# WHAT WE KNOW

## THE REALITY, RISKS, AND RESPONSE TO CLIMATE CHANGE

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

# THE AAAS CLIMATE SCIENCE PANEL

**Mario Molina (Chair)**
University of California, San Diego and Scripps Institution of Oceanography

**James McCarthy (Co-chair)**
Harvard University

**Diana Wall (Co-chair)**
Colorado State University

**Richard Alley**
Pennsylvania State University

**Kim Cobb**
Georgia Institute of Technology

**Julia Cole**
University of Arizona

**Sarah Das**
Woods Hole Oceanographic Institution

**Noah Diffenbaugh**
Stanford University

**Kerry Emanuel**
Massachusetts Institute of Technology

**Howard Frumkin**
University of Washington

**Katharine Hayhoe**
Texas Tech University

**Camille Parmesan**
University of Texas, Austin and University of Plymouth, UK

**Marshall Shepherd**
University of Georgia

For more information about the panel and the initiative,
please visit:
whatweknow.aaas.org

AAAS
ADVANCING SCIENCE, SERVING SOCIETY

The overwhelming evidence of human-caused climate change documents both current impacts with significant costs and extraordinary future risks to society and natural systems. The scientific community has convened conferences, published reports, spoken out at forums, and proclaimed, through statements by virtually every national scientific academy and relevant major scientific organization—including the American Association for the Advancement of Science (AAAS)—that climate change puts the well-being of people of all nations at risk.

Surveys show that many Americans think climate change is still a topic of significant scientific disagreement.[1] Thus, it is important and increasingly urgent for the public to know there is now a high degree of agreement among climate scientists that human-caused climate change is real. Moreover, although the public is becoming aware that climate change increases the likelihood of certain local disasters, many people do not yet understand that there is a small but real chance of abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts on people in the United States and around the world.

It is not the purpose of this paper to explain why this disconnect between scientific knowledge and public perception has occurred. Nor are we seeking to provide yet another extensive review of the scientific evidence for climate change. Instead, we present three key messages for every American about climate change:

**1. Climate scientists agree: Climate change is happening here and now.**

Based on well-established evidence, about 97% of climate scientists have concluded that human-caused climate change is happening. This agreement is documented not just by a single study, but by a converging stream of evidence over the past two decades from surveys of scientists, content analyses of peer-reviewed studies, and public statements issued by virtually every membership organization of experts in this field. Average global temperature has increased by about 1.4° F over the past 100 years. Sea level is rising, and some types of extreme events—such as heat waves and heavy precipitation events– are happening more frequently. Recent scientific findings indicate that climate change is likely responsible for the increase in the intensity of many of these events in recent years.

**2. We are at risk of pushing our climate system toward abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts.**

Earth's climate is on a path to warm beyond the range of what has been experienced over the past millions of years.[2] The range of uncertainty for the warming along the current emissions path is wide enough to encompass massively disruptive consequences to societies and ecosystems: As global temperatures rise, there is a real risk, however small, that one or more critical parts of the Earth's climate system will experience abrupt, unpredictable, and potentially irreversible changes. Disturbingly, scientists do not know how much warming is required to trigger such changes to the climate system.

**3. The sooner we act, the lower the risk and cost. And there is much we can do.**

Waiting to take action will inevitably increase costs, escalate risk, and foreclose options to address the risk. The $CO_2$ we produce accumulates in Earth's atmosphere for decades, centuries, and longer. It is not like pollution from smog or wastes in our lakes and rivers, where levels respond quickly to the effects of targeted policies. The effects of $CO_2$ emissions cannot be reversed from one generation to the next until there is a large-scale, cost-effective way to scrub carbon dioxide from the atmosphere. Moreover, as emissions continue and warming increases, the risk increases.

By making informed choices now, we can reduce risks for future generations and ourselves, and help communities adapt to climate change. People have responded successfully to other major environmental challenges such as acid rain and the ozone hole with benefits greater than costs, and scientists working with economists believe there are ways to manage the risks of climate change while balancing current and future economic prosperity.

As scientists, it is not our role to tell people what they should do or must believe about the rising threat of climate change. But we consider it to be our responsibility as professionals to ensure, to the best of our ability, that people understand what we know: Human-caused climate change is happening; we face risks of abrupt, unpredictable, and potentially irreversible changes; and responding now will lower the risk and cost of taking action.

Many Americans believe scientists disagree. Based on well-established evidence, about 97% of climate scientists have concluded that humans are changing the climate.

## I. CLIMATE REALITY

**A. Climate scientists agree: Humans are driving climate change.**

In 2013, only 42% of American adults understood that "most scientists think global warming is happening" and 33% said, "… there is a lot of disagreement among scientists about whether or not global warming is happening." Twenty percent said they "don't know enough to say."[1]

Even Americans who have come to recognize that climate change is occurring know there are limits to their ability to make this judgment from their own experiences. It might appear as if it's raining more or less often, that it's hotter than usual, or that there are more storms than in the past. But is this true climate change or just natural variation? Does a particularly cold or snowy winter, such as the one the eastern United States experienced in 2013 and 2014, or variations in the rate of global surface temperature change call global warming into question? If the climate is changing, are human activities responsible, or is it being caused by natural factors?

