

**Testimony of Dr. Michael Oppenheimer
Princeton University
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Introduction

My name is Michael Oppenheimer. I am the Albert G. Milbank Professor of Geosciences and International Affairs at Princeton University and a member of the faculties of the Department of Geosciences, the School of Public and International Affairs, and the High Meadows Environmental Institute. I would like to thank Chairwoman Johnson and the members of this committee for inviting my testimony at this hearing. The views expressed in this testimony are my own. I am not speaking as an official representative of Princeton University. Let me first describe my professional background. A complete CV accompanies this testimony.

I received an S.B. from MIT and a PhD in chemical physics from the University of Chicago and served as a postdoctoral fellow and then Atomic and Molecular Astrophysicist at the Harvard Smithsonian Center for Astrophysics, researching interstellar gases and Earth's upper atmosphere. Subsequently, I served as Chief Scientist for the Environmental Defense Fund, a private, not-for-profit research and advocacy environmental organization (where I continue to serve as a paid advisor on scientific matters). In 2002, I became a professor at Princeton University where I direct the Center for Policy Research on Energy and the Environment. I have published over 200 articles in professional journals. Almost all of those published over the past 30 years cover aspects of climate change science and climate change policy. My current research focuses largely on projecting sea level rise and coastal flood levels in a warming world with special emphasis on the contribution of the Greenland and Antarctic ice sheets; the risk to coastal areas from sea level rise; and adaptation and other responses to climate change, sea level rise, and extreme climate events, such as human migration. I have served in various capacities as an author of assessments produced by the Intergovernmental Panel on Climate Change (IPCC) since its First Assessment Report in 1990, most recently as a Coordinating Lead Author of IPCC's Special Report on *Oceans and Cryosphere in a Climate Change* (SROCC), published 18 months ago. I

shared responsibility for the chapter assessing sea level rise. I currently serve as a review editor on IPCC's Sixth Assessment Report for a chapter that synthesizes understanding of all risks associated with climate change. In 2018, along with six other experts in diverse fields, I published a book on scientific assessments, *Discerning Experts: The practices of scientific assessment for environmental policy*.

Purpose of This Testimony

The Committee invited me to discuss the state of our understanding of the effects of climate change on processes such as ice loss, sea level rise, coastal storms, and extreme heat; recent observations of accelerating rates of ice loss and sea level rise, and extreme heat events in the U.S., and how climate change is affecting the U.S. on regional and local scales. The Committee also asked for information on the relationship of climate change impacts to human migration, and the disproportionate impacts of climate change on vulnerable populations. In addition, I was asked to comment on the value of interdisciplinary research involving both the physical and social sciences in understanding climate risk, the importance of these fields of research to developing mitigation and adaptation solutions, and the importance of observations and modeling including research gaps or recommendations for additional investments in climate science that the Science Committee should address.

As background on the current state of the climate, some key findings of IPCC reports and research since their release are:

- In 2020, Earth was about 2°F (1.1°C) warmer than it was early in the industrial era.¹
- IPCC's Fifth Assessment stated, "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century",² i.e., the accumulation of greenhouse gases (such as carbon dioxide) in the atmosphere as a result of human activity (largely related to fossil fuel combustion to provide energy) is the primary cause of the observed global warming.

- Associated with this warming, pervasive changes have been detected in many features of Earth's climate system, including more frequent hot days and nights and fewer extremely cold ones, increases in the frequency, intensity, and amount of heavy precipitation events, greater intensity and duration of drought in some regions, increase in the intensity of North Atlantic hurricanes, and sea levels rising nearly worldwide.³
- Changes in heat, precipitation and sea level are attributed with medium or high confidence to the greenhouse gas buildup.³
- Characteristics of some extremely damaging events, like the intense precipitation from Hurricane Harvey, can now be attributed to the greenhouse gas buildup. In other words, it is no longer true that no single climate event can be connected quantitatively to the greenhouse gases – due to advances in computer modeling, many already have been.⁴
- All of these changes are projected with medium or high confidence to continue to build throughout this century. Those related to heat, precipitation, hurricanes, and sea level pertain to the US as well while the attribution of US drought changes is less clear.⁵
- Perhaps most important, global climate change cannot be halted unless emissions of the major greenhouse gases, particularly carbon dioxide, are eliminated. To keep warming from surpassing the Paris Agreement's long-term objective of maintaining the global average temperature well below 2°C with the aspiration of not exceeding a 1.5°C warming may require removing some carbon dioxide from the atmosphere by artificial means which are not yet economically viable.⁶

Sea Level Rise

According to IPCC's Special Report on *Oceans and Cryosphere in a Changing Climate (SROCC)*⁷, global sea level is rising largely as a result of three processes that are adding water to the oceans and causing their volume to increase.

