CLIMATE CHANGE: THE FISCAL RISKS FACING THE FEDERAL GOVERNMENT

A Preliminary Assessment

November 2016

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OVERVIEW

President Obama has said the Budget is "a roadmap to a future that embodies America's values and aspirations." Building and stewarding such a Budget over the long term requires a clear-eyed view of the challenges that put our aspirations at risk. No challenge poses a greater threat to future generations than climate change.

The Office of Management and Budget (OMB), in collaboration with the Council of Economic Advisers (CEA), recently embarked on an effort to assess what we can quantify today with regard to the fiscal risks posed by climate change for the Federal Government. To date, this effort has yielded two primary conclusions: first, that our current understanding of the fiscal risks of climate change is nascent, limited in scope, and subject to significant uncertainty; and second, that the evidence available thus far indicates the fiscal risks to the Federal Government could be very significant over the course of this century without ambitious action to reduce greenhouse gas emissions (GHGs) and adapt our communities to a changing climate.

This report outlines the contours of fiscal risk through five program-specific assessments: crop insurance, health care, wildfire suppression, hurricane-related disaster relief, and Federal facility flood risk. These programs were assessed because they are directly influenced by climate change, they have strong links to the Federal Budget, and quantitative scientific and economic models regarding the likely magnitude of impacts were available. This report also considers potential impacts to Federal revenues.

The Current Picture of Fiscal Risk

Climate change is already affecting communities across the United States. The most recent National Climate Assessment (NCA) clearly established the sweeping effects of climate change, many of which are already evident in the lives of Americans. Fifteen of the sixteen warmest years on record globally have occurred between 2000 and 2015, and 2015 was the warmest year on record (NOAA, 2016a). The trend is continuing in 2016, with each of the first eight months in 2016 setting a record as the warmest respective month globally in the modern temperature record, dating to 1880. August 2016 marked the 16th consecutive month that the monthly global temperature record was broken (NOAA, 2016b), while September 2016 was surpassed only by record-breaking September 2015 (NOAA, 2016c). In addition, heat waves, wildfires and some extreme weather events such as heavy rainfall, floods, and droughts have become more frequent and/or intense in recent years. While scientists continue to refine projections, it is clear that climate change will continue and its damaging impacts will intensify without considerable action to reduce GHG emissions and to respond with adaptive measures. Even with significant near-term emissions reductions, dealing with near- and mid-term impacts due to past and current emissions will still pose challenges.

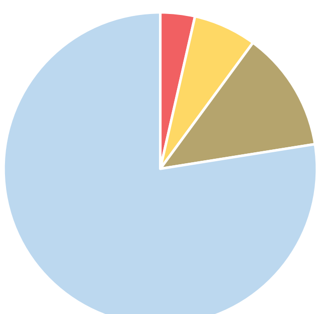
The impacts of climate change will also affect the Federal balance sheet. For example, an increase in the frequency of catastrophic storms will require more disaster relief spending and flood insurance payouts. Rising seas and heavy rainfall events will prompt investments to protect, repair, and relocate Federal facilities. Changing weather patterns and extreme weather events will affect American farmers and the Federal programs that support their risk management. Climate impacts affecting the nation's food, water, air quality, weather, and built and natural environments endanger the health of the American people and weigh on Federal health care programs. An increase in wildland fire frequency and intensity will place further strain on Federal fire suppression resources. Climate change shocks and stressors worldwide pose global security risks and affect resource needs for defense operations and infrastructure. Wide-ranging impacts will impede economic production and diminish Federal revenue.

Although the presence of risk across these and other exposure points is clear, we remain in the early stages of quantifying the total likely burden for American taxpayers. In several critical areas, quantitative projections of specific climate impacts are not yet available. The projections we do have are useful in approximating the order of magnitude of potential impacts of climate change on the Federal Budget, but are still subject to significant limitations and uncertainty. As a result, because of these limitations and because other impacts are not considered in this assessment, the total costs of climate change for the Federal Government may be greatly underestimated, and other costs affecting the American people are not considered here. Despite these limitations, the accumulated evidence suggests the fiscal impacts of further unmitigated climate change could leave a significant imprint on the Federal Budget over the course of this century.

Expenditure Impacts

On the expenditures side of the Federal ledger, each of the five program-specific assessments conducted for this report unambiguously illustrates that climate change will raise expenditures. The table below shows estimates of recurring, annual expenditures due to climate change across four of the five program areas—totaling $34-$112 billion per year by late-century, the equivalent of $9-$28 billion per year in today's economy.

Quantified Increases in Annual Expenditures Due to Climate Change in Modeled Scenarios [a]



Late-century mean

	Mid-Century			Late-Century		
Billions of Real dollars (GDP-Adjusted) [b]	Mean	Lo [c]	Hi [c]	Mean	Lo [c]	Hi [c]
Wildland Fire Suppression	**$1.3** ***($0.6)***	$0.8 *($0.4)*	$2.0 *($0.9)*	**$2.3** ***($0.5)***	$1.2 *($0.2)*	$5.0 *($1.0)*
Crop Insurance [d]	--	--	--	**$4.2** ***($1.0)***	<$0.1 *(<$0.1)*	$9.3 *($2.3)*
Air Quality-Health Care [e]	**$0.6** ***($0.3)***	<0.1 *(<$0.1)*	$1.5 *($0.7)*	**$7.7** ***($1.2)***	$0.6 *($0.1)*	$19.7 *($3.2)*
Coastal Disaster Relief	**$19** ***($8.7)***	$11 *($5.0)*	$31 *($14.2)*	**$50** ***($13.6)***	$32 *($8.7)*	$78 *($21.2)*
Total Annual Expenditures [f]	**$21** ***($9.6)***	$12 *($5.4)*	$35 *($15.8)*	**$64** ***($16.3)***	$34 *($9.0)*	$112 *($27.6)*

[a] The costs in this table are not predictions of the future; they are projections of costs that would be incurred by the Federal Government given a set of assumptions that form the scenarios modeled. See each assessment for more information.
[b] Estimates represent snapshots of average annual expenditures due to climate change in the year(s) modeled for this assessment. Topline estimates are in billions of real dollars. Below the topline estimates *(in parentheses)* are equivalent dollar estimates in today's economy in terms of percent of U.S. GDP. Adjustment factors vary due to differences in years modeled.
[c] The range between Lo and Hi estimates reflects only a portion of the uncertainty associated with cost estimates. See relevant sections of this report for more information.
[d] Crop insurance expenditures were only modeled for the late-century time period (2080).
[e] While the other three assessments compare an unmitigated climate change scenario to a scenario characterized by historical weather patterns, the air quality assessment compares an unmitigated climate change scenario to a *mitigation policy scenario*. As discussed in the assessment, mid-century estimates may capture less than half of the full cost increase due to unmitigated climate change, while late-century estimates likely capture the vast majority of the increase.
[f] Several likely areas of fiscal risk related to climate change have not yet been quantified.

Estimated costs reach into the tens of billions per year within just a few decades (2040-2060) and grow into late century (2060-2100). There is also evidence to suggest the costs incurred over the last decade related to extreme weather and fire have already been exacerbated by climate change.[1] Climate-related costs in these areas also appear likely to vary significantly from year to year, signaling the prospect of budgeting and other planning challenges and greater reliance on emergency supplemental appropriations. Even costs that represent a small portion of the Federal Budget can be severely challenging for individual agencies without responsive adjustments to Congressional appropriations.

In addition to these four program areas, OMB identified significant flood risks to Federal property after reviewing just a sample of the Federal inventory—including $83 billion in Federal assets located in the currently defined 100-year floodplain, $23 billion in assets located in the currently defined 500-year floodplain, and $62 billion in coastal assets that would be threatened by inundation or otherwise severely affected at high tide under a 6 foot sea level rise scenario—but has not estimated the likely costs associated with these liabilities over the coming decades.

Although the combined weight of the quantified mean expenditure estimates in the assessments in this report reaches into the tens of billions to hundreds of billions per year by late-century, this is only a narrow window into the full fiscal risks of climate change. Fiscal impacts in several areas exposed to potentially significant climate risk are not quantified in this report due to data limitations and other challenges. Among these are health care related to vector-borne diseases and other climate change health impacts, national security, the National Flood Insurance Program (NFIP),[2] transportation and water infrastructure, and inland Federal asset flood risk.

Revenue Impacts

Revenue impacts in an unmitigated climate change scenario appear to be significant. Climate change is projected to reduce economic output in the United States and across the globe. Reduced output in the United States means lost revenue for the Federal Government. The Intergovernmental Panel on Climate Change (IPCC)'s most recent midrange projection suggests that warming of four degrees Celsius over preindustrial levels will occur by 2100 if global emissions are allowed to continue unabated. Economists' estimates of the economic damages (in terms of reduced consumption) from this level of warming, projected using integrated assessment models (IAMs) of the climate-economy system, range from 1 to 5 percent of global gross domestic product (GDP) each year by 2100 (Nordhaus, 2013). One of the most frequently cited economic models places the estimate of annual damages from warming of four degrees Celsius at about four percent of global GDP (Nordhaus, 2010, 2013). That same model suggests that levels of warming that might occur by mid-century would result in lower annual damages—for example, an increase in 2 degrees Celsius could cause annual damages equivalent to about 1 percent of global

[1] For example, according to NOAA, nearly 1 foot of sea level rise around New York City over the last century, largely due to climate change, led to greater coastal flooding in New York and the surrounding region from Superstorm Sandy than would have occurred a century ago (Rosenzweig, 2012). Superstorm Sandy prompted more than $49 billion in appropriations to help communities rebuild. Wildland fire suppression costs have also increased as fire seasons have grown longer and the size and severity of wildland fires have increased, in part due to climate change (USDA, 2015).

[2] A 2013 study conducted for the Federal Emergency Management Agency (FEMA) found that by 2100 the number of NFIP policies would increase by 80-100 percent and the average loss cost per policy would increase by 50-90 percent largely due to climate change (AECOM, 2013). However, legislative changes to the program since this study was conducted may reduce the ultimate fiscal impact of these effects over time.