Americans look to experts for guidance. If people believe the experts are in doubt about whether global warming is happening, it is no surprise that they will have less confidence in their own beliefs. Perceived expert disagreement has other consequences for the American people. Research shows that Americans who think the scientific experts disagree about human-caused climate change are less likely to believe that it might have serious consequences. Failure to appreciate the scientific consensus reduces support for a broad societal response to the challenges and risks that climate change presents.[3]

So let us be clear: Based on well-established evidence, about 97% of climate scientists conclude that humans are changing the climate.

This widespread agreement is documented not by a single study but by a converging stream of evidence over the past two decades from polls of scientists, [4,5] content analyses of peer-reviewed literature,[3,6] and from public statements issued by virtually every expert scientific membership organization on this topic.[7] The evidence is overwhelming: Levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse, as is extreme precipitation. The oceans are acidifying.

The science linking human activities to climate change is analogous to the science linking smoking to lung and cardiovascular diseases. Physicians, cardiovascular scientists, public health experts, and others all agree smoking causes cancer. And this consensus among the health community has convinced most Americans that the health risks from smoking are real. A similar consensus now exists among climate scientists, a consensus that maintains that climate change is happening and that human activity is the cause. The National Academy of Sciences, for example, says that "the Earth system is warming and that much of this warming is very likely due to human activities."[8]

**B. Climate change is happening now. And it's going to get worse.**

No matter where they live, Americans are experiencing the effects of climate change. Of course, extreme weather events of varied intensity have always occurred. Family photo albums, community lore, and history books recount the big storms, droughts, and floods that communities have borne. Against this backdrop of natural variation, however, something different is happening. Greenhouse gases from manmade sources such as smokestacks and tailpipes have altered our climate system. Greenhouse gases have supercharged the climate, just as steroids supercharged hitting in Major League Baseball. Over the course of a baseball season in the steroid era, we witnessed more—and longer—home runs, even though we cannot attribute any specific homer to steroids. Similarly, even though we cannot attribute any particular weather event to climate change, some types of extreme events such as heat waves are now more frequent.

Extreme weather is not just an abstract concept. It is a reality that affects people across the country. In 2013, two out of three Americans said weather in the United States has been worse over the past several years, up twelve percentage points since spring 2012. Many (51%) say weather in their local area has been worse over the past several years. Not surprisingly, then, the gap between what we know as scientists (that global warming impacts are here and now) and what Americans perceive is narrowing: About six in ten Americans already say, "Global warming is affecting weather in the U.S."[9]

**The core science of global warming**

After remaining relatively stable at around 280 parts per million (ppm) for millennia, carbon dioxide ($CO_2$) began to rise in the nineteenth century as people burned fossil fuels in ever-increasing amounts. This upward trend continues today with concentrations breaking the 400 ppm mark just last year. The rate of increase during the past 100 to 150 years has been much more rapid than in other periods of the Earth's history. The warming effect of $CO_2$ and other heat-trapping gases is well established and can be demonstrated with simple science experiments and satellite observations. Without the natural "greenhouse" effect from gases in our atmosphere, Earth would be a frozen planet.

In addition to greenhouse gases, many other forces can cause changes in the Earth's climate—including the creation and destruction of the Earth's crust, the planet's wobbly path around (and tilt toward) the sun, variation in the sun's energy output, volcanic eruptions, shifting ocean currents, and natural changes in $CO_2$ and other greenhouse gases. These factors have driven the planet through eras of blazing heat and mile-thick ice sheets. But decades of human-generated greenhouse gases are now the major force driving the direction of climate change, overwhelming the effects of these other factors. Many studies show that the combined effects of natural drivers of climate cannot explain the temperature increase that has been observed over the past half century.

Since the late nineteenth century, Earth's global average temperature has risen by about 1.4° F. Although this may appear to be a small change, the temperature has remained nearly as stable as that of the human body over the course of Western civilization. Just as a 1.4° F fever would be seen as significant in a child's body, a similar change in our Earth's temperature is also a concern for human society.

The difference was about 9° F between the last Ice Age, when half of North America was covered in a mile-thick ice sheet, and today. However, whereas that warming occurred over thousands of years, today's atmosphere has already warmed by 1.4° F in just over 100 years. The projected rate of temperature change for this century is greater than that of any extended global warming period over the past 65 million years. The Intergovernmental Panel on Climate Change states that continuing on a path of rapid increase in atmospheric $CO_2$ could cause another 4 to 8° F warming before the year 2100.[10]

Climate change is already happening. More heat waves, greater sea level rise, and other changes with consequences for human health, natural ecosystems, and agriculture are already occurring in the United States and worldwide. These problems are very likely to worsen over the next ten to twenty years and beyond.

