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THE SCIENCE OF EXTREME EVENT ATTRIBUTION: HOW CLIMATE CHANGE IS FUELING SEVERE WEATHER EVENTS

HEARING

BEFORE THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

UNITED STATES SENATE

ONE HUNDRED EIGHTEENTH CONGRESS

FIRST SESSION

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COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

ONE HUNDRED EIGHTEENTH CONGRESS

FIRST SESSION

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C O N T E N T S

THE SCIENCE OF EXTREME EVENT ATTRIBUTION: HOW CLIMATE CHANGE IS FUELING SEVERE WEATHER EVENTS

WEDNESDAY, NOVEMBER 1, 2023

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, DC.

The Committee met, pursuant to notice, at 10:01 a.m. in room 406, Dirksen Senate Office Building, Hon. Thomas R. Carper (Chairman of the Committee) presiding.

Present: Senators Carper, Capito, Whitehouse, Merkley, Markey, Kelly, Padilla, and Boozman.

OPENING STATEMENT OF HON. THOMAS R. CARPER, U.S. SENATOR FROM THE STATE OF DELAWARE

Senator CARPER. Good morning, everyone. I am pleased to call the hearing to order.

Today, as you know, we are gathered to discuss a field of climate science known as extreme event attribution. My guess is you ask 100 people in this country what they think that means, they wouldn't have a clue. Until a couple of weeks ago, some of us would not have, either. But when we leave here today, hopefully we will know it and not just understand it ourselves, but actually be able to explain it to others.

I am told that this may be the first ever congressional hearing on the topic of extreme event attribution. To understand why we are holding today's hearing, I think it might be helpful to ask and answer a few questions.

First, what is extreme event attribution anyway? Besides being quite a mouthful, extreme event attribution looks at how a specific extreme weather event, such as a particular heat wave or flood, was made worse by climate change.

Second, why is this kind of climate science important, real important? To answer that question, we need to first acknowledge the fact that human caused climate change is increasing the frequency of extreme weather events.

Earlier this year, the American Meteorological Society issued a report by many of our Nation's leading climate scientists and meteorologists. That report detailed, as I am sure our witnesses know, how climate change has driven unprecedented heat waves, floods, and droughts this year and in recent years. We know that continues to be the case.

When Phoenix, Arizona, experiences an unprecedented 31 days of temperatures at or above 110 degrees Fahrenheit as they did this summer, or when historic rainfall leads to severe flooding in places like Florida and Vermont as it did this year, many of us find ourselves asking, is climate change to blame for this? The honest answer is yes, yes, it is.

It is true that we have always had heat waves, at least for as long as I have been around, 76 years. But it is also true that climate change is making them more intense. So, the better question to ask ourselves is, how much worse did climate change make this heat wave, or how much worse did it make that flood? That is the kind of question that extreme event attribution scientists, including at least one of our witnesses, Dr. Wehner, work to answer. These questions matter because the human harms and costs of climate change are massive, and sadly, they are growing.

As many of our colleagues know, I represent the lowest lying State in our Nation, Delaware. In Delaware, we are already losing our dunes, we are losing our wetlands to sea level rise and nor'easters. As we work to repair our homes, businesses, and infrastructure and replenish our beaches damaged by these events, we are already paying for the costs of climate change.

But this hearing is not just about Delaware. It is a hearing about 49 other States and a planet that we all share with people around the world. We are grappling with the costs of climate change.

Today, we are going to focus on how it is fueling extreme weather, and maybe even more important, what we can do about it.

Now, in one sense, climate change is already affecting every aspect of our weather. Overall, NASA tells us that global temperatures have increased a little more than 1 degree Celsius, that is about 2 degrees Fahrenheit, since 1880. That is due mostly to human caused climate change.

Because our planet is warmer, on average, the hot days are becoming hotter. And because a warmer atmosphere holds more water vapor, rain storms are growing more intense.

Warmer oceans are also producing stronger hurricanes. Last week, we saw Hurricane Otis wreak havoc, wreak devastation in Mexico when it rapidly intensified from a Category 1 storm to a Category 5 in less than 10 hours. Think about that. Less than 10 hours. I couldn't believe it, but it is true.

Let me close and turn it over to Senator Capito, but first let me say, you and I don't experience planetary averages. We live through, and we clean up from, and we pay for specific weather disasters. Extreme event attribution science helps us to explain these events.

So, recognizing that we as a planet must prepare for more frequent and intense weather in the future, and as elected leaders we also need to understand what to expect in our States and our communities. How much worse will our heat waves become in the years to come? How likely is it that a community will experience an even larger flood next time?

Extreme event attribution science is helping us answer those questions, as well. The ability to do so will be critical as we plan future infrastructure projects, we work a lot on that kind of stuff here in this Committee. We wrote big parts of the Bipartisan Infra-

structure Bill, this lady right here and I, and we had the privilege of managing it on the floor, one of the biggest infrastructure bills in the history of the country.

Making more informed policy decisions will help us protect more Americans from extreme weather and allow us to use taxpayer dollars more effectively.

Let me close by reminding everyone that while climate change is driving extreme weather, we are not helpless, and we are not hopeless. The situation is not hopeless. Working together, we can prevent the worst impacts of global warming by reducing greenhouse gas emissions. And that is what we are doing.

Thanks to the Bipartisan Infrastructure Bill that I just mentioned and the Inflation Reduction Act, we are beginning to turn this adversity into opportunity. Importantly, we are doing so in a way that invests in American made clean energy, lowers energy costs, creates good paying jobs all over the country, and makes communities all over the country more resilient.

Still, it is important to acknowledge that we have a lot more work to do ahead of us to tackle this challenge. So, as we take those steps to better prepare for extreme weather and manage its impacts, extreme event attribution can be an important tool.

With that, we look forward to hearing from our witnesses today about how communities can better understand and anticipate what is coming and increase their resilience to climate fueled extreme weather.

Before we do that, we will hear from our Ranking Member, Senator Capito, for her opening statement.

Senator Capito, welcome. You are recognized. Thank you.

OPENING STATEMENT OF HON. SHELLEY MOORE CAPITO, U.S. SENATOR FROM THE STATE OF WEST VIRGINIA

Senator CAPITO. Thank you, Chairman Carper.

Before I begin, I have a throat lozenge in my mouth, so if I sound weird, or if I start choking, I would ask you to help me out.

[Laughter.]

Senator CAPITO. So I apologize for that. It is preventing me from coughing.

Senator CARPER. I can see the headline: "Carper saves Capito from throat lozenge."

Senator CAPITO. An extreme throat event.

Anyway, I want to thank our witnesses and our Committee for its strong bipartisan work to reduce emissions and make our infrastructure more resilient. The Chairman talked about that.

Legislation such as the USE IT Act, reducing barriers to the deployment of carbon capture, the AIM Act, directing a phasedown of heat trapping HFCs, the Nuclear Energy Innovation and Modernization Act, supporting carbon free nuclear energy, and the Infrastructure Investment and Jobs Act that the Chairman talked about, with its investments in emissions reductions and resiliency, all passed in a bipartisan way.

As we continue to build on that record by passing the ADVANCE Act in the NDAA to help deploy advanced nuclear reactors and technologies, as well as to renew our efforts on passing a permitting bill that will allow us to unlock American innovation across all

types of technologies and bring American manufacturing back home.

Several provisions of the IIJA are especially relevant to today's topic. That law's reauthorization of our surface transportation programs included a climate title for the very first time, establishing formula programs to help States build more resilient infrastructure and reduce certain emissions.

The law also included funding for hydrogen hubs, like the Appalachian Regional Clean Hydrogen Hub, known as ARCH2, that will benefit my State of West Virginia and our region.

And the IIJA included $25 million to help EPA process Class VI permits and $50 million to help States obtain primacy for permitting Class VI wells, a necessary step toward broader deployment of carbon capture and storage.

Despite the resources we provided in the IIJA, the EPA has not granted Class VI primacy to any State under this Administration, nor has EPA granted an individual Class VI permit to store carbon dioxide since the Obama administration, with 169 Class VI wells now waiting to be permitted, under the EPA.

Commercial scale deployment of carbon capture and storage I think is vital if we are to meet our energy reliability needs while also addressing emissions. The Administration must quickly review and process Class VI primacy applications from States, as well as individual permit applications for projects in States without primacy.

As our bipartisan work continues, there is widespread agreement that the climate is changing and that greenhouse gas emissions are contributing to that change. But I am not sure that is the focus of the hearing. I am not sure that the focus of the hearing is on that scientific consensus.

At the end of the Obama administration, the National Oceanic and Atmospheric Administration published a question and answer page about extreme event attribution that remains on the agency's climate.gov website today.

One question posed there is, "What can't extreme event attribution tell us?" I will enter the entirety of the answer into the hearing record, but the short answer is it can't tell us whether global warming caused a specific event. With global warming and extreme events, it is not a yes or no question.

I want to be clear: This does not mean that climate change has no impact on the intensity of weather patterns. The trends are clear, and we need to be ready, and with technologies and adaptation strategies like those I have described, are policy areas about which this Committee has demonstrated expertise.

It is critical and crucial that we have effective solutions that reduce flood risk and coastal storm risk across the country.

Since 2014, the Committee has kept to a biennial schedule of passing bipartisan water resources legislation to advance these solutions. And I look forward to continuing this track record; we have already had several hearings, with our next, latest WRDA bill.

By contrast, I think some regressive regulatory policies or carbon taxes that pick winners and losers could inhibit our U.S. energy production disproportionately and will harm our most vulnerable communities through lost opportunities and displaced jobs. Rising

energy costs and weakening of our grid will leave these constituents without access to affordable electricity and other basic necessities. Recognizing this, the government should not put in place a one size fits all regulatory mandate.

Successful climate technologies of the future may not even exist today, so we need to make sure we provide the adequate conditions for necessary innovation to take place. So I think there are reasons to be optimistic, and the Chairman shared that optimism. American innovation will rise to the occasion.

I am interested in today's discussion of developing research, but I will be more interested to hear from our panel on what we should do today to build on the Committee's record of bipartisan solutions.

Thank you, Mr. Chairman.

Senator CARPER. Thank you very much, Senator Capito. ARCH is the name of your hydrogen hub, ARCH2?

Senator CAPITO. It is, ARCH2.

Senator CARPER. That includes also Ohio and Pennsylvania?

Senator CAPITO. Southwest Pennsylvania, yes.

Senator CARPER. First time I had ever heard of Arch, Arch One, was your father.

Senator CAPITO. That is why I can remember the name.

Senator CARPER. He was Governor of West Virginia when my sister and I were little kids in Lavinia and Raleigh Counties, West Virginia. Arch Three could be another member of your family.

Senator CAPITO. I have a grandson named Arch, so I have Arch Two.

Senator CARPER. And she has a son who, off the record, is running for Governor of the State of West Virginia, which is a great job.

Now we are going to turn to our panel of esteemed witnesses.

We are grateful to each of you for joining us today to discuss this important topic.

We are going to hear from our witnesses in this order. Dr. Michael Wehner is our lead off hitter. The second witness will be Jennifer Jurado, and last but not least, we are going to hear from Paul Dabbar.

Let me just say a word about each of our witnesses.

Dr. Michael Wehner is a senior scientist within the Applied Mathematics and Computational Research Division at the U.S. Department of Energy Lawrence Berkeley National Lab, whose research focuses on extreme weather and a changing climate. Dr. Wehner was the lead author for the 2013 Fifth and 2021 Sixth Assessment Report of the Intergovernmental Panel on Climate Change. He was also lead author for the second, third, fourth, and upcoming fifth U.S. National Climate Assessment.

Our second witness is Dr. Jennifer Jurado, Chief Resilience Officer and Deputy Department Director for Broward County, Florida. In this role, Dr. Jurado is responsible for leading climate resilience and environmental planning initiatives for Broward County.

Then we are going to hear from Paul Dabbar, Former Under Secretary for Science at the U.S. Department of Energy. Mr. Dabbar is also a senior research scholar at Columbia University and serves as CEO of Bohr Quantum Technology.

In reading through the bios, I came across someone who may have served in the Navy, is that true?

Mr. WEHNER. Yes, sir, Naval Academy.

Senator CARPER. Naval Academy, good for you. I got wait listed there, I had to go to Ohio State. But I turned out OK. So did you.

All right, with that in mind, we are going to hear from Dr. Wehner.

Please proceed with your statement. Your entire statement will be made part of the record. Then we will hear from our other witnesses; then we will ask some questions.

Thank you. Welcome.

STATEMENT OF MICHAEL F. WEHNER, PH.D., SENIOR SCIENTIST, APPLIED MATHEMATICS AND COMPUTATIONAL RESEARCH DIVISION, LAWRENCE BERKELEY NATIONAL LABORATORY

Mr. WEHNER. Thank you, Chairman Carper, Ranking Member Capito, and distinguished members of the Committee.

Good morning, and thank you for the invitation to testify at this important hearing on the science of extreme weather event attribution.

As you said, my research focuses on the behavior of extreme weather events and the changing climate. I must say that my remarks are my own, and not intended to represent positions of the Lawrence Berkeley National Laboratory, the University of California, or the United States Department of Energy.

According to the U.S. National Climate Assessments Annual Report to the Intergovernmental Panel on Climate Change, it is unequivocal that humans have heated the Earth's climate. The best estimate is that human activities, principally the use of oil, coal, and gas, is responsible for all of the observed global warming since 1900.

Our understanding about the effects of this human caused global warming on specific, individual weather events has advanced considerably in the past two decades. For many types of weather events, scientists can identify and quantify the ways that the human interference in the climate system has influenced extreme weather.

Obviously, as you said, we have always experienced extreme weather: Heatwaves, droughts, extreme storms, and the like. But extreme weather attribution science attempts to quantify the influence of climate change on these specific individual events by answering two related questions. First, has global warming affected the severity of an event of a particular frequency, say, once in 100 years? And second, given the observed intensity of an event, has global warming affected how rare it is? And I detailed this a little bit more in my written testimony.

Because we have only one planet Earth, to answer these questions, scientists must use both climate and statistical models to compare representations of weather events in the actual "world that was" to a "world that might have been" without climate change. Confidence is increased when multiple independent research teams use different approaches and arrive at similar conclusions consistent with observed trends.

Confidence in quantitative attribution statements is very high about the human influence on heatwaves, agricultural drought, and certain classes of severe storms, including hurricanes. Indeed, as the Earth warms, every heatwave that we now experience is hotter than it would have been without climate change, including those this past summer in the United States and throughout the Northern Hemisphere.

Throughout the lower 48 States, I estimate that any heatwave we now experience is 2 and a half to 5 degrees Fahrenheit hotter than it would have been. All Americans face increased health risks from these hotter heatwaves, particularly the very young, the very old, and the very poor in our society.

Extreme storms have been made wetter by climate change as well. For instance, of the more than 30 different hurricanes have been studied in an attribution context, all analyses reveals significant human fingerprint on the total rainfall amounts.

Recent advances in attribution science have gone beyond studying the human influence on the meteorology of extreme weather events to include the impacts of these events on real people. Take Hurricane Harvey and the record flooding it caused in the greater Houston area, for example. Global warming made the surface waters of the Gulf of Mexico about 2 degrees Fahrenheit warmer, increasing the rainfall during Hurricane Harvey by about 20 percent. This increased the area flooded by about 14 percent, importantly leading to a 32 percent increase in the number of flooded homes in Harris County.

I estimate that global warming is then responsible for about a third of the $150 billion in damages estimated by NOAA during Hurricane Harvey. These damages were not equally distributed across socioeconomic groups. Half of these flooded homes were in low income, Hispanic neighborhoods. As about a third of Harris County is characterized as low income Hispanic, this disproportionate impact represents an environmental injustice, in my opinion. We are finding similar injustice to the most vulnerable of our society in an analysis of flooding in New York, New Jersey, Pennsylvania from the remnants of Hurricane Ida.

This recent extension of attribution science from weather to impacts could be informative in negotiation for the Loss and Damages Fund to aid nations particularly vulnerable to climate change. This fund was established but not financed at last year's meeting of the Conference of Parties, the COP27, part of the United Nations framework convention on climate change, and will certainly be one of the topics discussed later this month at the COP28 in Dubai.

The human influence on extreme weather and its impacts on people is quite clear. I am often asked, why do we do these attribution studies? I have three answers to this question. First, the public demand for information about how climate change affects them personally is very high. People want to know.

Second, increasing the number and variety of individual extreme events studied increases our understanding of the extent of the human influence on them. And third, and perhaps most importantly, our quantitative understanding can aid decisionmakers, increasing the resilience of our society to a future, hotter world.

Extreme weather event attribution has shown us that dangerous climate change is already happening. How much more dangerous we let it become is up to us.

Thank you, and I welcome your questions.

[The prepared statement of Mr. Wehner follows:]

Testimony of Dr. Michael Wehner
Senate Environment and Public Works Committee
The Science of Extreme Event Attribution: How Climate Change Is Fueling Severe Weather Events

Chairman Carper, Ranking Member Capito and distinguished Members of the Committee, good morning and thank you for the invitation to testify at this important hearing on the science of extreme weather event attribution. I am Dr. Michael Wehner, a senior scientist at the Lawrence Berkeley National Laboratory. My research focuses on the behavior of extreme weather events in a changing climate. My remarks are my own and not intended to represent the positions of the Lawrence Berkeley National Laboratory, the University of California, or the United States Department of Energy.

According to both the US National Climate Assessments and the reports of the Intergovernmental Panel on Climate Change, it is unequivocal that humans have heated the Earth's climate. Indeed, the best estimate is that human activities, principally the use of oil, coal and gas are responsible for all of the observed global warming.

Our understanding about the effects of this human-caused global warming on specific, individual extreme weather events has advanced considerably in the past two decades. Indeed, for many types of weather events, scientists can identify and quantify the ways that the human interference in the climate system has influenced extreme weather. Obviously, we have always experienced extreme weather: heatwaves, droughts, extreme storms, and the like. Extreme weather attribution science attempts to quantify the influence of climate change on specific individual events by answering two related questions. First, has global warming affected the severity of an event of a particular frequency (say, once in a century)? And second, given the observed magnitude or intensity of an event, has global warming affected its rarity.

Because we have only one planet Earth, to answer these questions, scientists must use both climate and statistical models to compare representations of weather events in the actual "world that was" to a counterfactual "world that might have been" without climate change. Confidence in attribution statements is increased when multiple independent author teams use different approaches and arrive at similar conclusions consistent with observed trends. Confidence in quantitative attribution statements is very high about the human influence on heatwaves, agricultural drought and certain classes of severe storms, including hurricanes.

The graph in figure 1 of extreme temperatures in the Pacific Northwest shows how our two attribution questions are two sides of the same coin. Temperatures on the y-axis are plotted as a function of their rarity on the x-axis. The red curve is a simulation of the "world that was" with a realistic as possible representation of the composition of the atmosphere. The blue curve is a simulation of the "world that might have been" without the human changes to the composition of the atmosphere. To answer the first question, we would draw a vertical line down from the observed temperature on the red curve, say for example 106.8^{o}F, finding that it is a once in a century event. We then estimate that without climate change from the blue

curve, that the once in a century event would have been 104.2°F or 2.6°F cooler. Hence, global warming caused such heatwaves to be 2.6°F hotter. To answer the second question, we would draw a horizontal line from the observed temperature on the red curve to the same temperature on the blue curve finding that what is now a 100 year event would have been a once in 1500 year event without climate change. Hence, global warming increased the chances of experiencing such an observed temperature by a factor of 15. This example illustrates that framing of the attribution question is an important consideration when communicating the influence of climate change, if any, on individual extreme weather events.

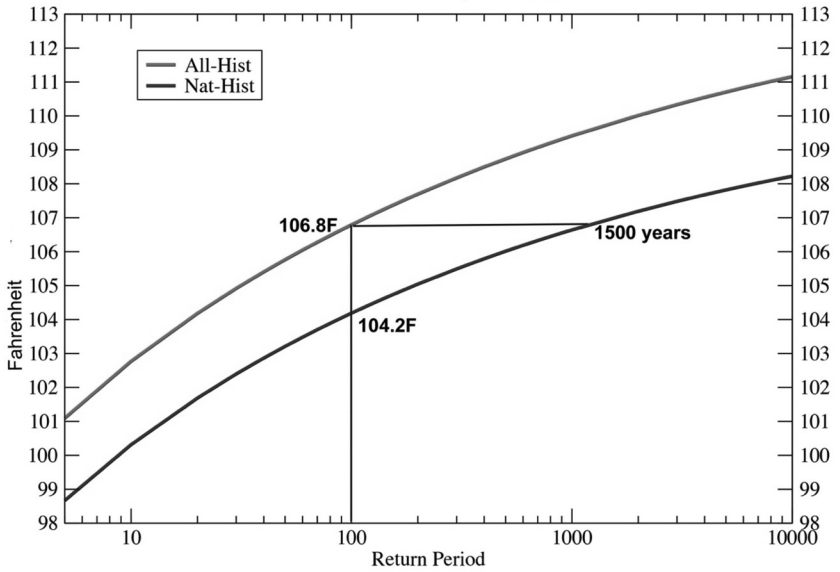

Figure 1: Analysis of the human influence on Pacific Northwest heatwaves using the Community Atmospheric Model (CAM5)[1,2]. What was a once in 1500 years event is now a once in a century event because of global warming.

It is also important to note that in a high quality attribution study, multiple climate models and observational datasets should be used if possible and a full analysis of the statistical confidence disclosed. Oftentimes, the calibrated language[3] of the Intergovernmental Panel on Climate Change (IPCC) is used to convey statistical analysis in plain language. For instance, the phrase "global warming *very likely* increased the chances of an event by *at least* a factor of X" is a very conservative statement. The key words in this sentence are "*very likely*" and "*at least*" as they are meant to convey that X is the lower bound of a 90% confidence interval on the estimated change in rarity. Any "best estimate" of such a change would generally be considerably larger.

Indeed, as the Earth warms, every one that we now experience is hotter than it would have been without climate change, including those this past summer in the United States and throughout the Northern Hemisphere. In the lower 48 states, I estimate that any heatwave of reasonable rarity is now 2.5 to 5 degrees Fahrenheit hotter than it would have been without the human interference in the climate system[2] as shown in figure 2. This increase has adverse health effects, including possible death, on all Americans but particularly the very young, the very old and the very poor. For instance, extreme heatwaves in California often lead to excess hospitalization and morbidity rates of outside laborers especially agricultural workers, many of whom are in the Latino/Latina community[4].

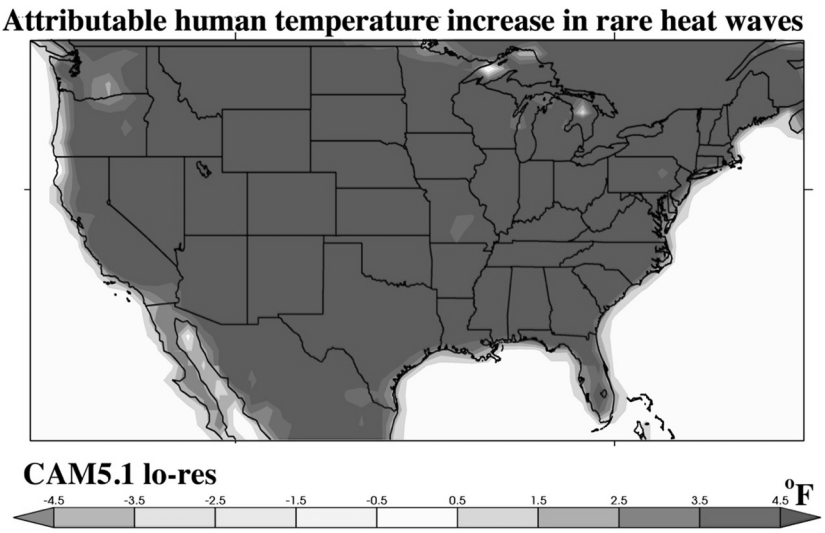

Figure 2: Attributable change in once in 20 year single day heatwaves as simulated by the Community Atmospheric Model (CAM5)[1,2]. Results are essentially the same for heatwaves of greater rarity.

Extreme storms have been made wetter by climate change as well. For instance, of the more than 30 different hurricanes that have been studied in an attribution context, all of the analyses reveal a significant human fingerprint on the total rainfall amounts[5–8]. Generally, these human induced increases in hurricane rainfall amount exceed that expected from the human induced thermodynamic increases in available moisture. Figure 3 and supporting literature reveal that the parts of hurricanes that rain the most experience the largest increase and become more efficient at raining out the increased moisture from the warmer saturated air due to climate change[9,10]. Shown is a "storyline" analysis of Hurricane Maria, a storm that devastated much of Puerto Rico in September 2017[6].

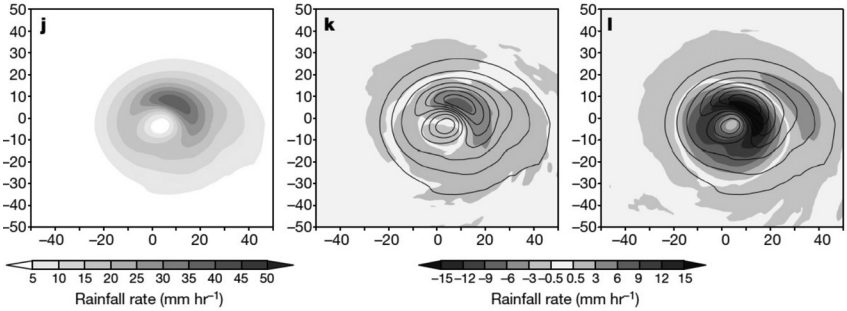

Figure 3: Left: A composite hindcast simulation of Hurricane Maria's rainfall. Center: The pattern of attributable rainfall changes under the current amount of climate change. Right: The pattern of projected rainfall changes at the end of the century under a "no-policy" high emissions scenario (RCP8.5).

I, along with many of my colleagues, feel that the state of the science has matured to the point that for certain extreme weather events, attribution statements could be made operational[9,11,12]. By that I mean that this responsibility could be transferred from the academic research community to an appropriate Federal agency capable of producing extreme weather event attribution statements on a regular basis. Indeed, several nations are considering doing this both to satisfy the public demand for this sort of information as well as increasing our scientific understanding.

Recent advances in attribution science have gone beyond just studying the human influence on the meteorology of extreme weather events to examine the human influence on the impacts that these events have on real people. Take Hurricane Harvey and the record flooding it caused in the greater Houston area. Global warming caused the surface waters of the Gulf of Mexico to be about 2 degrees Fahrenheit warmer than before the widespread use of coal, oil, and gas. These warmer waters caused the rainfall during Hurricane Harvey to be about 20% greater[13–15]. This increased rainfall caused the flooded area to increase by about 14%[16]. Because much of the flooding was in densely populated areas, using this estimate of the attributable increase in flooded area, the number of flooded homes in Harris County was increased by even more – by about 32%[17]. NOAA estimates about 155 billion dollars in damages occurred due to Hurricane Harvey flooding (https://www.ncei.noaa.gov/access/billions/dcmi.pdf) , so a crude estimate is that global warming is responsible for about one third of this amount, or 50 billion dollars.

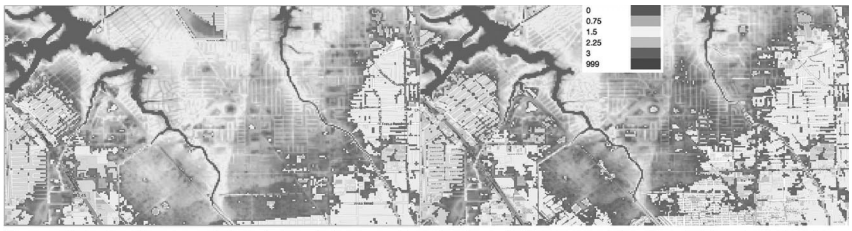

Figure 4: Left: Simulated flood depth (meters) in the South Houston, Texas neighborhood using observed Hurricane Harvey rainfall amounts. Right: Simulated flood depth in the South Houston, Texas neighborhood without climate change if global warming caused a 19% increase in Harvey's rainfall. If there was less rain, the flood would cover less area and be about 4 feet shallower in this neighborhood[16,18].

Figure 5: Climate Change-Attributed Flooding of buildings (Worst case:38% Scenario) in Harris County, Texas during Hurricane Harvey[17].

These damages were not equally distributed across socioeconomic groups. Half of these flooded homes were in low-income Hispanic neighborhoods[17]. As about third of Harris County is characterized as low-income Hispanic, this disproportionate impact represents an environmental injustice. We are finding similar injustice to the most vulnerable of our society in

an analysis of flooding in New York, New Jersey, and Pennsylvania from the remnants of Hurricane Ida: the most vulnerable portion of the local population was disproportionately affected, and climate change exacerbated this injustice[19].

This recent extension of attribution science from weather to impacts could be informative in the negotiations for the Loss and Damages fund to aid nations "particularly vulnerable" to climate change. This fund was established, but not financed, at last year's meeting of the Conference of Parties (COP27), part of the United Nations Framework Convention on Climate Change, and will certainly be one of the topics discussed later this month at COP28 in Dubai (https://unfccc.int/event/cma-4).

As my examples show, confidence in quantitative attribution statements is very high for heatwaves and certain classes of severe storms. As a member of the lead author team for the IPCC 6th Assessment chapter on extreme weather[20], we developed a protocol[21] for assessing confidence in attribution statements published in the scientific literature as shown in the flowchart of figure 6. As you can see, in order to assess "high confidence" as defined in the IPCC calibrated language[3], multiple and consistent lines of evidence from different author teams using different methods and datasets were required. Any single credible study, if assessed, was deemed "low confidence". However, it is important to note that "low confidence" in the IPCC calibrated language is not to be interpreted as no confidence.

