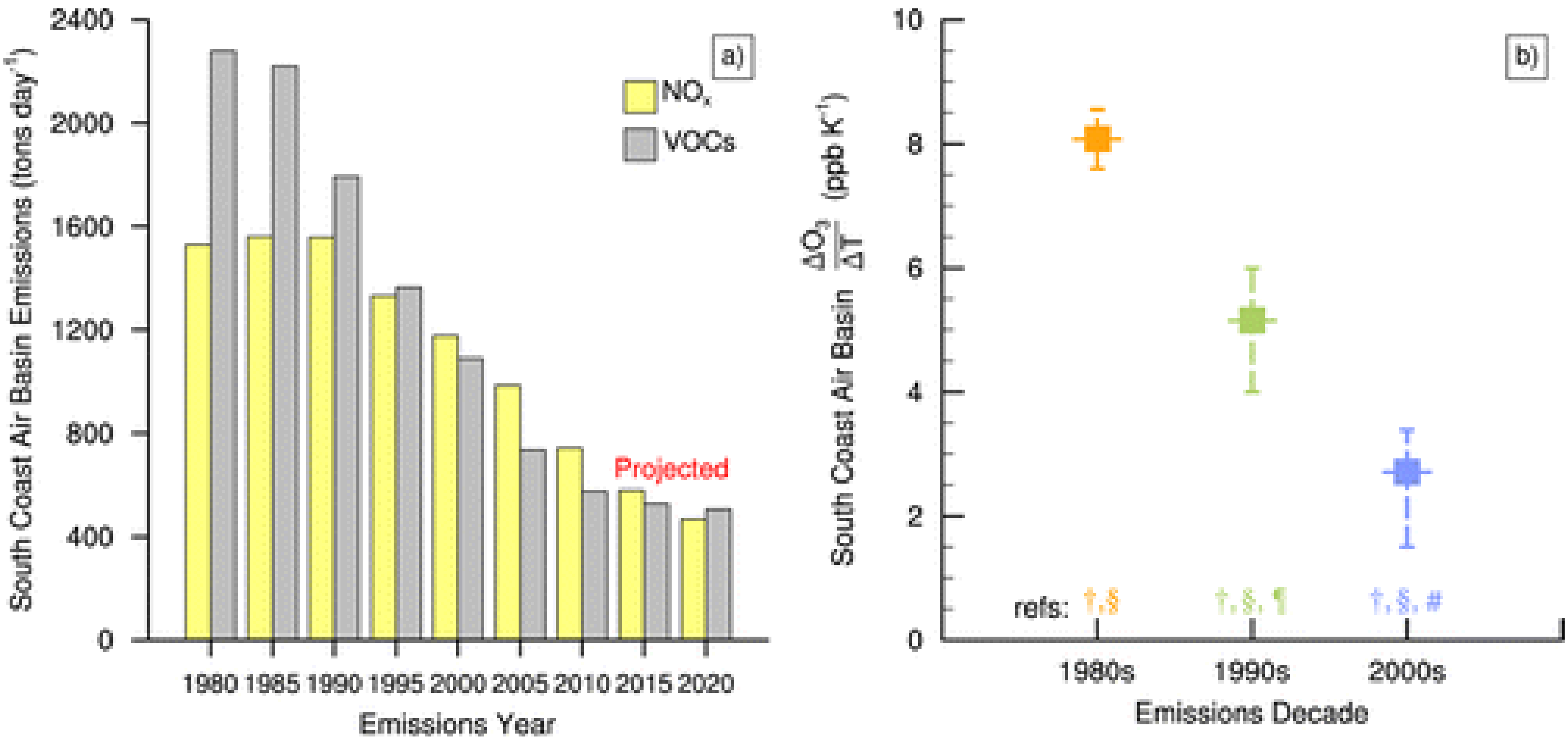
Bloomer et al., GRL, 2009

Fig. 13.2: Projected Changes in Summer Season Ozone

The maps show the change in summer averages of the maximum daily 8-hour ozone concentration (as compared to the 1995–2005 average). Summertime ozone is projected to change non-uniformly across the United States based on multiyear simulations from the Community Multiscale Air Quality (CMAQ) modeling system. Those changes are amplified under the higher scenario (RCP8.5) compared with the lower scenario (RCP4.5), as well as at 2090 compared with 2050. Data are not available for Alaska, Hawai'i, U.S.-Affiliated Pacific Islands, and the U.S. Caribbean. *Source: adapted from EPA 2017.*[1]



The Ozone Climate Penalty Decreases as Emissions Decrease



The Ozone–Climate Penalty: Past, Present, and Future,
D. J. Rasmussen, Jianlin Hu, Abdullah Mahmud, and Michael J. Kleeman,
Environ. Sci. Technol., **2013**

13 Key Message #2

Increasing Impacts of Wildfires

Wildfire smoke degrades air quality, increasing the health risks to tens of millions of people in the United States. More frequent and severe wildfires due to climate change would further diminish air quality, increase incidences of respiratory illness from exposure to wildfire smoke, impair visibility, and disrupt outdoor recreational activities.