Some the impacts of climate change that are already occurring and will increase over the coming years:

**Sea Ice**

Arctic sea ice has been shrinking dramatically, and the rate of loss is accelerating.[11] In September 2012, Arctic summer sea ice fell to a new record low at half the historical average—a loss in area nearly twice the size of Alaska.[12]

**Ice Sheets and Glaciers**

The melting of the Greenland and Antarctica ice sheets has also accelerated notably.[13] Glaciers continue to melt rapidly, contributing to sea-level rise and also affecting water supplies for as many as a billion people around the world.[14]

**Ocean Acidification**

The oceans are absorbing much of the $CO_2$ that smokestacks and tailpipes emit into the atmosphere. As a result, the oceans are rapidly acidifying, with early impacts on shelled organisms such as oysters already documented. The current acidification rate is likely the fastest in 300 million years.[15]

**Ecological Impacts**

As the world has gotten hotter, many of the world's plants and animals, on land and in the oceans, have begun moving toward the poles. Where possible, some terrestrial species are moving up mountainsides, and marine species are moving to deeper depths and higher latitudes. These changes are happening on every continent and in every ocean.[16,17,18] In some places, seasonal behaviors are occurring two or three weeks earlier than they did just a few decades ago.[19] The organisms that cannot adapt to the new climate conditions—because they cannot move fast enough or run out of room—will be worse off.

Extinctions are likely to increase as climate change combines with other human-related environmental pressures. Moreover, the impacts of climate change on ecosystem processes such as decomposition, plant production, and nutrient cycling—processes that determine how much fossil fuel–derived $CO_2$ the land and ocean will continue to sequester in coming decades—remain largely unknown.

**Sea Level Rise**

Sea level rise has also accelerated, making storm surges higher and pushing salt water into the aquifers that coastal communities depend on for fresh water, and increasing the extent of coastal flooding. Over the past two decades, sea levels have risen almost twice as fast as the average during the twentieth century.[20] Salt-water intrusion can be witnessed in southern Florida, where sea level rise is contributing to salt-water infiltration of coastal wells.[21]

**Floods, Heat Waves, and Droughts**

Global warming has changed the pattern of precipitation worldwide.[22] Flooding in the northern half of the eastern United States, the Great Plains, and over much of the Midwest has been increasing, especially over the past several decades. These regional flooding trends in the Northeast and upper Midwest are linked to increases in extreme precipitation and are consistent with the global trends driven by climate change.[23] At the same time, areas such as the U.S. Southwest are witnessing more droughts, and these too are consistent with global climate change patterns projected by climate models as a consequence of rising $CO_2$ levels.[24]

Since 1950, heat waves worldwide have become longer and more frequent.[25] One study indicates that the global area hit by extremely hot summertime temperatures has increased fifty-fold,[26] and the fingerprint of global warming has been firmly identified in these trends.[27] In the United States, new record high temperatures now regularly outnumber new record lows by a ratio of 2:1.[28]

**Wildfires**

Climate change has amplified the threat of wildfires in many places. In the western United States, both the area burned by wildfires and the length of the fire season have increased substantially in recent decades. Earlier spring snowmelt and higher spring and summer temperatures contribute to this change.[29] Climate change has increased the threat of "megafires"—large fires that burn proportionately greater areas.[30] Warming has also led to wildfires encroaching on some regions where they have been absent in recent history.[31]

**Effects on Health and Well-being**

Climate disruption is already affecting human health and well-being in many ways, and health threats are expected to intensify.[32] Some of the well-understood impacts include the direct effects of heat and the effects of other weather conditions such as droughts, floods, and severe storms. Heat waves cause deaths and illness, with urban dwellers, the elderly, the poor, and certain other especially vulnerable groups.[33] While heat-related deaths and illnesses have diminished in recent decades, thanks to better forecasting, early warning systems, and/or increased air conditioning, factors such as the aging of the population are expected to increase vulnerability.[34] Storms and floods can injure and kill victims in the short term, while lingering consequences may range from mold growth in flooded buildings (aggravating asthma) to contaminated drinking water supplies to post-traumatic stress and other mental health disorders.[35,36] Some air pollutants increase with climate change, with the potential to aggravate heart and respiratory diseases. Some plant products such as ragweed pollen reach higher concentrations for longer stretches each year, affecting people with allergies.[37,38,39,40]

Scientists have extensively studied the impact of climate change on the risk of infectious diseases.[41] Climate change affects the life cycle and distribution of disease-carrying "vectors"—mosquitoes, ticks, and rodents, which transmit diseases such as West Nile virus, equine encephalitis, Lyme disease, Rocky Mountain spotted fever, and Hantavirus Pulmonary Syndrome.[42] There is uncertainty about how climate change will affect infectious disease risk, because many factors other than climate affect the spread of disease. The role of climate change on the ranges of vector-borne diseases in the United States, such as Lyme disease, West Nile virus, and dengue, is an active area of research.[43]

**Climate Change and National Security**

Recent reports from U.S. Department of Defense (DOD) and National Academy of Sciences studies have called attention to the implications of current and probable future climate change for U.S. national security.[44] They identify obvious coastal concerns relating to sea level rise, and others linked to storms, freshwater availability, and agricultural productivity around the globe. For example: "Climate change could have significant geopolitical impacts around the world, contributing to poverty, environmental degradation, and the further weakening of fragile governments. Climate change will contribute to food and water scarcity, will increase the spread of disease, and may spur or exacerbate mass migration."[45] In the context of other global dynamics that give rise to political instability and societal tensions, changes in climate are considered as potential threat multipliers or instability accelerants, according to the CNA Military Advisory Board—a panel of our nation's highest-ranking retired military leaders.[46] Further, national security assets are often global first responders to humanitarian needs associated with natural disasters including typhoons, hurricanes, and flooding.