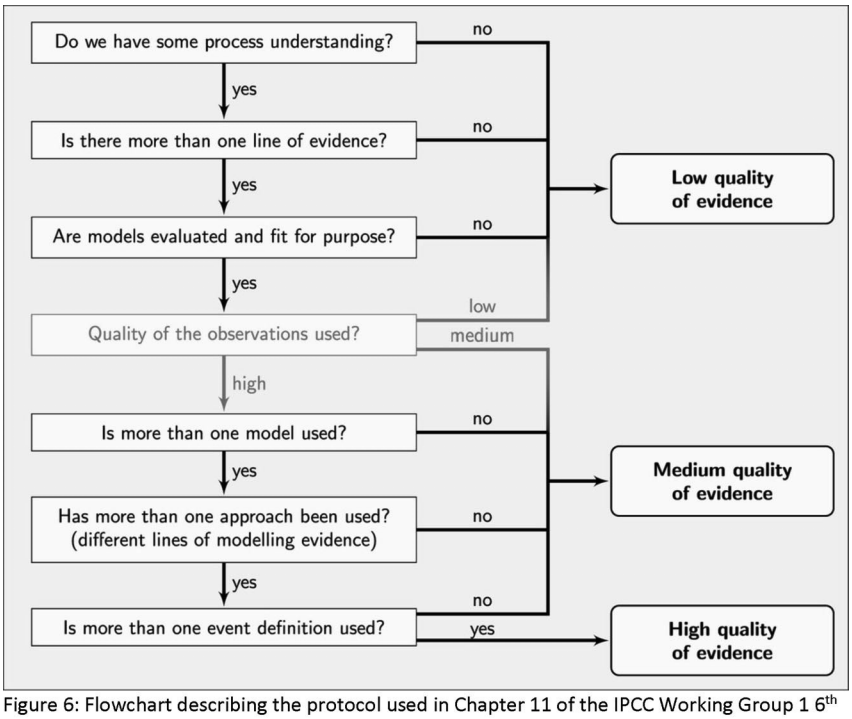

Figure 6: Flowchart describing the protocol used in Chapter 11 of the IPCC Working Group 1 6th Assessment Report to assess confidence in extreme event attribution statements.

The human influence on extreme weather and its impacts on people is quite clear. I am often asked why do we do these attribution studies. There are three answers to this question. First, the public demand for information of how climate change affects them personally is very high. Second, increasing the number and variety of individual extreme weather events studied increases our understanding of the extent of the human influence on them. Third, such quantitative understanding can aid decisionmakers in increasing the resilience of our society to a future yet warmer world.

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2. Wehner, M. *et al.* Early 21st century anthropogenic changes in extremely hot days as simulated by the C20C+ detection and attribution multi-model ensemble. *Weather Clim. Extrem.* **20**, 1–8 (2018).
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Senate Committee on Environment and Public Works
Hearing Entitled *"The Science of Extreme Event Attribution: How Climate Change Is Fueling Severe Weather Events"*
November 1, 2023
Questions for the Record for Dr. Wehner

Chairman Carper:

1. Your testimony mentions that advancements in attribution science could be informative in the negotiations for the Loss and Damages fund to aid nations "particularly vulnerable" to climate change.

    a. Please elaborate on the role of attribution science in helping to quantify loss and damages from climate change.

    Dr. Wehner: The science of quantifying the human influence on the meteorology of extreme weather events has advanced considerably in the last two decades. Research is now turning towards quantifying the human influence on the impacts of these events. I call this "end to end" attribution as it requires a chain of causal inferences from the weather to the hazards that impact people. For instance, to estimate the fraction of financial damages attributable to human-caused climate change from hurricane fresh water flooding, one needs to first estimate the human-induced increase in the local sea surface temperature. Then, the human-induced increase in the storm's precipitation can be calculated, followed by a determination of the corresponding human-induced increase in freshwater flooding. Finally, by comparing these results to real estate and census data, the financial damages due to climate change can be calculated, and if applicable, a statement about environmental injustice can be made. Attributing loss and damages from other extreme weather events would follow a similar process, recognizing that each event and location is unique.

    In a recent commentary[1], we examined the relevance of extreme event attribution to the Loss & Damage Fund to aid "particularly vulnerable" nations that was established at the 27th Conference of Parties (COP27) and will be a topic debated at the upcoming COP28. According to the World Meteorological Organization, the deadliest weather events in developing nations are, in order, famine (or agricultural drought), tropical cyclones, non-tropical cyclone flooding, and heatwaves[2]. Indeed, much attention to these four categories of extreme weather has been paid by the extreme weather attribution community, and the science is well established. Hence, we felt that extreme weather event attribution is well positioned to inform negotiations of claims made to the Loss & Damage Fund. We also noted that such information would be made considerably more reliable by the involvement of physical and social climate scientists from those vulnerable nations.

Finally, I must mention that there are other sources of loss and damages from climate change other than extreme weather events. For instance, sea level rise can cause property damage, and higher average temperatures can influence crop productivity. In our commentary, we expressed concern that the assumptions behind current macroeconomic models may be too oversimplified to capture the nuance of damages from extreme weather and these other slower processes. In particular, we are concerned that estimates currently used to describe the costs of climate change are far too low. While "end to end" attribution may be able to capture part of the true costs of climate change, if focused on only selected events it will be overly conservative.

2. Improving our resilience to climate change is absolutely critical. According to the just-released Fifth U.S. National Climate Assessment, transformative adaptation is necessary to adequately address the risks of current and future climate change.

    a. What would you expect to see in terms of extreme weather in the next few decades?

    Dr. Wehner: As one of the authors, I strongly agree with the findings of the Fifth U.S. National Climate Assessment (NCA5) and the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6). Each of these reports detail regional changes in extreme weather in the United States and its territories. The list of concerns in a future warmer world is long. We should expect:

    - Heat waves to be hotter;
    - Hurricanes and certain other classes of storms to have stronger winds and heavier rain;
    - Soils to be drier and hence more severe agricultural drought;
    - Storm surge to be higher due to both sea level rise and more intense storms;
    - Decreases in snowfall leading to reduced Western US mountain snowpack; and
    - Increased wildfire frequency and intensity.

    The risk of heat-induced illnesses will increase. The risk of coastal and inland flooding will increase. The risk of crop failure will increase. The risk of respiratory illness from poor air quality will increase.

    This list is certainly incomplete, and there are classes of extreme weather for which the influence of climate change is not fully understood. Of particular concern to me is how climate change affects the violent summer storms in the central United States that often involve tornadoes, hail and other damaging

weather. Advances in high performance computing are helping advance our understanding, but more progress is required.

3. How could the federal government operationalize the conduct of attribution studies, and what would be the benefits of doing so?

Dr. Wehner: The federal government already has the building blocks to operationalize the meteorological aspects of event attribution. By this, I am referring to the capabilities of the National Oceanic and Atmospheric Agency, in particular, the National Weather Service, the National Hurricane Center, the Climate Prediction Center, the National Centers for Environmental Prediction and the National Centers for Environmental Information. In my view, these organizations are second to none. Harnessing this expertise to utilize published attribution methodologies[3–5] would be of great benefit to the nation. Inclusion of other Federal agencies would benefit the extension of operational event attribution to impacts. I am pleased to note that some progress has been reported already in developing a U.S. rapid response capability for extreme temperatures and drought[6].

The first benefit would be that information provided to the public would be more reliable and complete than what the academic community can provide. The research community does not have the mandate nor the resources to investigate every extreme weather event of interest.

The second benefit would be in identifying and tracking the economic and human costs of climate change. These are certain to increase as the global climate continues to warm. As my oral and written testimony detailed, there are real disparities in the impacts of climate change within the United States. Generally, the disadvantaged portions of our society are both more severely impacted by an extreme weather event and are less able to respond afterwards. A more complete set of attribution studies could better enable an equitable Federal response to these disasters.

A third benefit would be to the scientific community. Expanding the number and types of extreme weather events examined in an attribution context and available by open access would increase our understanding of how climate change affects them. Thus, confidence in future projections of extreme weather changes in a warmer world would be increased.

4. Is there anything else that you would like to provide the Committee that was not included in your testimony or discussed during the hearing?

Dr. Wehner: The human influence on the climate system is unequivocal. The National Climate Assessments, the Intergovernmental Panel on Climate Change,

the World Meteorological Organization, and the National Academies of Sciences, Engineering, and Medicine (established by President Lincoln to advise the government on scientific issues) as well as the relevant scientific professional organizations all similarly state that human activities are the principal cause for the recent rapid observed warming and that there are no other credible explanations. Event attribution science has demonstrated how dangerous climate change has already become. The amount of future warming is not predetermined but rather controlled by our choices. It is clear that both adaptation measures and greenhouse gas emission reductions will be necessary to reduce the harmful impacts of climate change on the United States and the rest of the world.

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This work was supported by the Director, Office of Science, Office of Biological and Environmental Research of the U.S. Department of Energy under Contract No. DE340AC02-05CH11231 under the Regional and Global Model Analysis (RGMA) and Data Management Programs in the Earth and Environmental Systems Sciences Division.

Senator CARPER. Thanks very much for your testimony.

You mentioned one planet Earth, I heard that at one point in your testimony, you said one planet Earth. That reminds me of something, that, not a witness here, but a fellow who came from France a couple of years ago and spoke at a joint session of Congress, President Macron, he didn't say one planet Earth, but he did say, no planet B. He said, there is no planet B. We are only going to get one planet; this is it. We have to take care of it. I was reminded of his comments when you said that.

Next, we are going to hear from Dr. Jurado.

Dr. Jurado, we have already talked a little bit about your background. We are delighted that you are here. Please proceed.

STATEMENT OF JENNIFER JURADO, PH.D., CHIEF RESILIENCE OFFICER AND DEPUTY DIRECTOR, RESILIENT ENVIRONMENT DEPARTMENT, BROWARD COUNTY, STATE OF FLORIDA

Ms. JURADO. Good morning, Chairman Carper, Ranking Member Capito. Thank you for your leadership in convening this hearing today.

As you shared, I am the Chief Resilience Officer for Broward County, the 17th largest county in the U.S. and the second most populous in the State of Florida, with nearly 2 million residents. While we are leaders in many ways in adapting to a changing climate, we remain at the forefront of significant impacts.

South Florida is no stranger to extreme weather. To manage nearly 60 inches of rainfall we receive annually, we have made extensive investments in drainage, flood control, stormwater management systems. Even so, as we grapple with the impacts of climate change, the limitations of these investments are evident and record breaking events are becoming more damaging.

Most recently, on April 12th, 2023, a thunderstorm delivered an unprecedented 26 inches of rainfall in 12 hours, impacting much of our community. A 30 minute commute became a 3 hour navigation of flood waters. Flooded vehicles were abandoned en masse. The Fort Lauderdale-Hollywood International Airport closed for 40 hours. Fuel distribution from Port Everglades was disrupted, affecting 12 counties and 5 international airports. Water levels reached 2 to 3 feet in several older neighborhoods, and the city of Fort Lauderdale remains without a city hall. Yet this event occurred outside the hurricane season, a one in a 1,000 year rainfall event.

Less than 3 years earlier, Tropical Storm Eta delivered 22 inches of rainfall in 3 days. The 6 week rainfall total was four times the historic average in inland areas, some of which remained flooded for 2 weeks.

In 2017, an 18 inch rainfall event closed Sawgrass Mills, the region's largest shopping center, for 3 days. The economic loss was $30 million. These three extreme events all in the last 6 years account for the highest annual rainfall totals in the last 30, exceeding 88 inches in 2020.

Congress has helped to ensure South Florida remains dry during wet weather events. In 1948, Congress authorized the Central and Southern Florida Flood Control Project, the C&SF. It was con-

structed by the Army Corps of Engineers. Today, it serves 11 million residents, but it is under substantial stress, especially due to intense rainfall events and sea level rise.

Given these new extremes, we have advocated for a new look at the C&SF system, and thank the Committee for its authorization of the comprehensive study of this flood control project as part of the 2022 WRDA. Without this study and funding for improvements, our local efforts would not be as effective.

Of course, extreme conditions are not limited to flooding. This year, Broward County experienced 37 days with a heat index over 105 degrees Fahrenheit compared to an average of 5 days per year historically. We know that extreme heat disproportionately impacts the under-represented residents, outdoor workers, health compromised individuals, our youth and elders, affecting finances, earnings, and physical health.

To better prepare for extremes, Broward County has incorporated sea level rise and rainfall intensification in updated design standards for our drainage systems, seawalls, and building elevations. We are developing a countywide resilience plan to address both flood and heat risks with emphasis on green infrastructure, especially where heat islands and vulnerable communities intersect.

Although I am formally representing Broward County, I would like to highlight the efforts of our Southeast Florida Regional Climate Change Compact, a collaboration amongst Broward, Palm Beach, Miami Dade, and Monroe Counties to address shared climate challenges. Jointly, we are developing the priority climate action plan supported by the EPA's Climate Pollution Reduction Grant program under the Inflation Reduction Act, and expect to emphasize energy efficiency improvements in lower income housing.

We have also pursued grant proposals under NOAA's recent Coastal Resilience Challenge, and strongly support additional funding along these lines.

Additional Federal collaborations and programs aiding our efforts include modeling and monitoring supported by the USGS, technical assistance of NOAA, the Corps, USGS in providing future conditions guidance for planning, DOE grant support for electric vehicle charging infrastructure, the IRA's Direct Pay Tax Credits, aiding clean energy and energy efficient investments by local governments, FEMA's Brick and Hazard Mitigation grant programs, and the totality of the Corps' resilience efforts in our region, including shoreline protection, Everglades restoration, the C&SF project, Back Bay, and navigation studies.

Climate change is one of the most pressing issues facing our region. Continued leadership and support for transitions to clean energy, alongside aggressive adaptation actions, is critical to our economic and community vitality. We look forward to continued collaborations with our Federal agency partners, and thank you again for the opportunity to speak today.

Thank you.

[The prepared statement of Ms. Jurado follows:]

Written Testimony – Dr. Jennifer Jurado, Chief Resilience Officer, Broward County, FL
Environment and Public Works Committee
November 1, 2023

Good Morning, Mr. Chairman.

Thank you for your climate leadership and for convening this hearing today.

As you know, Florida, especially South Florida, is no stranger to extreme weather, with hot-humid summers, intense afternoon thunderstorms, and the seasonal arrival of tropical storms and hurricanes. These conditions have been well accounted for in our infrastructure planning, design standards, emergency operations procedures and local mitigation strategies.

Flood risk is an acute concern, a function of our extensive shoreline, flat landscape, and low land elevations. Accordingly, our communities, state, and federal agency partners have invested in extensive drainage, flood control, and stormwater management systems needed to store, convey, and discharge the nearly 60 inches of rainfall we receive annually, on average. Additionally, in southeast Florida, we have adopted rigorous building codes to ensure our homes and other structures can withstand hurricane force winds.

Even so, as our region of more than 6 million people – a population which exceeds that of 31 other states – grapples with impacts of climate change, the limitations of these historic standards and investments are a focus of renewed assessment. A decade ago, it was the increase in tidally-induced flooding that prompted calls for action; more recently, record-breaking storm events are proving far more damaging, with flood conditions worsened by the combined impacts of sea level rise, increase in storm surge, higher king tides, and groundwater table rise. The result is an increase in property damage, economic losses, and service disruptions affecting both inland and coastal communities.

Unlike gradual sea level rise to which communities can slowly adapt, extreme weather events deliver shocks that now overwhelm our infrastructure and systems. This was the experience on April 12, 2023, in the coastal municipalities of Fort Lauderdale, Dania Beach, and Hollywood when a seemingly innocuous afternoon thunderstorm delivered an unprecedented 26 inches of rainfall in 12 hours, resulting in immediate flash flood conditions just before the 5 o'clock commute.

The severity of on-the-ground conditions during this storm is difficult to describe.

- In an instant, a standard 30-minute commute degraded into a 3-hour navigation of flood waters.
- Ramps connecting artillery roads to the interstate were impassable, preventing any possibility of a formal evacuation.
- Stalled vehicles were abandoned en masse, with losses estimated at 2,000 vehicles (public and private).
- The Fort Lauderdale-Hollywood International Airport shut down and remained closed for 40-hours, with flood depths up to 5-feet. Over 1,000 flights were cancelled. Total damages were estimated at $17,500,000.
- Privately-owned oil terminals located at Port Everglades, which serve 12 counties and 5 international airports, experienced up to 26 inches of water in their facilities. Operations were suspended, disrupting the distribution of gasoline, diesel, and jet-fuel with shortages affecting the entire region, from Palm Beach County to the Florida Keys.

- Residents in the established Melrose Park and Edgewood communities were hit the hardest, with 2 to 3 feet of standing water.
- 600 residents were displaced and over 1000 homes sustained 'major' damage.
- FEMA delivered housing assistance for more than 3,800 applicants exceeding $13 million, with another $26 million in loans issued by the Small Business Administration.
- The City of Fort Lauderdale remains without a functional City Hall as the basement was filled with 5 feet of flood water, damaging a major energy transformer, the City's IT infrastructure, and servers, in addition to roof and other water damage.

Incredibly, the April 12, 2023, rainfall event occurred outside of the hurricane season, a 1:1,000-year event, having less than a 0.1 % probability of occurrence in any given year.

Yet similar unprecedented conditions were realized in November 2020, when tropical storm Eta delivered approximately 22 inches of rainfall over 3-days. With this event, extensive rainfall in the preceding weeks contributed to a total of 35 inches over 6 weeks (inclusive of tropical storm Eta). This rainfall amount was four-times the historic average for the same two-month period compared to the 30-year average.

While this event was also only characterized as a 1:100-year event, the flood conditions were worsened due to supersaturated soils following weeks of rain and king tides that prevented drainage from gravity operated stormwater systems. With the rise in the groundwater table, sanitary sewer collection systems were overwhelmed and wastewater utilities across the County urged residents to restrict household water use for days, including bathing, dishwashing, and laundry. Once again, the established community of Melrose Park (not located in a current flood zone) was under 2 feet of water along with western, inland parts of the County, which remained flooded for as much as 2 weeks.

In keeping with the 3-year interval, in June 2017, an 18-inch rain event required closure of Sawgrass Mills, the region's largest shopping center, for a period of 3 days, with an economic loss of $30 million. These 3 extreme events in the past six years account for the highest annual rainfall totals in the last 30 years, exceeding 88 inches in 2020, and 70 inches in 2017 and 2023.

Like the experiences of communities across the United States, extremes and exceedances have become south Florida's new norm, and the conditions are not limited to flooding. Extreme heat is increasingly recognized as an equal, if not more pressing, climate threat. As with flooding, the year 2023 also broke heat records and is expected to become the hottest on record for Broward County. This year we experienced 37 days with a heat index over 105°F, compared to a historical average of 5 days, and 80 days predicted by midcentury. 2023 also topped records with 17 consecutive days reaching this threshold, the next highest being just 6 days in 2020.

We know that extreme heat disproportionately impacts our disadvantaged and underrepresented residents, outdoor workers, health compromised individuals, our youth and elders. In heat surveys undertaken by our agency:

- 10% of respondents shared that they did not have access to air conditioning or could not afford to run it.
- 10% of respondents also identified work commute as their top-rated heat-related economic concern; 54% identified the cost of energy bills.

- 13% of respondents identified sleep as a top activity impacted by heat, with 67% noting outdoor recreation and/or exercise.
- 40% of respondents noted heat to have negatively impacted their health or physical wellbeing.

These extreme heat conditions and concerns led the County to undertake a comprehensive heat education campaign for workers and employers, explore the use of the County's electric bus fleet as mobile cooling centers, and pursue grant funding for deployable resilience hubs to support community cooling needs. The County Commission also petitioned the National Weather Service to lower thresholds for heat advisories and warnings in Broward County as in Miami-Dade County, for better alignment with temperatures recognized to affect public health to improve early warning systems and coordination with health care providers.

To respond and better prepare for greater flood extremes, Broward County has worked to incorporate future conditions projections, including sea level rise and rainfall intensification, in design standards for infrastructure. These improvements include:

- a future conditions groundwater table map to account for the influence of sea level rise on drainage and water management systems;
- resilience standards for seawalls, berms and other tidal flood barriers, accounting for the combined influence of sea level rise and high frequency storm surge on coastal water elevations; and
- a future conditions flood map that accounts for sea level rise, king tides, groundwater table rise, and rainfall intensification.

The United States Congress has also worked to ensure south Florida remains dry during wet weather events. Congress authorized the Central & South Florida (C&SF) Flood Control Project in 1948 – more than 70 years ago and it was constructed by the Army Corps of Engineers. The C&SF flood control system has served as an invaluable contributor to the economic success of Florida. However, it was designed to deliver flood protection for 2 million residents, not the 11 million it currently serves, nor the estimated 15 million people who are expected to live in the broader region in 30 years. Today, the C&SF system is under substantial stress due to changes in the physical environment, especially increased rainfall intensity and rising sea levels. Stormwater severely strains the system and sea level rise significantly threatens project operations.

As a region, we have advocated for the initiation of the Central and Southern Florida Flood Risk Resiliency Study led by the U.S. Army Corps of Engineers. We thank the Committee for its authorization of this Comprehensive Study as part of the 2022 Water Resources Development Act. Our communities heavily rely upon improvements to this network as the backbone for all water management operations in the region. This study will build upon a more focused Section 216 Study for the same system that the Administration and Corps of Engineers began a few years ago. We urge the Committee's support for the funds needed to expedite these studies and the timely construction of project recommendations. Without these improvements, our local efforts will not be as effective.

Concurrent with these federal efforts, Broward County is developing a county-wide risk assessment and resilience plan focused on addressing flood and heat risk through infrastructure improvements and redevelopment strategies, in conjunction with our 31 municipalities, the Seminole Tribe of Indians, and water management partners. This plan incorporates new rainfall intensification estimates (increasing from 13 to 20%) and incorporates storm surge in the flood elevation scenarios. The plan will maximize

green infrastructure investments for water management and heat mitigation benefits, particularly where urban heat islands and vulnerable communities intersect.

Core to this analysis is an evaluation of economic risk and benefits associated with no action versus adaptation outcomes. Initial economic exposures provided by McKinsey Global point to potential average annual flood damages to property and contents of $5 billion annually by the 2070, and losses in production equal to 0.7% of the value of the Broward economy, or $0.8 billion in current prices. Increasing flood risk coupled with risk-reflective pricing could drive a 70+% decrease in the National Flood Insurance Program policy penetration rate to only 6% county-wide, with a doubling in the average single family home flood insurance premium. Given the increase in insurance cost, single family home flood insurance policies could be unaffordable in 35% of census tracts. As flood insurance coverage decreases where risk increases, annual uncovered damage could rise to $1.5 billion by 2050, and $3.4 billion by 2070.

While the adaptation strategies and outcomes are still under development, previous economic investigations undertaken as part of the Southeast Florida Business Case for Resilience (June 2020) indicate an average 4:1 return on investment for building-level adaptation and a 2:1 return on investment for community-wide adaptation through protection of property values and tax base, avoided losses, preservation of economic sectors, and job growth. These figures reinforce the importance of early and effective adaptation strategies as well as the diverse benefits to be gained by reducing carbon emissions that contribute to warming and the severity of climate impacts.

With this in mind, Broward County's resilience efforts include robust emissions reductions strategies alongside comprehensive adaptation planning for the climate impacts already underway.

- The County has adopted a net zero goal by 2050 and is currently procuring consultant services to assist with plan development.
- We have committed to a clean fleet goal by 2030 and are transitioning our entire bus fleet by 2035.
- We are building out electric vehicle charging infrastructure across county sites and are working on a community electric vehicle charging strategy.
- The County is offsetting its electricity consumption (132 megawatts) via utility-scale solar while investing in large-scale rooftop and solar parking canopies at more than a dozen county sites (nearly 4 megawatts of installed capacity).

Broward County is a partner with neighboring counties of Palm Beach, Miami-Dade and Monroe in developing a priority climate action plan supported by the Inflation Reduction Act and EPA's Climate Pollution Reduction Grant. The region celebrates the announcement of $4.3 billion in implementation funds and is intent on achieving energy efficiency and related cost-saving for residents in multi-family housing. Our region also submitted several grant proposals in response to NOAA's coastal resilience challenge. We strongly support additional funding opportunities with a similar design.

In addition to the agency support already referenced, additional federal agency partners and valued program assistance includes:

- The United States Geological Survey (USGS), with whom we partner as a collaborator in hydrologic model development and environmental monitoring supporting essential to our resilience planning tools and activities.

- The technical assistance of NOAA, the U.S. Corps of Engineers, and USGS in developing sea level rise and rainfall intensification guidance for regional application.

- The Department of Energy's Charging Fueling Infrastructure (CFI) grant program, which offers extensive funding to further regional and local electric vehicle infrastructure charging initiatives.

- The IRA's direct pay tax credits for local governments, which is allowing our county to expand its most recent solar project by 30%, within our existing project budget.

- The Federal Emergency Management Agency's Building Resilient Infrastructure and Communities (BRIC) and Hazard Mitigation Grant Programs, providing vital funding sources for critical flood mitigation projects benefiting our County and region.

- The U.S. Corps of Engineers' partnership on the totality of resilience initiatives across the region of southeast Florida, including shoreline protection projects, the C&SF studies and future projects, and Back Bay and Navigation studies.

As our efforts advance, the sustained engagement of the U.S. Corps and federal support for the Central and Southern Flood Control Project is one of the most pressing needs for our region. This system is collectively recognized as already failing, with design standards already being exceeded and local partners scrambling to address immediate exposures while we press for the funds needed for comprehensive, long-term solutions.

While speaking in primary representation of Broward County, I would also like to highlight the efforts of the 4-county Southeast Florida Regional Climate Change Compact, established in 2010 as a collaboration amongst Broward, Palm Beach, Miami-Dade and Monroe counties to reduce greenhouse gas emissions and adapt to shared climate change impacts.

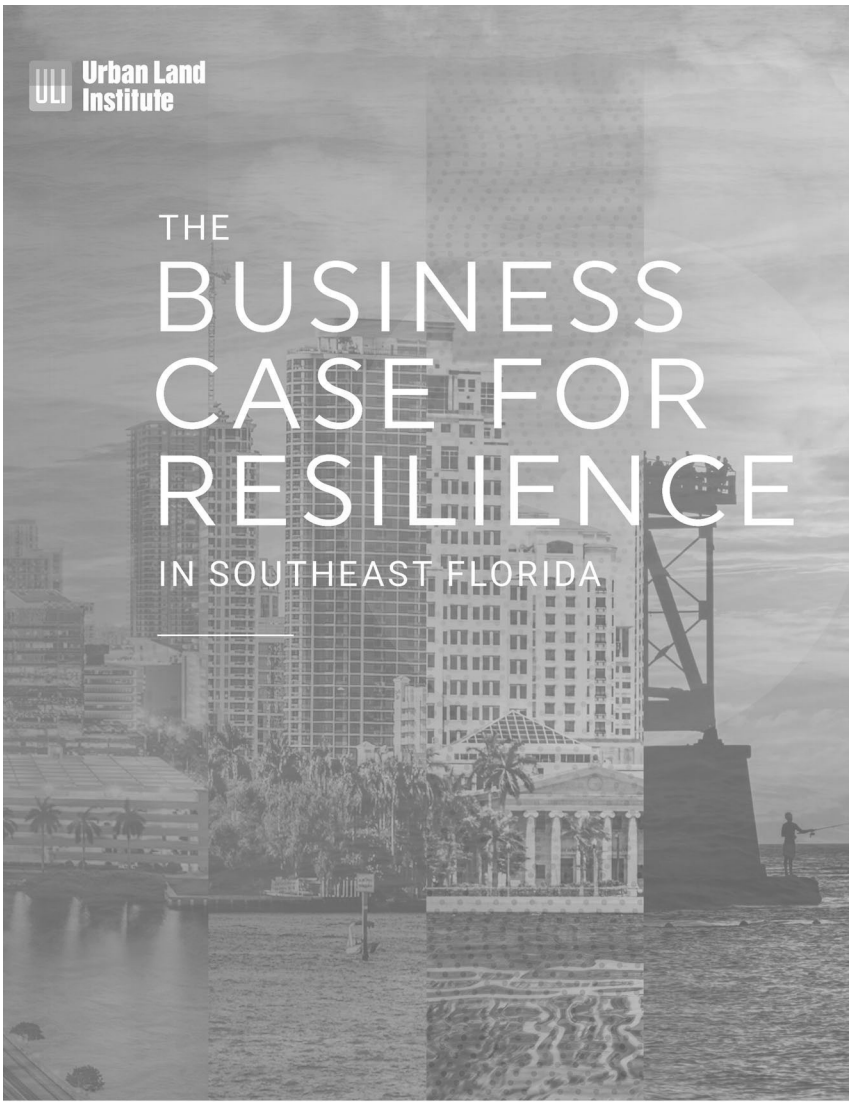
Nearly 14 years strong, our collaboration continues with recent notable accomplishments that include:

- Joint development and adoption of a 3rd iteration to our regional climate plan
- A strong focus on economic resilience, achieving broad endorsement by business leadership, including local chambers of commerce, and economic development councils across the region.
- Joint development and adoption of a 3rd iteration to our regional sea level rise projection.
- Preparation for our 15th Annual Regional Summit in just 2 weeks, hosted this year by Miami-Dade County, with a significant federal agency participation and a focus on coordination, risk reduction, and place-based strategies.

Increasingly, climate change will continue to test our systems and impact our communities in profound ways. Local governments remain on the front lines in resilience planning and investments needed, but federal leadership, technical expertise, and funding are paramount to timely and effective response. We must improve our ability to anticipate and deliver on risk reduction strategies, but we stand to deliver the greatest benefits for our communities if we can simultaneously work to reduce emissions. We urge continued leadership and support for more expansive and swift transitions to clean energy, alongside aggressive adaptation actions, so that we might preserve economic and community vitality as we transition, reposition, and reinvest.

Climate change is one of the most important pressing and all-encompassing issues facing our region, affecting all sectors. Please help us ensure that South Florida remains a vibrant, attractive, economically successful region for generations to come. We look forward to continued collaborations with our federal agency partners.

Thank you again for your support and the opportunity to speak to you today.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This report was reviewed for consistency and accuracy of the original economic analysis.

THE BUSINESS CASE FOR RESILIENCE

IN SOUTHEAST FLORIDA

Regional Economic Benefits of Climate Adaptation

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ABOUT THE URBAN LAND INSTITUTE

The Urban Land Institute is a global, member-driven organization comprising more than 45,000 real estate and urban development professionals dedicated to advancing the Institute's mission of providing leadership in the responsible use of land and in creating and sustaining thriving communities worldwide.

ULI's interdisciplinary membership represents all aspects of the industry, including developers, property owners, investors, architects, urban planners, public officials, real estate brokers, appraisers, attorneys, engineers, financiers, and academics. Established in 1936, the Institute has a presence in the Americas, Europe, and the Asia Pacific region, with members in 80 countries. More information is available at uli.org. Follow ULI on Twitter, Facebook, LinkedIn, and Instagram.