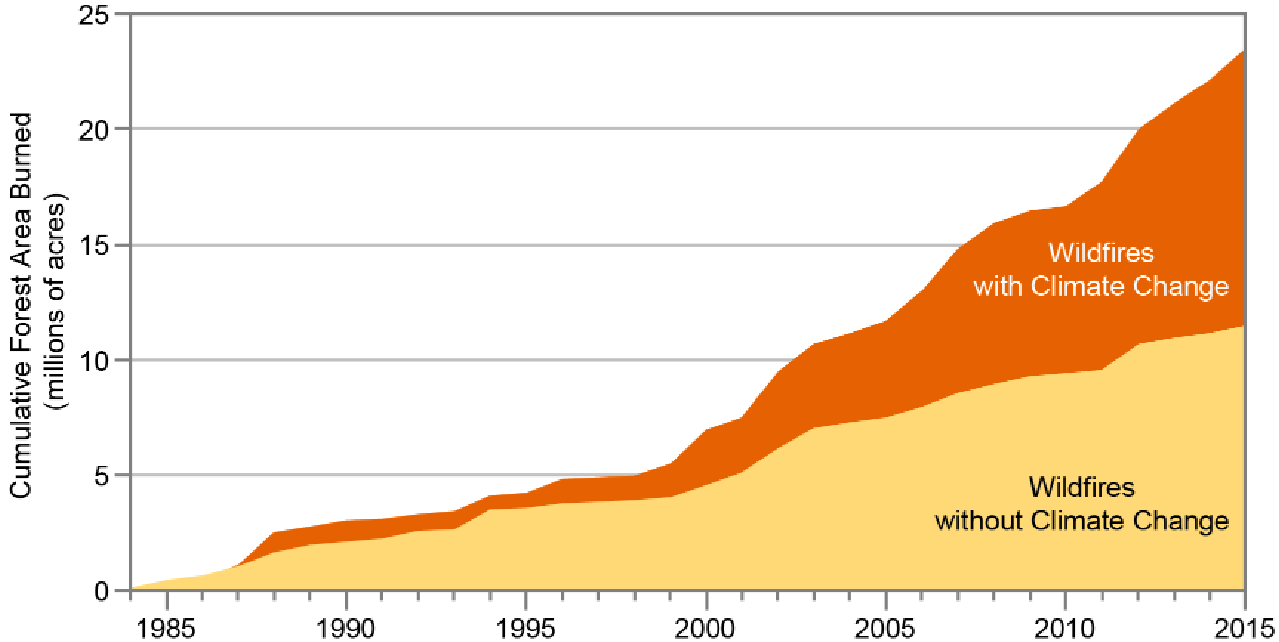


Fig. 25.4: Climate Change Has Increased Wildfire

The cumulative forest area burned by wildfires has greatly increased between 1984 and 2015, with analyses estimating that the area burned by wildfire across the western United States over that period was twice what would have burned had climate change not occurred. *Source: adapted from Abatzoglou and Williams 2016.*[7]

13 Key Message #3

Increases in Airborne Allergen Exposure

The frequency and severity of allergic illnesses, including asthma and hay fever, are likely to increase as a result of a changing climate. Earlier spring arrival, warmer temperatures, changes in precipitation, and higher carbon dioxide concentrations can increase exposure to airborne pollen allergens.

13 Key Message #4

Co-Benefits of Greenhouse Gas Mitigation

Many emission sources of greenhouse gases also emit air pollutants that harm human health. Controlling these common emission sources would both mitigate climate change and have immediate benefits for air quality and human health. Because methane is both a greenhouse gas and an ozone precursor, reductions of methane emissions have the potential to simultaneously mitigate climate change and improve air quality.

U.S. Global Change
Research Program

Recommended chapter citation

Nolte, C.G., P.D. Dolwick, N. Fann, L.W. Horowitz, V. Naik, R.W. Pinder, T.L. Spero, D.A. Winner, and L.H. Ziska, 2018: Air Quality. In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.CH13