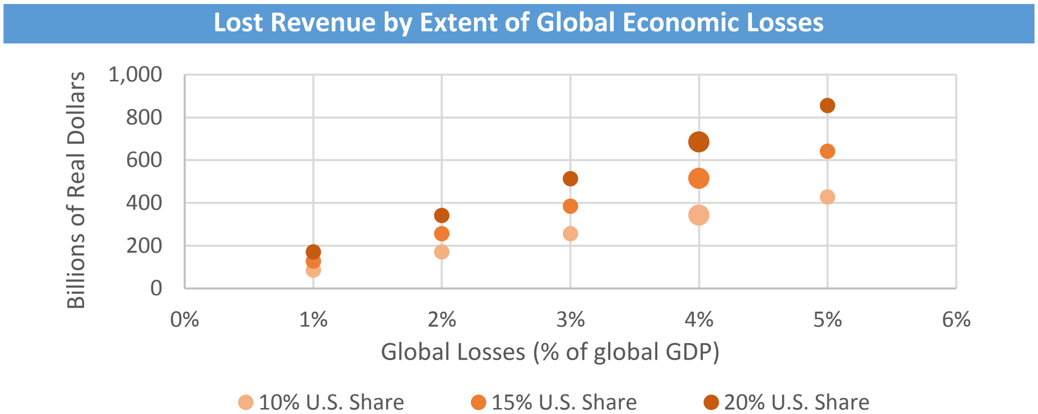
GDP—though there are many fewer estimates of climate damages for likely mid-century temperature increases (Nordhaus 2013).

A number of factors affect the magnitude and the known uncertainties of such estimates. For example, the estimates do not account for important factors that remain difficult to quantify in physical terms and are inherently difficult to monetize, such as biodiversity loss, ocean acidification, changes in weather related to changes in ocean circulation, increased severity of certain extreme events, tipping points associated with non-linear changes in the climate, and heightened political instability as a result of climate impacts. In addition, current models factor in economic damages over time but treat the *rate* of economic growth as if it is unaffected by climate change. A current debate in economics examines whether higher temperatures will decrease the rate of GDP growth in some countries (Dell et al. 2012, Burke and Emerick 2016, Heal and Park 2016). If that is the case, the estimates from IAMs discussed above could significantly understate the potential impact of climate change on global GDP over the long run. Additional research suggesting that economic productivity is nonlinear relative to temperature changes—that there are significant negative temperature threshold effects on productivity in affected sectors—also indicates that the IAM estimates of economic damages from climate change may be conservative (Burke et al. 2015).

The uncertainty of economic damage projections is compounded when attempting to estimate the associated potential for lost U.S. Federal revenue. The exercise relies on difficult assumptions about the U.S. share of global economic losses, the impact of economic losses on U.S. GDP, and Federal revenue as a share of U.S. GDP. For example, while economic losses are commonly expressed as a percent of global output, some portion of those losses occur in the form of non-market losses (e.g., premature mortality or biodiversity loss) that may not directly translate into lost GDP—or Federal revenue.

One simple approach to the first assumption—the U.S. share of global losses from climate change—is to assume that this share would be approximately equivalent to the U.S. share of global GDP (~22 percent of nominal global GDP in 2015). While the U.S. economy is growing faster than most other advanced economies, the U.S. share of global GDP is declining gradually over time, a trend expected to continue (IMF, 2016). In addition, although the United States has significant exposure to the physical impacts of climate change (Melillo et al., 2014), relative to many other strongly affected countries, high income and well-developed institutions (such as insurance markets, as well as public and private resources for emergency preparedness and disaster response) will help the United States to manage those impacts (Kellenberg and Mobarak, 2007). Both of these factors suggest that the U.S. share of climate change damages in mid- and late-century (expressed in terms of GDP) is likely to be lower than the current U.S. share of global GDP.

For illustrative purposes, the figure below shows outcomes for lost Federal revenue in late-century under a range of assumptions about global economic losses and the U.S. share of global losses, holding Federal revenue constant as a share of U.S. GDP and assuming all economic losses translate into lost GDP. At the commonly cited four percent global economic loss estimate at four degrees Celsius warming, lost Federal revenue ranges from roughly $340 to $690 billion per year depending on the portion of global losses that occur in the United States—equivalent to approximately $60-$110 billion per year in today's economy. These estimates are the product of a simple extrapolation from leading economic loss projections and should be interpreted as indicative of the order of magnitude of potential lost revenue, rather than precise estimates.



Global Losses

U.S. Share	1%	2%	3%	**4%**	5%
10%	$86 *($14)*	$171 *($28)*	$257 *($42)*	**$343 *($56)***	$428 *($69)*
15%	$128 *($21)*	$257 *($42)*	$385 *($62)*	**$514 *($83)***	$642 *($104)*
20%	$171 *($28)*	$343 *($56)*	$514 *($83)*	**$685 *($111)***	$856 *($139)*

Estimates are in billions of real dollars and *(in parentheses)* the equivalent dollar estimates in today's economy in terms of percent of U.S. GDP.

The Fiscal Case for Climate Action

Principled fiscal responsibility clearly calls for smart investments today that can avoid significant costs in the future. The evidence underscores the opportunity to significantly reduce costs by mitigating global GHG emissions and adapting to climate change. For example, keeping global temperature rise well below 2 degrees Celsius relative to pre-industrial levels, as reflected in the Paris Agreement, is likely to significantly reduce annual economic losses and U.S. Federal revenue losses from climate change by mid- and late-century, relative to more significant temperature increases. Similarly, as detailed in this report, mitigation would reduce by half the increase in crop insurance program costs due to climate change. Air quality modeling also demonstrates that mitigation reduces the vast majority of the increase in air quality-related illnesses and associated Federal health expenditures. In an independent analysis, EPA also found that adaptation can significantly reduce climate change impacts—for example, avoiding trillions of dollars of coastal property damages over the course of this century (EPA, 2015).

Despite the conventional wisdom that reducing emissions will constrain economic growth, recent trends and analysis demonstrate that the United States can achieve rapid emissions reductions while maintaining robust economic growth. In the United States, GDP has grown faster than most major advanced economies since 2010 (11 percent) while U.S. energy-related CO_2 emissions have fallen by almost 6 percent, leading to the first sustained period on record where GDP grew and emissions fell. While the correlation between economic growth and emissions has been weakening for years, recent evidence suggests that a sustained decoupling is possible. And delaying climate action only increases the costs associated with emissions-reducing measures because each year of delay means more damages from climate change, and also more stringent mitigation measures to take action in a shorter timeframe. If the world tries to hit the Paris Agreement goal of less than 2-degree Celsius increase, but waits a decade to do so, the cost of limiting the temperature change could increase by roughly 40 percent (CEA, 2014).

Higher emissions pathways would also disproportionately affect the health, economic well-being, and quality of life of vulnerable populations—children, older adults, and low-income communities. For example, existing health disparities and other inequities increase vulnerability to climate health impacts like heat waves, degraded air quality, and extreme weather. Low-income families are the most vulnerable to disruptive events that cause household breadwinners to miss work. And low-income communities are least equipped to manage impacts like flooding.

Well-designed public policies can maximize the net benefits from transitioning to a low-GHG pathway and create and preserve economic opportunities for all Americans.

Understanding the Risk Assessments in this Report

OMB selected five key areas that are clearly vulnerable to climate impacts, have a strong link to the Federal Budget, and for which the scientific and economic literature has produced quantitative modeling of impacts: crop insurance, health care, wildfire suppression, hurricane-related disaster relief, and Federal facility flood risk. In each of these areas, OMB and CEA worked with experts across the Federal Government to leverage the best available quantitative modeling to estimate key effects of climate change and the associated fiscal burden.

Each risk assessment draws either on findings from the best available scientific and economic literature or new analysis that uses existing models and datasets. While the assessments generally compare an unmitigated climate change scenario to a projected reference scenario without further climate change in mid- and late-century, specific climate scenarios, global change models (GCMs), and time periods vary across assessments due to differences in available studies, datasets, and models. As a result, findings are comparable across risk assessments only at the order-of-magnitude scale.

In addition, due to limitations in available models and the uncertainty inherent in projecting several decades into the future, the results of these assessments should be interpreted as indicative of the order of magnitude of potential impacts of climate change on Federal spending in the studied scenarios. Actual impacts will vary depending on a wide range of factors such as population and income growth, policy changes, technological development, changing behavior—including adaptive responses—and the magnitude and pace of further climate change.

Generally, the assessments do not attempt to fully represent the potential for adaptation or policy changes to attenuate fiscal impacts. For example, the Federal facilities assessment does not examine the potential for investments in protective coastal infrastructure to guard against the risk of inundation from sea level rise. The crop insurance assessment assumes farmers will shift crop rotations to maintain profitability in a changing climate, but does not examine the potential for technological advancements to bolster crop resilience to impacts like drought. Adaptation mechanisms like these, while costly, would also reduce the climate impacts that will actually be realized. As such, the results presented in this report are not predictions of the future; instead, they illustrate the magnitude of costs that would be incurred given the set of assumptions that form the scenarios modeled. Each assessment discusses the kinds of adaptation that are represented in the modeling and those that are not.[3]

The assessments are also not comprehensive. Due to modeling limitations, several are missing key risk drivers. For example, the health assessment captures only Federal spending for non-fatal health

[3] Similarly, the illustrative estimates of revenue impacts discussed earlier in the overview are drawn from IAMs that incorporate adaptation to varying degrees.

outcomes related to air quality—likely a slim component of the full fiscal risk related to health care and public health. Also not captured are several likely areas of fiscal risk such as national defense, Federal assistance for transportation infrastructure maintenance, and disaster aid for climate-related events other than hurricanes that will add to the total fiscal burden of climate change. In short, the actual fiscal risks to the Federal Government are likely to be much greater than the sum of what is quantified in this preliminary assessment.

Finally, fiscal impact estimates in mid- and late-century should be viewed in light of a growing economy. The Federal Government's ability to manage the fiscal burden of a major storm or severe drought, for example, will likely be greater decades from now than today, given that real GDP is projected to double by 2050 and quadruple by 2080. The estimates in the risk assessments that follow are presented both in real (current) dollars and GDP-adjusted dollars. The second approach conveys the estimates at their equivalent scale in today's economy in terms of the percent of U.S. GDP that they represent. The GDP adjustment simply rescales estimated costs from the modeled year to the present based on projected real GDP growth in the intervening period, such that real dollar estimates and GDP-adjusted dollar estimates reflect the same percentage of real GDP in the modeled year and present year, respectively.