ABOUT AECOM

AECOM is the world's premier infrastructure consulting firm, delivering professional services throughout the project lifecycle—from planning, design, and engineering to program and construction management. We partner with our clients in the public and private sectors to solve their most complex challenges and build legacies for generations to come. On projects spanning transportation, buildings, water, governments, energy, and the environment, our teams are driven by a common purpose to deliver a better world. AECOM is a Fortune 500 firm and its Professional Services business had revenue of approximately $13.6 billion in fiscal year 2019. See more at aecom.com and @AECOM.

ABOUT THE COMPACT

The Southeast Florida Regional Climate Change Compact (the Compact) is a partnership between Broward, Miami-Dade, Monroe, and Palm Beach counties to work collaboratively to reduce regional greenhouse gas emissions, implement adaptation strategies, and build climate resilience across the Southeast Florida region.

For more than a decade, the Compact counties have successfully collaborated on mitigation and adaptation strategies, built bipartisan support for climate action, and forged partnerships with key stakeholders including federal, state, and municipal governments and agencies; economic development entities; community-based organizations; and the academic community, enabling the development of a regional voice and vision for future prosperity in Southeast Florida.

ABOUT THIS REPORT

This summary report was created by ULI. Technical support for this study was provided by AECOM's Sustainable Economics Practice and is presented in *The Business Case for Resilience in Southeast Florida*, a technical report prepared for the Urban Land Institute and Southeast Florida Regional Climate Change Compact. Findings from the technical report are distilled here in addition to supplemental content and narrative provided by ULI. The project has been supported by a coalition of local partners, including Broward, Miami-Dade, Monroe, and Palm Beach counties; the Florida Department of Environmental Protection; the Beacon Council Foundation; Broward Workshop; Community Foundation of Broward; Greater Fort Lauderdale Chamber of Commerce; and Greater Miami Chamber of Commerce.

PROJECT PARTNERS

CONTENTS

PREFACE

During the development of this economic analysis and the creation of this coinciding summary report, the world was hit with the brunt force of the COVID-19 pandemic, which continues to lead to tragic loss of life, economic downturn, and many changes to the way people live, work, and interact with each other.

The sudden shock of the pandemic offers everyone, particularly the Southeast Florida region, a harsh reminder of the importance of preparing for both known and unknown risks. Coastal hazards arising from the impacts of climate change, such as increasingly intense storm events and sea-level rise, present major risks to the well-being of residents and to the safety of businesses, property, and infrastructure. These risks have only been compounded by the consequences of the pandemic, particularly given reduced municipal resources and the vulnerability of many communities to both COVID-19 and climate-related disruptions. Although the exact implications of the pandemic have yet to be realized, the need for the region to continue to prepare for the long-term challenges of a changing climate, even in the face of unexpected shocks, has become pivotal.

Flood events cause an increasing number of disruptions to the Southeast Florida economy through property damage and the loss of business continuity, threatening long-term economic decline. This opens a door for the real estate and land use industries to be more verbal on the issue of climate adaptation and to be a part of a conversation that has had no easy answers.

Developers have control over the confines of their own parcels; but, they could be faced with negative consequences from reduced investor interest and lack of financing and insurance—if this is the case, it may be too late to recover. Though financial assets are at risk, this is also the time for the real estate industry to coordinate with the public sector on resilience planning initiatives and co-create new models for partnerships, policy, and funding to help the region to continue to thrive.

The real estate industry has an opportunity to achieve a positive return on investment by futureproofing developments and investing in community-wide resilience infrastructure over time to build incremental solutions that protect people and property. This report explores and quantifies this business case for resilience in Southeast Florida.

We are grateful for the support and collaboration of our project partners, including the Southeast Florida Regional Climate Change Compact and the Regional Stakeholder Group, representing the region's local business community. We also want to thank AECOM for preparing the original technical report, which this report summarizes for an industry audience.

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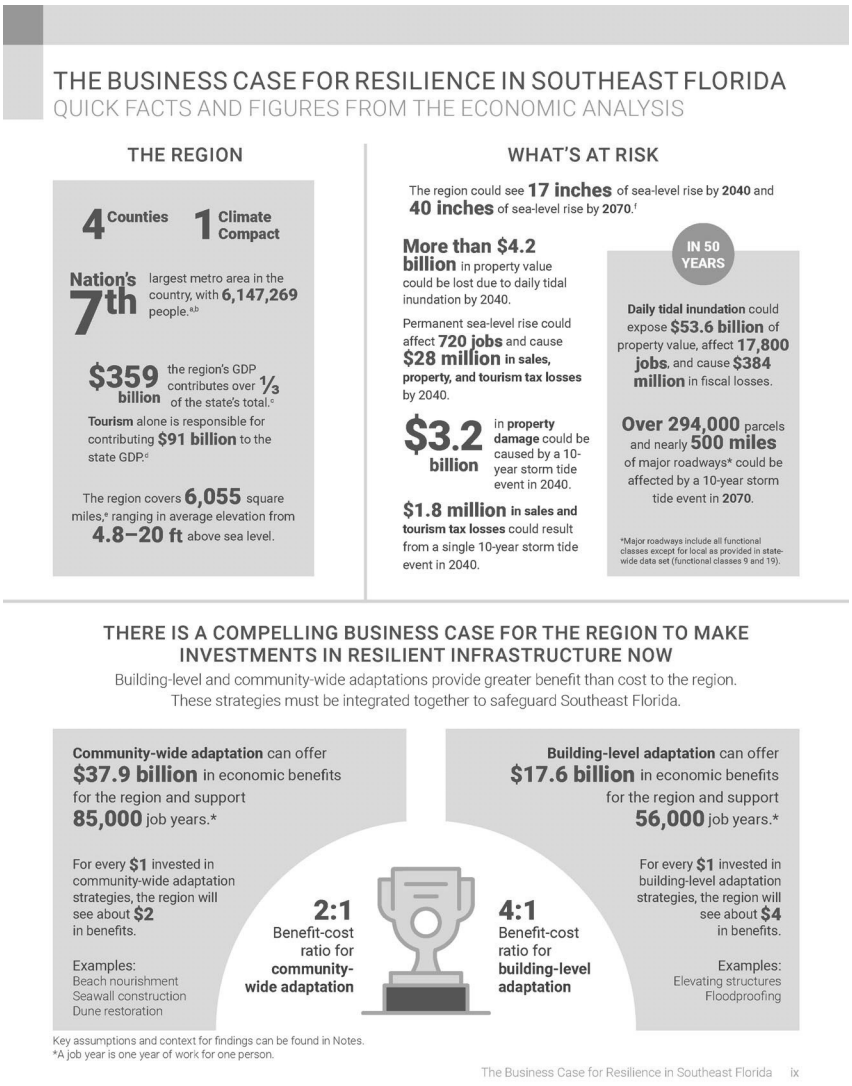
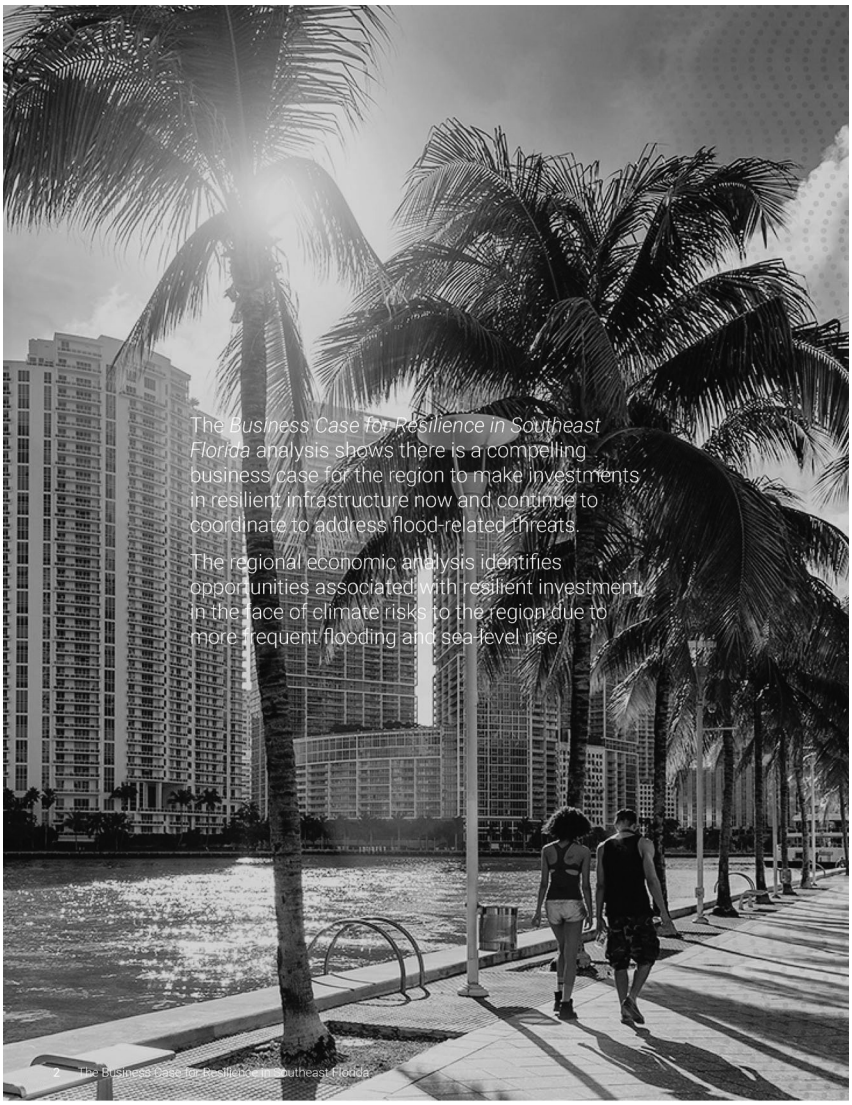

THE BUSINESS CASE FOR RESILIENCE IN SOUTHEAST FLORIDA
QUICK FACTS AND FIGURES FROM THE ECONOMIC ANALYSIS
THE REGION
4 Counties
1 Climate Compact
Nation's 7th largest metro area in the country, with 6,147,269 people.[a,b]
$359 billion the region's GDP contributes over 1/3 of the state's total.[c]
Tourism alone is responsible for contributing $91 billion to the state GDP.[d]
The region covers 6,055 square miles,* ranging in average elevation from 4.8–20 ft above sea level.
WHAT'S AT RISK
The region could see 17 inches of sea-level rise by 2040 and 40 inches of sea-level rise by 2070.[f]
More than $4.2 billion in property value could be lost due to daily tidal inundation by 2040.
Permanent sea-level rise could affect 720 jobs and cause $28 million in sales, property, and tourism tax losses by 2040.
$3.2 billion in property damage could be caused by a 10-year storm tide event in 2040.
$1.8 million in sales and tourism tax losses could result from a single 10-year storm tide event in 2040.
IN 50 YEARS
Daily tidal inundation could expose $53.6 billion of property value, affect 17,800 jobs, and cause $384 million in fiscal losses.
Over 294,000 parcels and nearly 500 miles of major roadways* could be affected by a 10-year storm tide event in 2070.
*Major roadways include all functional classes except for local as provided in state-wide data set (functional classes 9 and 19).
THERE IS A COMPELLING BUSINESS CASE FOR THE REGION TO MAKE INVESTMENTS IN RESILIENT INFRASTRUCTURE NOW
Building-level and community-wide adaptations provide greater benefit than cost to the region.
These strategies must be integrated together to safeguard Southeast Florida.
Community-wide adaptation can offer $37.9 billion in economic benefits for the region and support 85,000 job years.*
For every $1 invested in community-wide adaptation strategies, the region will see about $2 in benefits.
Examples:
Beach nourishment
Seawall construction
Dune restoration
2:1 Benefit-cost ratio for community-wide adaptation
4:1 Benefit-cost ratio for building-level adaptation
Building-level adaptation can offer $17.6 billion in economic benefits for the region and support 56,000 job years.*
For every $1 invested in building-level adaptation strategies, the region will see about $4 in benefits.
Examples:
Elevating structures
Floodproofing
Key assumptions and context for findings can be found in Notes.
*A job year is one year of work for one person.
The Business Case for Resilience in Southeast Florida ix



The *Business Case for Resilience in Southeast Florida* analysis shows there is a compelling business case for the region to make investments in resilient infrastructure now and continue to coordinate to address flood-related threats.

The regional economic analysis identifies opportunities associated with resilient investment in the face of climate risks to the region due to more frequent flooding and sea-level rise.

EXECUTIVE SUMMARY

The counties in the Southeast Florida region, including Broward, Miami-Dade, Monroe, and Palm Beach, are currently among the most proactive in the nation in planning for climate change. Local leadership within the counties created the Southeast Florida Regional Climate Change Compact (the Compact), and together have taken a leading role planning for the substantial risk associated with the impacts of climate change, including sea-level rise and stronger storms.

The Compact, along with local business and nonprofit communities, partnered with the Urban Land Institute (ULI) to comprehensively assess the economic impact of investment in resilience in the region. The findings illustrate the region's vulnerability to the impacts of climate change and the shared interest for action by both the public and private sectors when it comes to investing in proactive flood protection and climate adaptation measures. The economic modeling study found that climate adaptation measures are forecast to offer a significant return on investment for the region, protecting communities, jobs, and properties.

This *Business Case for Resilience in Southeast Florida* analysis presents estimates of the economic consequences to coastal counties in the region if local governments and business communities fail to take action to mitigate the impacts from tidal flooding and frequent coastal storms, compounded by sea-level rise. The analysis takes a regional perspective, considering the impacts to the region given the interconnected economies across all four counties. In addition, the study estimates the economic benefits from certain types of adaptation actions designed to mitigate the coastal hazard risks. These adaptation actions could all make a difference, but some of these actions are more suitable for some counties than others and each county may need a customized approach to address its own unique resilience challenges.

The research presented in this study builds on past work completed in the region and leverages a robust economic modeling tool, called REMI PI+, to estimate cascading economic impacts at multiple geographic scales. The findings present an important opportunity for the government and business community to contextualize and advance investment in resilience measures.

Coastal storms and sea-level rise have wide-ranging societal, economic, and environmental effects that extend beyond the borders of any one community. Accordingly, this study assesses the four counties and interconnected economies represented by the Compact. This region accounts for about 30 percent of the population of Florida and generates about 35 percent of the state's gross domestic product.[1]

Each coastal community in Southeast Florida has its own unique geography, its own set of challenges to confront (not limited to coastal hazards), and varying amounts of resources to address those challenges. At the same time, coastal communities in the region share many similar characteristics, especially with respect to their primary industries and revenue sources.

To advance economic resilience at the regional scale, the counties should avoid a divided approach to adaptation that fails to account for the complex interdependencies between local and regional economies and the critical role that regional infrastructure plays.

Developing an understanding of the economic consequences from current and predicted coastal hazards is critical to inform decision-making around how to best protect the communities, businesses, and natural resources that make coastal communities in Southeast Florida a strong business environment and world-class leisure destination.

WHAT WAS INCLUDED IN THE ANALYSIS

This study is a regional economic evaluation of flood risk and exposure, with the inclusion of predicted heights of sea level in 2020, 2040, and 2070. Coastal conditions modeled include the average daily high tide, or mean higher high water (MHHW), the king tide (one-year tide), and the 10-year storm tide. More frequent events were examined as part of this study because those events are less likely to be insurable in the future. Through catastrophic risk modeling, the region has a robust understanding of its risks from high-impact, less-likely events, such as strong hurricanes, which were not included in this study. In addition, the analysis does not incorporate flooding from precipitation or rising groundwater.

The study analyzed impacts avoided and cumulative costs of certain adaptation strategies and resulting benefit-cost ratios for both community-wide and building-level adaptation strategies from 2020 to 2070.

To account for broader regional dynamics, the REMI PI+ modeling platform was used to evaluate the effect of these high-frequency flooding events on the economy of Southeast Florida and the rest of the state. Not every strategy included within the analysis is applicable to all areas within the Compact.

During the development of this study, the region, country, and world were hit hard by the global COVID-19 pandemic. The pandemic led to tragic loss of life, economic downturn, and many changes to the way communities live, work, and interact with each other. These changes that arose from this sudden shock are a harsh reminder of the importance of preparing for both known and unknown risks. The region must continue to prepare for the long-term challenges of a changing climate, even in the face of unexpected shocks of events, like COVID-19.

WHAT IS THE SOUTHEAST FLORIDA REGIONAL CLIMATE CHANGE COMPACT?

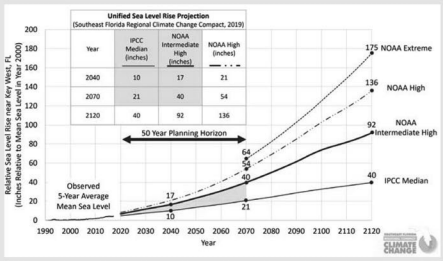
The Southeast Florida Regional Climate Change Compact is a coalition of the four counties of Southeast Florida—Monroe, Miami-Dade, Broward, and Palm Beach—that advances climate mitigation and adaptation strategies throughout the region. The Compact works collaboratively to address vulnerabilities caused by climate change and sea-level rise, to implement adaptation strategies, and to build climate resilience across municipal and county lines. The Compact represents a new form of regional climate governance, creating the first case in the United States where counties voluntarily committed to a joint regional effort to address climate change.

WHY 2020, 2040, AND 2070?

In this analysis, the 2017 National Oceanic and Atmospheric Administration (NOAA) Intermediate-High projections were selected for the planning time horizons of 2020 (existing conditions), 2040, and 2070, which align with the updated Southeast Florida Regional Climate Change Compact recommended regional sea-level rise projections. The Intermediate-High projections are recommended for high-priority projects, including evacuation routes, energy infrastructure, critical government fatalities, and infrastructure that may stay in place beyond a design life of 50 years.

These time horizons are important for near-, mid-, and long-term infrastructure planning and investments that are necessary for incremental steps to address sea-level rise impacts expected to occur over the coming century.

SOUTHEAST FLORIDA REGIONALLY UNIFIED SEA-LEVEL RISE PROJECTIONS SFRCCC, 2019



In 2019, the Compact released the third update to its Unified Sea-Level Rise Projections for the Southeast Florida region. (Southeast Florida Regional Climate Change Compact)

THE BUSINESS CASE FOR RESILIENCE: ASSUMPTIONS

In this study, the adaptation strategies evaluated only focused on high-level actions that are applicable across the four counties in Southeast Florida and that provide regional-scale protection from sea-level rise and high-frequency coastal storms. The study does not address the unique coastal hazard flood and stormwater risks and opportunities at a local scale.

The adaptation strategies selected present better cost benefit in certain areas, including dense areas with high-value properties. As such, not every action is viable in each county, but they serve as a test case to determine whether adaptation is cost-beneficial at the regional scale. Therefore, local cities and communities may consider developing a comprehensive adaptation plan that also examines the contextualized flood risk for the area, in addition to recognizing the regional flood protection strategies described in the study.

A phased approach to adaptation investment is assumed in the study, whereby the implementation of infrastructure meets specified modeled conditions in future years, as will likely be the case in practice.

KEY STUDY QUESTIONS

1. What vulnerabilities and threats will communities experience in the future due to coastal storms and sea-level rise?

2. What are the costs and benefits of different adaptation actions?

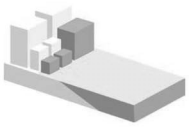
3. What actions can be taken today to promote resilience?

UNDERSTANDING AVOIDED DAMAGE

VISUALIZING DAMAGE WITH AND WITHOUT RESILIENT ADAPTATION

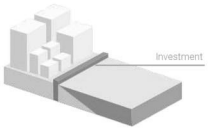
DAILY TIDE IN 2040
Without Adaptation Action

Without adaptation action, rising seas coupled with daily high tides threaten buildings and infrastructure.



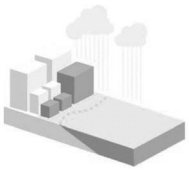
DAILY TIDE IN 2040
With Adaptation Action

With adaptation actions, buildings and infrastructure are more protected from rising seas and daily high tides.



COASTAL HAZARD IN 2040
Without Adaptation Action

Without adaptation action, a coastal hazard (storm) causes widespread damage to buildings and infrastructure.



COASTAL HAZARD IN 2040
With Adaptation Action

With adaptation actions, buildings and infrastructure are more protected from coastal storms.

WATER LEVEL CONDITIONS EVALUATED

MEAN HIGHER HIGH WATER (MHHW)
Average of the highest of the two high tides occurring each day, also referred to as daily tidal inundation.

1-YEAR TIDE
The highest annual tide, also referred to as the king tide.

10-YEAR STORM TIDE
A tide with a 10 percent chance of occurring in any given year. This event represents high-frequency conditions of temporarily elevated water levels due to coastal storms.

Additional definitions can be found in Key Terms on page 41.

OVERVIEW OF FINDINGS

A compelling business case exists for investing in climate adaptation in Southeast Florida. However, it will take a collective and coordinated approach to advance resilience throughout the region.

The analysis shows that it is cost-effective for the four-county region to make investments in resilient infrastructure now. These measures include community-wide infrastructure investments and building-scale adaptation measures that enhance resilience.

LACK OF ADAPTATION INVESTMENT AND INFRASTRUCTURE NOW WILL HAVE MAJOR CONSEQUENCES FOR THE FUTURE ECONOMIC WELL-BEING OF THE REGION

Investments in community-wide adaptation strategies could safeguard sales, tourism, and property-tax revenue and mitigate an economic ripple effect.

Key to promoting economic resilience is ensuring the continuity of business activity, which is heavily dependent on the function of community lifeline assets (e.g., utilities, roads).

Interruption to business activity, be it from direct or indirect coastal hazard impacts, can slow recovery and affect the creditworthiness of businesses and government (which rely on revenues generated from the business community), and can further constrain the ability of these entities to raise needed capital for investments in adaptation or other purposes.

In 2040, daily tidal inundation could expose **$4.2 billion** in property value, and one 10-year storm tide event could cause **$3.2 billion** in property damage.

In 2070, daily tidal inundation could expose **$53.6 billion** in property value, and one 10-year storm tide event could cause **$16.5 billion** in property damage.

Sunny-day flooding in Fort Lauderdale disrupts travel and services and causes damage to infrastructure.

DAMAGE AND LOSSES CAN BE REDUCED

Investing in adaptation provides direct benefits in the form of avoided losses to property, as well as the potential for indirect benefits such as reductions in insurance premiums, and stabilization or enhancement of property tax values and associated tax revenues. With an investment in flood infrastructure, businesses can mitigate property damages and employment impacts and continue to realize the value of business continuity.

COMMUNITY-WIDE ADAPTATION PRESENTS NET BENEFITS FOR THE REGION

Community-wide adaptation strategies such as sea walls, dune restoration and beach nourishment, and berm construction or raising[2] will protect property and communities beyond the asset level from gradual sea-level rise conditions. This type of protection provides significant benefits in the form of avoided property, sales, and tourist-development tax losses and broad economic benefits to the community due to reduced impacts to both property and infrastructure.

In this study, the benefit-cost ratio (BCR) for community-wide adaptation strategies implemented throughout the region is 2.06.

In 2040, one 10-year storm tide event could cause a **$2 million** loss in sales and tourism tax revenue, and daily tidal inundation could cause **$28 million** in tax revenue loss.

In 2070, a 10-year storm tide event could cause an **$8 million** loss in sales and tourism tax revenue, and daily tidal inundation could cause **$384 million** in tax revenue loss.

PROPERTY AND REAL ESTATE VALUES CAN BE PRESERVED AND INCREASE IN VALUE WITH BUILDING-LEVEL ADAPTATION

Adaptation is critical to supporting assets retaining their long-term value. Building-level strategies include elevating or floodproofing structures. Beyond protecting properties from damages, resilience investments can reduce insurance premiums and avoid losses or enhance property values and, therefore, reduce associated tax revenues.

The BCR for individual adaptation strategies at the asset level examined in this study is 3.97.

If effective partnerships and incentives are created to lead to more widespread market adoption of resilient development and design, an opportunity exists for property owners and developers to make current and future buildings more resilient at the asset level.

JOBS AND ECONOMIC ACTIVITY CAN BE PRESERVED AND GENERATED

Investing in adaptation at both the building and community-wide levels now is critical given the region's significant vulnerabilities to climate change.

Investments in adaptation can provide benefits to the region beyond the avoided impacts. For example, these investments can support construction, operations, and maintenance jobs.

INDUSTRIES MOST AT RISK

INDUSTRIES WITH HIGHEST SALES OUTPUT LOSS UNDER 2070 10-YEAR STORM CONDITIONS:

- Hospitality and food services
- Wholesale trade
- Retail trade

This resort in Palm Beach embarked on a dune restoration project to protect the property from coastal hazards.

BENEFITS OF ADAPTATION

ADAPTATION STRATEGY BENEFIT-COST ANALYSIS FOR THE REGION

The following table shows the estimates for the cumulative impacts avoided and the cumulative cost of adaptation, net impacts, and resulting benefit-cost ratios for community-wide and building-level adaptation strategies for all four counties combined. To maximize adaptation benefits to the region, both community-wide and building-level adaptations must be intrinsically implemented throughout.

	BENEFITS (avoided losses)	COSTS (of adaptation)	BENEFIT–COST RATIO	NET NEW JOB YEARS
COMMUNITY-WIDE ADAPTATION	$37.9 billion	$18.2 billion	2.08	85,000
BUILDING-LEVEL ADAPTATION	$17.6 billion	$4.4 billion	3.97	56,000

Note: Results presented in net present value terms using a 5 percent discount rate over the period of the analysis from 2020 to 2070. Estimated job years supported by direct investment in adaptation strategies in the four counties. Individual results at the county level vary.

WHAT IS BCR?

The benefit-cost ratio (BCR) presents the value of the benefits conveyed by adaptation, divided by the total present value of the costs of adaptation. A ratio greater than one implies a return on investment.

ADAPTATION PLANNING IN THE REGION

The physical effects of climate change present grave risks to the health of Southeast Florida residents and communities and to the safety of businesses, property, and infrastructure.

The region has an opportunity to build on ongoing initiatives, like public policy, and infrastructure and building-level interventions to protect communities and businesses from the threats brought on by climate change.

Enhancing resilience throughout the region should incorporate principles that consider climate, economic, and social aspects.

CLIMATE RESILIENCE

Climate resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events related to climate change—from the stresses induced by more gradual changes such as sea-level rise or weather patterns to the acute shocks of intense and frequent weather events including hurricanes, heavy rainfall, and wildfires.

ECONOMIC RESILIENCE

Economic resilience is the capacity to prevent, withstand, recover from, and otherwise bounce back better from natural or human-caused shocks or disruptions to the economy. In this report, economic resilience accounts for the ability of communities and the region to

- prepare for and withstand climate and coastal risks, and
- respond and recover when these risks manifest.

SOCIAL RESILIENCE

Social resilience is the ability of a human community to cope with and adapt to stresses such as social, political, environmental, or economic change. Social resilience is critical to addressing climate risk for low-income communities and communities of color, which are disproportionately impacted by climate change.

The Pérez Art Museum's first level is elevated more than 20 feet to protect art from flood risks.

RESILIENCE PLANNING IN THE REGION

The Southeast Florida region is one of the nation's champions in planning for the effects of more frequent flooding and sea-level rise. For more than a decade, the region has been working collaboratively to develop plans to address a changing climate. Through the Compact, the region has a Climate Action Plan, which sets a strong foundation for action. Miami-Dade County, Miami, and Miami Beach came together under Resilient305, and were the first group of local governments to collaborate on a shared resilience strategy for the 100 Resilience Cities program of the Rockefeller Foundation.

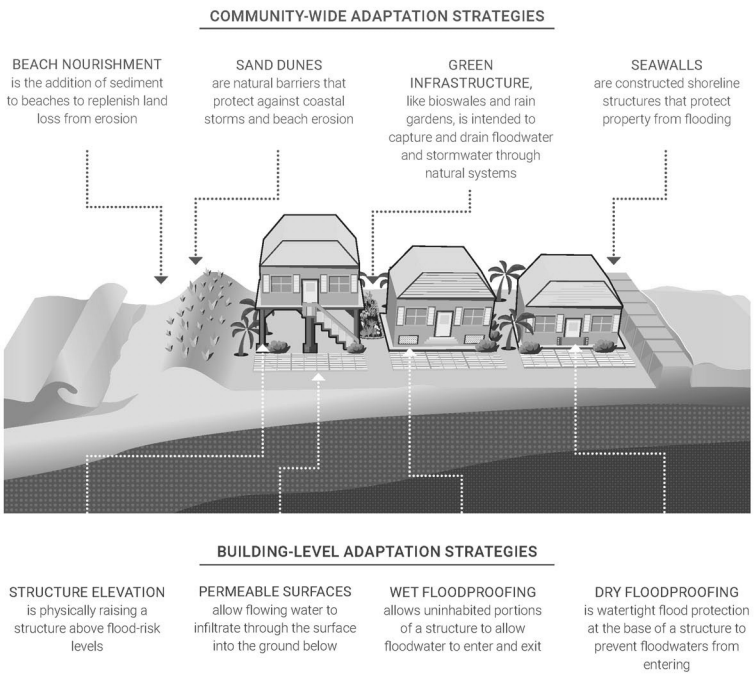
Beyond the collaborative efforts, seawall ordinances have been put in place across the region to mitigate the impacts of tidal flooding. The City of Fort Lauderdale and Broward County have seawall ordinances that have become the models for the region.

Eight local governments in Palm Beach County have come together under a Coastal Resilience Partnership and are currently performing a regional vulnerability assessment.

Monroe County is actively determining how best to raise roads in the county and is planning for stormwater and road improvements for future flooding conditions. These are a few examples of the significant number of planning and infrastructure projects in the region, some of which are profiled in this report as **ADAPTATION IN ACTION** case studies.

COMMUNITY-WIDE AND BUILDING-LEVEL ADAPTATION

COMBINED ADAPTATION STRATEGIES PRESENT MAXIMUM BENEFITS FOR THE REGION



RECOMMENDATIONS

ENHANCING ECONOMIC AND CLIMATE RESILIENCE

Alongside the economic analysis, the study provided high-level recommendations for Southeast Florida local governments to create an environment conducive to investment in climate adaptation.