- Liquids generally expand when heated, and the same is true of ocean water as heat trapped by the greenhouse gases penetrates to great depths. As a result, the oceans are taking up greater and greater volume which translates into sea level rising. In addition, two other processes are adding to the amount of water in the ocean and this also causes sea level rise:
- Mountain glaciers are in retreat nearly worldwide due to the warming and their meltwater generally winds up in the oceans.
- The major ice sheets have been losing ice faster and faster since about 1990. The Greenland ice sheet is melting at its lower elevations and the meltwater is running off into the ocean. In some locations, the ice is flowing faster down glacial fjords, breaking into icebergs at the coast, and in this way also adding more water to the ocean. Taken together, these two processes have caused a large increase in Greenland's contribution to global sea level rise. The Antarctic ice sheet is generally too cold to melt at its surface but, in several areas, warm waters beneath its floating shelves are causing melting from below, accelerating iceberg formation and causing a growing contribution to sea level rise (see Figure 2).
- As a result, the overall rate of sea level rise from 2006-2015 was about 2.5 times the rate during the 20th century (about 6 inches/century then; now about 14 inches/century). This may seem like a small amount but a rough rule of thumb applied to a typical East Coast beach estimates that each foot of vertical rise results in inland loss of about 100 feet due to erosion and permanent inundation, absent restoration. Taken together, losses from the ice sheets are now responsible for about 1/3 of the ongoing rise in sea level, and they are accelerating. *Sharpening our understanding of how fast the ice sheets will lose ice as the world warms further is a key to more precisely projecting sea level rise over this century.*

Sea level projection

The future behavior of the ice sheets presents the greatest uncertainty in projecting sea level rise. In a low emissions scenario that could meet the Paris target, global average sea level is expected to rise 7-13 inches by midcentury and 11-23 inches by 2100. In a high emissions scenario that could lead to global warming in excess of 9°F (5°C) above recent temperatures, sea level rise is expected to reach 9-16 inches by mid-century and 24-43 inches by year 2100 (Figure 1; all numbers compared to sea level around year 2000).⁷

However, sea level rise is not distributed uniformly around the world. Many local effects cause place-to-place variations of +/-30%. As it happens, the northeast US coast has already experienced sea level rise of 1.5-2.0 times the global average.