Charting a Path to a Clearer Picture of Fiscal Risks

The climate science literature continues to advance at a rapid pace, expanding our understanding of the likely physical and ecological effects of climate change. Economists have also made strides in assessing the macroeconomic impacts of climate change. More recently, the climate science literature has turned toward assessing impacts to particular sectors and regions, and economists are beginning to follow suit. This type of research is critical for informing decision-making by communities, businesses, and policymakers at all levels of government.

But work is needed to provide more specific and actionable information. Studies often overlook key dimensions of climate change impacts that would speak to the specific risks and tradeoffs facing decision-makers, such as those in the Federal Government, as they evaluate policy options and long-term investments and divestments. For example, while premature mortality will likely account for the overwhelming majority of economic losses from climate impacts related to health, the non-fatal and chronic health effects will impose the greatest burden for public and private health insurers. Similarly, while the impact of climate change on average agricultural yields has broad implications for global food security and the livelihoods of agricultural producers, changes in year-to-year variability in yield due to escalating risk are also an important dimension of both food security and producer profitability, and speak to fiscal impact on the Federal safety net.

In addition to capturing these dimensions of climate impacts in well-studied areas, considerable work remains in both climate science and climate economics to assess less well-studied impacts. The U.S. Global Change Research Program (USGCRP) Health and Climate Assessment (2016), for example, strengthened our understanding of health-related risks posed by climate change and also highlighted the lack of quantitative assessment in key areas like vector-borne disease and heat-related, non-fatal illness.

As the climate science and economics literatures continue to advance, further collaboration between OMB, CEA, USGCRP, and key Federal agencies will be necessary to ensure that our understanding of climate change risks facing the Federal Budget deepens, broadens, and sharpens. A key component of this effort is the NCA. In addition to the quadrennial NCA mandated under the 1990 Global Change

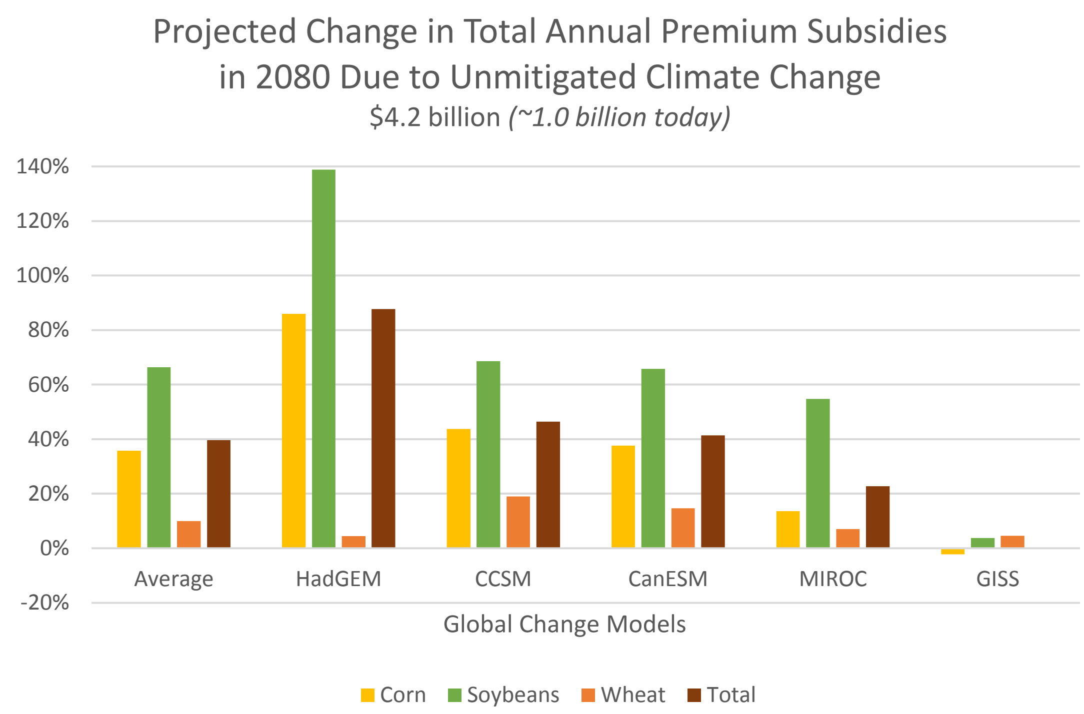
Research Act, USGCRP is implementing a sustained NCA process that enables new information and insights to be synthesized as they emerge.

The Sustained Assessment will enable new information and insights to be synthesized on a continuous basis, drawing on input from groups that use NCA information in assessments and planning. In this way, the Sustained Assessment will allow future fiscal and economic risk assessments like this one to build on an ever-growing body of relevant and reliable scientific information. The Sustained Assessment will be guided in part by a Federal Advisory Committee (FAC) comprised of non-Federal experts.

Finally, more work is needed to identify and quantify the impact of factors that can mitigate or compound climate change fiscal risk. With a few exceptions, this report mainly focuses on increases in expected multi-year average costs due to unmitigated climate change, holding demographic, economic, and policy factors constant or in line with current trajectories. Yet, investments in adaptation can significantly reduce the costs that will be realized in practice. Conversely, increased development in coastal communities could compound the economic and fiscal impact of hurricanes, for example, just as growth of the wildland-urban interface could further magnify the costs of fire suppression. Understanding these factors and how they interact with the impacts of climate change is important for identifying the conditions under which climate impacts could pose potentially catastrophic risks, as well as for taking steps to mitigate risk.

RISK ASSESSMENTS

1. Crop Insurance



The Federal fiscal burden of providing subsidized crop insurance to American farmers could increase by billions of dollars each year by late-century due to the effects of climate change. The figure depicts estimated percentage increases in total premium subsidies in 2080 in an unmitigated climate change scenario compared to a future characterized by historical weather patterns. Estimates are graphed for three crops under five global change models.[4]

Climate Change and Crop Insurance

Climate change is already affecting agricultural production and negative impacts are, on average, expected to grow more severe over the course of this century. Some effects may be positive—higher levels of carbon dioxide in the atmosphere tend to increase plant growth (so-called "CO_2 fertilization") and water-use efficiency. However, negative effects from increased extreme heat and drought, more intense precipitation and soil erosion, growing stress from disease and pests, shifting soil moisture and water availability for irrigation, and higher concentrations of ozone are generally expected to outweigh

[4] The Hadley Centre Global Environment Model (HadGEM), Community Climate System Model (CCSM), Canadian Earth System Model (CanESM2), Model for Interdisciplinary Research on Climate (MIROC), and Goddard Institute for Space Studies model (GISS) are global change models from the framework of models used by the IPCC to assess future changes in climate conditions in different emissions scenarios.

positive effects, reducing yields and increasing uncertainty for producers (Melillo et al., 2014; Marshall et al., 2015).

The Federal Government provides subsidized crop insurance to American producers to cover yield and revenue losses due to natural causes (weather, fire, disease, and wildlife) and market price changes. In 2015, more than 1.2 million individual policies were issued. These policies covered more than 120 crops across nearly 300 million acres, for a total Federal liability of more than $102 billion. Three crops—corn, soybeans, and wheat—account for two-thirds of insured acres and roughly three-quarters of total premium costs. By law, crop insurance premiums must be "actuarially fair"—calibrated to match the value of total expected losses on insured acres. However, the Federal Government currently pays for almost two-thirds of crop insurance premiums on average, at a cost of more than $6 billion in 2015.

Climate-related production shocks like drought are the dominant driver of crop insurance program indemnities (Wallander et al. 2013). Climate change could affect the Federal Government's crop insurance subsidy costs in a number of ways—most clearly by increasing the riskiness of crop production due to the impacts of shifting weather patterns and climate disruptions on yield, or the impacts of climate-related production challenges at home and abroad on crop price volatility. However, in some instances crop vulnerability could also decline due to the physiological response of crops to higher CO_2 levels. Mean production levels could also increase or decrease, affecting the total liabilities covered by the crop insurance program.

Risk Assessment

Modeling conducted by the USDA Economic Research Service (ERS) for this assessment indicates that unmitigated climate change[5] could increase annual crop insurance premium subsidy costs for corn, soybeans, and wheat by 40 percent by 2080 compared to a projected reference scenario characterized by historical weather patterns. This estimate is the average premium subsidy increase across the five GCMs used by USDA for the assessment. It assumes the average portion of total premiums paid by the government does not change over time, which implies that current law and current average coverage rates are both held constant. In a mitigation scenario that assumes some GHG reductions, the average projected cost increase for the crop insurance program across the five GCMs is about 23 percent.

The absolute fiscal impact of such an increase will depend largely on the total liabilities insured by the program in 2080, a product of future trends in agricultural productivity and global crop demand. In the 2080 "no climate change" reference scenario, the gross revenue for corn, soybeans, and wheat is $223 billion, compared to $122 billion in 2012. This modeling baseline is consistent with an annual growth rate of approximately 1 percent for both crop yields and demand.[6] In the 2080 reference scenario, the total premium subsidy for these crops is $10.6 billion, which, relative to the $5.4 billion actual subsidy in 2012, mirrors the increase in total revenue.

Given this baseline, the fiscal impact of modeled increases in premium subsidies would be $4.2 billion each year in the unmitigated climate change scenario, the equivalent of approximately $1.0 billion each year in today's economy. Three of the five GCMs produce estimated increases between $2.4 billion and

[5] The unmitigated climate change scenario modeled is the IPCC's Representative Concentration Pathway (RCP) 8.5, in which emissions continue to rise throughout the century, causing radiative forcing to increase by 8.5 W/m^2 relative to preindustrial levels. The mitigation scenario modeled is RCP 4.5, in which emissions peak around 2040 and then decline.