The communities in the Southeast Florida region should evaluate and advance their capacity for economic and climate resilience by considering the following strategies.

INCREASE CLIMATE RISK AWARENESS

Fundamental to resilience is increasing climate and flood risk awareness. Information about climate-change risks and their knock-on effects is not incorporated into most policies that govern public and private institutions. As a result, risky behavior is often incentivized or subsidized. Both the public and private sectors play a role in risk disclosure, through policies such as mandatory seller disclosure forms, loan terms, and technical assistance programs. Already, local government and planning initiatives are underway, such as Resilient305 and the Southeast Florida Regional Climate Change Compact.

DEVELOP ACTIONABLE FUNDING AND FINANCING PLANS TO PAY FOR RESILIENCE

The risks posed by a changing climate are too great for any one sector to take on alone. Therefore, investments in climate resilience should be made by both public- and private-sector actors, with an eye toward ensuring that all entities would benefit from such investments.

Opportunities to weave adaptation investments into ongoing infrastructure and capital improvement projects should be pursued to streamline processes and implement them efficiently.

Mangroves, as seen here in Key Largo, buffer wave action, prevent erosion, and absorb floodwaters, and they can play an important role in protecting waterfront property during tropical storms.

INVEST IN KEY VULNERABLE AND EMERGING INDUSTRIES

The analysis found that the retail, accommodation and food services, and wholesale industries are particularly vulnerable to coastal hazards. Vulnerabilities can stem from operating near the coast and from the interdependencies between industries. Efforts should be made to protect vulnerable industries like these, and promote economic diversification and innovation in the region, particularly those that operate near the coast.

The public sector should identify and invest in economic clusters of businesses and industries that make the region competitive for jobs, private investment, and emerging fields related to adaptation. Examples include industries in clean technology, life sciences, and information technology. Early investments in research and development can help with long-term economic opportunity for adaptation innovation-related industries.

DEVELOP AN OCCUPATIONAL ROAD MAP TO RESILIENCE

Certain workers may be more vulnerable to coastal hazards, such as workers in vulnerable industries, workers with less adaptable skillsets, lower-wage workers, and workers who travel far to get to work. At the same time, recovery efforts and adaptation investments will favor certain occupations over others, such as emergency responders and construction workers.

Business clusters and organizing bodies, such as business improvement districts, should develop coordinated business continuity plans that account for physical and economic impacts, and they should develop workforce and economic development initiatives to grow the local labor pool that provides the services needed to prepare for and recover from coastal hazard events. Doing so will keep more recovery funds in impacted communities, decrease the burden on supportive infrastructure, expand job skills training and potential future income-earning potential, and provide faster recovery after an event.

ENGAGE WITH AND PROVIDE SUPPORT TO THE SMALL-BUSINESS COMMUNITY

When small businesses are subject to the impacts of coastal hazards, they often lack the capital reserves, access to financing, or insurance coverage necessary to absorb a loss of income and the additional expenses that come with rebuilding. Streamlined access to capital and financing is critical to ensuring continued operations and related financial outcomes. Engaging with small businesses may be difficult given competing demands, but improved communications through digital platforms can help to exchange information both within business communities and between the public and private sectors.

MAKE MITIGATING SOCIAL VULNERABILITY A PRIORITY DURING ADAPTATION DECISION-MAKING

Historically marginalized communities, including low-income communities and communities of color, will be most significantly affected by climate change. To advance future infrastructure investments using cost-benefit analysis alone—considering property value, tax dollars at risk, and other monetary factors—would unfairly disadvantage these groups.

Marginalized communities also have faced the greatest risk during the COVID-19 pandemic, compounding climate-related and other vulnerabilities.

In addition, the growing income gap in the region and lack of living-wage jobs disproportionately challenges vulnerable communities' ability to address public and mental health concerns and the threat of pandemics and the risk from flood events.

Future decision-making needs to consider both economic impact and strategies for protecting communities with the highest needs, who have historically been discriminated against in land use and planning policies advanced at the federal and local levels.

PRIORITIZE PROJECTS STRATEGICALLY AND MONITOR EQUITY AND EFFICACY

Given the finite financial resources available for adaptation, communities and regions will be faced with difficult decisions regarding where investment should be directed, what types of adaptation projects should be pursued, when these investments should be made, and how much money should be borrowed to accelerate investments in resilience in a way that is commensurate with expected risks. When investments are to be made on adaptation projects, they should be developed through transparent evaluation frameworks that address societal vulnerabilities and ensure that the project plans incorporate a holistic approach to resilience, including offering benefits beyond protection from disruptive events such as economic development, workforce development, land use, and capital improvements.

Extensive dune rebuilding efforts were conducted in the aftermath of Hurricane Irma in 2017. The Broward County Shore Protection Project placed 413,000 cubic yards of sand along the 8.9 miles of shoreline reaching north from Fort Lauderdale, according to the U.S. Army Corps of Engineers.

The Palm Beach intracoastal hosts boat traffic year round. The marine industry has about a $2 billion annual impact in Palm Beach County, according to a study for the Marine Industries Association of South Florida.

Community lifelines such as energy, water, transportation, and communications infrastructure should be protected to avoid far-reaching direct and indirect consequences. To ensure that future adaptation projects provide their intended return on investment, the effectiveness of implemented adaptation strategies should be evaluated where feasible.

MAXIMIZE ADAPTATION INVESTMENTS BY COORDINATING BENEFITS

In a best-case scenario, resilient investments should leverage opportunities to maximize benefits to social, environmental, and economic outcomes. For example, investments in physical infrastructure intended to protect a community from hazards should strengthen a community against potential shocks, but also contribute to addressing stresses like flooding and to enhancing the region's economic development potential, or social cohesion. Local examples include beach nourishment in Miami Beach and Palm Beach County's Living Shorelines Program.

Local and regional governments, as well as property and business owners, will eventually need to invest in property development and redevelopment, infrastructure, and related public necessities. Therefore, an opportunity exists to design investments in adaptation to provide co-benefits to people, the economy, and the environment that address current needs.

UNDERSTAND AND PREPARE FOR REPUTATION RISKS AND ASSOCIATED ECONOMIC IMPACTS

The Southeast Florida region is already facing reputational risk; coastal hazards and the region's vulnerability to sea-level rise have received significant national coverage in the U.S. popular media.[3] Vulnerability to coastal hazards now and in the future can result in reputational risks and associated impacts such as property devaluation, insurance premium increases, bond-rating downgrades and increased borrowing costs, decreased tourism and associated spending, decreased public support, and risk from increased liability. Without sufficient, proactive investment in resilience, the region is at risk of further reputational damage, which could have ripple effects on investment and economic development.

Modeling reputational impacts, such as perceptions of future climate-change risk, was beyond the scope of this analysis. Yet, these are important and relevant considerations when interpreting the potential outcomes of the modeled project alternatives. Future research and analysis may provide additional quantitative insights into variations of this approach, and if this occurs, these findings should be updated.

CONDUCT FURTHER IN-DEPTH ANALYSES AT THE COUNTY AND PROJECT LEVELS TO OPTIMIZE BENEFITS AND COSTS

This study examined Southeast Florida from a regional perspective, considering interconnected infrastructure systems, economies, and social networks, but also recognizing very specific differences across the four counties. Further studies will be required for more granular assessments of risk at specific sites of interest. Each project or investment has a unique context that should be considered on a project-by-project basis to allow for more specific design considerations and hopefully more optimal return on investment.

At the municipal and regional level, future analyses can develop project-level roadmaps for action at a smaller geographic scale to better formulate adaptation and resilience strategies to meet community needs and to provide optimal returns to all parties.

Maximize resilience investment benefits by addressing other community needs, like incorporating a bike path into a seawall.

RESOURCES FOR ENHANCING SOCIAL RESILIENCE IN A CHANGING CLIMATE

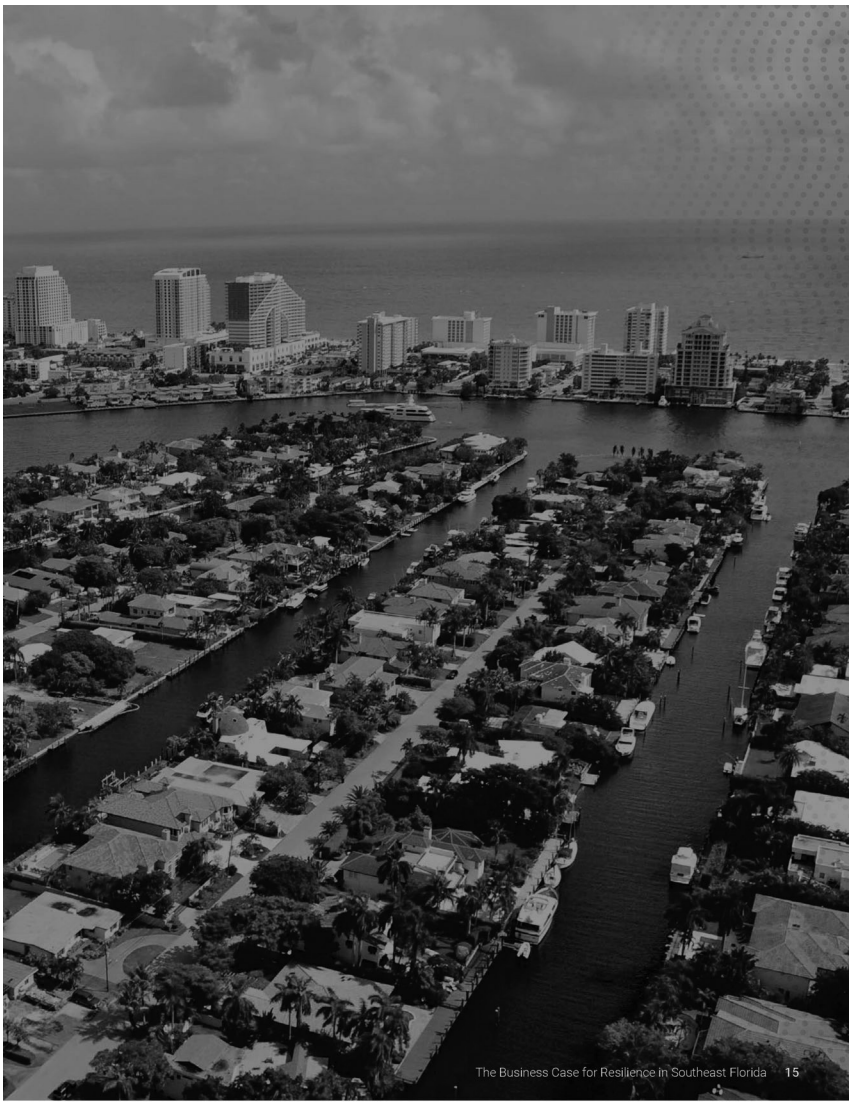
Resilience investments can help to minimize the shocks from coastal hazards, but they will not address underlying chronic stresses such as social equity, poverty, unemployment, and the lack of industry diversification that affect capacity of communities to respond to and recover from coastal hazard risks and shocks and stresses. The region must identify the structural factors that will affect its ability to be resilient to changing climate and flood conditions and, therefore, can enhance the livability and prosperity of the Southeast Florida region.

It is critical to not overlook the value of investing in communities most in need of support—primarily communities of color and low income. The study focused on assessing the economic impacts and the costs and benefits conveyed by certain specific adaptation measures compared to inaction. Although these reporting metrics are indicators of economic vulnerability, they do not explicitly account for community characteristics that may indicate social vulnerability.

To broaden decision-making considerations related to investments in adaptation and resilience, communities should consider the use of social vulnerability indices and other tools that can illustrate, in a standardized manner, the relative vulnerability of different populations to a range of shocks and stressors, both natural and human caused. Such resources incorporate indicators (e.g., age, poverty, vehicle access) that can help illuminate the social vulnerability of a community and its potential to be resilient in the face of disasters.

Helpful resources and frameworks include the following:

- Georgetown Equitable Adaptation Toolkit
- Institute for Diversity and Inclusion in Emergency Management (I-DIEM) resources and trainings
- Urban Sustainability Directors Network Resilience Hubs initiative
- Groundworks USA Climate Safe Neighborhoods plans
- Centers for Disease Control and Prevention Social Vulnerability Index



THE REGION'S ECONOMIC AND CLIMATE CONTEXT

Southeast Florida is a hub for the trade, logistics, health care, and creative industries, and a world-class tourist destination. The regional economy has experienced successful growth over the past decade until the recent disruption from COVID-19. Alongside the challenges of the pandemic, the local government and business community recognize the urgency and severity of a changing climate, and its current and future impacts to the region and its economy. Even in a time with many other urgent challenges, it is critical to remain focused on climate change, which presents both short-term and long-term threats to residents' public health and the region's economic vitality.

Although Southeast Florida has taken noteworthy steps to mitigate climate risks proactively through planning and public investments, the region must accelerate its efforts to drive climate adaptation.

This study illustrates that advancing economic resilience requires action by both the public and private sectors at various geographic scales, and that a shared interest in partnership exists for both communities. The study also shares lessons learned and best practices from other local governments addressing resilience by leveraging similar economic analyses.

ECONOMIC BACKGROUND

Southeast Florida is regarded as a world-class destination for business and leisure purposes alike. Over the past 50 years, the region's diverse and growing population has developed the region into a prosperous hub for tourism, health care, international banking and finance, supply chain and logistics, creative industries, and technology.

The region's economy is deeply interconnected among counties, cities, and communities. Residents and visitors work, play, and live across jurisdictional boundaries, providing reason for a coordinated effort to tackle climate change as a region.

POPULATION GROWTH

Florida has been experiencing steady population growth since the 1970s, making the state the third largest in the nation.[4] Overall, the population has tripled in the past 50 years. The Southeast Florida region alone is home to more than 6 million people, a population larger than more than half of other U.S. states.[5]

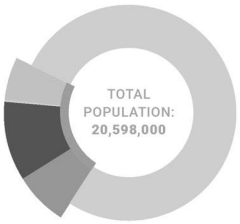
Though the Sunshine State has traditionally been thought of as a destination for snowbirds, studies show a growing trend of young professionals relocating to Florida. New employment opportunities in the state's strong job market attracted more than a third of new residents.[6] The largest group of incoming residents (40 percent) still cite retirement as their main motivation, however, the new influx of working adults feeds a robust workforce attracted by the strong economy.

Continuous emigration of Cuban, Caribbean, and Latin American populations to the region creates the diverse and vibrant culture for which the region is known.

POPULATION

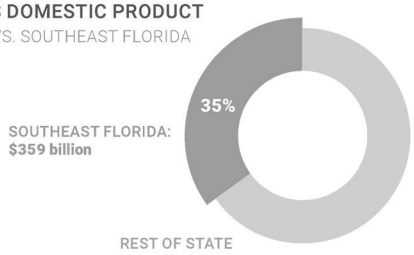
STATE VS. SOUTHEAST FLORIDA REGION

SOUTHEAST FLORIDA: **6,147,269**
PALM BEACH: **1,446,277**
MONROE: **76,325**
MIAMI-DADE: **2,715,516**
BROWARD: **1,909,151**



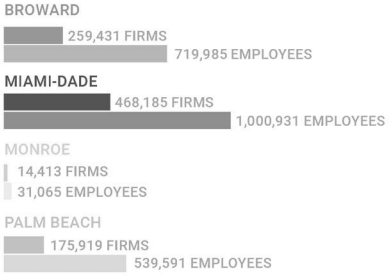
GROSS DOMESTIC PRODUCT

STATE VS. SOUTHEAST FLORIDA REGION



SOUTH FLORIDA'S WORKFORCE

FIRMS AND EMPLOYEES BY COUNTY



REGIONAL ECONOMY

Southeast Florida's economy has continued to strengthen in the past decade. In 2018, the region generated more than $350 billion in gross domestic product (GDP), contributing 35 percent of the state's total GDP.[7] In the same year, Miami-Dade, Broward, and Palm Beach represented third-ranked counties in the state, respectively, for GDP growth.[8] Compared with the rest of Florida, the Southeast has the largest labor pool, and the most cruise and trade ports.

The region's largest sectors and primary economic drivers are tourism, international trade, financial and professional services, health care, and real estate. Its status as an international business headquarters and a leading global real estate market is a major economic driver for the region, with the city of Miami being the second largest international banking center in the United States, behind New York City. The Greater Miami and Beaches area hosts more than 700 multinational companies.[9]

WATERFRONT AND OCEAN-RELATED ECONOMIES

Southeast Florida's waterfront is a key part of the economy—home to many residents and attractions, it creates opportunities for many key industry sectors, such as tourism and logistics. In 2016, total trade out of the Miami Customs District, which includes seaports and airports, reached a record $102.18 billion.[10]

Despite a strong economy, the region faces challenges due to a high cost of living, lower educational attainment, and low average wages. For example, Miami-Dade's middle class has shrunk from 65 percent of local households to 43 percent in the past 50 years.[11]

Port Miami, a critical part of the region's waterfront economy.

TOURISM AND NATURAL RESOURCES IN THE REGION

Tourism is the state's largest industry and the fourth largest employment sector, representing 12 percent of all jobs. Driven by Florida's coastlines and its warm climate, natural landscape, and beaches, tourism has direct benefits to the local counties, state, and beyond, with a total statewide economic impact of more than $90 billion, including $12.3 billion in state and local tax revenue alone (2018).[a]

Florida's natural landscape—including beaches, wetland areas, and coastal and ocean habitats—provides opportunities for recreational activites that attract tourists from around the world.

Visitors looking to explore and experience these areas constitute a significant portion of the region's annual tourism. A study on the economic impact of beach tourism in Palm Beach County found that out-of-county visitors spent nearly $200 million in connection to beach visits in a single year.[b]

Ecotourism—tourism focused on visiting natural areas, observing wildlife, and supporting conservation—is directly reliant on the health and vitality of these areas, and accounts for a significant portion of the region's tourism, with 2.9 million people visiting South Florida's national parks in 2019 alone, spending $242.5 million during their visits, and providing a net benefit of $352 million to the region.[c]

This direct spending benefits the local economy, and is largely subject to taxes that fund the operations and service provisions of state and local governments.

Tourism is Florida's top economic driver

$91 BILLION

tourism's contribution to gross state product in 2018[d]

Ocean-related tourism contributed

$24.7 BILLION

and over 70 percent of total jobs (about 395,000) in 2018.[e]

In addition to the economic benefits from tourism, Southeast Florida's beaches also provide important protection from coastal storms. Historically, the region has invested in beach nourishment and other forms of beach management practices to combat erosion and maintain the size and quality of beaches.

Given the fundamental tie between a strong tourism industry and beaches, these investments can provide rolling benefits in the form of mitigating coastal flooding conditions while also maintaining the quality of beaches that are a key draw for visitors who make significant contributions to local and state economies.

A kayaker navigates around mangroves in Everglades National Park.

UNDERSTANDING THE REGION'S FLOOD RISK

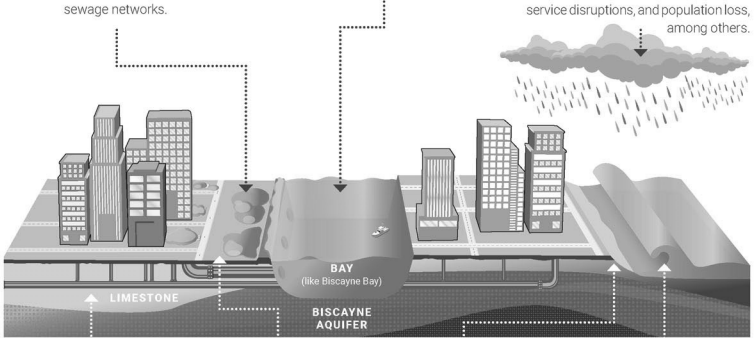
As the Southeast Florida region continues to grow and develop, so too do the region's unique flooding challenges that are heightened by increasing precipitation rates and storm activity, rising seas and groundwater levels, flat topography, and impervious land uses, as noted in the graphic below. As sea levels increase, it no longer takes a strong storm to cause flooding throughout coastal communities. Flooding now occurs at high tide for many locations due to a combination of sea-level rise, smaller storm events, onshore wind flows, and changing offshore current patterns that cause water to pile up along the shoreline.

Frequent flooding can cause damage, disrupt businesses and transportation, and corrode infrastructure over time. These environmental risks can lead to much broader socioeconomic impacts, such as loss or impairment of public services and infrastructure, decreases in property values and local government tax bases, increases in insurance costs, and displacement of disadvantaged and marginalized frontline communities.

TIDAL FLOODS
or "sunny-day floods" are above-normal tide events that cause water to overtop seawalls and waterfront barriers, seep through porous limestone, and infiltrate into the stormwater and sewage networks.

SEA-LEVEL RISE
along the Southeast Florida coasts adds to water levels caused by seasonal tide fluctuations and weather-based events.

HURRICANES
are a regular event in the region during the storm season (June–November). These large storms can have massive economic and social impacts in terms of damages, insurance, business and service disruptions, and population loss, among others.



POROUS LIMESTONE GEOLOGY
allows salty sea water to penetrate inland and push already-high groundwater levels closer to the surface.

LOW-LYING GEOGRAPHY
averages an elevation of about six feet above current sea levels, with a limestone ridge that reaches an average of about 11.5 feet as the only natural high ground.

COASTAL EROSION
lowers the region's defense against storms by reducing the natural beach and dune areas that act as a buffer between storm waves and coastal property and infrastructure.

STORM SURGE
the rise in seawater level during a storm, is one of the greatest threats to life and property. Storm surge impacts could be exacerbated by tidal flooding events and heavy rainfall.

The region is expected to experience an increase in rainy season months and more frequent storm events. In 2017, Hurricane Irma, one of the strongest hurricanes ever recorded in the Atlantic Ocean, struck South Florida, dropping four to twelve inches of rain and inundating some areas with three to five feet of seawater. The Category 4 hurricane left 65 percent of the state without power and caused more than $50.5 billion in damages in the Florida Keys alone.


POTENTIAL IMPACTS IN 2040
IN THE ABSENCE OF ADAPTATION
$4.2 BILLION
in property value exposed to daily tidal inundation
$3.2 BILLION
in property damage from one 10-year storm tide event
$2 MILLION
in sales and tourism tax losses from 10-year storm tide event
$28 MILLION
in sales, tourism, and property tax losses from daily tidal inundation
Results shown are not adjusted to account for financial discounting. Parcels affected by daily tidal inundation are excluded from the 10-year storm tide event damages.
The Business Case for Resilience in Southeast Florida 21

ANALYSIS FINDINGS

SOUTHEAST FLORIDA'S BUSINESS CASE FOR RESILIENCE

The avoided losses to property in Southeast Florida through building-level and community-wide adaptation strategies outweigh the costs 4:1 and 2:1, respectively.

The analysis shows that it is cost effective for the region to make investments in resilient infrastructure now. These measures include community-wide infrastructure adaptation investments and building-scale adaptation investments to enhance resilience in the region.

Investment in actions that can reduce coastal hazard risk and support adaptation to changing conditions can help to protect people, property, businesses, and infrastructure and reduce the amount of resources and investment needed to respond to and recover from coastal hazard events over the long term.

In addition, the study shows that regional action is critical as coastal storms and sea-level rise can have wide-ranging direct, indirect, and induced effects that extend beyond the borders of any one community.

A primary goal of investing in economic resilience is to ensure that communities can adapt to coastal hazard events when they do occur, so that shocks are manageable and not disruptive. By understanding the strengths and weaknesses of local and regional economies, opportunities for improving business-as-usual practices arise so that communities do not just survive but are best positioned to thrive.

INVESTMENT STRATEGIES AND BUSINESS CASE DIFFER DEPENDING ON COUNTY-SPECIFIC FACTORS

No single solution for adaptation will work across all jurisdictions and for every community. This study explores regionally consistent adaptation solutions across all four counties, referred to as the community-wide adaptation approach and building-level approaches. One of the challenges with analyzing the community-wide adaptation approach is that even within the Southeast Florida region, there is diversity in the local site and water conditions that would lead to different proposed adaptation solutions. Some measures evaluated are not as applicable in certain jurisdictions because of unique geographical factors. Each county and municipality will need to determine the exact adaptation options available given the local conditions.

Specifically, the types of solutions examined appear to be more cost beneficial for more densely developed areas of the mainland, like those in Broward County, Miami-Dade County, and Palm Beach County. Given the highly regulated growth and environmental resource management process, adaptation measures in Monroe County will be unique and hardened shorelines may not be feasible. Also, because Monroe County has very little beach or dune areas, those measures are less applicable. This analysis underestimates cost benefit in less urban areas of the region or those with more coastal environmental resources, like Monroe County, because different solutions would be used in those areas to better proactively address climate resilience given local conditions.

LACK OF ADAPTATION INVESTMENT AND INFRASTRUCTURE NOW WILL AFFECT REGION'S FUTURE ECONOMIC WELL-BEING

Investment in resilience actions can reduce coastal hazard risk and support adaptation to changing conditions. It can also reduce the amount of resources and investment needed to respond to and recover from coastal hazard events over the long term. Overall, investing in adaptation now can result in a positive economic return for the region.

Without an investment, the region risks experiencing cascading effects such as the following:

- Foregone property, sales, and tourism taxes
- Increased cost and/or barriers to access insurance coverage and mortgage financing
- Loss of wealth and/or income for property and business owners
- Downgrades to municipal bond ratings

These cascading effects could fundamentally alter the desirability of living and working in coastal communities, which in turn could result in the redistribution of populations and public and private investment, all of which can have significant impacts on local, regional, and state economies.

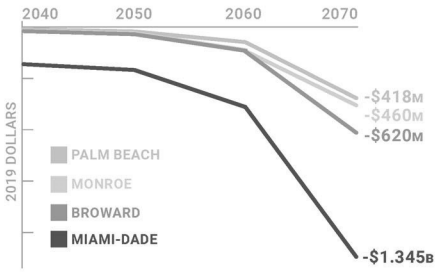
The study found that the failure to safeguard property from rising seas could result in significant property, sales, and tourism tax revenue losses, which are critical to local governments. Reductions to this revenue stream could hinder the ability of the public sector to fund its operations and invest in core community services and infrastructure, including adaptation.

The graph below shows the estimated property-tax revenues that could be lost over the next half century, based off property identified to be vulnerable to permanent sea-level rise and the modeled daily high-tide conditions. Further overview of fiscal impacts that might be realized by the counties are summarized below.

Long-term tax losses can deplete the region's ability to finance public goods and services and its ability to bounce back from shocks and stresses.

CUMULATIVE PROPERTY TAX LOSSES FROM SEA-LEVEL RISE
(MHHW)

The chart at right shows the estimated cumulative property tax revenues losses over the next half century. Cumulative property tax losses were estimated for each county by estimating the approximate year in which properties will be subject to daily high tides in the future.



Note: Impacts only account for parcels where 25 percent or more of the parcel footprint is exposed to the modeled coastal conditions. Results are not adjusted to account for financial discounting.

BUSINESS COMMUNITY CAN EXPERIENCE AVOIDED DAMAGES AND LOSSES

Increasing risks from sea-level rise and tidal flooding have the potential to undermine the strength of Florida's real estate market. The study found that $53.6 billion in regional property value will be exposed to daily tidal inundation under 2070 conditions.

Increasing evidence exists that projected flood inundation can decrease property value.[12] Previous studies show Miami-Dade properties at higher elevations in flood-risk areas appreciate at a higher rate than than properties at lower elevations.[13]

Population redistribution and investment in areas that face less risk to flooding due to their higher elevation can be a signal of climate gentrification, a situation in which properties become more valuable than others due to their ability to better accommodate settlement and infrastructure in the face of climate change, potentially pushing lower-income residents out of their neighborhoods.[14] Overall, studies show that the prices of tidally exposed properties tend to appreciate at lower rates than comparable properties not exposed to tidal flooding.

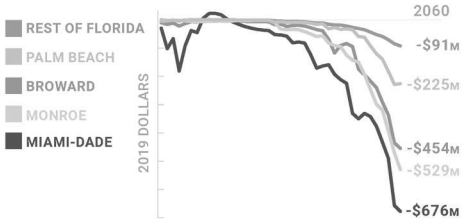
A storm event can cause structural damage and months of wage losses and associated job impacts that make doing business in the area more difficult, and potentially encourage relocation.

Implementation of the evaluated adaptation measures at both levels can deter flood impacts for the business community, like property damage and employment impacts, and maintain economic health.

GDP CHANGES DUE TO SEA-LEVEL RISE

NO-ACTION SCENARIO (MHHW)

If no action is taken, each county in the Southeast Florida region will experience a deterioration in GDP from tidal and storm events by 2060.



TOTAL LOSSES BY COUNTY IF NO ACTION IS TAKEN

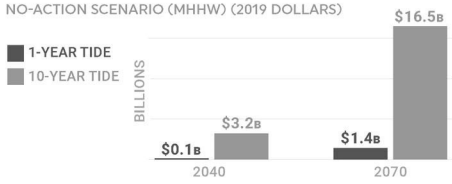
2020–2070 CUMULATIVE LOSSES (2019 DOLLARS)

	PROPERTY IMPACTS	SALES OUTPUT IMPACTS	SALES & TOURISM TAX IMPACTS	PROPERTY TAX IMPACTS
BROWARD	$63.911B	$5.279B	$161M	$825M
MIAMI-DADE	$106.5B	$8.354B	$361M	$2.388B
MONROE	$20B	$8.560B	$567M	$674M
PALM BEACH	$29.6B	$2.117B	$82M	$548M
REGION	$220.1B	$24.310B	$1.171B	$4.435B

Note: Results are not adjusted to account for financial discounting.

STRUCTURE AND CONTENT LOSSES FROM A SINGLE STORM

NO-ACTION SCENARIO (MHHW) (2019 DOLLARS)



ADAPTATION CAN YIELD LASTING BENEFITS FOR SOUTHEAST FLORIDA

The implementation of certain community-wide and building-level adaptation strategies could help to minimize the devaluation of real estate and mitigate a variety of economic and social effects. In general, community-wide strategies mitigate impacts from both temporary coastal storms and permanent sea-level rise to all inland assets while building-level strategies can mitigate impacts for individual assets that are exposed to temporary coastal storms and not permanent sea-level rise.