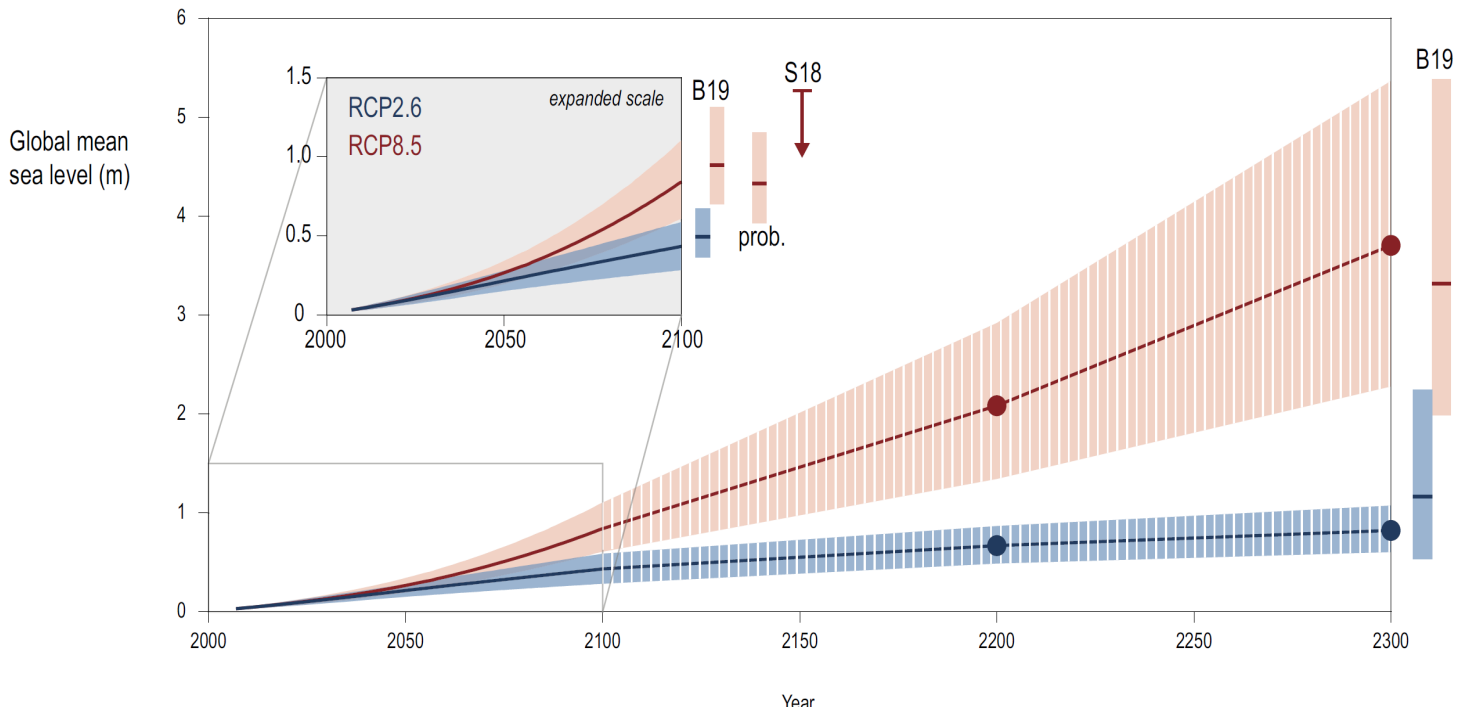


Figure 1. Projected global mean sea level rise for high (red) and low (blue) emissions scenarios. Large graph runs to year 2300, inset expands the period 2000-2100. Results are from mechanistic models that are based on equations describing the physics of ice. Solid lines are the median sea level rise for each case. The shaded blue or red areas above and below the median represent the 17–83% uncertainty range, combining both uncertainty in ice physics and uncertainty in climate and ocean sensitivity to

warming. Vertical bars show results from other estimation methods (sensitivity studies, partially probabilistic approaches, and expert elicitation) that may capture low-probability outcomes better than the mechanistic approach. From SROCC (2019), figure 4.2⁷

Due to the possibility of various ice sheet instabilities developing in response to ocean and atmospheric warming (Figure 2), retreat of Antarctic ice may occur faster than our best current models suggest, particularly beyond 2100. The potentially unstable sectors of Antarctica contain ice equivalent to roughly 15 meters (50 feet) of sea level rise. About 25% of that total may already be on the brink of unstable retreat. There is disagreement among experts as to how fast unstable retreat would occur once it begins, with estimates ranging from about 200-900 years to completion. Accordingly, SROCC recommended that stakeholders, including policy makers, take the possibility of higher sea level rise into account when making judgments related to building long-lived coastal infrastructure, such as coastal defenses.