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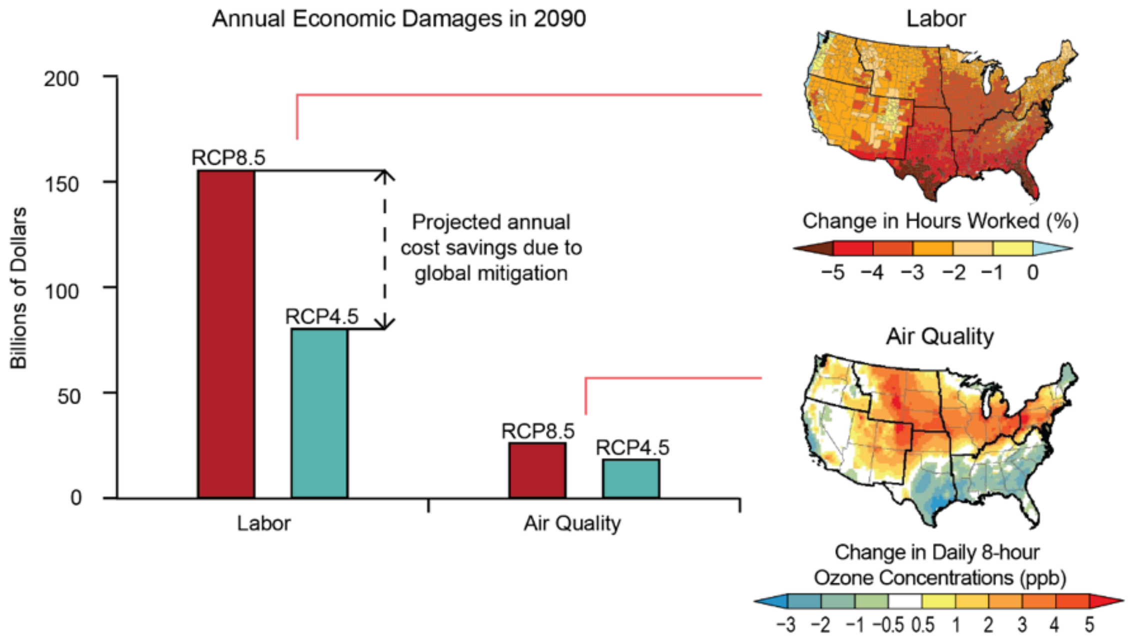
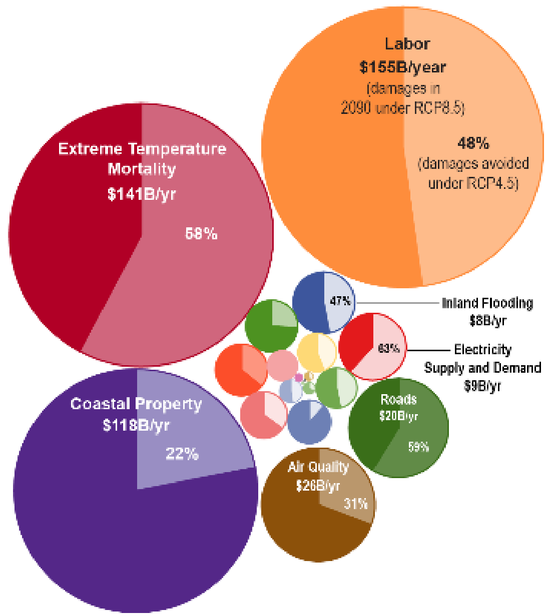


Fig. 1.21: New Economic Impact Studies

Annual economic impact estimates are shown for labor and air quality. The bar graph on the left shows national annual damages in 2090 (in billions of 2015 dollars) for a higher scenario (RCP8.5) and lower scenario (RCP4.5); the difference between the height of the RCP8.5 and RCP4.5 bars for a given category represents an estimate of the economic benefit to the United States from global mitigation action. For these two categories, damage estimates do not consider costs or benefits of new adaptation actions to reduce impacts, and they do not include Alaska, Hawai‘i and U.S.-Affiliated Pacific Islands, or the U.S. Caribbean. The maps on the right show regional variation in annual impacts projected under the higher scenario (RCP8.5) in 2090. The map on the top shows the percent change in hours worked in high-risk industries as compared to the period 2003–2007. The hours lost result in economic damages: for example, $28 billion per year in the Southern Great Plains. The map on the bottom is the change in summer-average maximum daily 8-hour ozone concentrations (ppb) at ground-level as compared to the period 1995–2005. These changes in ozone concentrations result in premature deaths: for example, an additional 910 premature deaths each year in the Midwest. *Source: EPA, 2017. Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. U.S. Environmental Protection Agency, EPA 430-R-17-001*.