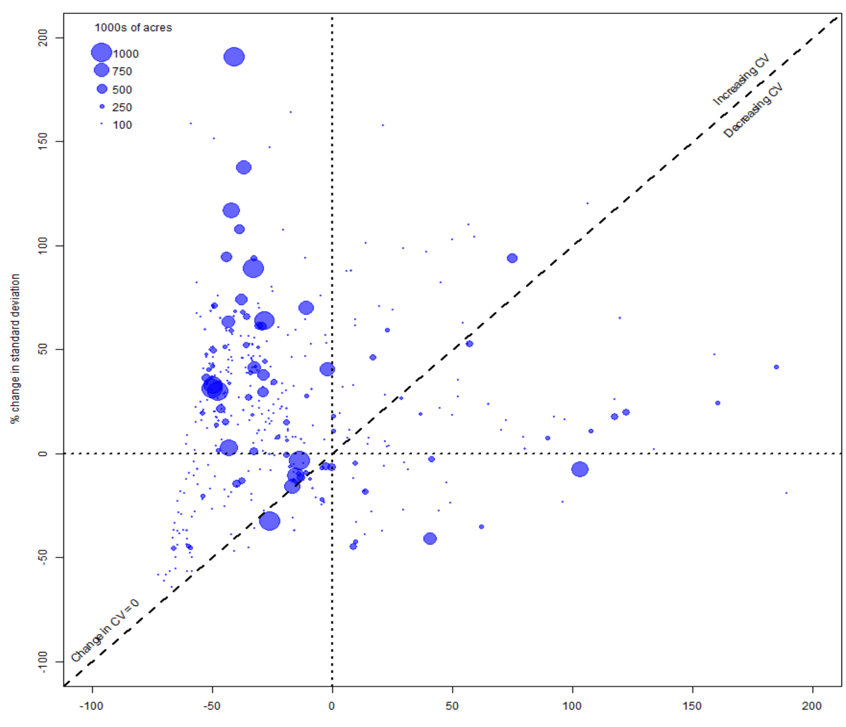
[6] Note this baseline is a projection for modeling purposes only and is not an official forecast.

$4.9 billion. HadGEM and GISS results provide upper and lower bounds at $9.3 billion and $17 million, respectively, the equivalent of approximately $2.3 billion and $4 million, respectively, in today's economy.

The GISS model yields weather patterns with significantly smaller increases in temperature and significantly more precipitation than HadGEM given the same emissions pathway. The GISS model also provides weather data at a coarser spatial resolution, but the possible effect of differences in resolution on modeled yield variability, if any, still needs to be explored. Excluding GISS results would push the total estimated increase in premium subsidies from $4.2 billion to $5.2 billion. In addition, if global crop demand growth is appreciably higher than assumed, the upper bound could reach into the tens of billions each year.

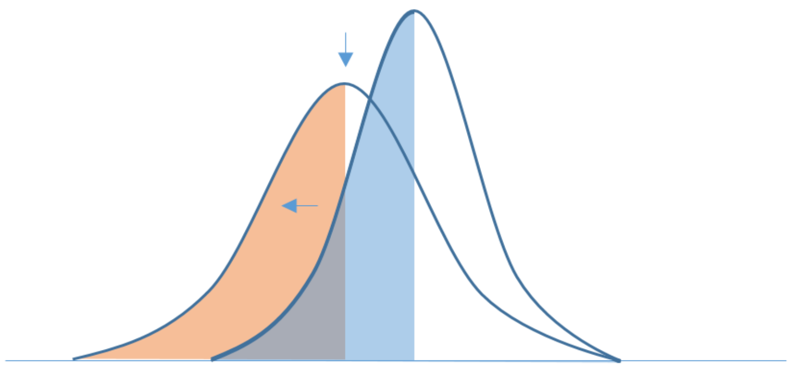
The increase in subsidy costs across the GCMs is driven by an increase in total premiums predominantly due to both higher yield risk in most regions and higher price risk faced by all producers due to climate change, as well as an increase of about 5 percent in the value of production compared to the reference scenario. However, a few additional factors also affect costs. First, to maintain expected profits despite shifting climate conditions, the land allocation model predicts that risk-neutral producers will adapt in some cases by expanding acreage into higher risk areas that produce a higher expected return under climate change but also have higher premium rates per dollar of revenue insured. Second, as explored in greater detail in Marshall et al. (2015), climate change leads to less irrigated area in most regions. This result tends to increase premium rates as dryland production is generally costlier to insure per unit of production (because irrigation is itself a form of insurance). Finally, acreage shifting between crops due to climate change in some areas may have the effect of reducing producers' crop diversification, thereby increasing the risk of total revenue losses.

Changes in Mean and Standard Deviation of Calibrated Soybean Yield by REAP Region for RCP 8.5



The dot plot above shows the percent change in mean yield and percent change in the standard deviation of U.S. soybean yield in the unmitigated climate change scenario compared to the reference scenario. Each dot represents a modeling region, and the size of the dot corresponds to the number of acres in production in that region. Dots above the 45 degree line have an increasing coefficient of variation (CV), a measure of variability per unit of crop production insured (standard deviation divided by mean). CV is highly correlated with premium rates. The plot clearly shows that far more of the regions are above the 45 degree line than below, indicating that yield variability (as indicated by CV) increases in most cases in the unmitigated climate change scenario.

Illustrative Shift in Yield Distribution



For this study, the simulated changes in means and standard deviations are calibrated to historical yields to preserve risk that is unrelated to weather and climate. Note that this calibration procedure involves a number of important and untested assumptions about future crop yields and, in particular, the nature of idiosyncratic (non-weather-related) yield risk. The calibration procedure is discussed in the Technical Supplement accompanying this report.

Since the crop insurance program insures against expected yield (or revenue), shifts in mean yields can be as important in changing yield risk as shifts in yield variability. Most regions see both a reduction in mean soybean yield and an increase in the variability of yield, which leads to increases in production risk (shown in the illustration above). In some regions, yield variability actually declines, but proportionately less so than mean yield, resulting in a net increase in risk. Some regions also see a reduction in risk (below the 45 degree line), including some regions where the standard deviation of yield increases but average yields increase proportionately more, which leads to a decline in risk.

This assessment builds on prior ERS modeling of climate change impacts on crop yield, cost, and production nationwide (Marshall et al., 2015) by estimating not only mean yields and prices but also yield risk and price risk when producers optimize planting decisions based on expectations but are exposed to weather variability—both as observed historically and as affected by various climate change scenarios. ERS then estimates total premiums and premium subsidies for revenue protection policies—the most popular insurance product for producers of major field crops.

For more information about the biophysical and economic crop production and acreage allocation models used for this assessment, see Marshall et al. (2015). For more information about the modifications made to these models for this assessment and the premium estimation methods, see the Technical Supplement accompanying this report.

Key Limitations and Uncertainties

The cost to the Federal Government of the crop insurance program over the course of this century will depend upon many factors, including climate change. Market conditions and technology will determine the total value of production. For example, a combination of strong demand growth and strong crop yield growth that continues historical trends would result in higher gross revenues, which in turn imply higher liabilities and therefore higher premiums and associated subsidies. The design of the insurance program and farmer participation decisions will also determine program costs. This assessment isolates the impact of climate change by assuming baseline levels of demand and supply growth, and holding program design and farmer participation decisions constant.

Estimates of the increase in crop insurance premiums due to climate change vary considerably across GCMs, reflecting sensitivity to variable climate change projections (e.g., changes in regional temperatures and precipitation patterns). In addition, the impacts of climate change on crop yield risk vary significantly by region; yield risk even decreases in some regions in the climate change scenarios. However, there is strong agreement across the GCMs that climate change will increase both price risk and yield risk in aggregate at the national level. The GCMs also demonstrate a high degree of consistency with respect to the direction of change in yield risk within regions. In particular, yield risk is increasing in much of the Corn Belt across GCMs, and decreasing in a portion of the Northern Plains. ERS also found reasonable consistency between the biophysical crop model and two alternative econometric crop yield models estimated on the same baseline weather data. Finally, while there is a fairly wide spread in fiscal impact estimates across GCMs simulations, four of the five models produce climate outcomes under which total premiums increase on the order of billions of dollars each year.

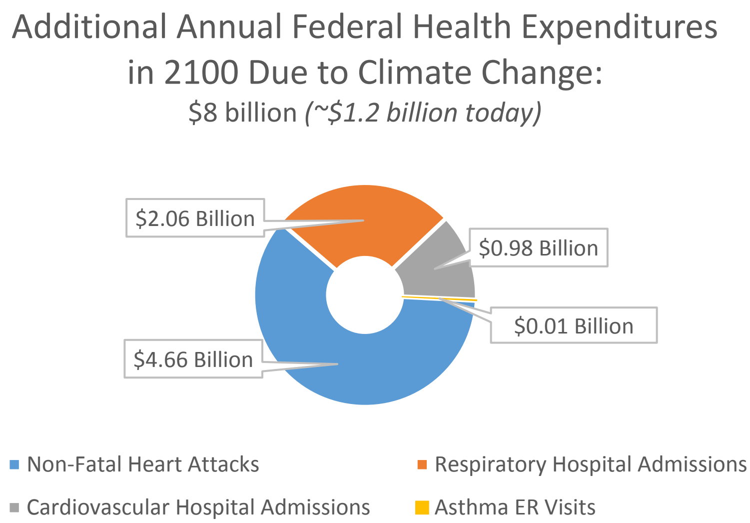
In addition to uncertainty stemming from the GCMs, the biophysical and economic crop production and acreage allocation models have several limitations that could cause estimates to be too high or too low. First, the models may underrepresent the full impact of climate change. The models capture the direct effects of changing temperature and precipitation patterns and CO_2 fertilization, but the crop production results are calibrated to hold constant the effects of other climate-related impacts on crops such as those due to pests, disease, exacerbated ozone concentrations, and the frequency of certain kinds of storms such as tornadoes, hurricanes, and flooding. The timeframe used to simulate weather conditions (40 years) was selected to capture the 30-year return frequency of major droughts, but may not provide a good measure of extreme risk—such as changes in the probability of a 1-in-100 year or 1-in-1,000 year mega-drought. The models also do not place constraints on irrigation water supply, even though ERS has found that irrigation water supply will decline significantly in some regions due to climate change (Marshall et al., 2015); irrigated acres currently represent roughly 15 percent of total insured acres for principal field crops.