COMMUNITY-WIDE ADAPTATION PRESENTS NET BENEFITS FOR THE REGION

Overall, the community-wide adaptation strategies would increase GDP and employment for the four counties. Community-wide adaptation measures, if implemented with best practices, have the potential to mitigate nearly all modeled coastal impacts. Community-wide adaptation strategies have the potential to protect the broader community and provide further benefits to individual property from gradual sea-level rise conditions.

PROPERTY AND REAL ESTATE VALUES CAN BE PRESERVED AND GENERATE VALUE

Investing in adaptation provides direct benefits in the form of avoided losses to property, as well as the potential for indirect benefits, such as reductions in insurance premiums, stabilization or enhancement of property values, and associated tax revenues. It is common knowledge that coastal property is priced at a premium compared with similar property not located by the coast. However, living near the coast comes with the risk of potential impacts from coastal hazards. Hazard risks have been shown to be capitalized in the value of property; in particular, properties subject to hazard risks are often sold at a discount compared with similar properties not subject to these risks, all else considered equal.

Adaptation to coastal hazards can be designed to offer benefits to the community in the form of an amenity, like this park in downtown Miami.

With proper incentives and partnership opportunities for the private sector, property owners and developers should make investments to develop/redevelop current and future buildings to be more resilient at the asset level. A regionally funded program that offers such incentives can support retention of long-term asset value and protect people.

JOBS AND ECONOMIC ACTIVITY CAN BE PRESERVED AND GENERATED

Adaptation avoids economic challenges, and it can create additional jobs and boost economic activity. Investments in adaptation can provide benefits beyond the avoided impacts, as described previously. For example, the construction industry would be expected to benefit from investment in adaptation. This major increase in construction spending can result in increased employment in the area for the construction industry as well as related industries. Funds used to construct a seawall will result in direct job gains for the construction industry, as well as downstream indirect (e.g., supply chain) and induced (e.g., spending by directly and indirectly affected workers) job gains.

Over the next 50 years, investments in community-wide adaptation could support 85,000 job years, and investments in building-level adaptation could support 56,000.

RETURNS ON INVESTMENTS IN ADAPTATION

A COMPELLING BUSINESS CASE FOR BUILDING-LEVEL AND COMMUNITY-WIDE ADAPTATIONS

The analysis shows that there is a regional business case for the local governments and business communities of Southeast Florida to start making investments in resilient infrastructure now, with phased investments over the coming decades. To develop an understanding of the costs and benefits of adaptation, the direct impacts on real and personal property under a no-action scenario were estimated and compared with the costs and benefits of community-wide and building-level adaptation strategies. The tables below show estimates for the cumulative impacts avoided and cumulative cost of adaptation, net impacts, and resulting benefit-cost ratios, which range from about 2 to 4. A benefit-cost ratio greater than 1 implies that the economic benefits outweigh the costs.

The economic benefits from both building-level and community-wide adaptation provide greater benefit than the cost to the region. However, these strategies must be integrated together to safeguard the region.

RETURN ON INVESTMENT: BUILDING-LEVEL ADAPTATIONS
CUMULATIVE 2020–2070 (NET PRESENT VALUE)

	CUMULATIVE IMPACTS AVOIDED	CUMULATIVE ADAPTATION COSTS	NET IMPACTS	BENEFIT-COST RATIO
BROWARD	$4.5 billion	$1.5 billion	$3 billion	3.04
MIAMI-DADE	$9.2 billion	$1.8 billion	$7.5 billion	5.18
MONROE	$459 million	$598 million	-$139 million	0.77
PALM BEACH	$3.3 billion	$545 million	$2.8 billion	6.08
FOR THE REGION	Benefits $17.6BIL ÷	Costs $4.4BIL =	Benefit-Cost Ratio 3.97	Job Years Supported 56,000

RETURN ON INVESTMENT: COMMUNITY-WIDE ADAPTATIONS
CUMULATIVE 2020–2070 (NET PRESENT VALUE)

	CUMULATIVE IMPACTS AVOIDED	CUMULATIVE ADAPTATION COSTS	NET BENEFITS	BENEFIT-COST RATIO
BROWARD	$9.601 billion	$4.128 billion	$5.473 billion	2.33
MIAMI-DADE	$19.461 billion	$2.101 billion	$17.360 billion	9.26
MONROE	$3.182 billion	$7.669 billion	-$4.487 billion	0.41
PALM BEACH	$5.613 billion	$4.325 billion	$1.288 billion	1.30
FOR THE REGION	Benefits $37.9BIL ÷	Costs $18.2BIL =	Benefit-Cost Ratio 2.08	Job Years Supported 85,000

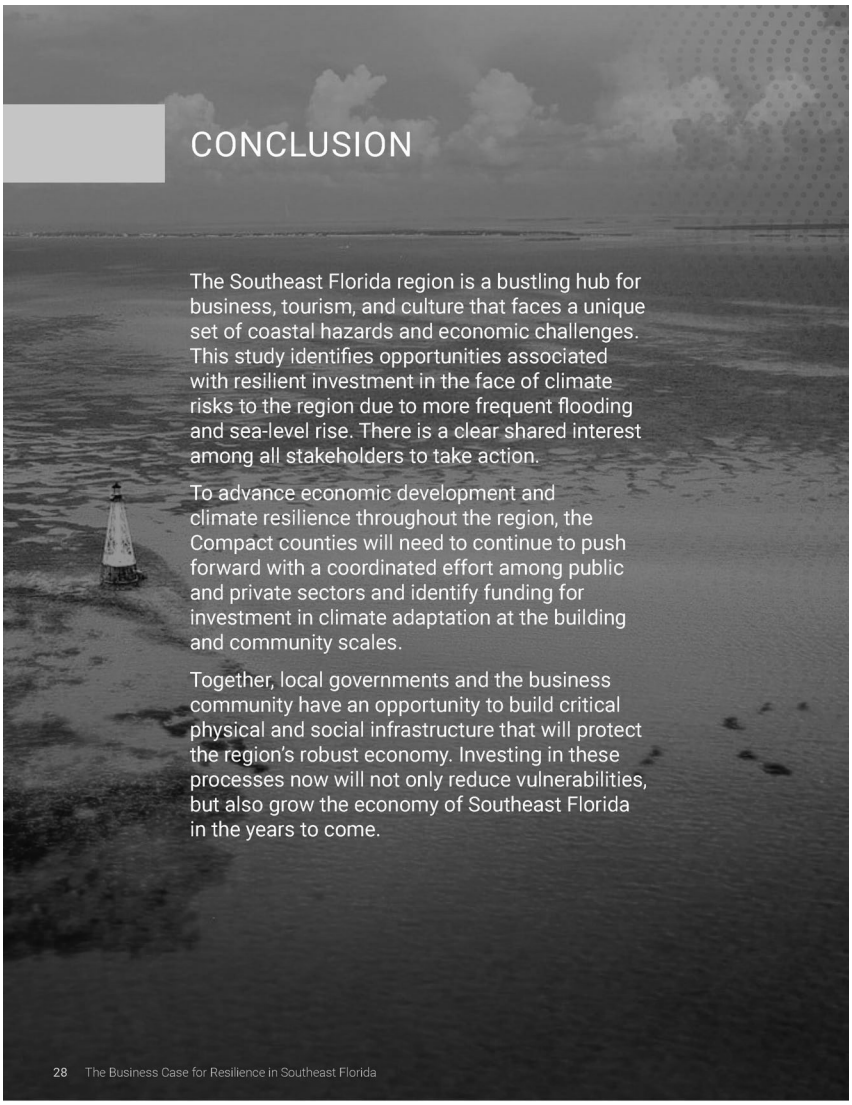
Notes: Results account for structure, content, land, and relocation impacts. Results are presented in net present value terms using a 5 percent discount rate over the period of the analysis from 2020 to 2070. For both the community-level and building-level adaptation strategies, the benefits outweigh the costs for all counties except Monroe. This does not imply that adaptation is not a cost-effective investment for Monroe County. Rather, the selected adaptation solutions examined in this study would not be the appropriate strategies to apply in Monroe County.

ECONOMIC BENEFITS FROM INVESTMENT IN SELECTED TYPES OF ADAPTATION MEASURES THROUGH 2040 (2019 DOLLARS, $MILLIONS)

There is a compelling case for investing in both community-wide and building-level adaptation in the Southeast Florida region. The table below shows the economic benefit from investments in community-wide and building-level adaptation strategies in 2020 and 2040 , which are the years when investment would take place as part of the phased adaptation approach in this study. Overall, both adaptation scenarios present a general positive impact on GDP and employment for the region.

	COMMUNITY-WIDE ADAPTATION INVESTMENT		BUILDING-LEVEL ADAPTATION INVESTMENT	
INVESTMENTS IN:	**2020**	**2040**	**2020**	**2040**
Economic Impact	*Combined difference from baseline*		*Combined difference from baseline*	
BROWARD				
Job years	6,780	5,280	2,530	15,010
GDP	$660 million	$780 million	$240 million	$1.97 billion
MIAMI-DADE				
Job years	15,200	9,550	3,190	18,470
GDP	$1.6 billion	$1.38 billion	$350 million	$2.67 billion
MONROE				
Job years	19,370	9,320	2,560	5,600
GDP	$1.26 billion	$810 million	$180 million	$530 million
PALM BEACH				
Job years	9,470	9,910	1,270	7,020
GDP	$730 million	$1.17 billion	$120 million	$880 million
REST OF FLORIDA				
Job years	-15,050	-11,320	300	1,130
GDP	-$1.34 billion	$1.23 billion	$30 million	$140 million

Jobs rounded to nearest 10. GDP rounded to nearest $10 million. Job years is equivalent to one year of work for one person; for example: a new construction job that lasts two years will equate to two job years. Results are not adjusted to account for financial discounting.



CONCLUSION

The Southeast Florida region is a bustling hub for business, tourism, and culture that faces a unique set of coastal hazards and economic challenges. This study identifies opportunities associated with resilient investment in the face of climate risks to the region due to more frequent flooding and sea-level rise. There is a clear shared interest among all stakeholders to take action.

To advance economic development and climate resilience throughout the region, the Compact counties will need to continue to push forward with a coordinated effort among public and private sectors and identify funding for investment in climate adaptation at the building and community scales.

Together, local governments and the business community have an opportunity to build critical physical and social infrastructure that will protect the region's robust economy. Investing in these processes now will not only reduce vulnerabilities, but also grow the economy of Southeast Florida in the years to come.

ADAPTATION IN ACTION: CASE STUDIES

EXAMPLES FROM SOUTHEAST FLORIDA

A1A IMPROVEMENTS PROJECT
Broward County
Building resilience into a post-hurricane emergency roadway reconstruction project

LIVING SHORELINES PROJECT
Palm Beach County
Implementing natural resilience and habitat restoration

NORTH MIAMI STORMWATER PARK
Miami-Dade County
Converting a repetitive loss property into a community stormwater park

STORMWATER RESILIENCE PROGRAM
Miami-Dade County
Managing stormwater at the community level in Miami Beach

SEAWALLS AND WATERFRONT ACCESS
Miami-Dade and Broward Counties
Implementing widespread adaptation requirements in Miami-Dade and Broward counties

FINDING THE BUSINESS CASE: PEER PROJECTS IN THE U.S.

CALIFORNIA
Protecting municipal land, and maritime and aviation operations

HAWAII
Directing adaptation among state agencies

LOUISIANA
Leveraging university partnerships to inform resilience investment

TAMPA BAY
Quantifying the cost of doing nothing

ADAPTATION IN ACTION

BROWARD COUNTY

A1A IMPROVEMENTS, POST-SUPERSTORM SANDY

CONSTRUCTED:	SIZE:	COST:
2014	0.988 miles	$20.1 million

In 2012, Superstorm Sandy moved along the eastern U.S. seaboard, causing devastating erosion that stretched for miles along Fort Lauderdale's beaches. The destruction that came with Superstorm Sandy undermined roadways and coastlines alike, causing sand and saltwater to encroach well past the shoreline and to infiltrate the thoroughfare. Whereas natural disasters, such as hurricanes, are readily abundant in Florida, our rapidly changing climate is worsening the frequency and severity of these events.

The City of Fort Lauderdale, Broward County, and the Florida Department of Transportation worked together to improve the resilience of the emergency repair reconstruction project. As a result of the damage caused by Superstorm Sandy, this project increased adaptation efforts by incorporating additional resilience into existing structures, as well as building completely new essential infrastructure. Notably, one of the improvements to Fort Lauderdale's State Road A1A was the installation of a sheet pile that is 40 feet deep and designed to withstand 15 feet of scour. Several other reconstruction improvements included raising the roads two feet, building a one-foot-higher wall, and installing new backwalls.

On Sunrise Boulevard, a back wall was added to prevent sand and saltwater from reaching the roadways. This back wall served a multitude of purposes by also preventing marine wildlife from entering the roadways and subsequently reducing light pollution from nearby traffic. The improvements made during this project were necessary and, therefore, not considered "new money." Resilience was deemed an imperative part of the overall project, reflecting the urgent need to continuously improve roadways and other public infrastructure amidst our changing climate.

ADAPTATION IN ACTION

PALM BEACH COUNTY

LIVING SHORELINES PROGRAM

Palm Beach County is home to a wide array of ecosystems, both natural and man-made, all of which may thrive in urban environments when suitable sediment, habitat, and water-quality conditions exist. Over the course of several years, the Palm Beach County Living Shorelines Program focused on reinforcing ecological resilience in these communities. Living shorelines have become an increasingly viable method of natural resilience and habitat restoration, while also being cost-effective, sustainable, and aesthetically pleasing. These shorelines act as natural barriers to wave energy and storm surge and create crucial habitats for native wildlife.

In 2012, Palm Beach County prioritized the creation of natural habitats for wildlife, as well as the development of green infrastructure that encouraged educational and ecotourism activities, for the South Cove Natural Area. Expanding on the existing seawall, a mangrove planter was installed to soften the edges and create a more natural shoreline within this urban estuary. Moreover, South Cove had historically been used as a dredge hole site. The dredge hole had slowly been filled in with organic matter, which when re-suspended can negatively impact water quality. This project enabled the creation of critical tidal islands, seagrass habitat, and oyster reefs by filling the existing dredge hole with clean sand, thus capping the organic matter at the bottom of the hole. In all, this project created six acres of mangrove, seagrass, and oyster habitat in the middle of downtown West Palm Beach complete with an elevated boardwalk and observation deck.

Five years later, the county, alongside the City of West Palm Beach, worked to rehabilitate the shoreline of Currie Park by using the habitat-restoration methods employed successfully in the South Cove Nature Area. The Currie Park project created seven mangrove and spartina planters alongside a concrete seawall. Similar to the South Cove Natural Area, Currie Park's living shoreline was constructed of limestone rock and filled with clean sand to create planters and soften the edges along the linear seawall. In addition, this project was centered around the local community, involving residents in volunteer opportunities, such as planting and cleanup events, as well as ongoing recreational activities within the park.

All of the resilience measures prioritized in each restoration project supported an enhanced ecosystem where countless native species can thrive for generations to come.

An oft-overlooked but key component of these types of projects is the beneficial reuse of existing suitable materials to create the various habitats. Clean rock and sand are often generated in urbanized estuaries through the management and operation of both the working waterfront and the adjacent navigational waterways. Handling and disposal of this material is usually costly and results in the loss of the material within the system. By partnering with public and private entities that generate clean rock and sand through dredging and excavation projects, living shorelines can make use of this material at a significant cost savings to all parties, resulting in habitat improvements and coastal resilience while supporting the local marine community.

ADAPTATION IN ACTION

MIAMI-DADE COUNTY

CONVERSION OF A REPETITIVE-LOSS PROPERTY TO STORMWATER PARK

COMPLETED:	SIZE:	COST:	DEVELOPMENT TEAM:
2019	13 blocks, 0.62 miles	$80,000	City of North Miami, Van Alen Institute, Department Design Office, local residents and stakeholders

The Arch Creek Basin is a low-lying area within the City of North Miami that regularly suffers from flooding and includes multiple FEMA-designated repetitive-loss properties (parcels that have filed for flood insurance twice in a 10-year period). Several of these sites have remained vacant for years.

The city reimagined a pilot site that transformed a repetitive-loss property into additional storage and retention for its stormwater management system through the creation of a stormwater park. The North Miami Stormwater Park was previously owned by an individual whose home flooded multiple times within a 10-year period, generating a claim from the National Flood Insurance Program (NFIP). This claim enabled the city of North Miami to "buy out" the property. It was vacant for several years until the city's initiative transformed it into a space where community members can cherish its beauty as well as its functionality.

The conversion from a repetitive-loss property to a requisite stormwater management system allowed the City of North Miami to strengthen its resilience efforts. The absorbent natural landscaping significantly increased the pilot site's ability to mitigate problematic flooding. The park also includes artistic elements like public art and colorful educational signage to create a sense of place and enhance curb appeal. The innovative use of this land has made it possible for all residents of North Miami to enjoy a shared space that emphasizes a sense of social and environmental resilience.

Repetitive-loss properties are increasingly disruptive to many communities—causing excessive flooding not only on the specific parcel, but also on neighboring properties.

During a recent rainstorm, the city anecdotally noted that the stormwater park flooded, as it was designed, and the areas surrounding the site experienced reduced flooding. This is a co-benefit of buying out repetitive-loss properties and transforming them into an integral tool of stormwater management. In addition, revamping of sites such as the Good Neighbor Stormwater Park allows homeowners to move to a safer location, and at the same time lessens the burden on NFIP by reducing the amount of flood-damage claims.

North Miami Stormwater Park is intended to provide a community-oriented space that increases stormwater retention capacity, supports local habitats, and increases public outreach and awareness of climate-related issues.

ADAPTATION IN ACTION

MIAMI-DADE COUNTY

MIAMI BEACH'S STORMWATER RESILIENCE PROGRAM

The City of Miami Beach has shown a commitment to addressing flood vulnerabilities, including identification of funds other than federal and state monies and execution of the initial phases of an integrated stormwater management program that will also incorporate quality of life improvements such as mobility and green infrastructure.

In 2019, through a multidisciplinary procurement process, the city selected ICF Inc. to conduct a business case analysis of its stormwater resilience program. The purpose of the analysis was to assess the effectiveness of infrastructure investments throughout Miami Beach at the individual, neighborhood, and citywide level to protect against flooding from high tides, storms, and sea-level rise. Miami Beach's stormwater management efforts included the installation of improved drainage systems and new water treatment systems and elevating roads and public seawalls.

This pilot study researched stormwater investments through data analysis and catastrophe, drainage, and economic modeling, focusing primarily on the potential benefits related to lowered flood risk, increased property values, and reduced flooding. The study examined the benefits of targeted resilience investments and how they can lead to substantial economic and societal advantages.

Through the study, ICF found that the city's investments can positively affect property values in two ways: by elevating surrounding roads and by reducing flood depths at individual properties. The study found that parcel elevation and nearby road elevation have a strong positive effect on property values in Miami Beach. The study also emphasized the need for private-property-owner investments. In study neighborhoods, for example, every $1 that residents invest in storm-surge protection returns nearly $3 in benefits.

ICF conservatively estimates that on the basis of a high-level analysis of property damages and property values alone, citywide public and private resilience investments of up to $2 billion could be justified: $1 billion for storm-surge protection and $1 billion for stormwater system improvements to reduce flood depths from king tides and heavy rain events.

Overall, the pilot study demonstrated that the city's targeted investments in stormwater and infrastructure improvements significantly outweigh their costs and they provide substantial benefits to the residents, businesses, visitors, and government of Miami Beach.

ADAPTATION IN ACTION

MIAMI-DADE AND BROWARD COUNTIES

SEAWALLS AND WATERFRONT ACCESS

The waterfront is an essential part of Southeast Florida's economy and lifestyle. With hundreds of miles of waterfront, countless access points, and rising seas, the region's communities must address options for adaptation, considering physical protection and economic development from the real estate and marine industries. Across Southeast Florida, communities are learning how to proactively address tidal flooding that overtops seawalls and other waterfront infrastructure.

The City of Fort Lauderdale has instituted one of the most progressive seawall ordinances, establishing fundamental triggers for upgrades or modifications. The ordinance sets the old maximum seawall height of 3.9 feet NAVD88 as the new minimum height (NAVD88 is North American Vertical Datum of 1988, a reference frame to compare measurements globally); sets the maximum seawall height as the base flood elevation, which is around five to seven feet NAVD88 for much of the coastal areas in Fort Lauderdale; and creates mechanisms for repair or replacement of the seawall.

Specifically, seawalls must be repaired or replaced when individuals fail to maintain a seawall in good repair, if major changes are made to the property or seawall, or if tidal waters enter their property and affect other properties or the public right of way.

Other cities in the region are using the innovative Fort Lauderdale ordinance as an essential template for their own seawall ordinances.

Similarly, the City of Miami Beach increased its requirements for minimum seawall height and now requires new private and public seawalls to be constructed at a minimum elevation of 5.7 feet NAVD88, up from 3.2 feet NAVD88. A seawall that is not being repaired or replaced can remain as is, as long as it

meets the four feet NAVD88 minimum and can structurally support up to 5.7 feet NAVD88 in the future.

In Broward County, a new land use amendment has introduced consistency for tidally influenced properties across the county. Notably, tidally influenced municipalities must adopt an ordinance that uses the regionally consistent top elevations for seawalls, banks and berms, and other waterfront infrastructure within the next two years. The county also passed an ordinance that applies to unincorporated Broward County. In addition, the new regulation applies to waterfront infrastructure, such as boat ramps.

To address the challenges of direct water access, the City of Hollywood upgraded the Hollywood Marina boat ramp to address frequent tidal flooding in the area. The project received a grant from the Florida Department of Environment Protection to aid with the cost of the project. This project is an example of the importance of waterfront infrastructure upgrades to reduce flooding likelihood and to increase access to the water for the general public.

Seawalls are a primary coastal defense for Southeast Florida and have become an integral part of our flood protection infrastructure. The decisions made today will affect the resilience of the community for decades to come. Proactive changes now, which add minimal construction cost, will reduce the need for substantial changes at higher cost down the road.

FINDING THE BUSINESS CASE: PEER PROJECTS IN THE U.S.

Determining the cost/benefit analysis for investment in resilient infrastructure is an emerging strategy for local governments that has been piloted in a small number of regions. A few examples highlighted below used such analyses to help steer decision-makers at state, regional, and district scales.

CALIFORNIA

The state of California enacted more than 300 statutes granting sovereign public trusted lands to local municipalities with stipulated uses like, ports, harbors, airports, or other means to facilitate commerce, navigation, recreation, and open space. Granted lands and assets are overseen and maintained locally but are governed by the California State Lands Commission. In 2015, the California Leislature adopted AB 691, also known as the Proactively Planning for Sea-Level Rise Impacts bill, to assess the impact of sea-level rise on those lands.

As a public trust land grantee, the Port of Oakland developed its sea-level rise assessment to comply with the bill and to better understand the port's economic vulnerability to future permanent tidal inundation as well as temporary storm events. The port has three business lines, including maritime, aviation, and commercial real estate, that collectively generate about $9.3 billion in business revenue and support more than 84,000 jobs in the region. The port's related impacts support more than 1 million jobs nationally (data is pre–COVID-19). The Port of Oakland creates cascading economic activity throughout the San Francisco Bay Area that contributes about $118 billion to the local economy each year.

The analysis evaluated fiscal impacts of damage to infrastructure and core port facilities, operational disruptions, and effects to recreational open spaces and natural habitats. The vulnerabilities assessments' process has led to considerations around future terminal retrofits and opened dialogue on the topic with other grantees and nearby maritime and aviation operators for knowledge sharing and coastal adaptation best practices. In addition, the Port of Oakland learned that planning for projects that will protect our lands from storm surge and sea-level rise is dependent on building and maintaining long-term trusting relationships with key stakeholders and surrounding communities. Those relationships need to be fostered so that successful collaboration and coordination are possible for multiyear planning and implementation of necessary infrastructure to mitigate for rising waters.

HAWAII

In 2017, the Hawaii Climate Change Mitigation and Adaptation Commission published the Hawai'i Sea Level Rise Vulnerability and Adaptation Report detailing sea-level rise projections and including discussion of considerations to address economic, land management, and infrastructure challenges that the islands may face in the future, given land conservation needs. The projections include an aggregate sea level that includes passive flooding, storm surge, coastal erosion, and ground water flooding. The directive for adaptation planning among state agencies was set legislatively in 2014. Recommendations, specific to each agency, outline how to foster natural resources, conduct critical infrastructure, identify where development needs to either relocate or adapt, and how to maintain traditional Hawaiian culture and water quality. The report findings are supporting ongoing initiatives to update permitting processes and building setback regulations.

San Francisco Skyline and the Port of Oakland.

FINDING THE BUSINESS CASE: PEER PROJECTS IN THE U.S.

LOUISIANA

The state of Louisiana is addressing major coastal land-loss challenges due to land subsidence, relative sea-level rise, and related flood risks—about 2,000 square miles of land have been lost over the past century and that amount may be doubled in the next 50 years. Economists at Louisiana's public universities have partnered with the public sector to study the state's risks from flooding and related economic implications in the coastal regions and the state. Initiatives in 2015 and 2017 were designed to bring economic context into the planning process and to spark a policy discussion around coastal resilience and investment.

In 2015, researchers from Louisiana State University (LSU) and the RAND Corporation released *Economic Evaluation of Coastal Land Loss in Louisiana*, a comprehensive assessment of the potential economic losses from sea-level rise, coastal erosion, local infrastructure projects, and the compounding complexities of storm events at a statewide level, on behalf of Louisiana's Coastal Protection and Restoration Authority (CPRA). CPRA is tasked with leading recovery from the Deepwater Horizon oil spill in 2010 and is directed to balance funding streams to support immediate needs for coastal restoration, but also understanding the economic need to protect the region from other coastal hazards.

In 2017, LSU built on the 2015 findings to take a more regional approach, specifically analyzing how coastal erosion, land subsidence, sea-level rise, and the compounding risk of storm surge can affect New Orleans, Baton Rouge, Houma, Lafayette, and Lake Charles' economic viability and the potential economic benefits to the regions yielded by the state's continued investment in coastal restoration and protection. The study, called the Regional Impacts of Coastal Land Loss and Louisiana's Opportunity for Growth, supports the region's cause for state funding assistance and informs decision-making for developing strategic long-term planning documents and communicating the economic links between direct impacts to coastal regions and economic implications further inland.

Tampa's downtown as seen from Plant Park, a 6.9-acre park overlooking the Hillsborough River.

TAMPA BAY, FLORIDA

In 2017, the Tampa Bay Regional Planning Council (TBRPC) published the *Cost of Doing Nothing: Economic Impacts of Sea-Level Rise in the Tampa Bay Region* analysis that assessed the direct and indirect impacts of sea-level rise on the regional economy by 2060 and evaluated the effect of sea-level rise on property, jobs, tax revenue, and income from tourism. The report found that impacts of seas rising as much as 2.9 feet over the next 40 years would accumulate to $162 billion in the region's GDP. TBRPC conducted the analysis to make the connection between climate change and economic viability. In addition, the study helped generate interest in regional climate action plans that were underway and eventually it sparked support for additional studies to further understand coastal risk and opportunity for resilience in transportation planning at the project level. Since then, a regional coalition of local governments throughout the greater Tampa Bay region, companies, and utilities has formed to prepare a Regional Action Plan.

APPENDIX A: PROCESS AND METHODOLOGY

The analysis summarized in this report included a multistep modeling approach to estimate results of:

- the economic risks of flooding and the augmentation of that risk due to rising sea levels,
- the economic benefit of a resilience action as a function of risk reduction,
- the economic opportunities associated with resilience investments, and
- recommended strategies to incentivize and improve resilience for the Southeast Florida community.

HAZARD SCENARIO SELECTION AND EXPOSURE ANALYSIS

The first stage of the analysis involved a selection of high-frequency coastal conditions, accounting for water levels that accounted for projected sea-level rise expected in 2020, 2040, and 2070.

Water level conditions evaluated included: the average daily high tide, represented by the mean higher high water level (MHHW); the 1-year tide level, which could occur one to two times each year; and the 10-year tide level, representing a small coastal storm.

Using these modeled conditions, an exposure analysis was conducted for major categories of assets. Exposure mapping was conducted across parcels and core community infrastructure assets (e.g., parcels, roadways, hospitals) that are necessary for life safety or public and private service continuity, or that could pose a significant social consequence if damaged.

Asset exposure was evaluated using readily available mapping layers from the University of Florida's Sea Level Scenario Sketch Planning Tool; the leveraged mapping layers represent an extension of water surface at the shoreline over inland topography, accounting for a variety of high-frequency storm conditions and sea-level rise. The maps show a high-level screening assessment of the timing and the extent of potential shoreline overtopping and asset exposure due to rising sea levels.

ECONOMIC MODELING OF AVOIDED LOSSES AND BENEFITS

Avoided losses were estimated for the region and compared with the cost of specific adaptation measures to develop an understanding of the return on investment from taking action to mitigate coastal hazard risks. The following outlines the key steps applied to calculate the benefits of taking action:

- Estimate the consequences to assets directly exposed to the modeled coastal hazard conditions in a no-action scenario.
- Estimate the consequences to assets directly exposed to the modeled coastal hazard conditions in scenarios where investments in adaptation are made.
- Subtract the estimated consequences in scenarios with adaptation from the estimated consequences in a no-action scenario.

Two sets of adaptation strategies were analyzed: building-level (e.g., floodproofing, elevating) and community-wide (e.g., dune restoration, beach nourishment, and berm and seawall construction).

Categories of potential consequences (direct property impacts, business employment impacts, and fiscal impacts) from coastal storms and sea-level rise were selected. The impacts range depending on the type of risk endured (i.e., temporary impacts from coastal storms or permanent impacts from sea-level rise).

The combined community-wide and building-level strategies were modeled using a phased approach whereby the design features meet the specified modeled conditions in future years. For example, constructing a seawall in 2020 that will provide benefits through 2040 and that can be further elevated in 2040 to provide protection through 2070. In this example, the benefits provided by the seawall are assumed to begin accruing in the base year of the analysis (i.e., 2020) and to continue to accrue until the end year of the analysis (i.e., 2070).

All measures were modeled for the four counties as a region, however, some of the adaptation actions are more suitable for some locations than others because of unique issues or geography. Several flood consequences were evaluated for different types of coastal flood hazards. The economic consequences calculated in a no-action scenario are representative of event-based impacts that could be expected if the modeled hazard events were to occur in each of the Southeast Florida counties today.