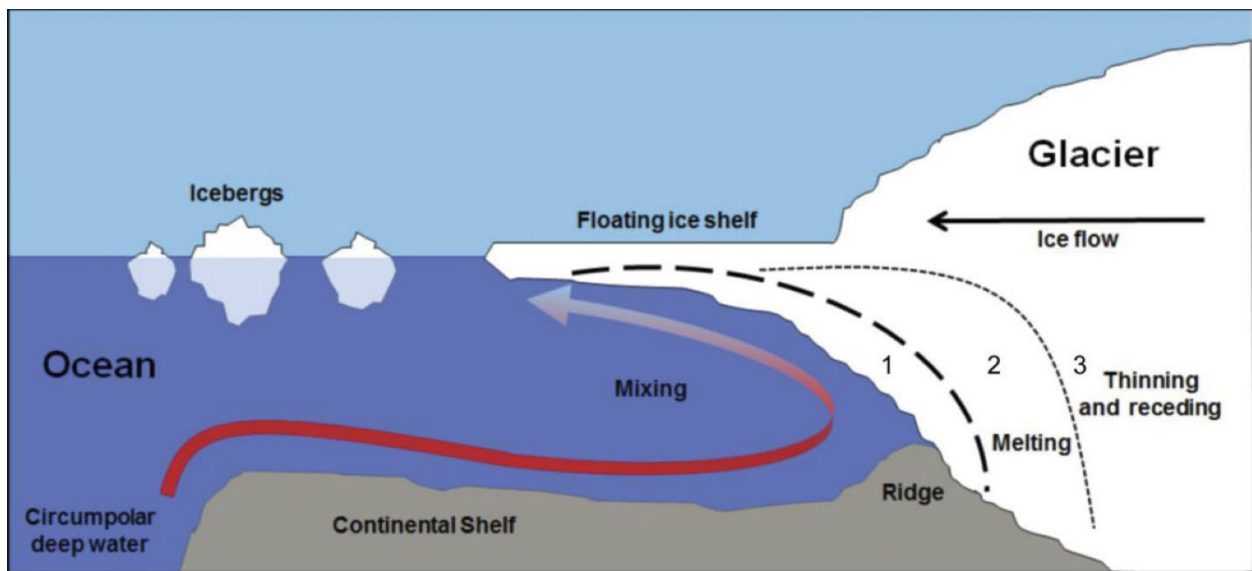


Figure 2: Warm water circulating under the floating ice shelf (red arrow) reaches the boundary, or grounding line, between ice resting on bedrock and the floating ice. Forward motion of the grounded ice there is obstructed by ridges in the bedrock but the warm water melts away some ice causing the ice just behind to lift off the ridge and accelerate into the ocean. This process can cause parts of the ice sheet to become unstable.⁷ Figure from reference 8.

The flip side of this argument, indicated in figure 1, is that we have a pretty clear picture of sea level rise through 2050, when uncertainties are not large and provide a sound basis for coastal planning and implementation.

Consequences of sea level rise

Higher sea level sets a new baseline for the elevations along the coast and inland reached by water during high tides as well as the coastal storms like hurricanes and nor'easters that are accompanied by surge. That means that flood levels reached only rarely in recent times will become common as the sea rises. For example, at many US coastal locations, as well as worldwide, with about 2°C global warming, the historical once-per-century water level is expected to occur *every year* or more often by 2050. The list of such locations includes Savannah, Jacksonville, Miami, Los Angeles, San Diego, and Honolulu. By 2100, New York and others will join this list.⁷ Different cities will be affected to different extents – for some of these locations, particularly along the West Coast, the current hundred-year water level is a high tide rather than a storm so the corresponding flood level is lower than would be the case at, for instance, an East Coast city where the current hundred-year water level typically results from a hurricane. Nevertheless, substantial amounts of infrastructure have been built of the past century or two with the historical high-water level in mind, whether from a high tide or storm. Those sites will need to be reconsidered carefully, well before 2050, because building protection or implementing planned retreat to higher ground can take decades.

The effects of higher sea levels are already evident. The once-per-decade flood height in New York Harbor in 1940 now arrives once every five years. Sections of the old bulkhead that remains the only defense for some sections of lower Manhattan are only 5-6 feet tall,⁹ about the same height as the current once-in-five-year event, leading to overtopping. Sunny-day or tidal flooding has become a regular event (several times

per month) at many places along the coast where it was heretofore rare. Certain neighborhoods in Miami provide costly examples.

Adapting to the Risk

Recent experience with a growing list of deadly and costly climate disasters [Hurricane Katrina (2005), Hurricane Sandy (2012), Hurricane Harvey (2017), Hurricane Maria (2017), wildfires in California and elsewhere in several recent years, the Texas cold snap (2021) and several others] serves as a warning that we are not as effective at anticipating and adapting to *today's* level of risk as we should be. Yet, we are going to need to become much more effective, very quickly as climate change increases the likelihood of extreme heat, category 4 and 5 hurricanes, wildfire, and more frequent episodes of coastal high water.

We should learn from each case and start immediately to deal with the weak spots in our responses. Otherwise, the coming decades will bring ever more disastrous outcomes for more and more Americans. Before delving into causes, let me point out that there is some encouraging experience to learn from – *worldwide, deaths in coastal storm surge (e.g., accompanying hurricanes) have decreased since 1900.*¹⁰ The same trend appears in US data but the uncertainty is larger due to the sparsity of events. While the reasons for this trend are unclear, improved forecasting has in all likelihood made an important contribution.