Fig. 29.2: Projected Damages and Potential for Risk Reduction by Sector

The total area of each circle represents the projected annual economic damages (in 2015 dollars) under a higher scenario (RCP8.5) in 2090 relative to a no-change scenario. The decrease in damages under a lower scenario (RCP4.5) compared to RCP8.5 is shown in the lighter-shaded area of each circle. Where applicable, sectoral results assume population change over time, which in the case of winter recreation leads to positive effects under RCP4.5, as increased visitors outweigh climate losses. Importantly, many sectoral damages from climate change are not included here, and many of the reported results represent only partial valuations of the total physical damages. See EPA 2017 for ranges surrounding the central estimates presented in the figure; results assume limited or no adaptation.[2] Adaptation was shown to reduce overall damages in sectors identified with the diamond symbol but was not directly modeled in, or relevant to, all sectors. Asterisks denote sectors with annual damages that may not be visible at the given scale. Only one impact (wildfire) shows very small positive effects, owing to projected landscape-scale shifts to vegetation with longer fire return intervals (see Ch. 6: Forests for a discussion on the weight of evidence regarding projections of future wildfire activity). The online version of this figure includes value ranges for numbers in the table. Due to space constraints, the ranges are not included here. *Source: adapted from EPA 2017.*[2]



Annual Economic Damages in 2090		
Sector	Annual damages under RCP8.5	Damages avoided under RCP4.5
Labor	$155B	48%
Extreme Temperature Mortality◊	$141B	58%
Coastal Property◊	$118B	22%
Air Quality	$26B	31%
Roads◊	$20B	59%
Electricity Supply and Demand	$9B	63%
Inland Flooding	$8B	47%
Urban Drainage	$6B	26%
Rail◊	$6B	36%
Water Quality	$5B	35%
Coral Reefs	$4B	12%
West Nile Virus	$3B	47%
Freshwater Fish	$3B	44%
Winter Recreation	$2B	107%
Bridges	$1B	48%
Munic. and Industrial Water Supply	$316M	33%
Harmful Algal Blooms	$199M	45%
Alaska Infrastructure◊	$174M	53%
Shellfish*	$23M	57%
Agriculture*	$12M	11%
Aeroallergens*	$1M	57%
Wildfire	–$106M	–134%

Air pollutants can cause both warming and cooling.

- Ozone is greenhouse gas
- Black carbon portion of $PM_{2.5}$ is warming
- Sulfate portion of $PM_{2.5}$ is cooling
- Methane is a greenhouse gas, and also a precursor to ozone
- NO_x changes atmospheric radical chemistry, which alters lifetime of methane and impacts ozone