Climate change can influence resource competition and place new burdens on economies, societies, and governance institutions. The reports call attention to the fact that these burdens can trigger violence. There is a growing recognition that the displacement of large numbers of people because of water scarcity and agricultural failure, as in the recent history of Syria, can exacerbate tensions that lead to civil unrest. Senior officers and officials in the U.S. DOD are now regularly speaking publicly about how an unabated rise in greenhouse gas emissions could add additional burdens to the infrastructure and mission capacity of our military forces.[47]

## II. CLIMATE RISKS

We manage risk every day, often without thinking about it. We buckle our seat belts, latch our kids into car seats, and buy insurance for a host of unlikely but serious possibilities such as losing our homes or belongings to theft, fire, or flood. We don't think these things will happen, but we cannot be sure they won't. Uncertainty means risk. Much of our day-to-day risk management is to lessen the danger directly. For example, we purchase cars with the latest safety devices and use these. But another form of risk management is to spread the risk, as with insurance. This helps with recovery if the unthinkable happens.

Given the high stakes, it is valuable to understand not just what is **most likely** to happen, but what **might possibly** happen to our climate. There is a possibility that temperatures will rise much higher and impacts will be much worse than expected. Moreover, as global temperature rises, the risk increases that one or more important parts of the Earth's climate system will experience changes that may be abrupt, unpredictable, and potentially irreversible, causing large damages and high costs.[48]

When we take the long view on climate change, we face these same uncertainties and risks. Climate projections for the year 2100 (when many children born this year will still be living) give a range of plausible temperatures. We are uncertain whether we will experience the high or low end of the range, but the risks of bad outcomes increase greatly at the high end of warming scenarios. By analogy, we are acting like people who take risks with their health (e.g., with behaviors such as smoking and poor food choices) but still hoping to live long lives free of serious illness.

To make decisions about managing a risk, we consider the likelihood that a particular event will happen, the consequences if it did, and the cost of effective actions to prevent it. These are the same steps that go into making decisions about climate change. The process starts with an understanding of the risks. What is the likelihood that extreme climate changes will occur—and if they do, what consequences will we face? How much will it cost to prevent the risk?

**A. High-risk scenarios: the high-side projections**

Where there is a range of uncertainty, the high-side projections represent tail risk, a common concept in the world of finance. As most people understand, no investment is a sure thing. There is a range of possibilities about how that investment will fare. You could lose all you invested or make many times what you paid, but the most likely result is closer to the middle of these extremes. Although the chance of a very bad outcome—or tail risk—is small, it cannot be ignored. That is why advisors often recommend against investing any more than you can afford to lose.

With our future health and well-being at stake, it is common sense to consider the tail risks of climate change as a part of future plans. Consider the example of a seaside community in Florida. There are three futures to consider. Even under the most optimistic scenario (very aggressive greenhouse gas reductions and minimal melting), sea level is projected to rise about 1 foot this century.[49] The middle-of-the-road projection for the current pathway is about 2 feet. This is a fairly likely possibility. The Intergovernmental Panel on Climate Change estimates the probability of a sea level rise of 2 to 3 feet to be more than 60%.[50] But the tail risk projection as forecast by the U.S. National Climate Assessment sees the community contending with a sea level rise of nearly 7 feet.[51]

Below are some of the high-side projections and tail risks we incur by following the current path for $CO_2$ and other greenhouse gas emissions. Most of these projections derive from computer simulations of Earth and its climate system. These models apply the best understanding that science has to offer about how our climate works and how it will change in the future. Many such models exist, and all of them have been validated to varying degrees by their ability to replicate past climate changes.

**Global Temperature**

According to the IPCC, given the current pathway for carbon emissions the high end of the "likely" range for the expected increase in global temperature is about 8˚ F by the end of the century.[52] This is similar to the roughly 9° F warming that ended the last ice age. It is important to remember that temperature change due to $CO_2$ emissions is essentially irreversible for several hundred years because this $CO_2$ is removed from the atmosphere only very slowly by natural processes.[53]

**Floods, Heat Waves, and Droughts**

Globally, if human society follows the high-end scenario, extreme heat events that currently occur only once every twenty years are projected to occur annually.[54] Global warming will also lead to shifting precipitation patterns and concentration of precipitation into heavier downpours—critical risk factors for flooding and drought.