Now to the bad news: recent events show that we are still leaving much too much undone, or improperly done, before a big event strikes and it remains unclear how long the learning from any one event lasts. The levees that failed in Katrina in 2005 were the product of experience with Hurricane Betsy 40 years earlier. The current defenses are doubtless an improvement but are not designed to handle the higher surge that a category 5 storm may bring. Hurricane Sandy struck a metropolitan area (New York) that seemed to have grown complacent due to the lack of catastrophic coastal events in previous decades. Critical infrastructure (hospitals and an electric utility substation) were flooded, causing massive service disruptions and necessitating emergency evacuation of hospitalized patients and an enormous cost for repairs, on the order of a

billion dollars in the case of one hospital. The subway system, the lifeblood of the City, was flooded and shut down for 3-4 days. Figure 3 shows that although Sandy was an unusual event with a return time of about 250 years, nine storms in the 60 previous years had *almost* flooded the system¹¹, yet little or nothing had been done to protect it.

Much of the damage could have been averted by measures taken only *after* Sandy struck: hardening low-lying subway entrances and ventilation systems, raising emergency generators and fuel to upper floors of hospitals where they had sat basements, forbidding construction of new hospitals in the flood zone. The same sort of hardening and rezoning is underway or has been completed for existing substations.

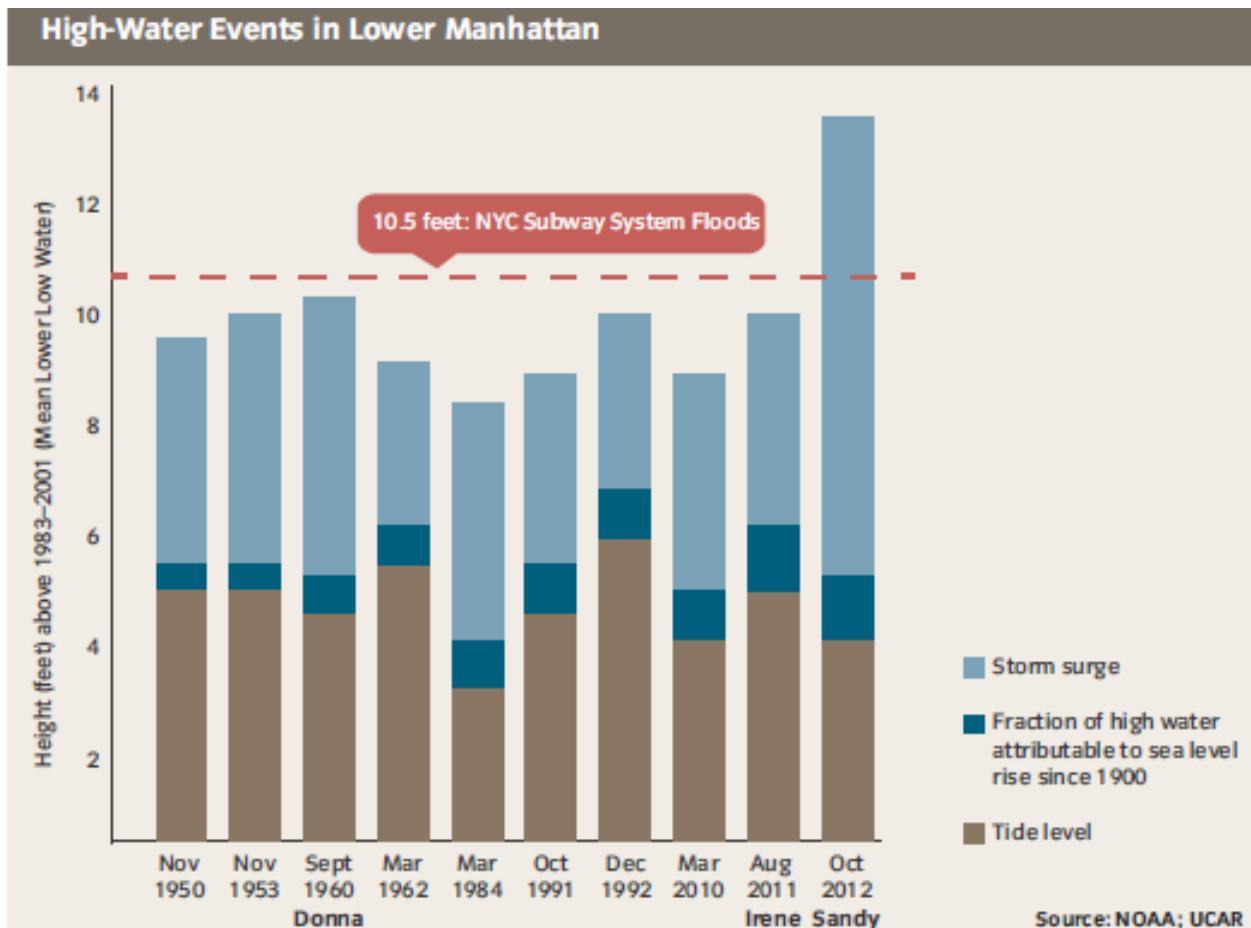


Figure 3: Nine highest flood levels at the southern tip of Manhattan (The Battery) preceding Hurricane