Second, the models do not capture changes in global crop prices due to climate-related events outside of the United States. For example, a decline in wheat production abroad due to rising temperatures could put upward pressure on global wheat prices, increasing the value of the insured wheat crop and associated crop insurance premiums in the United States.

Third, the models likely underrepresent the potential for adaptation by producers and the agricultural sector in general. For example, although crop productivity is assumed to increase year over year in both the reference and climate change scenarios due to general technological advancement, the possibility for technological improvements that may affect resilience to climate change is not represented. Some adaptive responses could reduce yield risk. For example, a considerable body of current research is focused on improving crop drought tolerance. However, as seen in the modeling results, other adaptive responses could actually increase yield risk in exchange for higher expected (mean) returns. The models assume that producers are risk-neutral and make decisions only to maximize expected profits.

Finally, the models do not consider changes in crop insurance subscription or coverage levels. Preliminary analysis suggests two potentially offsetting effects. On the one hand, an increase in risk may prompt farmers with crops that are not currently insured (roughly 15 percent of nationwide planted acreage of principal field crops in 2015) to purchase some level of coverage. This effect would increase total premiums and premium subsidies. On the other hand, increases in risk raise the actuarially fair price of insurance, which may induce farmers to purchase lower levels of coverage to reduce their total premium expenditure. This effect would reduce total premiums and premium subsidies.

2. AIR QUALITY AND HEALTH CARE



By 2100, tens of thousands to hundreds of thousands of additional Americans could suffer from illnesses due to the effects of climate change on air quality, requiring billions of dollars in additional Federal health care spending each year. This is just a small portion of the total fiscal risk posed by the health impacts of climate change.

Climate Change and Health Care

The USGCRP's Climate and Health Assessment further established that climate change is a significant threat to the health of the American people. Climate change endangers our health by affecting the nation's food, water, air quality, weather, and built and natural environments.

Increased extreme temperatures are projected to increase heat-related death and illness, which is generally expected to outweigh any benefits from a reduction in extreme cold and cold-related death and illness (USGCRP, 2016). Changing weather patterns, including warmer temperatures, and increased incidence of wildfire are also projected to increase exposure to two local and regional air pollutants with significant health impacts—fine particulate matter ($PM_{2.5}$) and ozone—across large swaths of the country (Garcia-Menendez et al., 2015). These pollutants are associated with premature mortality as well as increased incidence of non-fatal respiratory and cardiovascular disease. Climate change is also expected to alter the risk of vector-borne disease by changing the distribution of existing disease vectors and causing new vector-borne pathogens to emerge. Risk of food-borne illness may grow with increased exposure of food to certain pathogens and toxins. Risk of exposure to water-borne pathogens and algal toxins may also increase as water temperatures rise (USGCRP, 2016).

All of these pathways can cause an increase in both premature death (mortality) as well as non-fatal health problems (morbidity). Higher morbidity rates in particular cause health care utilization to grow over the long-term, increasing total health care expenditures by private insurers as well as public programs like Medicare and Medicaid.

In order to identify the full breadth of Federal fiscal risk related to climate change and health, more work is needed by climate scientists, epidemiologists, and others to quantify potential morbidity outcomes from the broad set of climate change health effects pathways. Despite a rapidly growing body of scientific literature, quantitative projections are not available even for several health effects for which the link to climate change is clear—for example, Lyme disease or West Nile virus (USGCRP, 2016).

In this assessment, OMB and CEA examined just one health effects pathway where quantitative projections are available: the impact of climate change on outdoor air quality and associated health effects. Given the breadth of health effects pathways, including several that could prompt appreciable increases in health care utilization, the results of this assessment reflect a small portion of the total health-related fiscal risks of climate change.

Risk Assessment

By late-century, Federal health care spending could increase by billions of dollars each year, as tens of thousands to hundreds of thousands of Americans suffer from illnesses due to the effects of climate change on air quality—including non-fatal heart attacks, emergency room visits for asthma attacks, and hospital admissions for respiratory and cardiovascular conditions. The mean estimate of the analysis conducted for this assessment is an increase of roughly $8 billion in Federal spending, with a range of roughly $1 billion to $20 billion in 2015 dollars,[7] the equivalent of approximately $1.2 billion per year ($100 million - $3.2 billion) in today's economy.

Due to available modeling, this estimate reflects increased costs in an unmitigated climate change scenario compared to a *mitigation scenario*, rather than current weather conditions as in the other assessments in this report. The full impact by late-century compared to current weather conditions is likely to be larger, although air quality modeling indicates that GHG mitigation results avoids the vast majority of increases in average population-weighted annual $PM_{2.5}$ and ozone concentrations that would otherwise occur by late-century (Garcia-Menendez et al., 2015).

However, the mid-century estimates likely understate the full fiscal burden compared to current conditions by a wide margin, as mitigation avoids roughly less than half of the increases in population-weighted annual $PM_{2.5}$ and ozone concentrations that would occur by 2050 due to unmitigated climate change. The estimated mean effect in mid-century is nearly $600 million each year, with a range of $21 million to $1.5 billion, they equivalent of approximately $100 million per year ($10-$700 million) in today's economy. The full effect relative to current weather conditions could be twice as large.

This assessment builds on Garcia-Menendez et al. (2015), who evaluated the impact of climate change on U.S. air quality and health in mid- and late-century using the same model that the U.S. Environmental Protection Agency (EPA) uses to evaluate the health effects of air quality regulations. Garcia-Menendez et al. (2015) quantified the extent to which climate change would significantly affect ozone and $PM_{2.5}$ concentrations in the United States, due to a number of feedbacks between climate and air pollution. They also examined the potential rise in health problems associated with these local and regional pollution increases related to climate change. Although the final published study was limited to

[7] This range reflects differences in the way $PM_{2.5}$- and ozone-related morbidity results were reported for this assessment. The range reflects 95 percent of the distribution of results for $PM_{2.5}$, and 90 percent of the distribution of results for ozone.

mortality results due to the fact that premature mortality accounts for the overwhelming majority of total economic damages from air pollution, the study authors also estimated impacts of climate-related air pollution increases on morbidity endpoints (non-fatal heart attacks, respiratory hospital admissions, cardiovascular hospital admissions, and emergency room visits for asthma) and provided these new results for this assessment. Estimated morbidity results were then converted to expected changes in Federal health care costs. For more information on the approach, see Garcia-Menendez et al. (2015) and the Technical Supplement accompanying this report.

Key Limitations and Uncertainties

Health outcomes attributed to climate change are sensitive to assumptions and limitations in underlying global change and atmospheric chemistry models, and the concentration response functions that translate pollution exposure levels to expected health outcomes (USGCRP, 2016). For example, although Garcia-Menendez et al. results show significant increases in $PM_{2.5}$ concentrations, the strong influence of changes in precipitation and atmospheric mixing on $PM_{2.5}$ levels—combined with variability in projected changes to those variables—has prevented consensus in the scientific literature with regard to the net effect of meteorological changes on $PM_{2.5}$ levels in the United States. In addition, the simulation used here does not factor in the possibility of future changes in air quality regulations,[8] population distribution, healthcare or other technology, or human behavior that may impact the extent and pattern of air pollution exposure across the United States and associated morbidity outcomes. For example, Americans may migrate to areas of the country with cleaner air, install air conditioning in greater numbers, or make greater efforts to stay indoors when air quality is poor.

The model also does not capture the effects of climate-related increases in severe wildfire on $PM_{2.5}$ and ozone formation, morbidity outcomes like acute bronchitis that do not result in hospitalization but may still lead to significant health care costs, the effects of climate-related changes in airborne allergens on allergic disease, or changes in health care costs associated with premature mortality. Changes in wildfire in the western United States in particular could have a significant impact on $PM_{2.5}$ concentrations (Spracklen et al., 2009). Also not captured are the possible effects of warmer temperatures on human physiological responses to air pollution—for example, increasing the risk of mortality from exposure to a given level of ozone on warmer days. These assumptions and limitations are generally consistent with the existing peer-reviewed climate and health assessment literature.

In addition, estimates of fiscal burden attributed to modeled health outcomes may be sensitive to several economic and policy assumptions such as Medicare enrollment growth rates and health care cost growth. However, even significant changes in these assumptions (e.g., reducing Medicare enrollment growth to match total population growth, or toggling excess cost growth between -1 percent and 2 percent) do not on their own alter the order of magnitude of results. This assessment also does not consider the effect of modeled health outcomes on Federal subsidies to private insurance coverage, or changes to Federal health care policy or economic trends that may impact the Federal share of health care costs—except to the extent that these changes or trends are represented in the health care cost and enrollment growth assumptions used.

[8] Although the Garcia-Menendez et al. estimates used in this assessment draw on a mitigation scenario, the study was designed to isolate the "climate penalty" on air quality and did not include the benefits associated with simultaneous reductions in co-emitted pollutants in the mitigation scenario.

3. WILDFIRE SUPPRESSION

Additional Annual Federal Wildland Fire Suppression Expenditures in 2090 Due to Climate Change:

$2.3 billion *($500 million today)*

3 MILLION ACRES BURNED: HISTORICAL ANNUAL AVERAGE[11]	6 MILLION ACRES BURNED: CLIMATE CHANGE SCENARIO MID-CENTURY ANNUAL AVERAGE	9 MILLION ACRES BURNED: CLIMATE CHANGE SCENARIO LATE-CENTURY ANNUAL AVERAGE

While many factors will affect wildland fire and Federal suppression expenditures over the course of this century, the risk posed by climate change for suppression budgets at Federal land management agencies is immense. All else equal, climate change could significantly increase area burned each year in the U.S., causing suppression expenditures to double within just a few decades and nearly triple by late-century.