**Sea Level Rise**

Sea level rise projections over the next century vary considerably, with the high-end scenarios yielding a rise of up to 6 or 7 feet by 2100.[55,56] About 7 to 8 million people in the United States live within 6 feet of the local high-tide line, and storm surge can extend flooding far beyond the high-tide line, as witnessed in Superstorm Sandy.[57] Coastal flooding events that currently occur once every hundred years will occur much more frequently, possibly as often as yearly for many locations, rendering many cities and communities uninhabitable as is.[58]

Current greenhouse gas emissions would have considerable impact on sea level rise beyond the year 2100. In addition to driving sea level rise in the twenty-first century, current emissions might lead to dramatically higher sea level rise in the distant future, possibly beyond 16 feet, which is higher than the elevation of many major cities around the world. There is a slight risk that such large rise could occur faster than expected (see below).[59]

**B. Abrupt climate change**

Most projections of climate change presume that future changes—greenhouse gas emissions, temperature increases, and effects such as sea level rise—will happen incrementally. A given amount of emission will lead to a given amount of temperature increase that will lead to a given amount of smooth incremental sea level rise. However, the geological record for the climate reflects instances where a relatively small change in one element of climate led to abrupt changes in the system as a whole. In other words, pushing global temperatures past certain thresholds could trigger abrupt, unpredictable, and potentially irreversible changes that have massively disruptive and large-scale impacts. At that point, even if we do not add any additional $CO_2$ to the atmosphere, potentially unstoppable processes are set in motion. We can think of this as sudden climate brake and steering failure, where the problem and its consequences are no longer something we can control. In climate terms, abrupt change means change occurring over periods as short as decades or even years.[60]

The risk of abrupt climate change is particularly challenging because, although it is plausible, we have few historical measurements to guide our judgment of likelihood. The financial meltdown of 2008 was a good example of this kind of risk. We had no history of intertwined real estate and financial markets to draw on, and few experts recognized the risk indicators that led to enormous and rapid economic consequences. It is no surprise that we use a metaphor of bursting bubbles for such highly damaging financial events. We do not recognize we are in one—things seem stable, until suddenly they are not.

If human emissions cause temperatures to increase toward the high end of our projections, we increase the risk that we will push parts of our climate system past certain thresholds that lead to abrupt, unpredictable, and potentially irreversible changes to our planet and impacts for Americans and people worldwide.

Some of the planetary climate-related systems—both physical and biological—that could trigger such abrupt changes for the planet, if pushed past their limits, include: large-scale ice sheet collapse, collapse of part of the Gulf Stream, dieback of the Amazon rainforest, and coral reef die-off. Disturbingly, there is low confidence in the estimates of the temperature thresholds that would trigger such changes. Although some scenarios—such as the disruption of the Gulf Stream/Atlantic Meridional Overturning Circulation (AMOC) and rapid methane release from the sea floor—are considered very unlikely based on the latest research, this does not mean their likelihood has gone to zero.[61] Given the complexity of these systems and uncertainties in how they will respond to high-end warming, there may be surprises that we are not yet aware of. As per the National Academy of Sciences Report on Abrupt Impacts of Climate Change: "…'dragons' in the climate system still may exist."[62]

**Some potential climate change scenarios include:**

**Ecosystem Collapse**

Climate change threatens the collapse of some ecosystems and amplifies extinction pressures on species, which have already elevated extinction rates well above natural background rates.[63,64,65] The rate of climate change now may be as fast as any extended warming period over the past 65 million years, and it is projected to accelerate in the coming decades.[66] When rapid climate change is added to other sources of extinction pressure such as ocean acidification, land use, invasive species, and/or exploitation, the resulting rates of extinction are likely to place our era among a handful of severe biodiversity crises in the Earth's geological record.

**Arctic Sea Ice Collapse**

Warmer Arctic temperatures have caused Arctic summer sea ice to shrink rapidly over the past decade, with potentially large consequences including shifts in climate and weather around the northern hemisphere. Projections suggest that late-summer sea ice may disappear entirely in the coming decades.[67] The loss of Arctic sea ice has serious consequences for the Earth's climate system. Arctic sea ice covers an important portion of the planet's surface and reflects sunlight back into space that would otherwise warm the ocean. The loss of Arctic sea ice creates a feedback loop, as lost ice leads to additional ocean warming. The ice loss has major effects on the Arctic, and may have effects on weather patterns extending into the lower latitudes.[68,69]

**Large-scale Ice Sheet Collapse**

Large-scale melting of both the Greenland and Antarctic Ice Sheets include large-scale losses of ice, potentially leading to tens of feet of sea level rise. Although most of these losses are projected as being unlikely to occur before 2100, we may pass the point where these losses will be set in motion in the coming decades, with at least a slight chance that we have already done so.[70]

In Antarctica, marine ice/ice sheet instability threatens abrupt and large losses from both the West Antarctic Ice Sheet (WAIS) and portions of the East Antarctic Ice Sheet. Any significant ice loss likely would be irreversible for thousands of years. Simulations of warming and ice loss during earlier warm periods of the past 5 million years indicate these areas can contribute 23 feet of sea level rise.[71]