Sandy (tenth bar on right). Flood level where seawater enters the subway system indicated by red dashed horizontal line. Fraction of high-water due to sea level rise, tide, and storm surge indicated.¹¹

Ignoring even recent experience, and failing to adequately anticipate and adapt to extreme events was by no means unique to Hurricane Sandy, as Hurricane Katrina and the Texas cold snap vividly illustrate. The situation will grow more perilous as the probability of some extreme events continues to increase.

Lessons for other Climate Change Risks

Some systematic problems with the US approach to climate adaptation, like those plaguing the National Flood Insurance Program, are unique to governmental arrangements for coastal and inland flood preparation. Other such failings inhibit attempts to design effective climate adaptation across the board. While our understanding continues to evolve, the social science and psychology literature provides some explanations for the shortcomings discussed above.

- The general public's memory of even disastrous events is short. Along with the long implementation times for infrastructure projects like hard coastal protection, this reduces pressure on local officials to develop long term plans and initiate their implementation.
- Political rewards favor *ex post* cleanup to *ex ante* preparation because the public tends to see the latter in terms of its immediate cost to them while benefits may become obvious only years or decades into the future. This situation is exemplified and exacerbated by the relatively sparse federal funding for adaptation measures not tied to a specific disaster(s) compared to the vast sums spent *ex post* on clean up (e.g., under the Stafford Act). The result is a perverse incentive to local officials to continually defer adaptation actions.¹²

- Households sometimes take a single action to prepare in advance, like raising their houses above the level of a recent damaging flood, rather than a broad set of actions, e.g., purchasing insurance as well, just in case a yet higher flood event occurs. This “single-action bias” is especially troublesome when households assume that a government action is sufficient, like dune restoration, and take no further action to reduce the risk to lives and property.¹³
- States and localities often lack sufficient revenue to execute large scale adaptation projects without substantial federal assistance. In the case of coastal and inland flooding, resources dedicated to the US Army Corps of Engineers partially meet these local needs but it is doubtful whether appropriations and priority setting are aligned with the increasing risk from climate change. Other areas of risk, like wildfire on private land, lack any established federal adaptation funding, planning, or insurance role.
- As illustrated by the case of the failure of the New Orleans evacuation plan when Hurricane Katrina made landfall (see next section), characteristics of vulnerable groups are often not accounted for when designing either adaptation or emergency response. Questions over looming gentrification¹⁴ have been raised about Miami’s response to increasing tidal flooding and about some of the voluntary buyout programs implemented in the wake of Hurricane Sandy. Some of this reflects the realities of the real estate market but program design is also a concern.

My bottom line is that the current US system for dealing with climate adaptation is highly fragmented across many dimensions, is performing far from adequately to meet today’s level of risk, and must be reformed across the board to keep from falling far, far behind as risk increases. Furthermore, as mentioned above and as we now show in the context of extreme heat, under some circumstances, adaptation planning aggravates rather than ameliorates the problems of vulnerable populations.

Extreme Heat and Impacts on Vulnerable Populations

Some populations are more vulnerable than others to a range of climate impacts whether due to age, illness, persistent racial discrimination, or economic status. Any federal program to assure effective climate adaptation must address this inequality or it will fail a significant portion of the US population. I'll use the example of extreme heat to illustrate how this unequal distribution of vulnerabilities plays out in practice.

Extreme heat is the leading cause of climate-related death in the US. Heat is a contributory cause of about 700 deaths per year as indicated by death certificates. Heat also plays an indirect role as indicated by the much larger number of excess deaths attributed to high temperature, as many as 19,000 per year in one study.¹⁵ Climate change will bring more frequent, more intense, and longer heat wave episodes. How we adapt will be critically important to avoiding a large increase in mortality, morbidity, and economic losses. Evidence between 1987-2005 suggests a decrease in heat-related deaths for the overall population but the constant death rate found for people 65 years and older is troubling.¹⁶

Adaptation to extreme heat is largely relegated to the household level and commonly includes air conditioning as well as behavior changes like shifts to less exertion and wearing lighter clothing. However, among the tens of millions living in the densest parts of urban areas where temperatures are generally several degrees above those of the surrounding countryside, are found many residents who cannot afford air conditioning. Many of them are among the aforementioned vulnerable groups as a consequence of race, income, health status, or age.