Climate Change and Wildland Fire

In 2015, the USDA Forest Service published a report acknowledging the role of climate change in the rising cost of wildfire operations (USDA Forest Service, 2015). Climate change has led to fire seasons that are now on average 78 days longer than they were a half century ago. The six worst fire seasons since 1960 have all occurred since 2000. The number of acres burned each year has doubled in the past few decades due to the combined effects of climatic factors and a legacy of aggressive fire suppression—and may double again in the next few decades. Higher temperatures and variable and unpredictable precipitation are magnifying the risk and driving up the cost of suppressing wildfire, compounding the effects of increasing development in the wildland-urban interface (WUI). The Forest Service noted that, as the impacts of climate change intensify, wildland fire management efforts will be further complicated by limited water availability for suppression, more fire-prone vegetative composition, and further lengthening of the fire season—reaching up to 300 days in many areas of the country (USDA Forest Service, 2015). While Federal fire suppression expenditures represent a small portion of the total Federal Budget, they comprise a large and growing portion of the budgets of Federal land management agencies.

[9] Acres burned on Federal land in the continental United States (excluding Alaska).

Risk Assessment

Modeling by the USDA Forest Service for this assessment indicates that the impact of climate change alone on fire suppression expenditures[10] in the contiguous United States could be in the billions each year within just a few decades. Median estimates are $1.3 billion by mid-century and $2.3 billion by late-century, with ranges of $800 million to $2.0 billion per year and $1.2-$3.5 billion per year, respectively. In comparison, historical average total expenditures (1995-2013) were just over $1.3 billion. The estimated cost increases are the equivalent in today's economy of approximately $600 million per year ($400-$900 million) in mid-century and $500 million per year ($200 million - $1 billion) in late-century.

Climate change is one of several factors that will affect the pattern, extent, and cost of wildland fire in the United States over the course of this century, and results suggest that, all else equal, the impact of climate change could double Federal fire suppression expenditures by mid-century and triple them by late-century, relative to historical average expenditures. These additional costs could put considerable pressure on the Federal land management agencies responsible for fire suppression, as well as allocations across the Federal Budget.

In addition, these costs could be compounded by continued growth in the WUI. Gebert et al. (2007) found that suppression expenditures are 0.11 percent higher per 1 per cent increase in housing value in proximity to an ignition. Holding that relationship constant and assuming that WUI property value increases commensurately with real GDP,[11] total Federal fire suppression costs could be 13 percent higher in mid-century and 44 percent higher in late-century. This would bring the combined effect of climate change and WUI development on Federal fire suppression expenditures in late-century to $3.6 billion with a range of $1.7-$5.0 billion.

The first step of this assessment analyzed historical relationships between maximum daily temperature and other variables, and the total area burned by fire on USFS- and DOI-managed lands using multiple regression. Since temperature has been shown to influence fuel moistures, fire season length, extreme fire weather, and lightning and storm tracks, it serves as a rough proxy for many ways that climate can influence wildfire.

The second step estimated the relationship between area burned and suppression expenditures, also using regression. The third step used projected increases in temperature from climate models in an unmitigated climate change scenario to project changes in area burned. Finally, the fourth step used projected climate-related changes in area burned, together with the results of the second step, to project mid- and late-century changes in suppression expenditures. Uncertainty in the temperature change projections from climate models as well as uncertainty related to regression model estimates of area burned and suppression expenditures were quantified using Monte Carlo simulation, producing the ranges presented above.

Key Limitations and Uncertainties

While there is little doubt that both a changing climate and a long-term growth trend for residential and commercial development in the WUI are already impacting—and will continue to impact—wildland fire management, substantial uncertainty remains regarding the extent of those impacts over the coming

[10] Estimates include wildland fire suppression expenditures only and do not include other wildland fire management expenditures.

[11] This assumption is roughly consistent with both past trends and future projections for the net effect of household formation, housing depreciation and demolition, and home price growth.

decades. The size of the range of suppression estimates reflects only a portion of this uncertainty; climate change could cause actual suppression expenditures to increase by less than the lower bound or more than the upper bound. In addition, the model used in this assessment does not incorporate several key factors—including four in particular that could have substantial bearing on the pattern and implications of fire over the course of the 21st century.

First, while average maximum temperature is a reasonable proxy for many of the effects of climate change on fire, it may not capture the full impact of climate change. In particular, it may represent increased incidence of temperature extremes fairly well, but may only partly capture increases in prolonged high-temperature periods and drought expected to occur with climate change. For example, fire season length, while related to temperature, may also increase due to other climate change phenomena, and this could affect expenditures in ways not captured by this analysis. Increased variability in precipitation and changes in fuel moisture and water availability for suppression are also not represented.

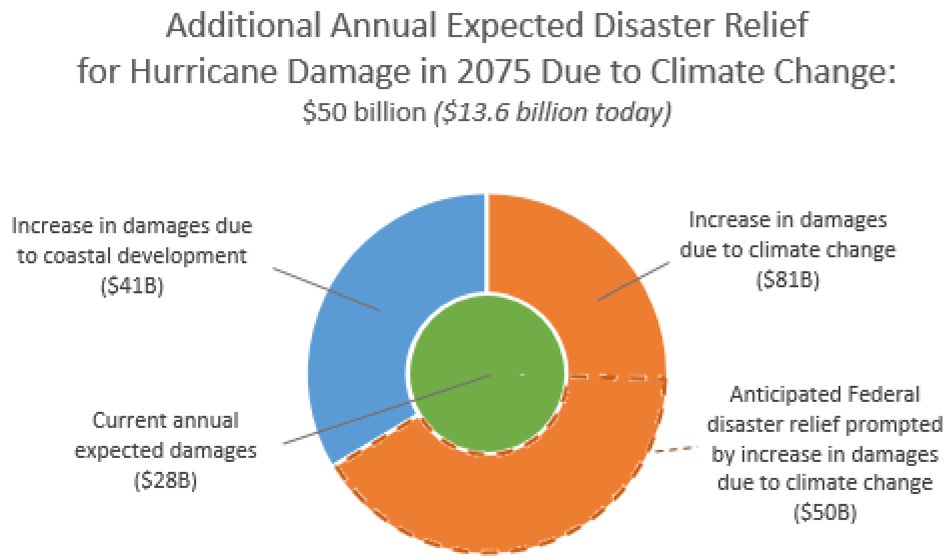
Second, both fire and climate are expected to substantially change vegetation composition over the coming 85 years, including the prevalence of vegetative fuels that enable and sustain fires. Detailed vegetation modeling would be required to determine the extent to which these changes would occur, and the extent to which they would alter area burned or suppression expenditures.

Third, growth in the WUI could influence wildfire ignitions and area burned and hence heighten efforts and suppression expenditures to protect life and property. Population and income variables were not used in the model as they were generally found either not to be significant or not to appreciably increase the predictive power of the area-burned model—perhaps due to relatively small sample size given a limited historical data set. The estimates provided above for the compounding effect of WUI development, based on Gebert et al. (2007), are intended to illustrate the potential sensitivity of fire suppression expenditures to WUI development.

Finally, the model holds constant the general approach to wildland fire management. Changes in wildfire suppression strategies and technologies, wildland fuels management practices, and other risk management strategies could affect the area expected to burn or the expenditures incurred per unit area. Some of these changes may occur as an adaptive response to growing wildland fire risks and/or as part of efforts to enhance carbon storage in the land sector. Previous shifts in management regime can be detected in historical data. For example, an upward shift in expenditure pattern occurred in FY 2000, corresponding to changes associated with the National Fire Plan. A second structural shift is detectable in FY 2011. However, any future shifts would be policy-dependent and uncertain in their timing and magnitude, so they are not projected.

The USDA Forest Service white paper detailing the modeling conducted for this assessment provides additional discussion of major uncertainties and limitations.

4. COASTAL STORM DISASTER RELIEF



Modeling by the Congressional Budget Office (CBO) suggests the Federal Government could incur additional disaster relief expenditures of tens of billions each year by 2075 due to higher sea levels and more intense hurricanes caused by climate change.

Climate Change and Disaster Relief

When a storm devastates a community, the Federal Government responds. Discretionary spending to provide relief in the aftermath of coastal hurricanes has exceeded $200 billion since 2000 (CBO, 2016). Climate change is driving sea level rise and more intense hurricanes, amplifying the probability of catastrophic storm damages each year in America's coastal communities and posing a significant fiscal risk for the Federal Government (Melillo et al., 2014; CBO, 2016).

A CBO study estimated that total expected economic damages[12] would be roughly $120 billion higher per year in real dollars by 2075 compared to today, or roughly 0.18 percent of 2075 real GDP (Congressional Budget Office, 2016). The study shows that, assuming population and incomes continue to grow in coastal communities, climate change contributes roughly two-thirds of the modeled increase in expected hurricane damages, or about $80 billion per year by 2075. About half of this climate change-attributed increase is essentially the effect of climate change on existing coastal property, and half is the effect of climate change on expected future development in coastal communities. The remaining one-third of the total increase ($40 billion) would occur due to continued coastal development alone, holding current sea levels and hurricane frequency constant.

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[12] Expected damage reflects the average annual costs that can be expected for over several years, but is typically higher than actual damage in most years since it captures small probabilities in each year of particularly catastrophic storms.

Risk Assessment

Based on CBO modeling of hurricane damages and associated Federal aid, the expected Federal fiscal burden attributable to the effect of climate change on expected hurricane damages is $19 billion per year by 2050 and $50 billion per year by 2075—or the equivalent in today's economy of approximately $8.7 billion and $13.6 billion, respectively. The likely range for these estimates is $11-$31 billion in 2050 (equivalent to approximately $5.0-$14.2 billion in today's economy) and $32-$78 billion in 2075 (equivalent to approximately $8.7-$21.2 billion in today's economy).[13] These estimates are derived by applying the historical ratio of Federal disaster relief, as estimated by CBO, to the portion of estimated economic losses from catastrophic hurricanes across 777 counties in 22 states that is attributable to climate change assuming development will continue in coastal communities.

Note that OMB's approach to determining the contribution of climate change to total expected damages, reflected in the figures presented above, differs from CBO's approach. OMB's approach assumes population and incomes in coastal communities will continue to grow as modeled by CBO, and attributes to climate change all damages that would not occur if not for climate change. CBO splits the combined effects of climate change and coastal development between the two factors in proportion to the effect of each in isolation—or 45 percent to climate change and 55 percent to coastal development.