This portion of the analysis only tells one part of the story of how coastal hazards can affect the economies of Southeast Florida. Given the interconnectedness of regional economies, ripple effects are likely—for example, business closure or displacement due to property damage can result in an increased cost of goods, decreased worker productivity, or a decline in the regional labor force. Or, after a coastal storm, money will likely be directed to rebuilding damaged property, which would result in positive gains to the construction industry. To account for these complicated economic responses the REMI PI+ model was used to estimate changes in GDP and the creation of job years.[15]

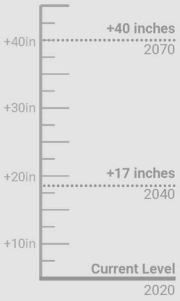
With an understanding of the avoided losses as well as the economic benefits of adaptation strategies, a benefit-cost analysis was also conducted to estimate the cost effectiveness of the building-level and community-wide adaptation strategies. The benefit-cost analysis was focused on accounting for the primary effects to society at large.

WHAT IS REMI PI+?

The REMI PI+ model is a robust economic analysis modeling platform that estimates the impact of public policy on local economies throughout the United States. This tool is useful because it helps users understand links between demographic and policy variables and the potential cascading effects in the economy. This economic impact modeling platform accounts for the common functions of an input-output model in addition to price elasticities and changes in consumer or industry behavior.

JOB YEARS

2019 COMPACT UNIFIED SEA-LEVEL RISE PROJECTIONS



The selected water-level conditions for the study were based on the 2019 Southeast Florida Regional Climate Change Compact Unified Sea Level Rise Projections. This graph shows the sea-level rise projections selected for the study.

PROJECT MODEL: ECONOMIC IMPACTS OF SEA-LEVEL RISE AND COASTAL STORMS ANALYSIS IN DANIA BEACH

In 2018, the city of Dania Beach commissioned an economic study to analyze the effects of sea-level rise and coastal storms on the local business community and the benefits conveyed through adaptation actions.

The analysis looked at direct property impacts, displacement impacts, business and employment impacts, and fiscal impacts. Cumulative damages from coastal storms were estimated at $719 million from coastal storm events and $1.2 billion from sea-level rise between 2030 and 2070 (applying a 5 percent discount rate over the period of analysis).

In addition, the analysis looked at several different types of adaptation responses including relocation, fortification (seawall construction), and accommodation (building elevation) to understand the costs and benefits associated with different investments in respect to property and asset values, tax base, and the local workforce. A survey sent to the business community informed more policy-oriented and qualitative discussion on preparedness, awareness, and vulnerability to changing climate conditions.

The study's findings support resilient land use design and development at a microeconomic level. The study's success encouraged the Compact to scale this model up for the Southeast Florida region and informed the process for the *Business Case for Resilience* economic analysis.

TEMPORARY AND PERMANENT IMPACTS

Core to this four-county analysis is the concept that temporary storm events (i.e., one-year tide, 10-year storm tide) and permanent sea-level rise (i.e., daily tidal inundation) cause various impacts to properties, businesses, and community revenue streams. As sea levels rise and flood events occur more frequently, some of these impacts may become irreversible.

	TEMPORARY IMPACTS (coastal storm)	PERMANENT IMPACTS (sea-level rise)
DIRECT PROPERTY IMPACTS	Structure damage	Property value loss
	Content damage	
	Relocation costs	
BUSINESS & EMPLOYMENT IMPACTS	Sales output loss	Sales output loss Income loss Job loss
	Income loss	
	Job Loss	
FISCAL IMPACTS	Sales tax loss	Property tax loss Sales tax loss Tourist-development tax loss
	Tourist-development tax loss	

APPENDIX B: KEY TERMS

1-YEAR TIDE
The highest annual tide, also referred to as the king tide.

10-YEAR STORM TIDE
A tide with a 10 percent chance of occurring in any given year. This event represents high-frequency conditions of temporarily elevated water levels due to coastal storms.

ADAPTATION
Strategies that anticipate and adjust human and natural systems to moderate the projected or actual impacts of climate change.

AVOIDED IMPACTS
This value represents the difference between the estimated impacts under the no-action scenario to the estimated impacts for the modeled adaptation scenario, essentially reflecting the amount of impact avoided as a result of investment in adaptation.

BEACH NOURISHMENT
The practice of adding sand or sediment to a beach to combat erosion, absorb wave energy, and prevent destructive waves from reaching upland development.

BENEFIT-COST RATIO (BCR)
The total present value of benefits conveyed by adaptation divided by the total present value of costs of adaptation. A ratio greater than one implies a return on investment.

BUILDING-LEVEL ADAPTATION
Structural modifications and improvements made to individual properties to protect against the threats of flooding. Examples include elevating structures and floodproofing.

CLIMATE-CHANGE MITIGATION
Strategies that focus on preventing the causes of climate change, specifically reducing or capturing anthropogenic emissions of greenhouse gases.

COASTAL HAZARDS
Physical risks related to coastal conditions, which have the potential to cause harm to humans, ecosystems, and property; the term encompasses different types of flooding, including storm surge, high tides, and sea-level rise.

COMMUNITY-WIDE ADAPTATION
A combination of soft and hard engineering investments made at the shoreline to minimize coastal hazard impacts and provide protection at the community scale. Examples include beach renourishment and seawall raising.

CUMULATIVE IMPACTS
The estimated impacts for each year in the period of analysis, which account for the likelihood of the modeled hazards occurring, are summed to develop an estimate of cumulative impacts. When calculating the benefit-cost ratio for this study, cumulative impacts were discounted to account for the time value of money.

JOB YEARS
Job years is equivalent to one year of work for one person; for example, a new construction job that lasts two years will equate to two job years.

MEAN HIGHER HIGH WATER (MHHW)
Average of the highest daily high tides occurring each day, also referred to as daily tidal inundation.

NET IMPACTS
The net impacts are calculated by subtracting the cumulative present value costs of adaptation from the cumulative present value of benefits (or impacts avoided) conveyed by investing in adaptation. A positive net impact generates a positive return on investment.

UNIFIED SEA-LEVEL RISE PROJECTIONS
Sea-level rise estimates produced by the Compact that are intended to assist decision-makers at the local and regional levels in Southeast Florida, and to ensure that major infrastructure projects have the same basis for design and construction relative to future sea level.

NOTES

This report summarizes the findings from a regional economic analysis conducted by AECOM. The full technical report can be accessed at: AECOM, *Business Case for Resilience in Southeast Florida*, August 2020.

QUICK FACTS & FIGURES

Disclaimer: this study represents a high-level regional analysis, leveraging readily available and regionally standardized physical and economic data, replicable analysis techniques, and generalized assumptions. Parcels impacted by daily tidal inundation are excluded from the 1- and 10-year tide damages. Results shown under the "What's at risk" findings are not adjusted to account for financial discounting. The 10-year storm tide results shown account for the impacts of one storm event and are not adjusted for probability of the storm event occurring. "What's at risk" findings were calculated assuming the superimposition of future physical conditions on the existing built environment and economy.

a. Data available at https://www.statista.com/statistics/183600/population-of-metropolitan-areas-in-the-us/.

b. 2018 American Community Survey 5-Year Estimates.

c. BEA Regional Data: 2018 Gross Domestic Product summary.

d. BEA Regional Data: 2018 Gross Domestic Product summary.

e. 2018 American Community Survey 5-Year Estimates.

f. Southeast Florida Regional Climate Change Compact Unified Sea Level Rise Projections (2019).

Rest of data obtained from AECOM, *Business Case for Resilience in Southeast Florida*, August 2020.

REPORT

1. According to 2018 American Community Survey 5-Year Estimates and BEA: Current-dollar gross domestic product (thousands of dollars)/Current-dollar gross domestic product (millions of current dollars) (https://www.bea.gov/).

2. Berm raising was not quantified in the study, although it is widely understood that the protection of beaches is a key element in supporting economic activity for the region outside of the Florida Keys.

3. The Real Deal, "Watch: Developers and Brokers Weigh In on Miami Sea-Level Rise," October 23, 2019, https://therealdeal.com/miami/2019/10/23/watch-developers-and-brokers-weigh-in-on-miami-sea-level-rise/.

4. Office of Economic and Demographic Research, "Demographic Overview and Population Trends," January 28, 2020 (http://edr.state.fl.us/Content/presentations/population-demographics/DemographicTrends_1-28-20.pdf).

5. According to Coastal Resilience, https://coastalresilience.org/project/southeast-florida-and-the-florida-keys/.

6. The Suddath Companies (global mobility company based in Florida) analyzed recent moving data to determine what was attracting Florida's new residents. "The findings show the state's robust job market is drawing in young talent from across the United States, with more than 30 percent of new Florida residents stating that it was a fresh opportunity provided by job transfers or new employment that made them want to call Florida home."

7. BEA Regional Data: 2018 Gross Domestic Product summary.

8. SmartAsset's interactive investing map: https://smartasset.com/investing/investment-calculator#florida/GDP.

9. See "Resilient305 Greater Miami and the Beaches" (http://www.mbrisingabove.com/wp-content/uploads/Resilient305_final.pdf).

10. Beacon Council economic overview (https://www.beaconcouncil.com/data/economic-overview/trade/).

11. Andres Viglucci, "Miami-Dade's Tale of Two Cities: 30 Billionaires and the Economic Inequalities of Colombia," *Miami Herald*, April 22, 2019.

12. S.A. McAlpine and J.R. Porter, "Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida." *Population Research and Policy Review* 37 (2018): 871–95.

13. S.A. McAlpine and J.R. Porter, 871–95.

14. Global Resilience Institute, "Climate Gentrification: Why We Need to Consider Social Justice in Climate Change Planning," Northeastern University (https://globalresilience.northeastern.edu/climate-gentrification-why-we-need-to-consider-social-justice-in-climate-change-planning/).

15. One job year is one year of work for one person. For example, one construction job that will take five years is five job years.

TOURISM AND NATURAL RESOURCES IN THE REGION

a. Rockport Analytics, "Picking Up the Pace: Florida's Tourism Performance Jumps into a Higher Gear" (https://www.visitflorida.org/media/30679/florida-visitor-economic-impact-study.pdf).

b. William B. Stronge, "The Economic Impact of the Beaches of Palm Beach County 2014," Nova Southeastern University (https://www.fsbpa.com/2016TechPresentations/Stronge.pdf).

c. National Park Service (https://www.nps.gov/bisc/learn/management/statistics.htm); National Park Service, "2019 National Park Visitor Spending Effects Report: Economic Contributions to Local Communities."

d. Rockport Analytics, "Picking up the Pace."

e. Florida Ocean Alliance, "Securing Florida's Blue Economy: A Strategic Policy Plan for Florida's Oceans and Coasts" (draft), 2020.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United States Senate Committee on Environment & Public Works

Dr. Jennifer Jurado

Chief Resilience Officer,
Deputy Department Director,
Broward County Resilient Environment

BROWARD COUNTY FLORIDA | RESILIENT ENVIRONMENT

Abandoned Vehicles, Broward Boulevard April 2023

Floods, Fort Lauderdale Hollywood International Airport Miami Herald, April 2023

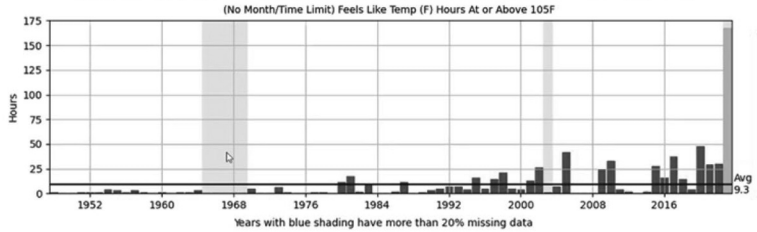
Neighborhood Floods, Melrose Park November 2020

Flooded parking lots, Sawgrass Mills

CBS News, June 2017

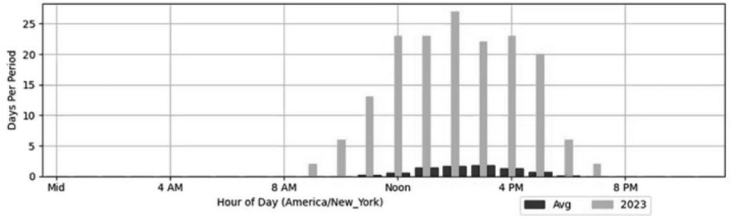
HOURS WITH HEAT INDEX AT OR ABOVE 105°

MIAMI AIRPORT 1948 - 2023



RECORD HEAT IN 2023

BY HOUR OF DAY



Source: NWS Miami/South Florida Forecast Office

Senate Committee on Environment and Public Works
Hearing Entitled *"The Science of Extreme Event Attribution: How Climate Change Is Fueling Severe Weather Events"*
November 1, 2023
Questions for the Record for Dr. Jurado

Chairman Carper:

1. Advances in attribution science help the public and lawmakers understand the tangible impacts that climate change is having on our communities, businesses, and daily lives. This helps us further quantify the impacts and costs of climate change.

    a. How would you recommend that Congress use attribution science to make better policy?

Response: Thank you again for the opportunity to testify before the Committee and for the invited response to this question. It is currently difficult for many community stakeholders to grasp the implications and/or benefits of climate scenarios associated with limits of 1.5 and 2ºC temperature rise. Based on my own interactions, many are unaware of the benefits that emissions reductions and constraints on warming can generate in the way of improved climate futures to be realized within our own lifetimes. Without these communications, even with great success in our efforts, as we experience increasingly extreme climate conditions with all the associated impacts, it may be difficult for those living under these worsening conditions to appreciate how favorable this outcome might be relative to the averted scenario. This might be analogous as to how once perceives a new community, lacking history relative to previous gains and losses, we might only recognize conditions that exist at the time of our arrival.

We all stand to connect more directly to the incremental advantage of policy outcomes if federal agencies were able to help translate climate policy goals to acceptable limits on environmental conditions and to better attribute climate outcomes to environmental drivers. For example, if we attribute some relative amount of sea level rise to warming in a given timeframe, attribution science could be used to set a limit on the amount of sea level rise we are willing to tolerate –an upper limit so to speak. Furthermore, setting limits on sea rise would provide better metrics to measure damage, risk, or progress.

The same might be true for drought conditions, extreme heat, rainfall extremes, etc. Such an approach might help better demonstrate the relevance and need for climate policy supporting public health, economics, environmental conditions and livelihoods in timescales meaningful to current residents who will realize direct benefits of these outcomes in their own lifespan, as well as the generations that follow.

The Committee might explore this approach by directing a report/analysis on how sea rise connects to the rapid intensification of storms and storm surge. This could include the holding of a hearing and a report generated from expert testimony.

2. Is there anything else that you would like to provide the Committee that was not included in your testimony or discussed during the hearing?

Response: I only wish to reiterate the dramatic and desperate need for strong federal leadership and partnerships to accelerate, through all mechanisms possible, the policies, funding, programs and projects critical to driving the climate solutions needed from local to international levels. Local governments are eager partners, unable to delay adaptation investments as climate events and economic pressures (e.g., insurance costs) grow increasingly severe. As such, of increasing urgency is the federal leadership, policy framework, investments and incentives needed to further the emissions reductions and the green economy core to climate stabilization, with all the associated environmental gains, public health outcomes, and new economic opportunities. We cannot afford any deferrals in action and are therefore immensely grateful to the Committee for this holding this hearing and continued leadership to accelerate climate solutions and expand adaptation investments.

Senator CARPER. Thank you, Dr. Jurado. You packed a lot into 5 minutes. That is pretty impressive. I could learn from you.

Finally, we are going to hear from Mr. Dabbar.

You are recognized. Thanks so much for joining us. Please proceed.

STATEMENT OF HON. PAUL DABBAR, FORMER UNDER SECRETARY FOR SCIENCE, DEPARTMENT OF ENERGY, SENIOR RESEARCH SCHOLAR, COLUMBIA UNIVERSITY

Mr. DABBAR. Chair Carper, Ranking Member Capito, I am honored to be before the Senate again, for the first time before this Committee, to discuss climate impact, energy innovation, and policy.

Over my career, I have been engaged on all the various aspects of energy, including liberating neutrons at a reactor, and addressing solutions for the environment, in particular as Under Secretary for Science at the Department of Energy.

Other than Senator Kelly, I have likely traveled to more remote locations to collect climate data. I am one of the few people who has been to both the geographic North and South Poles, both in government service, and in part both missions were around climate data gathering.

As Under Secretary, we supported gathering data and computer simulation of the climate, including the work of Dr. Wehner, at many of the national labs I ran including Lawrence Berkeley, as well as at NETL and others in support of research at universities in everyone's State here at the Committee.

The world has been successful at reducing different types of emissions, due to innovation. And I believe the right strategy for the world today is to continue discovery, innovation, and deployment of new options. America has been the dominant country at investing in discovery, and the lead in deployment of new energy technologies, and America is the global leader of the pipeline of new prospects.

I am quite positive about these prospects due to the U.S. being the world's leader in public and private energy R&D, including at the world's leading universities and national labs, the dominant winner of Nobel prizes in the physical sciences, and the global leader in venture capital and startups.

I reach this positive conclusion based on a lot of data. Most of what we are deploying today was invented within the last generation, such as commercially effective lithium-ion battery chemistry, wind turbines, innovative drilling technologies, and PV solar. As Under Secretary I enjoyed the Nobel prize reception in the Senate vestibule for winning the Nobel for the lithium-ion chemistry.

The pipeline of future innovation is very strong. For example, Form Energy, which has recently opened a plant in West Virginia, has developed an iron-air battery, that literally rusts and de-rusts for its chemistry, that produces power for 25 times longer than lithium-ion, and is 80 percent cheaper. X-energy, an SMR fission company, is in the process of building the next generation of nuclear all over the country. And Montana Technology has developed a MOF based HVAC cooling technology that uses up to 75 percent less energy and emissions than current compressor systems, and no

freon. American innovation has and will continue to lead the way to solutions.

One final innovation take away that we should consider is that regulators or elected officials mandating winning energy technologies is poor technology policy. The innovation ecosystem has a track record of inventing new options that were not predicted.

For example, President Bush's famous 2001 energy assessment had a long list of predictions of winning energy technologies, and most them were significantly wrong. Unpredicted innovations in drilling, solar, and batteries came along and remade the landscape, including for emissions. It is better policy for the EPA and States to allow for technology neutral, innovation open strategies, that allow for the competition of discovery.

We need balance in energy policy. We need to concurrently care about increasing energy availability, lowering energy costs, lowering emissions, and national security. Due to American innovation and a solid all of the above bipartisan pro-supply policies over the last generation, we were able to deliver on all those concurrently. I have confidence we can do that again this generation.

While we certainly need to understand the drivers of climate change, we should focus on solutions also. America is the global energy superpower. We went from the largest energy importer in the world to the largest energy exporter. We invented for us and the world a portfolio of technologies that are making an impact on emissions. And there is a pipeline of even better ones to come. Policy to allow the ingenuity of Americans to harness and allow deployment of their new ideas, will be the solution.

[The prepared statement of Mr. Dabbar follows:]

STATEMENT BY

THE HONORABLE PAUL M. DABBAR

FORMER UNDER SECRETARY FOR SCIENCE
U.S. DEPARTMENT OF ENERGY

SENIOR RESEARCH SCHOLAR
CENTER ON GLOBAL ENERGY POLICY
COLUMBIA UNIVERSITY

CHIEF EXECUTIVE OFFICER
BOHR QUANTUM TECHNOLOGY

BEFORE THE SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

ON THE SCIENCE OF EXTREME EVENT ATTRIBUTION

NOVEMBER 1, 2023

Chair Carper, Ranking Member Capito, and Members of the Committee, I am honored to be before the Senate again, and the first time before this Committee, to discuss climate impact, and energy innovation and policy.

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As Under Secretary, we supported gathering data and computer simulation of the climate, including the work of Dr. Wehner, at many of the Nationals Labs I ran including Lawrence Berkeley, and supported research at universities in all of your states.

The world has been successful at reducing different types of emissions, due to innovation. And I believe the right strategy for the world today is to continue discovery, innovation and deployment of new options. America has been the dominate country at investing in the discovery, and the lead in deployment of new energy technologies. And America is the global leader of the pipeline of new prospects. I am quite positive about those prospects due to the U.S. being the world's leader in public and private energy R&D, including at the world's leading universities and National Labs, the dominate winner of Nobel prizes in the physical sciences, and the global leader in venture capital, start-up's and large energy companies.

I reach this positive conclusion based on a lot of data. Most of what we are deploying today was invented within the last generation, such as commercially effective lithium-ion chemistry, wind turbines, innovative drilling technologies, and PV solar. As Under Secretary I enjoyed the Nobel prize reception in the Senate vestibule for us winning the Nobel for the lithium-ion chemistry.

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While we certainly need to understand the drivers of climate change, we should focus on solutions. America is the global energy superpower. We went from the largest energy importer to the largest energy exporter. We invented for us, and the world, a portfolio of technologies that are making an impact on emissions. And there is a pipeline of even better ones to come. Policy to allow the ingenuity of Americans to harnessed, and allow deployment of their new ideas, will be the solution.

Senate Committee on Environment and Public Works
Hearing Entitled *"The Science of Extreme Event Attribution: How Climate Change Is Fueling Severe Weather Events"*
November 1, 2023
Questions for the Record for The Honorable Paul Dabbar

Ranking Member Capito:

1. Deploying advanced nuclear energy would increase grid reliability and resilience in the face of extreme events and rapid premature power plant retirements. Chairman Carper, Senator Whitehouse and I introduced the ADVANCE Act, which went through regular order and passed out of this committee 16-3, to do just that. How important is deploying new nuclear reactors to achieving greenhouse gas emission reductions?

Currently the only proven zero emission, base load, fully dispatchable power generation technology is nuclear power. New nuclear power plants will be needed for both replacement for existing nuclear plants as they slowly decommission over the next few decades, as well as additional capacity as power growth continues.

   a. How important is reforming the regulatory licensing process to deploying new nuclear in a reasonable timeframe?

Regulatory processes for approving energy infrastructure have become a significant impediment for energy capacity growth. Over the course of time, regulatory processes generally become increasingly challenging, nuclear regulatory processes among them. Due to increasing cautiousness among the NRC staff, and an ever growing body of court rulings imposing approval costs and slowing reviews. It is required to have full reform legislation periodically to clean up impediments that have built up over decades from those trends. Major reform legislation like the ADVANCE Act are important to re-streamline regulatory processes.

2. In your testimony, you mentioned Form Energy's plant in Weirton, West Virginia that will manufacture new iron-air batteries and help make the grid more resilient through providing more affordable and efficient electricity storage. Can you expand on the ability of Form Energy's iron-air batteries to mitigate the impacts of extreme weather events and increase energy security?

Extreme weather events periodically have extended impact of energy availability. In some cases power can be out for weeks for certain customers. Some power plants, like nuclear, are significantly hardened to sustain operations during major storms, or have the ability to immediately restart after short storm downtime. Wind and solar are significantly less hardened, and can sustain significant damage during a storm leading to extended unavailability.

As wind and solar become a larger portion of the generation supply stack, the risks of extended lack of power supply as a result of storms in significantly increasing. Currently grid-scale lithium-ion batteries are insufficient to support these challenges. At their nameplate capacity, their supply duration is only four hours, which is significantly too low to support this scenario. Building multiple banks of lithium-ion capacity to extend availability beyond four hours is significantly too expansive compared to other dispatchable power sources.

Long duration storage, like Form Energy's technology, can operate for ~25 times longer than lithium-ion, and costs ~80% less per unit of capacity. There are other potential long duration chemistries that are also being developed from Department of Energy discovery efforts.

a. Are there any reforms that might be necessary to enable the deployment of these energy storage resources?

Power region operators like Regional Transmission Organizations and Independent System Operators have not developed bid and compensation systems that fully compensate long duration storage for the value it brings to power supply. FERC should look to order better compensation market structures. Or the Senate could pass a reform of the Federal Power Act that would require FERC and the regional power systems to do that.

3. What technological solutions do you think should be on the table for reducing greenhouse gas emissions?

Given it is hard to predict which technology solutions being developed can make material and cost effective contributions, a best technology policy would be an "all-the-above" technology option policy. There are some well developed technologies, like large-scale nuclear, hybrid and fully electric cars, and geothermal that can contribute. And there are many on the horizon such as beyond lithium-ion chemistries, net-zero gasoline, artificial intelligence for energy, advanced nuclear and fusion. In general, supporting early stage development on a wide set of possible technologies is the best policy, and let innovators and technology competition determine the most successful options.

a. What approach would you endorse for mitigating the effects of climate change?

Investment in infrastructure has significantly reduced death rates from weather events the last century. Further investment, including in new technologies, will continue that trend.

4. As I mentioned in my questioning, the data show that mortality from natural disasters is significantly lower in technologically advanced societies with abundant access to energy and resilient infrastructure. What new technological advancements and innovations could continue to help improve on already improving natural disaster mitigation and storm recovery operations?

Natural disaster mitigation can continue to make progress through infrastructure investment and technology deployment. Our ability to build out structures that can withstand natural disasters continues to improve each year, and we should invest in those prospects. Storm

recovery operations also is improving significantly. For example the power outage time from disasters in Florida continues to improve every year, due to increasing sophistication of cities and utilities preparing for events, and increasing rapid execution of recovery after events.

5. As the Department of Energy's fourth Under Secretary for Science, you played an instrumental role in advancing the research and innovation of low-carbon energy technologies. What role do you think technological innovation can and should play in America's energy future?

Much of what we are currently deploying in the energy sector did not exist commercially just twenty years ago. Technologies such as advanced/unconventional drilling technologies, lithium-ion batteries, advanced nuclear, and electric vehicles did not exist commercially. Now they are all being deployed, and combined has not only led the U.S. from moving from the largest energy importer to the largest energy exporter, they also provided the capabilities for the country to continue to lead the world in the reduction of tons of emissions per year.

And the pipeline of possible new technologies is even stronger than what we saw the previous generation. The Senate had strong leadership in investing in new energy discovery after the end of the sequester in 2017. That has led to great successes we are seeing deployed today, like the iron-air battery. However, recently appropriations have been focused on deployment of already discovered technologies, and support for discovery have been growing at less than our current high inflation, leading to layoffs of researchers working on what's next, and reduced efforts in discovery.

I would recommend the Senate review the allocation of appropriations, and look at fully supporting the Science sections of the Chips & Science Act, vs current real dollar shrinking of discovery support.

6. What promise do emerging technologies such as advanced nuclear, fusion energy, and zero-emission gasoline, hold for reducing greenhouse gas emissions?

All of those technologies have strong prospects. But they are getting materially less support than other areas currently.

   a. Are these technologies being disadvantaged by government policies that favor other technologies?

Yes.

7. In your testimony, you cautioned against government entities picking energy technology winners through legislative carve outs or preferential treatment, arguing it is better to fund innovation and allow the private sector to compete. The Biden Administration has done the exact opposite with the Inflation Reduction Act by positioning wind, solar, and electric vehicle technologies as their declared winners. Are there other promising energy

technologies that you support that have been disadvantaged by the Inflation Reduction Act's passage?

Yes. A wide set of other technologies that could make an even higher impact in performance or cost are possible. Which have received little or no support in the IRA. Examples of technologies that are receiving little or no support include fusion, advanced nuclear, and beyond lithium ion chemistries. As a result, it will be hard for those excluded technologies to develop equally when the competing technologies are receiving significant subsidies.

8. You published an op-ed in The Hill earlier this year criticizing California's electric vehicle mandate. What does California's regulatory approach to mandating electric vehicle production and sales get wrong?

California has taken a regulatory tact to mandate a specific light duty vehicle technology, namely electric vehicles ("EV's), with some flexibility on hydrogen. What it does not take into account is that other technologies might be able to also make material advances in emissions, and do so with additional flexibility, better operating characteristics and/or more cost-effectively. We are already seeing some options that could exceed EV's.

   a. Did California fail to consider other promising technology options with its burdensome regulations on the automotive industry?

Yes, California picked a narrow set of technology options, and has not allowed for new technology options that have evolved. Their law does allow for more flexibility. It would be better technology policy to change their technology regulations, or for their legislature to amend their law to allow for that flexibility.

   b. Should innovation rather than regulation be prioritized instead?

Yes. Much of what we are deploying today was not invented just one generation ago. We are benefiting today from policies that allowed the competition of innovation to develop those successful technologies. Regulation may have restricted those ultimately good ideas, and technology specific mandates today could impede improved options.

9. A leading macroeconomic story has been the massive increase in the cost of renewables and the financial difficulties that wind and solar manufacturers are facing due to the reckless spending in legislation such as the American Rescue Plan and the Inflation Reduction Act, which in turn has fueled inflation and high interest rates. Did the Biden Administration and Congress, by legislating imprudent industrial policy, harm the renewable energy sectors it was trying to help?

In today's recently changed capital markets and construction cost environments, even including new incentives from those Acts, net power costs from new renewable projects are materially higher than just a few months ago. That means that the negatives from those higher construction and capital costs have out-weighed the subsidies in the Acts. And it is unlikely that will be reversed for the foreseeable future. As a result we are seeing that many renewable developers' pipelines of new projects is shrinking.

A conclusion of that data is that macroeconomic policies driven by fiscal and monetary policies that are negative for costs of construction and for debt and infrastructure equity cost of capital, due to high interest rates, are more impactful in the negative, than the positives of subsidies.

10. Are there other factors besides climate change, such as poor forest management or infrastructure resilience, which contribute to severe weather events?

Yes, there are a wide set of drivers that effect the impact of severe weather events.

a. Do you agree that improved permitting for wildfire mitigation, infrastructure projects, and grid improvements will benefit our energy infrastructure and extreme event preparedness?

Yes.

b. Are there permitting reforms in this committee's jurisdiction that you think would be particularly helpful in enabling a more resilient electric grid?

While not familiar with every aspect of EPW's scope, certainly reform to NEPA would be very valuable, as would water reform legislation. Bills currently being reviewed such as RESTART and ADVANCE would make a positive difference.

11. Are there specific provisions in the RESTART Act that would help address future impacts from extreme events?

EPA reviews of infrastructure projects have become significantly more cumbersome. In addition, the EPA regional offices sometimes create new standards that have no support in the studies that have been conducted. Reform of various statutes to better define scope of reviews will reduce review times, reduce the risks of construction filers of unexpected new EPA standards, and reduce court uncertainty that has significantly increased over time.