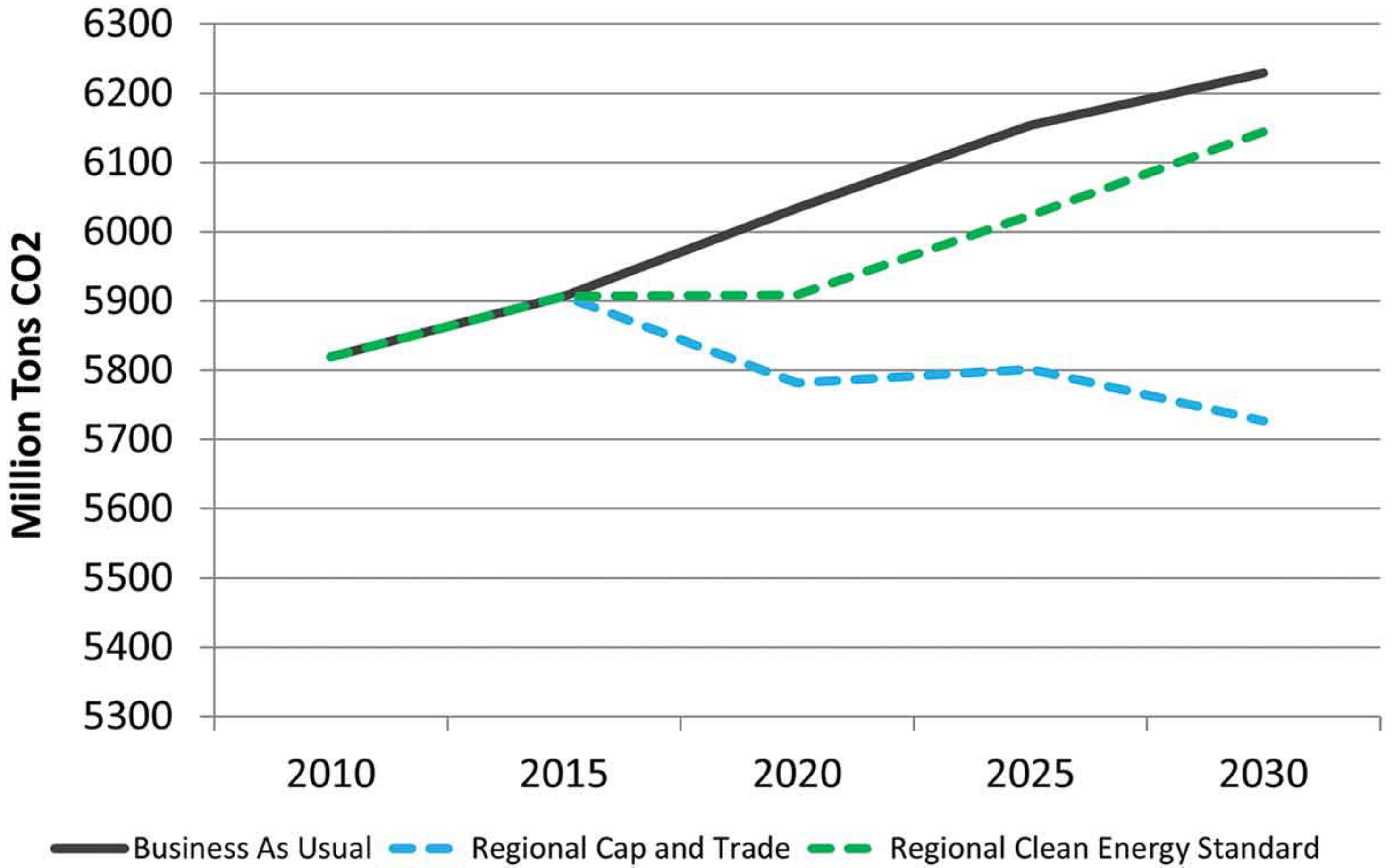
Co-benefit

- GHG emission reductions can result in major improvements in air quality (or not depending on measures)
  - The economic value of co-benefits often represent a significant portion of the cost of emission controls
- Of course, the reverse is can also be true – air quality emission reductions can help mitigate climate change (e.g. methane, black carbon)
- After decades of research and model development, we can now evaluate the detailed impact of GHG reduction policies on regional air quality
- Is “co-benefit” the best language to use?