CBO used projections by leading researchers to define the probability distribution of future sea levels and hurricane frequency, and its own projections to define distributions of future population and per capita income in coastal communities. CBO then used those distributions to simulate future hurricane damages with and without climate change using commercially developed damage functions that translate sea levels, hurricane occurrence, and property exposure into expected damage.

The sea level rise projections used in the CBO study combine potential outcomes associated with three different GHG emissions pathways—RCPs 2.6, 4.5, and 8.5. RCP 8.5 is an unmitigated climate change scenario, while RCP 4.5 is a moderate mitigation scenario and RCP 2.6 requires net-negative global emissions in the last quarter of this century. The result of combining sea level rise projections for these emissions pathways is average sea level rise in the United States between 1.4 feet and 2.8 feet by 2075 (CBO, 2016).[14]

In contrast, the 2014 NCA considered 1-4 feet to be the likely range and 6.6 feet to be an appropriate upper bound for risk-averse planning through 2100. While the difference in global sea level rise across these emissions pathways through 2050 is relatively small, more significant differences emerge in the second half of the century—up to 1.3 feet additional feet in RCP 8.5 compared to RCP 2.6 by 2100 (Kopp et al., 2014).[15]

In addition, half of the draws CBO used in its simulations of hurricane frequency were based on RCP 4.5, while half were based on RCP 8.5. Given CBO's approach on both sea level rise and hurricane frequency, CBO's results may be a fair reflection of the range of possible outcomes given global mitigation efforts, but as a whole underestimate the full effects that would occur in an unmitigated climate change scenario—especially in late-century. See CBO's report for more information on its methodology.

[13] The likely range reflects the middle two-thirds of CBO's simulations.
[14] The extent of sea level rise at the local level varies due to vertical land motion, such as subsidence, glacial rebound, or large-scale tectonic motion.
[15] The 90 percent confidence intervals in 2050 are ~0.6-1.1ft above 2000 levels in RCP 2.6 and ~0.7-1.2ft in RCP 8.5, and by 2100 increase to ~1.0-2.7ft in RCP 2.6 and ~1.7-4.0ft in RCP 8.5 (Kopp et al. 2014).

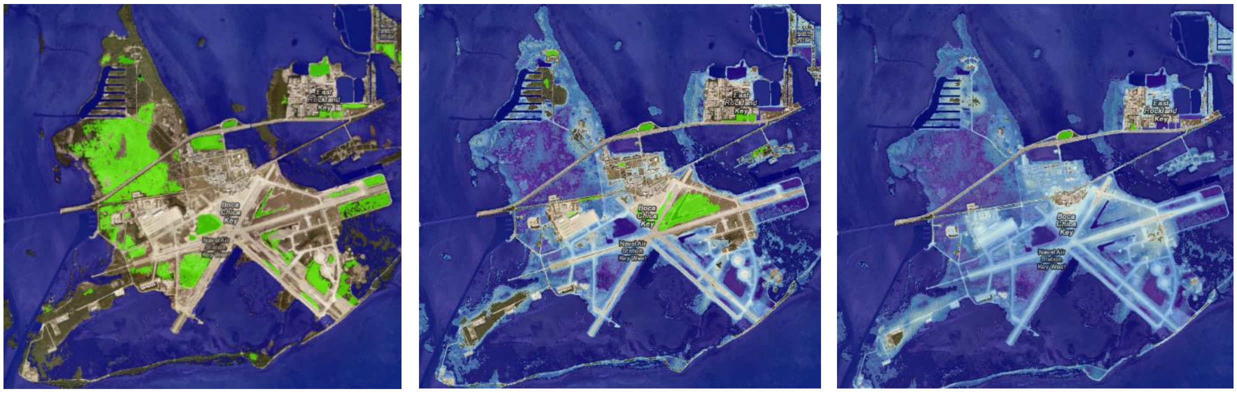
Key Limitations and Uncertainties

Economic damages attributed to climate change are sensitive to assumptions and limitations in underlying global change models and damage simulations. Uncertainty in hurricane frequency modeling in particular is evident in the spread of CBO's "likely range" of damage estimates. In addition, note that CBO's projections only extend to 2075, while global change models show that sea level rise could increase substantially in the final quarter of the century, depending in part on future emissions. The study scope was also limited to hurricane damage, and does not address non-hurricane flood damage in coastal areas (e.g., nuisance flooding at high tide due to sea level rise) or inland areas.

Another significant factor creating uncertainty is the extent to which coastal communities will adapt to growing risks. Several assessments have demonstrated that adaptation mechanisms like protective built and natural infrastructure as well as prudent development patterns can significantly reduce increases in storm damages due to climate change. The CBO study incorporates some representation of adaptation, in particular by generally assuming that damages increase less than proportionately with increases in population and per capita income, as well as by assuming that population and per capita income growth would slow in heavily affected counties. CBO found that expected damages could be 20 percent higher or lower depending on the extent to which hurricane damage is assumed to increase with population and income growth. This highlights the sensitivity of damages to the extent of adaptive response, but also suggests that the order of magnitude of expected damages may not change.

Estimates of fiscal burden attributed to expected hurricane damages depend entirely on the extent to which Federal disaster relief is assumed to be appropriated in the wake of catastrophic storms. The CBO study applies the average ratio of Federal relief to total economic damages for major storms since Hurricane Katrina in 2005. The Federal cost share may grow or shrink over time due to political and other factors that are difficult to predict. However, the share has tended to grow over time (CBO, 2016).

5. FEDERAL FACILITY FLOOD RISK



Hundreds of billions of dollars of Federal assets nationwide face flood risk today—and tens of billions of dollars of coastal assets could be inundated or severely affected by sea level rise by the end of this century. Depicted above, from left to right, is Naval Air Station Key West at typical high tide today, with 2 feet of sea level rise, and with 4 feet of sea level rise. Green represents low-lying but hydrologically unconnected areas. Blue represents areas inundated at high tide. Source: NOAA Sea Level Rise Viewer (https://coast.noaa.gov/slr/).

Climate Change and Flood Risk

Just as American homeowners and businesses face growing flood risks due to climate change, so does the Federal Government.[16] The NCA found that climate change may intensify flooding in many U.S. regions, even where total precipitation is projected to decline. Increasingly heavy downpours can cause flash and urban flooding and, along with more rapid spring snowmelt, can exacerbate river flooding. Climate-related sea level rise from thermal expansion of ocean water and melting of glaciers and ice sheets can cause coastal flooding and compound damages from storm surges (Melillo et al., 2014).

A common measure of flood risk for a given structure is whether it would be inundated by flood hazards that have at least a one percent annual chance of occurring based on historical hydrological patterns—the so-called "100-year floodplain."[17] With climate change, the current 100-year floodplain is expected to widen, while structures in the current 100-year floodplain are generally expected to see more frequent and severe flooding (AECOM, 2013). While FEMA has mapped the 100-year floodplain in the areas of the United States with the majority of the population, the projected 100-year floodplain area as influenced by climate change is not readily available.

However, changes in risk are more easily identified in coastal areas, where sea level rise projections have been mapped. The 2014 NCA considered 1-4 feet of additional sea level rise as the likely range by

[16] The Federal Government owns more than 775,000 individual buildings and structures with a total estimated replacement cost of nearly $1.9 trillion.
[17] The 100-year floodplain is the area that will be inundated by the flood event having a 1 percent chance of being equaled or exceeded in any given year.

the end of the century, depending on future emissions and other factors (note that global sea level has risen by about 8 inches since reliable record keeping began in 1880, and the rate of sea level rise since 1992 has been roughly twice the rate observed over the last century). However, the NCA painted 8 inches and 6.6 feet as bounds for risk-averse planning. The NCA also noted that sea level rise will not stop in 2100 and may continue for many centuries even if global warming is stabilized (Melillo et al., 2014). Since the 2014 NCA, more recent findings about the rate of melting in Antarctica suggest the high end of the range may be closer to 8 feet (DeConto and Pollard, 2016).

The National Oceanic and Atmospheric Administration (NOAA) has mapped projected sea level rise in the continental U.S. and Hawaii, delineating the area that would be inundated under the typical high tide under different degrees of future sea level rise. In addition to areas inundated at typical high tide, sea level rise will affect a broader area by increasing the risk of storm surge and "nuisance flooding" with strong tides. For example, the NCA documented how even a 1 foot sea level rise above mean high tide in 2050 could cause the level of flooding associated with today's 100-year storm to occur instead as often as once a decade or even annually (Melillo et al., 2014).

Risk Assessment

The Federal Government has not yet created a comprehensive dataset of location data for all Federal buildings and structures to allow them to be easily mapped. Due to this fact, the Federal Real Property Profile (FRPP) data were used to map Federal assets. As the FRPP was not designed to provide robust mapping capability, a full and complete assessment of Federal property flood risk is not feasible with the FRPP. FRPP includes precise location data for about one-third of federally owned buildings and structures located within the United States. Within this subset of the inventory, OMB identified 18,000 individual buildings and structures with a total replacement cost of $83 billion located in the current 100-year floodplain, based on FEMA floodplain maps—roughly 8 percent of the subset of records and 14 percent of the subset replacement value. Tens of thousands of additional assets, with a total replacement cost of $25 billion, were identified in the current 500-year floodplain.

The structures not examined have a total replacement cost of $1.0 trillion. Generally, assets without precise location data are national security facilities, as well as several types of non-building assets such as transportation and communications infrastructure. The portion of assets reviewed generally includes non-defense facilities like office buildings, warehouses, housing, laboratories, and hospitals.

The extent of future changes in flood risk has not been estimated across the full Federal inventory. However, OMB used NOAA sea level rise maps to assess inundation risk at a sample of coastal facilities—including facilities that were excluded from the floodplain assessment due to lack of precise location data. Of 57,000 inventory records reviewed in coastal areas, OMB identified 12,000 individual Federal buildings and structures, with a replacement cost of $62 billion, that would be inundated or severely affected[18] by the average high tide under a six foot sea level rise scenario. The majority of these assets are associated with the Department of Defense. A significant portion of these facilities appears to be located outside of the current 100-year floodplain, reinforcing the expectation that sea level rise will appreciably expand the number and value of Federal facilities facing flood risk in the coming decades.