Some studies indicate that abrupt and irreversible ice loss from WAIS is possible, yet uncertainty regarding the threshold is such that it is not possible to say what temperature rise is necessary to trigger collapse.[72,73] An abrupt change in the WAIS this century is deemed plausible, with an unknown but probably low probability.[74] Recently an acceleration of ice loss from the WAIS has been observed, and it is not possible to dismiss or confirm that these changes are associated with destabilization of the WAIS.[75]

**Destabilizing of Sea Floor Methane**

Frozen methane in the shallow shelves of the Arctic Ocean represents an unlikely but potentially strong feedback loop in a warming climate. Methane is a short-lived but potent greenhouse gas. Although the release of these deposits due to global warming is likely to be slow and mitigated by dissolution into the sea, the deposits are large and vulnerable to warming expected on the higher emission pathway.[76] The release of Arctic methane hydrates into the atmosphere would further increase—perhaps substantially—the rate of global warming.[77]

**Permafrost Melt**

The release of $CO_2$ and methane from thawing Arctic permafrost represents another critical feedback loop triggered by global warming.

The amount of carbon stored in the permafrost is the largest reservoir of readily accessible organic carbon on land.[78] However, the positive feedback warming due to the loss of carbon from frozen soils is generally missing from the major climate change models.[79] Not surprisingly, methane and carbon dioxide emissions from thawing permafrost are thus regarded as a key uncertainty in climate change projections.

Disturbingly, there is low confidence in the estimates of expected emissions from thawing permafrost.[80] Although an abrupt release on the timescale of a few decades is judged unlikely, this conclusion is based on immature science and sparse monitoring capabilities.[81] The high end of the best estimate range for the total carbon released from thawed permafrost by 2100 is 250 GtC on the higher pathway. Other individual estimates are far higher.[82]

## III. CLIMATE RESPONSE

**A. The sooner we act, the lower the risk and cost.**

What steps society takes to meet the challenge of climate change—the questions of when, how, and to what extent we respond—are a matter on which all Americans must decide. We urge that these decisions be guided by two inescapable facts: First, the effects of any additional $CO_2$ emissions will last for centuries. Second, there is a risk of abrupt, unpredictable, and potentially irreversible changes in the Earth's climate system with massively disruptive impacts.

Emissions of greenhouse gases today commit the planet to unavoidable warming and other impacts in the future. As we continue to increase greenhouse gas emissions, we accelerate and compound the effects and risks of climate change into the future. Conversely, the sooner we make a concerted effort to curtail the burning of fossil fuels as our primary energy source and releasing the $CO_2$ into the air, the lower our risk and cost will be.

The longer we wait to respond, the more the risks of climate change will increase. Conversely, the sooner we take action, the more options we will have to reduce risk and limit the human and economic cost of climate change.

We've successfully faced environmental challenges before. There's much we can do to respond to the challenge and risks of climate change, particularly by tapping America's strength in innovation.

**B. There is much we can do.**

The United States is one of the most resourceful and innovative societies in the world. We are a nation of problem solvers. When scientists identified the grave environmental threats posed by acid rain and the ozone hole, they worked together with other stakeholders—consumers, industry, and government—to develop solutions that would successfully reduce the threat while minimizing short- and long-term economic impacts. As we hope this paper has made clear, however, successfully responding to climate change will test our resolve and ingenuity in ways unlike any other environmental challenge we have faced.

Many of our major cities—New York, Seattle, Boston, and Chicago are just a few—have assessed the scientific evidence, and decided to reduce greenhouse gas emissions and prepare for the impacts of climate change.

We believe that our responsibility as scientists is to ensure, to the best of our ability, that people fully understand the climate realities and risks we face. Prior experience shows that we and future generations will be better off when science effectively informs decision-making and action. Armed with scientific understanding about the gravity of certain environmental problems, our nation has successfully used innovative approaches to address these challenges.

In summary, responding effectively to the challenge of climate change requires a full understanding that there is now a high degree of agreement among climate scientists about the fact that climate change is happening now, because of human activities, and that the risks—including the possibility of abrupt and disruptive changes—will increase the longer greenhouse gas emissions continue.

# BIBLIOGRAPHY


1 Leiserowitz et al. (2013). *Climate change in the American mind: Americans' global warming beliefs.* Yale Project on Climate Change Communication and the George Mason University Center for Climate Change Communication. http://environment.yale.edu/climate-communication/files/Climate-Beliefs-April-2013.pdf

2 National Research Council (2013). *Abrupt Impacts of Climate Change: Anticipating Surprises.* Washington, DC: The National Academies Press.