Tammy M. Thompson, Sebastian Rausch, Rebecca K. Saari & Noelle E. Selin (2016) Air quality co-benefits of subnational carbon policies, Journal of the Air & Waste Management Association, 66:10,988-1002, https://www.tandfonline.com/doi/full/10.1080/10962247.2016.1192071

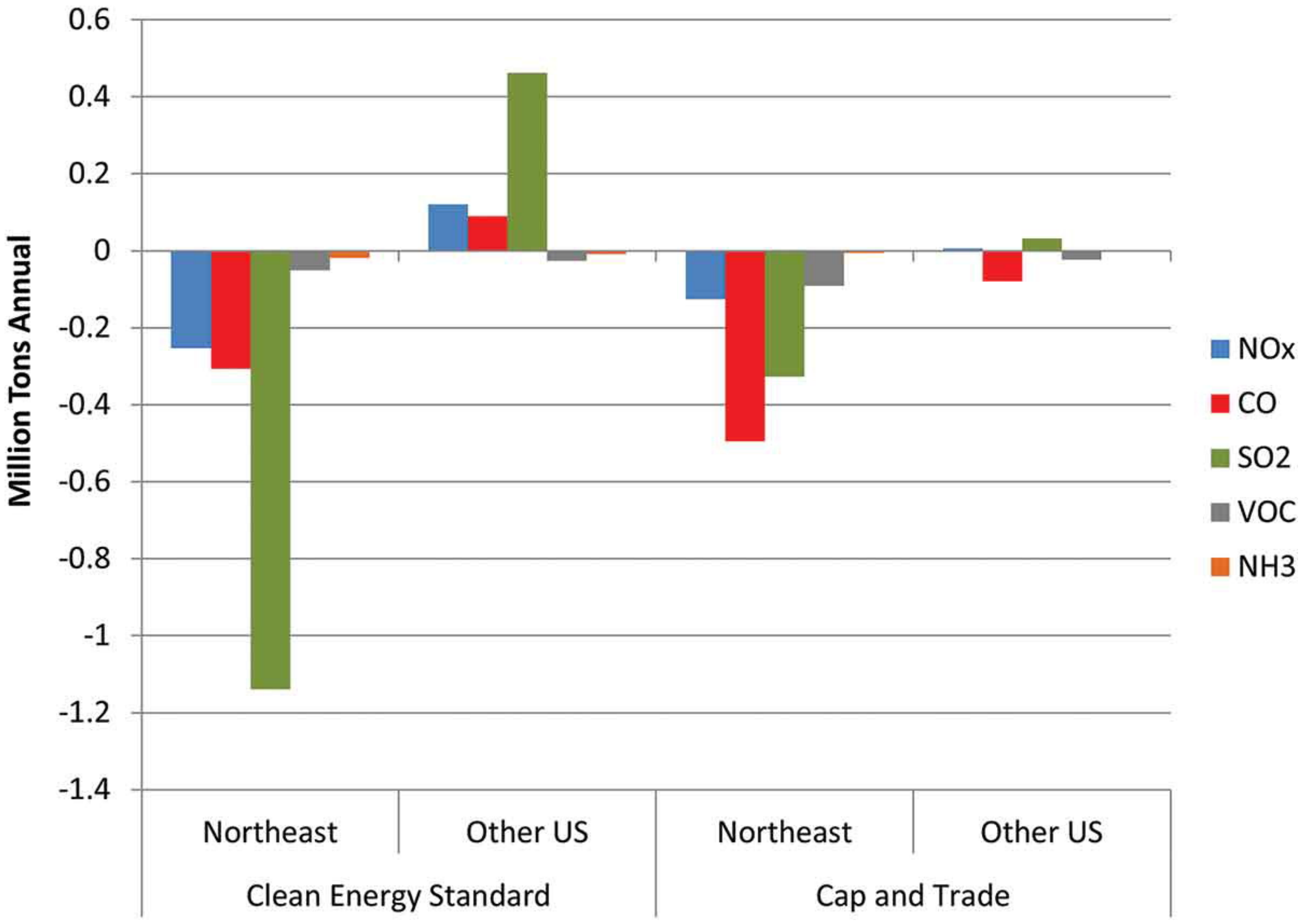
- Model 3 future scenarios for 17 NE US States to 2030,
  - BAU business as usual
  - CES clean energy standard, certain fraction of electricity sales “clean”
  - CAT cap-and-trade, covering emissions from all sectors
- Both CAT and CES scenarios, a 14% carbon emissions reduction in 2030