12. As an expert in technology innovation and deployment and the former Under Secretary for Science at the Department of Energy, you are intimately familiar with the work that is required to develop and deploy new energy technologies, especially those that you worked on as Under Secretary. Do you believe carbon capture and storage is a promising energy technology?

Yes.

a. What are some of the challenges carbon capture and storage deployment faces?

CCUS still has a number of challenges. Overall, capture technologies still need industrial scale deployment testing, but those are moving forward. Costs for the capture process need to be driven down. And the storage regulatory process is not working very well currently. That could be improved if the EPA executed on state primacy/delegation of authority requests that are pending.

b. Do you support mandating carbon capture and storage at fossil fuel-fired power plants?

Likely mandating in all circumstances would be hard to execute with current technologies without significantly reducing energy availability and reliability.

c. Do you believe that carbon capture and storage is commercially viable and adequately demonstrated at present?

Additional technology development and demonstration plant efforts would be a good policy. While basic operational processes have been tested, they have not been tested at full commercial scale. And final cost structures have not been tested at scale. Full commercial scale testing is necessary.

d. Do you believe the siting and permitting requirements for carbon capture and storage present an unreasonable challenge to the near-term, mandatory deployment of carbon capture?

Yes, current approval policies are impeding developers who would like to move forward with projects.

13. Should we be more focused on looking for climate solutions and building societal resilience to a changing climate, rather than simply highlighting the negative effects of human-caused climate change?

Yes. America has solved previous challenges of emissions by focusing on solutions. Such as sulfur oxide, nitrous oxide, and mercury. Ingenious Americans of this generation will innovate our way to solutions, just like previous generations did.

Senator CARPER. Great, thank you very much.

Let me start with Dr. Wehner.

Your colleague to your right, Dr. Jurado, has told us that Fort Lauderdale and surrounding communities in southeast Florida have experienced several devastating torrential rainfall events over the last couple of years, including 26 inches of rainfall over 12 hours last April. Twenty-six inches over 12 hours. My question, Dr. Wehner, is would you consider this torrential rainfall event unusual? Should we expect to see more extreme rainfall events as climate change worsens?

Mr. WEHNER. Thank you, Senator.

Yes, indeed, we talked briefly prior to the hearing about this storm. And what she said to me about this astonishing amount of rainfall, and most of it falling in a very short period of time, is completely consistent with my previous work on extreme storms, showing that the rainfall increases at a rate greater than humidity increases.

Now, humidity increases at a certain rate determined, that we know, very rigorously from first principles. But rainfall seems to be supercharged from climate change.

So what I would interpret is that this storm has been made more violent and hence more efficient at increasing this available moisture. And we would expect yet more of that throughout the country, not just in Florida, actually throughout the world.

Senator CARPER. How about heat waves? Absent climate change, would we be experiencing events such as the Pacific Northwest 2021 heatwave, or this past summer's heatwave in the U.S.?

Mr. WEHNER. It is interesting that you would highlight the 2021 heatwave in the Pacific Northwest. I consider this one a teachable moment for climate scientists. If you had asked me before that event when it would be 120 degrees in Canada, I would have said not for a long time.

Senator CARPER. Would you have said when hell freezes over?

Mr. WEHNER. No, I would have said about 2060.

[Laughter.]

Senator CARPER. That is when it is scheduled to freeze over.

Mr. WEHNER. So that was a surprise to us. This will be an event that is probably the most stunning extreme weather event of all time. Currently, there are at least 20 different papers on an event that happened just over a year ago. I have three myself, three of those 20 are mine.

We are learning a lot. And it is kind of scary, because it was scary beforehand, and clearly this event was unprecedented, caused a lot of people to die. How many more died because of climate change is not something I know.

But I would say that it was at least 2 degrees warmer from climate change, possibly 4, not much more than that. That doesn't sound like a lot. But when you look at the effect of high temperatures on mortality, a small change from 110 degrees to 114 degrees actually has a large effect on the number of people that die. So that is important.

Senator CARPER. One last question of you, Dr. Wehner, then we will turn it over to Senator Capito.

We have been joined by two of our colleagues; welcome, gentlemen.

Dr. Wehner, as communities across our Nation experience increasingly extreme weather events, resiliency, and adaptation are front of mind for State and local officials, in Delaware and West Virginia and every State that is represented here. Our infrastructure, our roads, our bridges, our pipes, our wires, are essential to our daily lives. They have to be able to withstand more frequent and severe weather events.

My question is, would you please share an example of how attribution science can inform the design and engineering of infrastructure projects to better manage the impacts of these extreme weather events when they occur?

Mr. WEHNER. Yes, Senator, I can. I had a project with the San Francisco Public Utilities Commission, which I believe is the first time that a city actually funded research at a national laboratory. The city of San Francisco is charged with rebuilding the wastewater management, the sewers. And they are charged with considering climate change in this. They had people telling them about sea level rise.

They asked me about extreme precipitation. So what we did is we asked them to give us a dozen storms since the satellite era that were impactful, and we would take a look at them. We were able to analyze six of those. The atmospheric river storms that had the so called bomb cyclone associated with them responded in a way that again I was surprised about twice the expected rate. and that was used by their consultants to modify their IDF curves.

Senator CARPER. What are IDF curves?

Mr. WEHNER. Intensity Duration and Frequency. It is a design tool that engineers use. And that is the extent of my knowledge.

I will quote what Susan Leal said, who was the former director of the Public Utilities Commission, and now one of their consultants. She said, "There ain't no pipe big enough." That has sent the engineers and designers back to the drawing room, saying, how are we going to accommodate these storms, in a world that might be considerably warmer.

Senator CARPER. I am going to ask you to hold it right there.

Dr. Jurado, I am going to come back to my next round to ask another question, and ask you to follow up on what he has already said.

But now, Senator Capito. Thank you.

Senator CAPITO. Thank you, Mr. Chairman.

Mr. Dabbar, I love this one term that you used in your statement, "technology neutral, innovation open." I think we need to focus on solutions. Everybody has talked about it.

As one of the things we have seen in the data, that mortality from natural disasters is significantly lower in more technologically advanced societies with access to energy and resilient infrastructure. Recent reports by reliability experts show that we are projected to go, we as a Nation, are projected to go backward on our grid reliability this decade. And many point to some regulations that will lead to early power plant retirements. We also see the rise of the electric economy that is being moved forward rather rapidly.

Everybody has mentioned that the most vulnerable are those that are in the lower economic echelon of our society. That is troublesome, obviously, for me.

How will extreme weather impact energy demand, and how do you think grid reliability will impact our vulnerability in these events?

Mr. DABBAR. Yes, Senator. I agree with your point that greater reliability has actually been decreasing. I think the most stark example that most people don't know about is that there have actually been more power plant shutdowns in many areas of the country. New England is one, New York is another, Texas is another, it is actually all over.

More power plants are being decommissioned, for various reasons, than are being built. The ones that are getting built have a lower capacity factor, so the number of megawatt hours is way lower.

So I think we should be concerned about that. That gets to regulatory processes and siting, whether it is State or Federal. In the kind of world that we are trying to electrify, we are actually de-electrifying. I think that is a long and complicated process that needs to be streamlined.

Senator CAPITO. OK, thank you.

We have had near term emission reductions, but we are still and will continue, I think everybody is in agreement here, experience climate change impacts until globally our greenhouse gases are reduced. But it may continue then. There is stuff we don't know, that we don't know into our future.

How do we create economic conditions for innovative solutions, for technology neutral innovation opened, that would increase our resilience and our disaster readiness? At the Department of Energy you probably saw this, you probably see this as well, certainly overseeing the national labs. Dr. Wehner is at a national lab.

Are there near term technologies that can be deployed to improve our adaptation strategies?

Mr. DABBAR. Yes, Senator. As I mentioned, we don't know, we cannot clearly see which technologies are going to be best. So having regulatory processes or mandates from States and so on that allow for those new things, instead of mandating, we are only going to have this type of technology, we are only going to have EVs, we are only going to have nuclear, we are only going to have wind, whatever it is, is poor technology policy. We should be allowing all of those to be neutrally supported, whether it is through EPA or State approvals or through funding. Because if you overly fund one area, you are going to get more of that. Being more neutral across that for regulatory and funding purposes is better technology policy.

Senator CAPITO. Thank you.

In terms of where we are headed, I thought it was interesting in your statement you mentioned that President Bush in 2001 was trying to predict, his commission was trying to predict over 20 years where we are going to go. How do you see what accelerated now? I feel like we are on a much more accelerated path through some of the bills that we have passed. How do you see that devel-

oping? Are we the global leader here, or are there other technologies around the globe that we are looking at?

Mr. DABBAR. America by far leads the world in energy discovery. Manufacturing is a different topic. But when it comes to energy discovery, America rules the roost on many different metrics.

So there are many things; we are accelerating, Senator. There is a reason why that process has improved significantly. But you can look at California, or you can look at what is going on in Massachusetts, fusion is much more likely than it used to be for various reasons. And many others.

So I think the acceleration of discovery has dramatically improved. We are in a much better space on that front.

Senator CAPITO. Thank you.

Mr. Chairman, I want to go back to my first question, when I talked about electricity reliability. I want to submit a letter, it is to Administrator Regan from the Chairman of the West Virginia Public Service Commission and the Chairman of the Delaware Public Service Commission, that is cautioning what the Administration is doing on the Clean Power Plan to look at how it will impact our States.

Senator CARPER. Without objection.

Senator CAPITO. Thank you.

[The referenced information follows:]

Public Service Commission of West Virginia

Delaware Public Service Commission

October 4, 2023

Honorable Michael S. Regan, Administrator
U. S. Environmental Protection Agency
1200 Pennsylvania Avenue N.W.
Washington, D.C. 20460

Dear Administrator Regan:

Regarding the Environmental Protection Agency (EPA) latest proposed rule impacting baseload, dispatchable, fossil-fuel-fired power plants, EPA-HQ-OAR-2023-0072[1], the signatory Commissions[2] herein request the EPA to, at a minimum, adopt the recommendations of the Joint ISOs/RTOs[3], and further recommend the EPA to work with the Federal Energy Regulatory Commission (FERC) to consider reliability effects of this EPA rule in combination with other recent environmental regulations.

Many reports continue to echo a growing concern about reduced reliability and resilience of our electricity supplies as dispatchable (mostly fossil-fuel-fired) resources retire and are being replaced mostly by intermittent, non-dispatchable resources. The North American Electric Reliability Corporation (NERC), for example, has identified such risks in its recent reliability assessments. PJM Interconnection expressed concerns about reliability risks due to an accelerated level of retirements of baseload steam-driven generation plants and increased reliance on intermittent resources in a recent report[4].

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[1] "New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions from Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule."
https://www.federalregister.gov/documents/2023/05/23/2023-10141/new-source-performance-standards-for-greenhouse-gas-emissions-from-new-modified-and-reconstructed

[2] Public Service Commission of West Virginia, and Delaware Public Service Commission.

[3] https://downloads.regulations.gov/EPA-HQ-OAR-2023-0072-0673/attachment_1.pdf

[4] "*Energy Transition in PJM: Resource Retirements Replacements and Risks.* Feb 24, 2023

With regard to the various existing EPA rules or proposed rules impacting electricity reliability, a group styled as "Joint ISOs/RTOs" comprised of the Electric Reliability Council of Texas (ERCOT), Midcontinent Independent System Operator (MISO), PJM Interconnection (PJM), and the Southwest Power Pool (SWPP), filed comments with the EPA (cited at footnote 3) in its latest proposed rule impacting baseload, dispatchable, fossil-fuel-fired power plants, EPA-HQ-OAR-2023-0072.

The Joint ISOs/RTOs noted that they are:

> *responsible for maintaining the reliability of the bulk power system that provides electric service to over 154 million Americans. The geographic reach of the Joint ISOs/RTOs is broad, encompassing an area of approximately 2 million square miles, in all or parts of 30 states and the District of Columbia.*

In its filing, this group of RTOs/ISOs made strong arguments that the EPA was jeopardizing the reliability of the electric systems within their footprints, serving nearly one-half of the United States. They warned:

> *The Joint ISOs/RTOs are concerned that the substance of the Proposed Rule as presently configured, as well as its timing, have the potential to materially and adversely impact electric reliability. Moreover, the Proposed Rule, when combined with other EPA rules and other policy actions, could well exacerbate the disturbing trend and growing risk wherein the pace of retirements of generation with attributes needed to ensure grid reliability is rapidly exceeding the commercialization of new resources capable of providing those reliability attributes.*

It would be risky to disregard the reliability warnings of the institutions that have been handed the responsibility for managing power supply and transmission of our electricity, which is an economic necessity for our country and a necessity of life for our citizens.

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https://www.pjm.com/-/media/library/reports-notices/special-reports/2023/energy-transition-in-pjm-resource-retirements-replacements-and-risks.ashx

Many individual state utility commissions have similarly expressed concern regarding the need for baseload, always-available, electricity generation or storage resources. State commissions also have a responsibility to assure that electricity supply planning places reliability front and center in the resource planning of the load serving entities in our respective jurisdictions. When the national and regional planners warn that EPA rules could undermine reliability, it is our responsibility to urge EPA to adopt rules that do not increase the risk of reliability problems in order to protect our economies and citizens.

We are not advocating against intermittent resources. They can provide valuable energy into the power grid on an intermittent basis when the sun is shining, and the wind is blowing. However, these resources cannot be expected to provide constant and consistent voltage and frequency even when they are generating and online. Batteries or other energy storage devices may be a backup source, frequency provider, or even base-load provider in the future, but that scenario may be very far into the future and is not likely to occur within the short timelines of EPA rules, which will certainly lead to the premature retirement of the resources that can provide backup, frequency control and baseload power when needed. Until storage is at a more mature stage of development, the potential loss of a substantial level of dispatchable thermal resources could threaten grid reliability.

The EPA has taken major steps in a very short period of time that negatively impact fossil-fuel-fired electricity resources:

- Good Neighbor Rule (Finalized March 2023);
- "New National Emission Standards for Coal- and Oil-Fired Electric Utility Steam Generating Units (Proposed April 2023);
- Proposed Supplemental Effluent Limitations Guidelines and Standards for Steam Electric Power Plants; and
- New Source Performance Standards for Greenhouse Gas Emissions From New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emission Guidelines for Greenhouse Gas Emissions From Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule" (Proposed May 2023).

Unless modified, these regulations may force the premature retirement of always-available dispatchable resources. We are not aware of any comprehensive and thorough analysis by EPA of the stacked reliability consequences of these rules based on NERC's definition of reliability which encompasses both resource adequacy and operating reliability. Reliability is not dependent solely on installed generation capacity. Intermittent generating capacity that is double or triple the megawatt load requirements on the system is not going to provide necessary reliability services such as voltage control, frequency support, and always-available backup reserves.

As state regulatory commissions, we have listened to, and will act upon, the warnings of the ISOs, RTOs and NERC. They are telling us that the grid cannot be operated reliably without essential reliability services. The Federal Government, through EPA, FERC and DOE should likewise place reliability of the electricity supply foremost in their planning and regulatory agendas.

We respectfully urge EPA to, at a minimum, adopt the recommendations of the Joint ISOs/RTOs . EPA should optimally join with other federal agencies, the RTOs and ISOs, and the electricity generators and load-serving entities to conduct reliability analyses based on NERC's definition prior to any of the rules listed above being implemented. Moreover, a memo of understanding with DOE that the EPA will consult with DOE and consider near-term reliability concerns for waivers of parts of its rules after they go into effect may be insufficient to preserve necessary and sufficient dispatchable generation resources. Once the ball is placed in motion for retirement of these units it is a downhill path to retirements that cannot be easily, or quickly, reversed.

In the meantime, we are also asking the Federal Energy Regulatory Commission to consider reliability effects of the EPA rules, particularly when it is being told by the organizations that were championed by the FERC, the ISOs and RTOs, that the EPA is moving too far and too fast on rules that will force the premature retirement of the resources that are needed for reliability. We are pleased that the FERC has scheduled a technical conference for November 9 to assess the impact of the proposed Carbon Rule on grid reliability. The combined impact of these rules must be considered rather than the Isolated and non-comprehensive analysis of reliability given by the EPA to date.

Thank you for what we hope will be your renewed and expanded attention to electricity reliability, which is a critical national security, economic and health and safety issue.

Sincerely,

Charlotte R. Lane, Chairman
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201 Brooks Street
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Delaware Public Service Commission
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Dover, DE 19901
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CC FERC, DOE, WV Senators and House Members.

Senator CARPER. I was reminded in that exchange that just took place that we can be proud as Americans that we are leading the pack in terms of addressing climate change. There is a statement, I don't know if it is in the Bible or what, to whom much is given, much is expected. We are a Nation richly blessed, as you know. And we are, frankly, a leader in putting emissions in the air in our planet that are actually leading to climate change and global warming.

So, given that we helped create this problem we have maybe an oversized obligation into addressing it. I think we are. I think we are, we are doing good work in this panel, we are doing good work with this Administration, and hopefully with the next Administration that comes, much will be put around the country. Thank you.

OK, we have been joined by Senator Markey. Senator Markey has been working on these things for a long time, and we are delighted that has joined us, along with Senator Boozman and Senator Padilla.

Senator Markey.

Senator MARKEY. Thank you so much.

So we are the first generation to suffer from climate change, but the last generation which can do anything about it. That is our challenge. In answer to Senator Capito, in terms of innovation, up in Massachusetts we have a center, it is called Green Town, there are 300 companies up there all doing, like MIT, Harvard, Tufts related research. One of the companies is called Form Energy, which is actually creating a manufacturing plant down in West Virginia for 800 jobs.

Senator CAPITO. Mr. Dabbar talked about that in his opening.

Senator MARKEY. Great. That is a perfect partnership between the innovation community up in Massachusetts, the manufacturing capacity in West Virginia, and there are many more companies up there who are looking at West Virginia, for example, for where they will be doing the manufacturing to accelerate this.

By the way, their breakthrough is, for batteries, it is not lithium-ion, it is iron, I-R-O-N, which is going to be the battery, the third most common element in the world. So that is a big breakthrough in terms of battery technology.

There is just so much that is happening, because of the IRA, the tax benefits that flow, and then the State of West Virginia or other States then have initial benefits to manufacture there. So I think it is a good team effort to accelerate this transformation.

And just like the many things historically, this year alone we have seen severe flooding and deadly heatwaves. And we need to be able to do something about it.

Dr. Jurado, you mentioned in your testimony that Melrose Park, a predominantly Black neighborhood in Broward County, was disproportionately affected by flooding in April. Dr. Jurado, does effectively managing climate fueled disasters, including flood management, mean prioritizing investment in infrastructure in neighborhoods that have suffered from chronic disinvestment for decades, environmental justice communities like Melrose Park? Would they be benefited?

Ms. JURADO. Yes, Senator, absolutely. We are conducting comprehensive modeling, overlaying vulnerability and disease, really

focusing on the combined impacts and exposures with flood risks, damages, heat exposures, economic conditions, economic burden, all of those things being overlaid. We are desperately concerned about uninsured losses. We saw with the April event many residents lost their homes in addition to their vehicles. And in the circumstance of Melrose Park, this is a community that is not in a flood zone and has been hit twice in the last 6 years with this level of flood impacts.

So it is bringing to light these very dramatic exposures, and the need to bring all of our community into the solutions to support their well being.

Senator MARKEY. Thank you.

And we know it is not a coincidence that disproportionately Black, Brown, and low income communities are more likely to struggle with extreme weather events fueled by climate change. Dr. Wehner, in your research, do disasters fueled by climate change hit some neighborhoods harder than others? And does that drive increasing inequality resulting from climate injustices?

Mr. WEHNER. Yes, it certainly does. But I would caution that every event, every disaster is different, and affected differently. I think the important point is that the very poor are indeed the most vulnerable, because they are the least able to recover from these kinds of events. So that is pretty obvious.

Senator MARKEY. Yes, it is obvious. And do you agree with the research that says that extreme weather events are up from three times per year in the United States in the 1980s to 20 per year now in the 2020s? Do you agree with that?

Mr. WEHNER. I might have written that.

[Laughter.]

Senator MARKEY. Please expand. Because obviously that is a sevenfold increase in the number of extreme weather events in the United States over the last 40 years. We know it hits poor people disproportionately, although it hits all people who are impacted.

Mr. WEHNER. Senator Capito made a point that climate change didn't cause these events. I think that is something I completely agree with. We borrow from epidemiology techniques to sort of understand how climate change has affected these events. Some events might be less frequent, blizzards, for instance, in a warmer world, they become rainstorms.

But certainly for heatwaves and violent rainstorms, like hurricanes or this one that hit Fort Lauderdale, are more frequent.

Senator MARKEY. Let me ask another way. NOAA data shows that disasters that cause more than $1 billion in damage rose from three per year in the 1980s to more than 20 a year in the 2020s. Do you agree with that?

Mr. WEHNER. Yes, absolutely.

Senator MARKEY. Dr. Wehner, does climate attribution science show that fossil fuel pollution is underpinning this rapid increase in devastating, expensive disasters?

Mr. WEHNER. I would agree with that, too.

Senator MARKEY. OK. I think that is the important factor, it has gone from three to 20, it is not all attributable to one thing, but from your research, it is the underpinning of the rapid increase, is that correct?

Mr. WEHNER. Yes, it is.

Senator MARKEY. Yes. And then we know that poor people are going to be ultimately disproportionately negatively impacted.

Thank you so much, sir.

Senator CARPER. Senator Padilla, welcome. You are on. Thanks.

Senator Whitehouse, nice to see you. Thanks for joining us.

Senator PADILLA. Thank you, Mr. Chairman.

I know I am speaking a little bit to the choir here, but for the record, according to the Fourth National Climate Assessment, which is a report from a congressionally mandated program, climate attribution studies have indicated that throughout the western United States human induced climate change is substantially reducing winter and spring snow pack, which is then increasing the likelihood of chronic drought.

The report also indicates that under no change to water management practices, several important western U.S. snow pack reservoirs, including in Sierra Nevada, California, will effectively disappear by the end of this century. Dr. Wehner, as a contributor to the assessment, can you walk us through the impact of snow pack loss for California and other western States?

Mr. WEHNER. Yes, Senator, I can. In fact, our research was initially performed by Dr. Alan Rhoades at Berkeley Lab when he was a graduate student.

In that we are basically, if we continue on a business as usual or a no policy scenario of emissions, by the end of the century the snow pack in the Sierra would be effectively gone, as it would also in the Wasatch Mountains, which is an important source of water for Utah and Salt Lake City.

So in California and throughout the West, we rely on the snow pack as a temporary reservoir to supply water for both agricultural needs and for our urban requirements. And that infrastructure was built over the past century and was assuming that the snow would melt on a schedule that was in the past. And that has changed. There are studies that show that the snow melt has begun earlier. As that continues, it will overwhelm our ability to manage water, so we will run out in the latter parts of, before it starts snowing again or raining again.

Senator PADILLA. Yes, we are just compounding the effect. This last winter was an anomaly, so we have less precipitation earlier, quicker runoff that leads to very difficult scenarios later in the summer and early fall each and every year, with a growing population and a growing economy. So just laying that out for my colleagues. We need to do different going forward, and we need both policy and investments building on what we have done with the Inflation Reduction Act, building on what we have done with the Bipartisan Infrastructure Law.

Now, speaking of precipitation, I do want to also acknowledge the historic summer events that took place this last winter that illustrated our Nation's vulnerability to heavy precipitation and flooding, when we get the little rain that we do get too much too quickly. Atmospheric river rainstorms are responsible for nearly 85 percent of flooding on the West Coast, which threatens our vital infrastructure and vulnerable communities. In California specifically, we had nine successive atmospheric rivers in January, which

caused flooding, power outrages and mudslides resulting in an estimated $4.6 billion worth of damages.

I lay that out because it is important to get the data to better understand what we are grappling with here, so we can inform how we adapt and how we respond. So I was actually glad to see the President's supplemental request funding for NOAA's acquisition of two hurricane hunter aircraft replacements, which is something that both Senator Graham and I, both members of the Committee, pushed hard on.

These plans can help provide real time data from inside atmospheric rivers to increase vital decisionmaking which is important to protect life and property.

Dr. Wehner, back to you, in your testimony you mentioned that climate attribution research in heatwaves and hurricanes is more advanced. Can you talk more about the need for research and development around atmospheric river events?

Mr. WEHNER. Indeed, the literature on hurricanes is long and detailed. Although we don't know everything, obviously, about hurricanes. Atmospheric rivers weren't even named such until about 20 years ago. And so it is a much younger field of research, and there is much more to be done.

In fact, what you mentioned about sending airplanes out into these storms has only just begun. But it is really critical to get that kind of data, so we understand why some of these disturbing findings that we have found about atmospheric rivers, particularly the ones that are associated with the so called bomb cyclones, have such a sensitive response, large response in their precipitation amounts from climate change.

Senator PADILLA. Thank you.

I know my time is up. I will just end with this. Having been briefed post these atmospheric river events earlier this year, a lot of the impact on the ground to communities, particularly vulnerable communities, were a result of the atmospheric river storms not behaving as they were initially predicted, again, because of the lack of research historically when it comes to atmospheric rivers.

So the quicker and better we can understand how they are more likely to behave, whether they just stay stationary over a certain geographic area or move further north, south, east, west depending on greater climate factors, the more we can prepare to protect life and property on the ground.

I appreciate all your research and testimony here today.

Thank you, Madam Chair.

Senator CAPITO [presiding.] Senator Whitehouse.

Senator WHITEHOUSE. Thank you.

Dr. Jurado, I am a Senator from Rhode Island, a fellow ocean State. So I think I will focus my questions on you. I gather you are seeing continuing and increasing tidal flooding, sometimes referred to as sunny day flooding that has nothing to do with a rainstorm, but has to do with sea level rise and tidal action?

Ms. JURADO. Yes, Senator, absolutely. I think that these events were first observed with increased regularity about 10 years ago. Then we began to see longer fall tidal flooding. Now, the flooding also occurs into the spring months.

So you can really set your clock by the expansiveness and frequency of these events. They are particularly compounding flood conditions, because when it rains and we are having this high tide flooding, none of our flat landscape can drain. We actually find tidal flooding contributing to inland flooding miles inside the county, because of the interconnectedness of these systems.

Senator WHITEHOUSE. A head up to my next question, well done. So if you are nowhere near the coast in Rhode Island, but you are potentially in a riparian zone, near a river that is going by, or a canal that is going by, you could well be flooded with fresh water because of the sea level rise creating hydraulic back pressure on the escape of that fresh water from Florida's land surfaces?

Ms. JURADO. That is exactly the condition. In fact, some of our most western communities, we see tidal signals in the canal network that are 15 miles inland. And so that increase in water level that carries through the entire network is not constrained to the coast by any means. But clearly the most severe impacts are happening in the coastal area. But that can extend 6 miles inland.

And it is not only affecting what happens with surface water flooding, but we also find a rise in the groundwater table that is extending 6 miles inland as well. And that affects all of the drainage infrastructure associated with site development, roadways, transportation projects as a whole.

Senator WHITEHOUSE. Along with the rise in the groundwater from effectively hydraulic sea level rise pressure, are you also seeing that salt water is intruding through the limestone into what previously were freshwater wells and water sources for homes and businesses?

Ms. JURADO. That too is absolutely the case. We have estimated that we have lost about 30 percent of the coastal wells, or will, to salt water intrusion by about the year 2050, 2060. We partnered with Palm Beach County to develop a very large surface water reservoir as an alternative water supply, holding 35 million gallons of water to help compensate for what is happening with salt water intrusion. It is very much driving the practices as we look at long term water supply investments, and impacts on our wastewater collection system as well. Because that water is driving into those connections.

Senator WHITEHOUSE. And is the warming of the ocean offshore, including measured up to literally Jacuzzi recommended temperatures, causing an effect on the strength of storms that hit Florida, particularly hurricane level storms that come from the ocean?

Ms. JURADO. I believe the science is well documented that the warming is causing an intensification of these systems that contributes to additional rainfall that indeed, these storms move more slowly, they carry more rain, they dump more water on communities. So those impacts are very real, in addition to the environmental consequences for the reefs, which are suffering under 100+ temperatures.

I think we are very much interested in looking at, in addition, how much of this additional warming is going to drive sea level in the short term and what types of measures can we take to really work to constrain the upper limit on sea level rise in addition to just talking about temperature, what can we do to really drive a

cap on how much we're willing to accommodate in additional rise in sea level and as it impacts our infrastructure.

Senator WHITEHOUSE. How is the insurance industry responding to all these new risks?

Ms. JURADO. Certainly we have seen sizable adjustments in what is happening with flood insurance policies. And then we have our windstorm policies on top of that. I shared at a roundtable at the White House a couple of weeks ago while the national average on homeowner's policies is about $1,400, most of the people I know in Florida are paying about $8,000 a year currently. That is just windstorm, not counting flood.

Senator WHITEHOUSE. And from what I understand, nearly a dozen local insurance companies have gone bankrupt facing claims, others have stopped renewing policies in order to avoid future risk. National companies are walking away entirely from Florida markets. And there is a resulting flood, if you wish, to a flight to your State backed insurance company. How much of a burden do you think your State backed Citizens Property Insurance Company will end up carrying?

Ms. JURADO. It is hard to say. But currently, the Citizens program is trying to depopulate, and I know that many are receiving notices that they are required to consider these alternative policies. And one I read about recently was a 450 percent increase in the annual premium to move to a private holder.

So the options are significantly reduced. The costs are escalating beyond the level of affordability. And I think that it is one of the most treacherous conditions affecting home ownership. And the ability to live in South Florida, where we need people to be able to work and prosper, they can't even afford an annual insurance premium.

Senator WHITEHOUSE. Thanks very much.

I have gone over my time. I appreciate the indulgence of my colleagues.

I would only add that when I last checked, Citizens Property Insurance had reserves of $4 billion, Idalia so far is over $10 billion, Hurricane Ian was over $110 billion. So there is an enormous gap there.

Senator CARPER [presiding]. There certainly is. Thank you, Sheldon.

Senator Merkley, good to see you. Welcome. Delighted you have joined us.

Senator MERKLEY. Thank you very much.