3 Oreskes, N. (2004). The scientific consensus on climate change. *Science,* 306. http://cmbc.ucsd.edu/Research/Climate_Change/Oreskes%202004%20Climate%20change.pdf

4 Doran, P. and M. Zimmerman (2009). Examining the scientific consensus on climate change. *Eos, Transactions,* American Geophysical Union, 90 (3), 22–23. http://onlinelibrary.wiley.com/doi/10.1029/2009EO030002/abstract

5 Cook et al. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters,* 8 024024. doi:10.1088/1748-9326/8/2/024024

6 Ibid.

7 National Aeronautics and Space Administration. Consensus. http://climate.nasa.gov/scientificconsensus

8 National Research Council (2010). *Advancing the Science of Climate Change.* Washington, DC: The National Academies Press.

9 Leiserowitz et al. (2013). *Extreme weather and climate change in the American mind,* April 2013. Yale Project on Climate Change Communication and the George Mason University Center for Climate Change Communication. http://www.climatechangecommunication.org/report/climate-changeamerican-mind-series-spring-2013

10 IPCC (2013). Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY. Table SPM.2, Page 25.

11 Ibid.

12 National Snow and Ice Data Center (2012). Arctic sea ice extent settles at record seasonal minimum. *Arctic Sea Ice News and Analysis,* September 19, 2012. http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum/

13 IPCC (2013). Summary for Policymakers.

14 Ibid.

15 Hönisch et al. (2012). The geological record of ocean acidification. *Science,* 335 (6072), 1058–63. doi:10.1126/science.1208277

16 Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology Evolution and Systematics,* 37, 637–69.

17 Cleland, E.E., I. Chuine, A. Menzel, H. A. Mooney, M. D. Schwartz (2007). Shifting plant phenology in response to global change. *Trends in Ecology and Evolution,* 22, 357–65.

18 Parmesan, C. and G. Yohe (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature,* 421, 37–42.

19 Linderholm, Hans W. (2006). Review: Growing season changes in the last century. *Agricultural and Forest Meteorology,* 137. http://research.eeescience.utoledo.edu/lees/papers_PDF/Linderholm_2006_AFM.pdf

20 IPCC (2013). Summary for Policymakers.

21 Langevin, C. D. and Zygnerski, M. (2013). Effect of sea-level rise on salt water intrusion near a coastal well field in southeastern Florida. *Ground Water,* 51, 781–803. doi: 10.1111/j.1745-6584.2012.01008.x

22 Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research,* 47, 123–38.

23 Melillo et al. (2013). *Third National Climate Assessment Draft Report.* Washington, DC: United States Global Change Research Program.

24 Ibid.

25 Trenberth, K. E., P. D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J. A. Renwick, M. Rusticucci, B. Soden, and P. Zhai (2007). Chapter 3, Observations: Surface and Atmospheric Climate Change. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

26 Hansen, James, Makiko Sato, and Reto Ruedy (2012). Perception of climate change. August 6, 2012. *Proceedings of the National Academy of Sciences,* 10.1073/pnas.1205276109. http://www.pnas.org/content/early/2012/07/30/1205276109.abstract

27 Gutowski, W. J., G. C. Hegerl, G. J. Holland, T. R. Knutson, L. O. Mearns, R. J. Stouffer, P. J. Webster, M. F. Wehner, and F. W. Zwiers (2008). Causes of Observed Changes in Extremes and Projections of Future Changes. In *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands.* [T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray (eds.)]. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

28 Meehl, G. A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel (2009). Relative increase of record high maximum temperatures compared to record low minimum temperatures in the U.S. *Geophysical Research Letters,* 36, L23701. doi:10.1029/2009GL040736.

29 Karl, T. R., G. A. Meehl, and T. C. Peterson (2009). *Global Climate Change Impacts in the United States.* Cambridge, UK: Cambridge University Press.

30 Melillo et al. (2013).

31 Ibid.

32 McMichael T., H. Montgomery, and A. Costello (2012). Health risks, present and future, from global climate change. *BMJ* 2012; 344:e1359. doi: 10.1136/bmj.e1359.

33 Luber, G. and M. McGeehin (2008). Climate change and extreme heat. *American Journal of Preventive Medicine,* 35 (5), 429–35.

34 Kalkstein, L. S., S. Greene, D. M. Mills, and J. Samenow (2011). An evaluation of the progress in reducing heat-related human mortality in major US cities. *Natural Hazards,* 56, 113–29.

35 Lane, K., K. Charles-Guzman, K. Wheeler, et al. (2013). Health effects of coastal storms and flooding in urban areas: A review and vulnerability assessment. *Journal of Environmental and Public Health,* 2013, Article ID 913064. http://dx.doi.org/10.1155/2013/913064

36 Landesman, L. Y. (2005). *Public Health Management of Disasters.* Second Edition. Washington, DC: American Public Health Association.

37 Kinney, P. L. (2008). Climate change, air quality, and human health. *American Journal of Preventive Medicine,* 35, 459–67.

38 Tagaris, E., K. Manomaiphiboon, K. J. Liao, L. R. Leung, J. H. Woo, S. He, P. Amar, and A. G. Russell (2007). Impacts of global climate change and emissions on regional ozone and fine particulate matter concentrations over the United States. *Journal of Geophysical Research,* 112 (33), D14312.