[18] For example, a building was considered "severely affected"—even if it would not be inundated itself—if its major access roads or ports would be inundated, or if major facilities on a shared campus would be inundated.

OMB has not estimated the likely costs associated with this liability over the coming decades.[19] Replacement cost is an imperfect indicator of the rough scale of fiscal risk. Severe flooding or the promise of recurring inundation could require outright abandonment and/or replacement. In many cases, however, an individual flood event or the presence of flood risk may prompt less costly investments in protective infrastructure and repairs. The Federal Flood Risk Management Standard requires Federal agencies to consider current and future risk when rebuilding structures that have been damaged in a floodplain. Some protective investments may require one-time expenditures; others may occur and even increase over time as flood risk intensifies. Nonetheless, such investments for any given asset could be significantly smaller than the asset's total replacement cost. For more information on the assessment, see the Technical Supplement accompanying this report.

Key Limitations and Uncertainties

The Federal Government remains in the early stages of identifying the full extent of flood risk facing Federal facilities under current and future conditions largely due to persistent data limitations.

First, the Federal Government lacks projected nationwide floodplain maps that reflect expected changes due to climate change. A 2013 study conducted for FEMA demonstrated the scale of climate impacts on flood risk, finding that by 2100 the typical 1 percent annual chance floodplain area would grow by 40-45 percent largely due to climate change (AECOM, 2013). However, FEMA's maps are used to implement the National Flood Insurance Program and to provide communities with accurate flood hazard information, and therefore reflect existing flood risk. Without future projections, the full extent of the impact of climate change on flood risk for Federal facilities is not clear.

Second, detailed damage modeling has not been conducted on the Federal inventory to determine actual expected costs due to flooding. This type of assessment is conducted routinely by insurance companies in the private sector and would provide a clearer picture of Federal fiscal risk exposure than replacement cost. An assessment was also conducted for FEMA's National Flood Insurance Program in 2013, finding that the total number of policies would increase by 80-100 percent by 2100 in part due to climate change, and that the average loss cost per policy would increase by 50-90 percent (AECOM, 2013). In combination with good analytics on current and future flood risk, damage modeling on Federal property would enable better planning for investments and divestments across the Federal inventory.

Third, the Federal Government has not yet created a comprehensive dataset that would enable precise spatial analysis of the entire Federal property inventory. Due to national security concerns, the FRPP does not include geographic coordinates for a broad set of defense and homeland security facilities. Similarly, the FRPP includes several types of non-building assets such as transportation and communications infrastructure for which geographic coordinates are not reported and street addresses are unreliable for the purposes of accurately determining flood risk.

In addition to these data limitations, risk assessments in this area are also affected by scientific uncertainty. In particular, local flood impacts from climate change can be difficult to project due to the challenges of downscaling global change models to the local level. In addition, while there is high confidence that sea levels have already risen and will continue to rise over this century and beyond, the future *rate* of sea level rise remains difficult to predict.

[19] Note that a portion of these costs associated with vulnerable Federal coastal assets is implicitly included in the coastal storm disaster relief estimates; however, those results do not capture any costs for facilities on the west coast or in Hawaii, or non-hurricane costs associated with sea level rise for assets on the east and gulf coasts.

REFERENCES

AECOM, 2013. The Impact of Climate Change and Population Growth on the National Flood Insurance Program through 2100. Prepared for the Federal Emergency Management Agency.

Burke, Marshall, Solomon M. Hsiang, and Edward Miguel. 2015. Global non-linear effect of temperature on economic production. *Nature* 527: 235-239.

Burke, Marshall, and Kyle Emerick. 2016. Adaptation to climate change: evidence from U.S. agriculture. *American Economic Journal – Economic Policy* 8(3): 106-140.

Coble, K., and R. Dismukes. 2008. Distributional and Risk Reduction Effects of Commodity Revenue Program Design. *Review of Agricultural Economics* 30:543-553.

Congressional Budget Office. 2016. Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget. https://www.cbo.gov/publication/51518.

Cooper, J., and B. Delbecq. 2014a. A Multi-Region Approach to Assessing Fiscal and Farm Level Consequences of Government Support for Farm Risk Management. Paper presented at AIEAA Conference, June 2014.

Cooper, J., and B. Delbecq. 2014b. A Multi-Region Approach to Assessing Fiscal and Farm Level Consequences of Government Support for Farm Risk Management. *Bio-Based and Applied Economics* 3(3):205-227.

Cooper, J. 2010. Average Crop Revenue Election: A Revenue-Based Alternative to Price-Based Commodity Payment Programs. *American Journal of Agricultural Economics* 92(4):1214-1228.

Council of Economic Advisers (CEA). 2014. The Cost of Delaying Action to Stem Climate Change. https://www.whitehouse.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.

DeConto, Robert M. and David Pollard. 2016: Contribution of Antarctica to Past and Future Sea-Level Rise. *Nature* 591-597, 30 March.

Dell, Melissa, Benjamin F. Jones, and Benjamin A. Olken. 2012. Temperature shocks and economic growth: evidence from the last half century. *American Economic Journal: Macroeconomics* 4(3): 66-95.

Environmental Protection Agency. 2016. Final Ozone NAAQS Regulatory Impact Analysis. https://www.epa.gov/ozone-pollution/2015-national-ambient-air-quality-standards-naaqs-ozone.

EPA. 2015. Climate Change in the United States: Benefits of Global Action. United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001.

FY 2017 President’s Budget, Analytical Perspectives Volume. 2016. Chapter 24: Federal Budget Exposure to Climate Risk.

Garcia-Menendez, F., R. Saari, E. Monier, N. Selin. 2015. U.S. Air Quality and Health Benefits from Avoided Climate Change under Greenhouse Gas Mitigation. *Environmental Science & Technology 49* (13), 7580-7588 DOI: 10.1021/acs.est.5b01324. Available online at http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b01324.

Gebert, Krista M.; David E. Calkin; Jonathan Yoder. 2007. Estimating suppression expenditures for individual large wildland fires. Western Journal of Applied Forestry. 22(3): 188-196

Heal, Geoffrey, and J. Park. 2016. Goldilocks economics? Temperature stress and the direct impact of climate change. *Review of Environmental Economics and Policy* 10(2): 347-362.

Heisey, P. 2009. "Science, Technology, and Prospects for Growth in U.S. Corn Yields." *Amber Waves.* (December 1, 2009). USDA Economic Research Service.

International Monetary Fund (IMF). 2016. World Economic Outlook. http://www.imf.org/external/pubs/ft/weo/2016/01/pdf/text.pdf.

Kellenberg, D., and A. M. Mobarak. 2011. The economics of natural disasters. *Annual Review of Resource Economics* 3: 297-312.

Kopp, R. E., Horton, R. M., Little, C. M., Mitrovica, J. X., Oppenheimer, M., Rasmussen, D. J., Strauss, B. H. and Tebaldi, C. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. Earth's Future, 2: 383-406. doi:10.1002/2014EF000239.

Malcolm, S., M. Aillery, and M. Weinberg. 2009. *Ethanol and a Changing Agricultural Landscape.* USDA Economic Research Service, ERR-86.

Malcolm, S., E. Marshall, M. Aillery, P. Heisey, M. Livingston, and K. Day-Rubenstein. 2012. *Agricultural Adaptation to a Changing Climate: Economic and Environmental Implications Vary by U.S. Region.* USDA Economic Research Service, ERR-136. http://www.ers.usda.gov/publications/err-economic-research-report/err136.aspx.

Marshall, E., M. Aillery, S. Malcolm, and R. Williams. 2015. *Climate Change, Water Scarcity, and Adaptation in the U.S. Fieldcrop Sector.* USDA Economic Research Service, ERR-201.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. 2014. *Climate Change in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program, 841 pp. doi:10.7920/J0Z31WJ2.

NOAA National Centers for Environmental Information. 2016a. State of the Climate: Global Analysis for Annual 2015. Accessed 13 October 2016. https://www.ncdc.noaa.gov/sotc/global/201513.

NOAA National Centers for Environmental Information. 2016b. State of the Climate: Global Analysis for August 2016. Accessed 13 October 2016. https://www.ncdc.noaa.gov/sotc/global/201608.

NOAA National Centers for Environmental Information. 2016b. State of the Climate: Global Analysis for September 2016. Accessed 10 November 2016. https://www.ncdc.noaa.gov/sotc/global/201609.

Nordhaus, William. 2013. *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World*. New Haven, CT: Yale University Press.

Nordhaus, William. 2010. Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences* 107(26): 11721-11726.

Ray, D.K., J.S. Gerber, G.K. MacDonald, and P.C. West. 2015. "Climate Variability Explains a Third of Global Crop Yield Variability." *Nature Communications.* 6 (Art. 5989). http://www.nature.com/ncomms/2015/150122/ncomms6989/full/ncomms6989.html.

Rosenzweig, Cynthia. 2012. Superstorm Sandy and Sea level Rise. National Oceanic and Atmospheric Administration. https://www.climate.gov/news-features/features/superstorm-sandy-and-sea-level-rise.

Spracklen, D.V., L.J. Mickley, J.A. Logan, R.C. Hudman, R. Yevich, M.D. Flannigan, and A.L. Westerling. 2009. Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western United States. *Journal of Geophysical Research: Atmospheres,* **114,** D20301. http://dx.doi.org/10.1029/2008JD010966.

U.S. Department of Agriculture, National Agricultural Statistics Service. Quick Stats, various years. http://quickstats.nass.usda.gov/.

Wallander, S., Aillery M., D. Hellerstein, and M. Hand. 2013. *The Role of Conservation Programs in Drought Risk Adaptation.* USDA Economic Research Service, ERR-148.

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville. 2014. Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather.

USDA Forest Service. 2015. The Rising Cost of Wildfire Operations: Effects on the Forest Service's Non-Fire Work. http://www.fs.fed.us/sites/default/files/2015-Fire-Budget-Report.pdf.

USGCRP. 2016. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds. U.S. Global Change Research Program, Washington, DC, 312 pp. http://dx.doi.org/10.7930/J0R49NQX.