Total U.S. carbon emissions



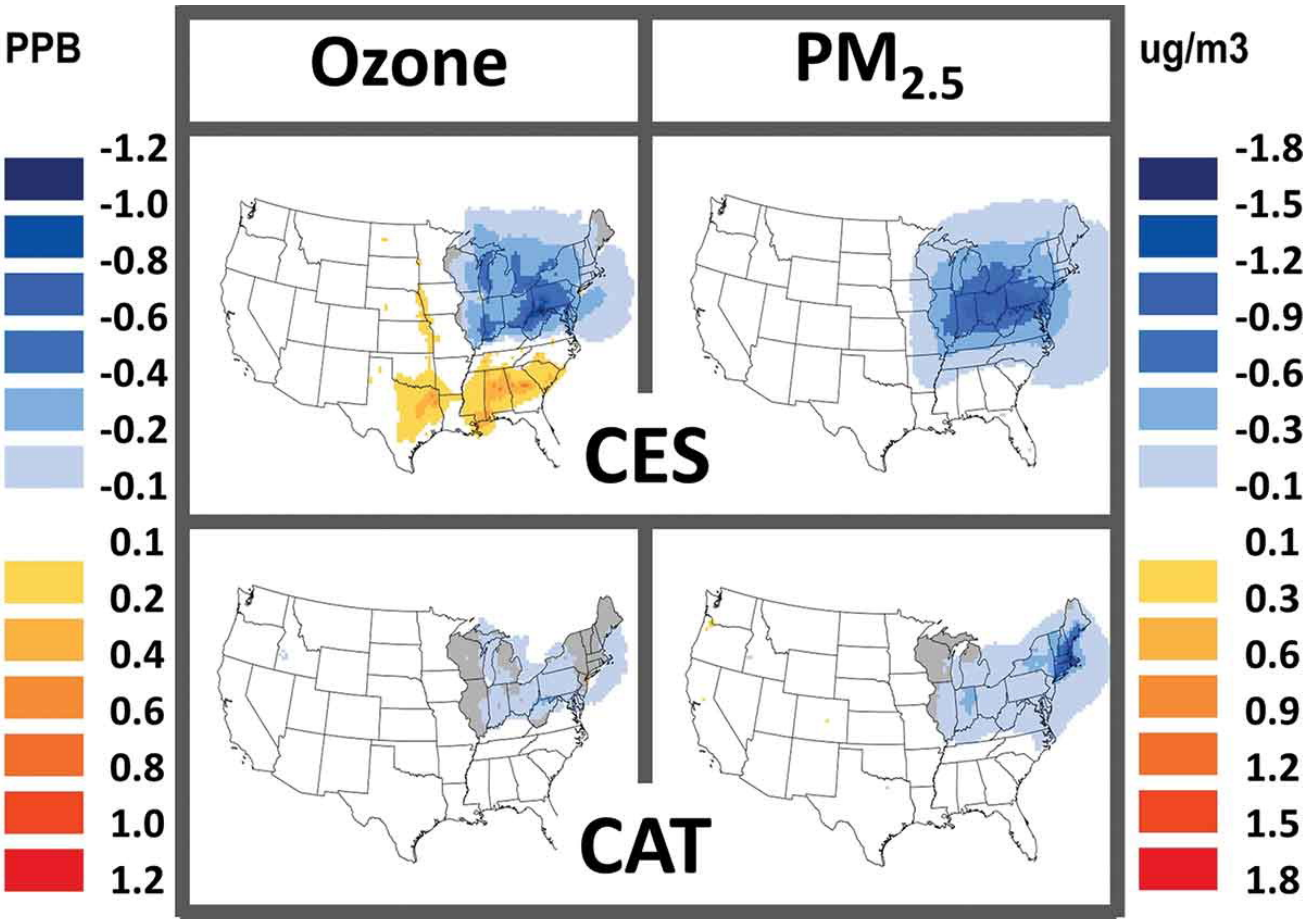
Thompson et al., 2016

Year 2030 annual change of five common air pollutants



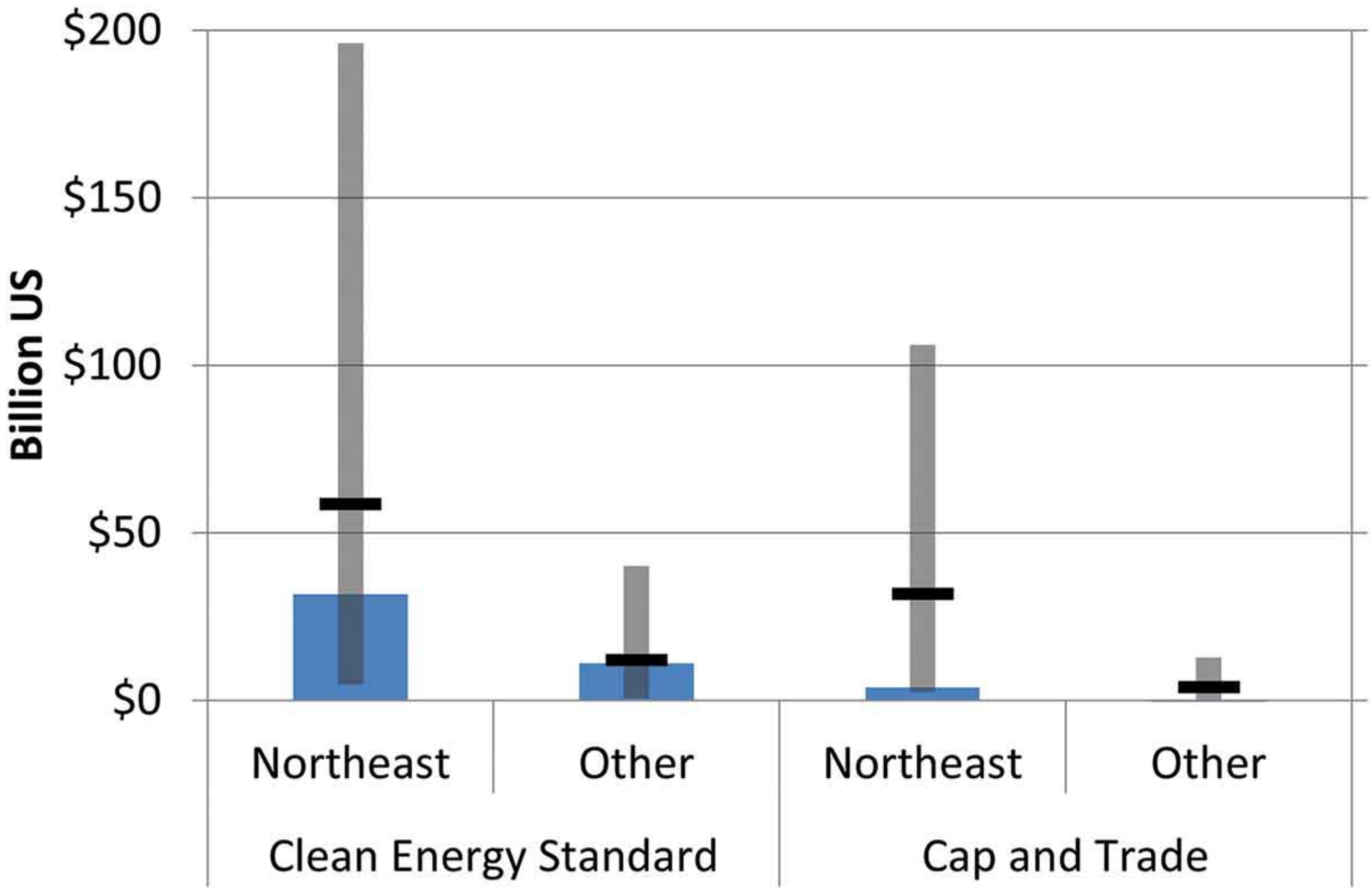
Thompson et al., 2016

Modeled changes in ozone and $PM_{2.5}$ as a result of three policy scenarios



Thompson et al., 2016

Economic costs of the regional carbon policies with human health co-benefits



Thompson et al., 2016

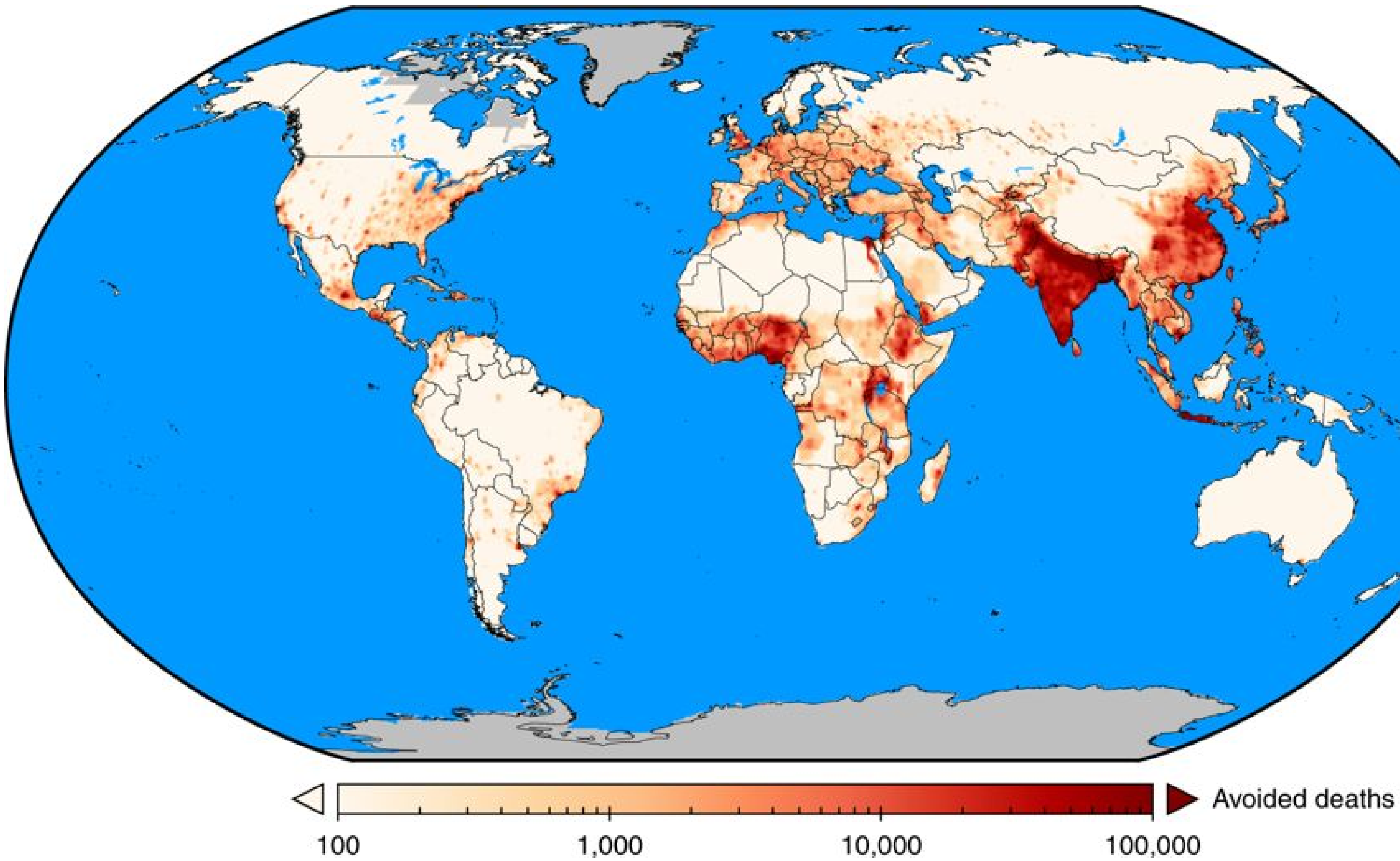
Emerging results

Quantified, localized health benefits of accelerated carbon dioxide emissions reductions, Drew Shindell, G. Faluvegi, K. Seltzer, C. Shindell, Nature Climate Change v8, 291–295 (2018) https://www.nature.com/articles/s41558-018-0108-y

Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges, Toon Vandyck, K. Keramidas, A. Kitous, J.V. Spadaro, R.V. Dingenen, M. Holland, B. Saveyn, Nature Communications, v9, 4939 (2018) https://www.nature.com/articles/s41467-018-06885-9

Co-benefits of global and regional greenhouse gas mitigation for US air quality in 2050, Yuqiang Zhang, J.H. Bowden, Z. Adelman, V. Naik, L.W. Horowitz, S.J. Smith, J.J. West, Atmos. Chem. Phys., 16, 9533–9548, (2016) https://www.atmos-chem-phys.net/16/9533/2016/

Reduction in annual premature death from air pollution under accelerated CO_2 emission reductions



Shindell et al. 2018