39 Ziska, L., K. Knowlton, C. Rogers, D. Dalan, N. Tierney, M. A. Elder, W. Filley, J. Shropshire, L.B. Ford, and C. Hedberg (2011). Recent warming by latitude associated with increased length of ragweed pollen season in central North America. *Proceedings of the National Academy of Sciences,* 108, 4248–51.

40 Ariano, R., G. W. Canonica, and G. Passalacqua (2010). Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Annals of Allergy, Asthma & Immunology,* 104, 215–22.

41 Altizer S., R. S. Ostfeld, P. T. Johnson, S. Kutz, and C. D. Harvell (2013). Climate change and infectious diseases: From evidence to a predictive framework. *Science,* 341 (6145), 514–19.

42 Karl, T. R., G. A. Meehl, and T. C. Peterson (2009). *Global Climate Change Impacts in the United States.* Cambridge, UK: Cambridge University Press.

43 Ibid.

44 United States Department of Defense (2011). *2014 Quadrennial Defense Review.* Washington, DC. http://www.defense.gov/pubs/2014_Quadrennial_Defense_Review.pdf

45 National Research Council (2011). *National Security Implications of Climate Change for U.S. Naval Forces.* Washington, DC: The National Academies Press.

46 Goodman, S. and G. Sullivan (2013). Climate change as a "threat multiplier." *Politico.* http://www.politico.com/story/2013/02/climate-change-is-threat-multiplier-87338.html

47 Castellaw, Lt. Gen. J., R. Adm. D. Titley (2014). The U.S. military leads on climate change. *The Hill.* http://thehill.com/blogs/congress-blog/energy-environment/200412-the-us-military-leads-on-climatechange

48 National Research Council (2013).

49 IPCC (2013). Summary for Policymakers.

50 Ibid.

51 Melillo et al. (2013).

52 IPCC (2012). IPCC Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. "Likely" defined by the IPCC as a probability of 66%–100%.

53 IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

54 IPCC (2012). *Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

55 Melillo et al. (2013).

56 Ibid.

57 Strauss, B. H. et al. (2012). Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters,* 7, 014033. doi:10.1088/1748-9326/7/1/014033.

58 Stocker, T. F., D. Qin, G.-K. Plattner, L. V. Alexander, S. K. Allen, N. L. Bindoff, F.-M. Bréon, J. A. Church, U. Cubasch, S. Emori, P. Forster, P. Friedlingstein, N. Gillett, J. M. Gregory, D. L. Hartmann, E. Jansen, B. Kirtman, R. Knutti, K. Krishna Kumar, P. Lemke, J. Marotzke, V. Masson-Delmotte, G. A. Meehl, I. I. Mokhov, S. Piao, V. Ramaswamy, D. Randall, M. Rhein, M. Rojas, C. Sabine, D. Shindell, L. D. Talley, D. G. Vaughan and S.-P. Xie (2013). Technical Summary. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

59 Strauss, B. (2013). Rapid accumulation of committed sea-level rise from global warming. *Proceedings of the National Academy of Sciences.* http://assets.climatecentral.org/pdfs/Strauss PNAS-2013-v2.pdf

60 National Research Council (2013).

61 Ibid.

62 Ibid.

63 Ibid.

64 Ibid.

65 Peterson, T. C., D. M. Anderson, S. J. Cohen, M. Cortez-Vázquez, R. J. Murnane, C. Parmesan, D. Phillips, R. S. Pulwarty, and J. M. R. Stone (2008). Why Weather and Climate Extremes Matter. In *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands.* [T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and W. L. Murray (eds.)]. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC.

66 National Research Council (2013).

67 Ibid.

68 Francis, J. A. and S. J. Vavrus (2012). Evidence Linking Arctic Amplification to Extreme Weather in Mid-Latitudes, *Geophysical Research Letters,* 39, L06801. doi:10.1029/2012GL051000.

69 Tang, Q., X. Zhang, X. Yang, and J. A. Francis (2013). Cold winter extremes in northern continents linked to Arctic sea ice loss. E*nvironmental Research Letters,* 8, 014036.

70 Stocker et al. (2013).

71 Stocker et al. (2013).

72 Ibid.

73 National Research Council (2013).

74 Ibid.

75 Stocker et al. (2013).

76 Ibid.

77 Ibid.

78 Ibid.

79 Ibid.

80 Ibid.

81 National Research Council (2013).

82 Stocker et al. (2013).

We would like to thank the following people and organizations for providing financial support for the AAAS "What We Know" initiative:

**Grantham Foundation for the Protection of the Environment**
The Grantham Foundation seeks to raise awareness of urgent environmental issues and supports individuals and organizations working to find solutions.

**Lawrence H. Linden**

**Robert Litterman**

**The MacArthur Foundation**
The John D. and Catherine T. MacArthur Foundation supports creative people and effective institutions committed to building a more just, verdant, and peaceful world.

**Rockefeller Family Fund**
Rockefeller Family Fund is a U.S.-based, family-led public charity that initiates, cultivates, and funds strategic efforts to promote a sustainable, just, free, and participatory society.

**Henry M. Paulson**