The frequent failure of governments to account for such differences in vulnerability was perhaps best illustrated during Hurricane Katrina – the New Orleans emergency evacuation plan was developed with the assumption that all residents had access to motor vehicles and could drive out of town. This assumption made no sense for a city whose residents were disproportionately of low income. Partially as a result, many people wound up in the Superdome or drowned. A similar lack of

attention to vulnerable groups seems to characterize urban responses to heat emergencies.

Cities deal with this risk by establishing cooling centers. However, as shown by one recent study¹⁷ of three US cities (Phoenix, New York, and Chicago), the locations of these centers bear no systematic relationship to the vulnerable populations that need them most and distances from their neighborhoods to cooling centers were often such as to make them effectively inaccessible to those aged, ill, or without access to a motor vehicle. Furthermore, days and hours of operation varied inexplicably from center to center.

Multidisciplinary Research to Address Climate Change

It should be apparent from the examples above that managing the climate change problem successfully requires a solid basis not just in the physical climate sciences (for which support certainly needs to be maintained and strengthened) but the social sciences, psychology, and climate economics, and for joint collaborations among these specialties. Such multidisciplinary research shouldn't mean experts burrowing ever deeper into their professional silos, then coming together periodically to share insights over lunch before returning to their silos. Rather, it means that specialists should assemble teams that are truly multidisciplinary and work together, sharing methods, and developing questions and answers in close collaboration. Universities were slow to realize what sort of arrangements for research and graduate education this requires but gradually, they are changing. None have solved the problem of how to do this optimally but many experiments are afoot, including on my own campus. The National Science Foundation has played a leadership role in supporting such efforts in the past but resources for the social sciences remain inadequate to fund multidisciplinary research. That would be my top priority for NSF and other agencies that consider it

their mission to actually solve problems relevant to climate change that fall on real people.

Other priorities that are more specific to coastal defense, extreme heat, and other issues discussed in this testimony are too numerous to mention so here are my top 3 - my apologies for the many I have slighted. The first draws on traditional approaches but I place it there to underscore its importance.

- Continue and expand polar research programs including modeling of ice sheets and the ocean-ice sheet interaction, measurements and remote observations, because the fate of the ice sheets is a key unknown in projecting sea level rise.
- Expand research programs on voluntary migration, involuntary population displacement, and other forms of human mobility likely to be intensified by climate change. This requires a broadly multidisciplinary effort.
- Develop a comprehensive program to support research on adaptation to climate change including when, how, and why people make decisions about risk, what information these are based on, what actions result under which circumstances, and policies to encourage responses that are effective from both individual and collective perspectives.

Conclusion

Let us assume for the moment that the world, hopefully led by this country, attains the Paris Agreement's long-term objective. Even then, a large-scale, well-planned US adaptation effort, coordinated across the complex layers of government in our federal system, and adequately funded decade after decade, will be required to avoid calamity for many.

Absent such a program, the unavoidable warming that will occur, including what is already baked into the climate system, will cause more difficulties than much of the US population, not to mention the rest of humanity, can deal with.

On the other hand, if rapid, deep reductions in greenhouse gas emissions are not implemented, then we will eventually find ourselves in situations beyond our capacities to successfully adapt. Every few tenths of a degree of warming will bring more and more extreme heat, sea level rise, wildfire, decreases in access to water, and ecological destruction, accompanied by a panoply of social and political challenges.

Neither emissions reductions alone nor adaptation alone are sufficient. Only the combination of strong, persistent adaptation efforts coupled with transformation of our energy systems and modification of lifestyles sufficient to bring emissions sharply down to zero will solve the climate problem.

Only if both emissions reduction and adaptation are designed and implemented with our most vulnerable groups at the table rather than an afterthought, or as too often happens today, overlooked entirely, is the political consensus for this monumental task likely to gel. In this case, “vulnerable” includes not just those vulnerable groups I mentioned above in the context of adaptation, but also those who might come out at the losing end of the energy transformation needed to meet these challenges.

I’d like to thank the committee once again for affording me the opportunity to testify.

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