I want to continue the impact on insurance. I picture middle class families who have a mortgage, and their mortgage generally says, you must maintain homeowner insurance. And so the family gets a notice saying, sorry, we are canceling your homeowner insurance. And the family has to go out and find separate homeowner insurance, otherwise the mortgage company will put the homeowner insurance on a very, very expensive policy. But it becomes increasingly hard to find that.

So are middle class families who are really in the middle of a mortgage, they are not buying a new house, if you will, finding that they are in trouble in terms of securing the insurance they need to maintain their mortgage in good standing?

Ms. JURADO. Thank you, Senator.

I think the circumstance is one of, again, affordability. There is a lot of conversation of people simply needing to move out of the area because they can't afford the insurance options that allow them to afford their mortgage payment that allow them to stay in their home. Most recently, as well, the Citizens insurance provider has also required flood insurance coupled with the hurricane coverage.

So again, it is another cost that somebody who was able to barely afford a mortgage at the time, at which they secured it may be just in a situation of having to let go. We do see many individuals leaving the State as a result.

Senator MERKLEY. We do see in Oregon a lot of families affected by flood insurance issues. But I really want to focus, when you think about Oregon and climate chaos, you might hear people talk about the pine beetle infestation, you might hear them talk about the decreasing snow pack in the Cascades, which has dropped by an average of 240 inches over 90 years, so basically half the snow pack is gone. You might hear them talk about ocean acidification affecting the sea life off our coast. We have one of the richest grounds in the combination of the Pacific upwelling, the California current.

But the thing that really is on people's minds are fires. We have seen such a growth in forest fires. In 2020, we had three simultaneous fires in three major watersheds. We had the Santiam Canyon fire, the Almeda Fire, the South Oberchain, and Echo Mountain, more than three. Essentially, we lost 4,000 homes. I traveled 600 miles up and down the State, never got out of the smoke. We had massive collapse of communities turning up at the fairgrounds in refugee status. Seeing the burnt remains of towns, some 12 different towns were either obliterated or deeply damaged by those fires.

I think maybe this is more for you, Dr. Wehner. People used to talk about 100 year events, they used to talk about 1,000 year events. I think you framed in your testimony that things that occurred every 1,500 years have become once in a century events. Things that are very rare are happening with increasing frequency.

You didn't mention in your testimony wildfires as a category of extreme weather which can be attributed with reasonable certainty. What can climate attribution science tell us about individual wildfires?

Mr. WEHNER. It can tell us quite a bit, Senator. I was the chapter lead author on chapter eight of the Fourth National Climate Assessment, Volume One, and fires was part of that chapter. That was back in 2017, and we saw a clear trend, particularly in Washington, Oregon, and California, of large wildfires, an increasing trend. That of course is much worse since 2017, there have been a lot of major fires in all those States.

In anticipation of your question, I did do a little more research last night, trying to find specific things to Oregon. I don't have one. I have some more general statements, though. The leaders in this actually turned out to be Environment Canada and Victoria. They of course studied Canadian fires. But that is not all that different than Oregon.

They found that the fire weather metrics that led to that big fire in 2018 in British Columbia were made 2 to 4 times more likely, and more importantly, that the area of the fire was increased by a factor of 7 to 11. So it became a record kind of fire.

Senator MERKLEY. The fire was 7 to 11 times more destructive?

Mr. WEHNER. The area burned was 7 times larger, at least.

Another study said that nearly all the observed increase of the burned area in California over the past half-century is attributable to anthropogenic climate change. So I am sure this is true in Oregon as well.

Fire is very difficult, and perhaps one of the more challenging areas for event attribution, because there are, as all these kinds of extreme events, multiple causes. Wind is an instigator, and one of the things that my research and some others have found is that there is little trend in extreme wind. And so this increase in fire weather conditions is almost entirely due to higher temperatures drawing out the fuel of the forest, so that the fire seasons are longer. This is also reflected in the budgets of firefighters, wildfire fighters. They have to pay more because they are out there longer.

Senator MERKLEY. We used to, if you asked an Oregonian 20 years ago, when to come to Oregon, they would be like, oh, well, July, August, into early September are our golden time. Now if you ask Oregonians, they will kind of pause and go, you know, we have had a lot of smoke in July and August and September. It is just a huge change. We have furniture stores that can't sell their inventory because of smoke damage, we have wine grapes that have been contaminated by smoke damage, we have people in the hospital with asthma aggravated by smoke, we have communities trying to set up clean air sectors.

In other words, it is so palpable, the change within a few decades is so real. If you are trying to hike the Pacific Crest Trail, there were hikers that used to come through in August, you cannot come through. There are so many fires on the Pacific Crest Trail or near it, threatening it. My wife and I have had to change our plans a number of times for those hikes. You don't want to be in the middle of wilderness with no cell phone connection or knowledge of fires erupting and be on a very remote trail. It is so many dimensions of our life in Oregon that have been affected. The Ashland Shakespeare Festival, huge challenge with cancellations due to air smoke quality.

So it is very important for us to be able to capture this. We have seen the fire season grow longer. That one set of fires on Labor Day, 2020 burned over a million acres, and 4,000 homes. A dozen communities were affected. It sent a very powerful messages to people across the country. They remember Paradise, California.

Well, the devastation was greater in Oregon, but it was kind of like, oh, well, now it is not new, devastating fires that burn a community to the ground, and you see cast iron bathtubs and steel staircases still standing in beds of ashes and molybdenum wheels, where they melted and ran across the ground, creating strange sculptures. It is an architecture that we have just never witnessed before, or a scene we have never witnessed.

So I think understanding this continued impact is incredibly important. Thank you all for bringing your insights to bear on the

evolution and dynamics in many dimensions, certainly floods, droughts, and fires.

Thank you.

Senator CARPER. Thanks for those very thoughtful questions.

We are going to start a second round. You are both welcome to stick around if you can, and have another shot.

I want to go back to Dr. Jurado. We had a question earlier, and I said I was going to ask you to pick it up. I think the question I asked was of Dr. Wehner, I asked him if he would give us an example or two of how attribution science can inform the design and engineering of infrastructure projects to better manage the impacts of these extreme events when they occur. I just want to ask, Dr. Jurado, are you the Chief Resilience Officer for Broward County?

Ms. JURADO. Correct.

Senator CARPER. How important is it to have scientific information about the size of events that we may be faced with next? How important is that? And how can results of attribution studies inform local infrastructure planning and decisionmaking?

Ms. JURADO. Thank you.

It is an absolute criticality. One of the greatest challenges that we faced in South Florida was trying to account for rainfall intensification. We knew it was taking place. We have to be able to accommodate this additional volume of rainfall. If a one in 100 year event used to deliver 13 inches, but now it delivers 15 or 18, it alters the whole of infrastructure across the community, not just how we plan locally, but the integration with all of the State funded and federally funded projects as well.

So we need to have harmonization across infrastructure, and we need to know with certainty, at a decent level of certainty, what is the percent change that we should be accommodating in our infrastructure for this intensification. So we worked very deliberately with our Federal agency partners to account for initially a 13 percent increase in rainfall, and ultimately made that adjustment to 20 percent.

So this 20 percent intensification for rainfall events is now embedded in the design standards that we have for drainage infrastructure, surface water management infrastructure, we are ensuring that the improvements to the C&SF project also account for this rainfall intensification. It drives our flood elevations.

So absolutely, we needed to be able to embed this in the various types of design infrastructure, and then be able to account for how it influences change in groundwater table, plus the flood elevation, plus the conveyance and storage needs. Very critical.

And having that information allows us to not only design appropriately but also consider to the extent to which our mitigation activities in terms of reducing emissions and decreasing the intensity of these events can work to make a longer term difference over the course of the next several decades, how much of that can we mitigate through our missions improvements.

Senator CARPER. Thanks for that.

I am going to come back to Dr. Wehner for another question, one dealing with beliefs and attitudes.

In fact, I will hold off on that. We have been joined by one of the two retired Navy captains who serves in the U.S. Senate these

days, and a former astronaut, a guy who has done all kinds of things in life, a guy who married up, as I did, Mark Kelly.

Mark, thank you.

Senator KELLY. Thank you, Mr. Chairman. Clearly married up, no doubt about that.

Thank you, everybody, for being here today. I apologize for running a little late.

Every summer in Arizona, it is hot. We know that. But this year, the heatwave hit a whole new level. In the month of July, Phoenix had a 31 day streak where the average temperature was above 110 degrees Fahrenheit, 31 days in a row. And in total, we had in Phoenix 55 days above 110 this summer. And that is unprecedented.

The one stat that I saw describing this summer's heat stands out above the rest. I was just looking at a plot, this is a couple months ago, this is actually a global plot on worldwide temperature. And when you look at the summer of 2023, it kind of stands out. Data from the Copernicus Climate Change Service found that the average global temperature, which is what I am talking about, when I looked at this, it was a 3 sigma variation, three standard deviations away from the norm. To me, as somebody who used to do a lot of stuff with data as a test pilot, it could be a bad data point. Could be.

But you know, temperature is a pretty easy thing to measure. So in my view, and in my mind, it is either bad data, which it is not, or something very unusual has happened. That same data shows that in July and August of this year, we were 1.5 degrees Centigrade warmer than pre-industrial levels.

Dr. Wehner, when we see data like this, how easy or difficult is it to attribute all or even part of this to a change in the climate? When we see data increases like the change in summer temperatures from last year to this one, it is sometimes hard to communicate why this is such a big deal.

So how does climate attribution shape the ways that we talk about the impact of climate change on data? If you can address those.

Mr. WEHNER. Thank you, Senator.

Yes, this year is a particularly unusual one. Arizona wasn't the only place that had a heatwave. At the same time we had heatwaves in the United States, we had heatwaves in Europe and China simultaneously. So the whole northern hemisphere was hot. That is part of the reason why the global mean is a 3 sigma event.

Now, some of that is going to be an El Niño effect, we can quantify that. But not nearly all of it. Some part of it is quite clearly the anthropogenic effect, the human caused effect from our consumption of fossil fuels and our changes to the composition of the atmosphere.

Senator KELLY. Dr. Wehner, could I ask you, if you go back decades or over the last 100 years, has there been another 3 sigma event in temperature?

Mr. WEHNER. Not that I am aware of. But my knowledge isn't complete on that.

So it is an unusual event. When I was coaching ice hockey, I would call this, in the words of the great basketball coach John

Wooten, a teachable moment. This is a teachable moment for many of us, including climate scientists, so that we can better understand that. And attribution science is part of the key to understanding how all these different factors led to this 3 sigma event.

Senator KELLY. So part of it could be El Niño?

Mr. WEHNER. Some of it certainly is. Some of it could be natural.

Senator KELLY. We have had El Niños in the past.

Mr. WEHNER. Of course.

Senator KELLY. What is the cycle on an El Niño?

Mr. WEHNER. It is every 4 to 7 years. But 1988 was another huge El Niño year, and then years afterwards were cooler. I had to write papers afterwards saying, the title of the paper was, "Is the Climate Warming or Cooling?" It is because people were saying, well, climate change stopped. That is wrong, of course, you can't just start your analysis in the hottest time of the year, or hottest data point.

Senator KELLY. Yes, the CO_2, methane, carbon monoxide just didn't vanish from the atmosphere.

Mr. WEHNER. No. So the longer the data records, the more informative it is.

Senator KELLY. And do you expect future 3 sigma events to occur more frequently?

Mr. WEHNER. That I cannot say. I don't think we understand changes in variability nearly as well as we do changes in the average. But I certainly can tell you that this summer event throughout the world was unusual. But it will be the norm in a very short period of time.

Senator KELLY. And do you feel that the messaging in the United States and across the planet on this issue and this 3 sigma event is sufficient, or do you feel like maybe media and others are falling short?

Mr. WEHNER. I am not sure how to answer that question. To me, the data always speaks for itself. But I am not an expert on media relations. So I think I will defer on that question, if you don't mind.

Senator KELLY. When I saw the data, I was reading an article and just saw the plot. My reaction was wow, that is different.

Mr. WEHNER. One of the things my colleagues and I are working on is would this temperature have been impossible without climate change, would this summer have been impossible without climate change. Give me a few more months and we will get back to you on that.

Senator KELLY. Yes, please, let me know. Thank you.

Thank you, Mr. Chairman.

Senator CARPER. Thank you.

Did you say that you were an ice hockey coach?

Mr. WEHNER. Yes. I coached teenagers. It was fun.

Senator CARPER. Do you still do it?

Mr. WEHNER. Not any longer. I can't skate any more, unfortunately.

Senator CARPER. Who do you think was maybe the greatest hockey player who ever played the sport?

Mr. WEHNER. Wayne Gretsky.

Senator CARPER. Wayne Gretsky was once asked, Mr. Gretsky, why are you the greatest hockey player on the planet? He replied,

as you probably recall, he said, I go where the puck will be, not where the puck is. I go where the puck will be, not where the puck is. That is a little bit like attribution science, you are going to help figure out where the puck is going to be to be able to address this. It works pretty well.

I was just coming back to Dr. Wehner for some follow up questions. We may be joined by another colleague or two. I think every other committee in the Senate is meeting almost at the same time. We have a big bipartisan forum going on right now on artificial intelligence. This is our hearing here today, so we have some people who would like to be here and just can't be here. But they are very much interested. Some are watching, this is being televised live, and some are watching it along with their staffs. So the impact you are having is probably far greater than you might imagine. It is really important.

I want to finish my question of you, and then I am going to tell a story and then maybe wrap it up. I was saying earlier, when we were joined by one of our colleagues, I said, in a recent poll on attitudes toward climate change, 55 percent of Americans said they had not personally felt the effects of climate change. During the July heatwave that Senator Kelly and others have alluded to, however, two-thirds of the U.S. population were under heat alerts and other climate driven events from wildfires to hurricanes. It harmed a lot of folks.

It is worth noting that only 5 percent of TV news coverage of the heatwave even mentioned climate change. Didn't even mention climate change. So I think attribution science provides an opportunity to help Americans understand that what they are experiencing is actually the effect of climate change, it is not their imagination, it is not something that may or not be happening, it is actually explainable.

As you explained in your testimony, Dr. Wehner, attribution studies detail the effects of climate change on extreme weather events. What are some specific ways that we can use this information to help the public better understand how climate change impacts their daily lives?

Joe Biden, he and I have a lot of sayings that we swap back and forth. We rode the trains together to DC for years. I think I know every one of his, and he knows all of mine. One of my favorite Biden words is "splainer," as in explainer. He is always looking for good splainers, I am surrounded on either side by good splainers. We are looking for ways that we can be better splainers. How do we do a better job helping the public understand how climate change impacts their daily lives?

Mr. WEHNER. In some sense, that is my job, is to try to put numbers on what has mainly this past few years become very painfully obvious. Maybe you don't even need me to tell you the climate is changing, and the weather is getting worse. All you have to do is pay attention.

We talked about fires. I have lived in California now for almost 40 years, and I don't remember bad air days like we have had. I have a photograph taken from near my house where the sky was orange, an orange like an unnatural orange, like orange soda. It was apocalyptic; it was frightening.

You don't need to be a climate scientists to know that that is weird, and that is unusual. These heat waves have affected a lot of people, they have killed a lot of people. They have killed a lot of people's grandparents. I think that is a very personal and very distressing thing, if that were to happen.

These storms, Hurricane Ian in Florida was a very devastating storm. We wrote recently that climate change made the storm 20 percent wetter, but that is only part of the damages. We had this huge storm surge in Fort Myers, like 15 or 20 feet, that wiped homes right off their foundations. Then a few days later, the fresh water, the rainfall ran through the systems and flooded a large fraction, a large number of homes outside of Tampa.

So the insurance rates are an issue, it is an issue in California. Mine went from $2,000 to $5,000, my own. How this information is used I think is a question for you. I can tell you what happened, what is going to happen, our best guess as to what is going to happen. But what we do about it is up to you, it is not something I decide. That is something that the people decide through their elected representatives.

Senator CARPER. Thank you.

I want to follow up with Dr. Jurado. How could policymakers and the media more effectively communicate this information that we are talking about here to the public?

Ms. JURADO. Thank you for the question.

I think the media conversation is the significant one. It is interesting; I have been in DC over the years and hear meteorologists speaking about climate change as part of the weather delivery. When it happens, it is almost stunning.

But why aren't our weather forecasters integrating discussion of climate as part of the weather forecast? When was the last time that we collectively looked at the CO_2 concentrations at Mauna Loa? I remember when it passed 400 parts per million. Do we ever talk about having lost that benchmark, and where we are going, and how these conditions relate to on the ground effects?

Government at the local level, we are not the best communicators. We need assistance with this. No matter how many presentations we give and websites we deliver, the majority of the public are not aware of the conversation or the amount of work that is taking place.

So I think it is about recognizing impacts, celebrating wins, celebrating investments, talking about the change in individual circumstance that comes with investing in resilience, broadcasting the types of programs that are available because of the concerns that are being expressed, providing more funding for the types of projects that the EPA, the Climate Production Reduction grant, great start. But $4.3 billion across all of the communities in the United States is just one shot at a much larger problem that we have in terms of helping residents adapt and celebrating the types of investments that are making quality of life improvements as climate change is taking place.

Senator CARPER. Thanks for that response.

As if things couldn't get any busier, the Senate is now beginning to vote. So we have all these hearings going on, this big bipartisan

forum that is going on on AI, and we are trying to solve climate change here for the morning.

Senator Capito has gone to vote, and I don't know that she is going to be able to come back and finish up with another round of questions. I have one or two more that I am going to ask, then we will wrap it up.

One of the closing questions, I will ask you to think about this, I talked about ice hockey, and I am going to use a baseball metaphor, telegraphing my pitch. You can tell in baseball the way the pitcher holds the ball, maybe delivers the baseball to the batter, you can tell what kind of pitch it is, fast ball, curve ball, slider. But I am going to tell you my pitch. I am going to ask a question: Where do we agree? Where do the three of you agree? Maybe 10, 15, or 20 years ago there wouldn't have been as much agreement in this room, at this table.

One of the Ranking Members here was a fellow named Jim Inhofe from Oklahoma, who was a climate change denier. He readily admitted it. I remember when it snowed here one time in warm weather, and we had about six inches of snow in the lawn in the front of the Capitol. He went out and made snowballs. He brought the snowballs onto the Senate floor and said, climate change, I don't believe that is real, look at these snowballs here in August. By the time he left here, he was a senior Republican on this Committee, he was my lead Republican on the Diesel Emission Reduction Act.

So people can change their minds. They can learn.

Quick question, then we will move toward wrapping it up. A question about how Inflation Reduction Act programs boost resiliency. The Inflation Reduction Act and the Bipartisan Infrastructure Law, which I am proud to say were largely written in this room, but in any event, they include programs to help States, programs to help Tribes, to help cities, to help counties reduce greenhouse gas emissions and to improve their resiliency.

One example is the EPA's Climate Pollution Reduction grants. My question, Dr. Jurado, is, does your community down in Broward County want and need this Federal assistance? A follow up question to that is, how are you using Federal grant programs and clean energy tax credits? Is this assistance sufficient for communities to address climate change by driving down emissions and increasing resilience?

Ms. JURADO. Thank you for the question, Senator.

The support is absolutely needed. I am sure that many are aware that our State passed on the CPRG funding, and most recently on the solar project funding for residential investment. If that money is not made directly available to communities, meaning municipalities, Tribes, and counties, many of us will not be able to take advantage of these very critically needed investments. There frankly aren't alternative funding sources.

Another challenge that we have is we have no investment in energy efficiency by our local energy utility. There are no programs. The statement is made that it is not cost effective. Well, it is not cost effective for the utility provider, but no matter how clean the energy is that is being produced, you still have many lower income individuals who are contending with significant rise in tempera-

ture. They are already energy burdened, and many are struggling with how to provide air conditioning just to sleep through the night.

Older individuals who need that cooling, children cannot sleep and study well if they don't have an opportunity for their bodies to cool at night. The CPRG funding, that Climate Pollution Reduction Act funding, is critical for being able to aid with investments that help energy efficiency in single family, multi-family residences that need that support. We are also very eager to take advantage of that funding to support solid waste improvements where we have clean energy initiatives, with waste energy plants and those investments that are taking place in our community.

It is a great initial start. We hope to see that funding renewed, or a continuation of that funding in some form. We know that those plans that are underway will be ignited with this individual investment, but the plans that are being worked on by our communities are intended to go far beyond the next 5 years and continued investment there would go a long way to help meet our own goals, which include net zero by 2050.

In addition, with regard to the direct pay tax credits, certainly in Broward County, we have been looking for innovative models to help support renewable energy projects over the years. We have maybe 14, 15 very large scale solar projects. But these tax credits are now allowing us to increase the size of our solar projects by 30 percent beyond what we could have otherwise.

So it is a tremendous benefit to our ability to participate proactively with clean energy solutions that are coupled with our infrastructure and our sites, as well as electric vehicle charging networks, transitions within our fleets, support for community and local government projects.

Senator CARPER. Thank you for that response.

I telegraphed my pitch, and said I was going to ask before we adjourned that, where do you all agree. Do you think there is a consensus in this panel, we might not have had it in this room at a similar hearing a couple of years ago, I won't ask you what has happened, I could ask you what has happened here, but let me start with Mr. Dabbar.

Go ahead, if you would, please.

Mr. DABBAR. Yes, Senator.

I think as we collect more data and look at new solutions, I think that is a consensus driver. I think coming out of the sequester, very large bipartisan support for innovation, which has led to a lot of these technologies like Form Energy and others that we have been talking about here today.

I would like to comment to the data aspect of fire that was brought up previously. There are solutions, and once again, you have these problems, but there are solutions.

Let me give you one example around data and solutions on fire, which is, you could use, I ran the National Quantum Initiative for the United States, you could use the photons on the fiber that go down the power lines, and you can detect the power quality and ergo, the resistance of the power lines. You can predict when they are going to fall. We haven't been able to do that.

So, using quantum networking and quantum sensing for these things going on in California and elsewhere, you could use that sort of new technology and detect meter by meter as the resistance of that line is degrading, and you could go fix it before the line falls.

So this is an example of innovation that I think, back to your question, Senator, around consensus. I think the consensus around innovation, American leadership, things like the example I just gave you that would probably save lots of lives in Hawaii or California or elsewhere, I think that is part of the reason why things are moving forward.

Senator CARPER. Good.

Dr. Wehner, same question, please.

Mr. WEHNER. I think we are in agreement on a lot of things. John Holdren, who was the science advisor for President Obama, said we have three choices. We can mitigate, we can adapt, or we can suffer. I would like to minimize the suffering. That means we have to mitigate more, and adapt more.

So the things that Mr. Dabbar has talked about in terms of making our energy systems more, reducing the emissions of these technologies, is something this country can lead in. I strongly support that. But I think we also have to recognize that no matter what we do, we are going to be continuing to experience more severe and more frequent weather disasters, and so we need to adapt.

One thing I did not get to say with the fires, in particular, is all of us, myself included, are exposed to this smoke. The eastern part of the United States this year was exposed to, for the first time, I think, to the levels that westerners are used to. I am particularly concerned about the effect on children. I raised this with a local politician recently. He told me something I didn't know, that there is a program in California to distribute HEPA air filters to families in need. I think those kinds of actions are things that are really necessary if we are to protect our most vulnerable, especially our children.

Senator CARPER. Great. Thank you for that.

Dr. Jurado.

Ms. JURADO. I think as we have moved on through time, we just see more in the way of personal impacts, friends and family that have been impacted in one way or another. It becomes undeniable that these conditions are being more broadly experienced.

We have also, though, I think, appreciated with time that there is a great ability to take advantage of an opportunity to innovate, to look at the economic opportunity that comes with new technology, new investments, community betterment, areas where we have needed to make investments anyway, but we can add to the benefits being delivered.

So it isn't just about adaptation; it is about economic innovation and really embracing an opportunity to create a much better future through coupled investments that address energy and adaptation and community betterment and economic opportunity all tied together. So I think being able to look at it as not just a burden or exposure, but an opportunity for repositioning our communities at the same time.

Senator CARPER. Thank you.

Before we close, Senator Whitehouse is trying to get back here. He has already voted; I need to go vote very shortly.

Our staffs, Democrat and Republican staffs, have heard me tell this story before, so I will ask their indulgence. I like to take the train; I love the train, and I take the train a lot up and down the Northeast corridor. Albert Einstein used to take the train a lot, too. I think he taught at Princeton. He would get on the train at Princeton and go to New York, he would come down here. He was a regular on the train, similar to how Joe Biden and I have been over the years.

One day he got on the train and found a seat and started looking for his ticket. He reached into his pockets and his trousers and his briefcase, and he couldn't find his ticket. And finally, the conductor came up to him and said, Dr. Einstein, you ride the train a lot; we know who you are. You don't have to worry about it; we know who you are.

Dr. Einstein kept looking for his ticket. The conductor walked away, and the conductor started walking into the next car, he turned around and looked back. Dr. Einstein was down on his hands and knees looking for his ticket. The conductor rushed back and said, Dr. Einstein, you don't have to do this. We know who you are.

And Dr. Einstein looked up at the conductor, on his hands and knees he looked up to the conductor and said, "I know who I am too, I just don't know where I am going."

[Laughter.]

Senator CARPER. I think we know where we are going if we don't work together, pull together. We use science to guide us. I must say, I wish you could all have been here, I have been on this Committee 22 years, I wanted to be on this Committee when I got here 22 years ago. But to have heard the kinds of conversations we had then on climate change compared to what we had in this incredibly constructive conversation. I applaud each of you for taking the time to join us.

Everything, as proud as I am of the work we have done in the Inflation Reduction Act and the work we have done on the climate change provisions within the Bipartisan Infrastructure Bill, everything I do, everything we do we can do better. Everything we do, everything we do we can do better.

It is one thing to write legislation and get it signed into law. The really important piece now is implementation. One of the things that Senator Whitehouse and my colleague, Senator Capito, are interested in doing is making sure we do a good job on the implementation. We don't just write legislation on this Committee; we actually help implement, we do oversight. We need to do a whole lot of that in the days going forward.

I am going to hand the gavel over to Senator Whitehouse. I leave it in good hands.

Folks around the country think we don't like each other here, Democrats and Republicans hate each other, we never want to work together. I have people who say to me, at least every week, Sheldon, when I am getting on the train station and getting on a train here or up in Delaware, people say, can't you guys just work together? Can't you work together? Can't you get something done?

I wish they could have sat through this hearing. They might have been encouraged a little bit, because I think we have a pretty good idea of what is wrong. And we have a lot of good ideas about how to address it. If the American people would hear that, I think they would be encouraged.

There was once a woman who ran for President not long ago, and her campaign slogan was stronger together. Stronger together. And I think that really applies here. I think that we are largely together, and we are stronger because of that. I just love getting things done. I love getting things done, and we are getting some good things done. If we keep this attitude going, we will do better still.

Thank you for what you do with your lives, and thank you for joining us today.

With that, a fellow who does great things with his life, from a small State, but as we know from Delaware, small States do great things, and they produce, at least in his case, in his State's case, great legislators.

Sheldon.

Senator WHITEHOUSE. Small coastal States are the best, I think.

Senator CARPER. I am going to run and vote.

Senator WHITEHOUSE [presiding]. I will close out the hearing after my questions.

I want to go back to Dr. Jurado again, because of the experience that you have had. In Rhode Island, our CZMA agency, the Coastal Resources Management Council, took a look at the FEMA flood maps and determined that they were defective. We have seen, for instance, in the Houston flooding, that it hit about 50 percent accuracy rate. So FEMA really seriously needs to upgrade its mapping.

What has been your experience in your geographic area with respect to FEMA flood mapping and its predictive quality?

Ms. JURADO. Thank you, Senator Whitehouse.

I know that when our last FEMA flood map, well, let me say two things. First of all, FEMA utilizes our, Broward County's, hydrologic model. We developed a fully integrated surface groundwater model. FEMA has used our model; they have improved our model. The South Florida Water Management District has used our model and improved the model. Now we are utilizing the same model again. So we have the benefit of all of us utilizing the same model for existing planning, existing conditions and future conditions planning.

Senator WHITEHOUSE. Just let me interject for 1 second. In working on future conditions, do you take things like climate change and resulting sea level rise and storm severity into account?

Ms. JURADO. Yes, sir. In fact, right now in our current modeling effort, we are coupling, we are evaluating 2 and 3 foot sea level rise scenarios, carrying the modeling out to 2070. It is actually 3.3 feet of sea level rise. We account for the change in the groundwater table.

We account for the high tide condition under each of those sea level rise scenarios. We account for various storm surge conditions including 25, 50, 100 year storm surge. And we couple that with a variety of what we call design storm events. So 10, 25, 15, 100

year rainfall conditions, and look at the compound flooding under all those scenarios.

So we are utilizing that now as the basis for our countywide water management planning and redevelopment strategies. How far can we adapt through infrastructure investments and development approaches, versus how much can we not address, such as with the one in 1,000 year rainfall event. There is going to be some element of flooding that again, just can't build a large enough pipe or have enough storage area.

But with the FEMA flood mapping, I know at the time of our last update, we actually had 60 percent of the existing parcels that were removed from the map. Our engineers would say that that map by and large more accurately reflected current condition today flooding only because of a lot of refinements in the data. It was just better data, like LIDAR data that came into the modeling effort.

However, just like Melrose Park, we still have communities that are not in a flood zone, which is always the case, that are still vulnerable to flooding. So we knew that when that 60 percent of those parcels moved out that they would come right back in as climate conditions continue to evolve.

So we actually use our own future conditions flood map that is not what we use a variety of tools for setting finished floor elevations. FEMA is one. But we require the highest of all of our tools be used for planning. And we have a future conditions flood map that integrates much of what I just described as one of those tools.

So in many areas of the county, we are not relying upon the FEMA flood map. The FEMA flood map is most impressive where it now incorporates the coastal A zone. The distinction there was that we account for sea level rise, but hadn't accounted for storm surge. FEMA was accounting for storm surge, but not sea level rise. And that is why this current modeling effort is so critical, because it brings everything together.

Senator WHITEHOUSE. So the multi-party effort has been a significant improvement over FEMA alone in the wild doing mapping?

Ms. JURADO. Improving the models with time and everyone jointly using the same models, but also integrating future conditions. Because we have to account for risk tomorrow, not just the risk today for all of our infrastructure. That is our perspective.

Senator WHITEHOUSE. Do you think the flood insurance program requirement that you build back in place needs adjustment where properties are predictably going to be flooded over and over and over again in order to protect the integrity of the Federal Flood Insurance program?

Ms. JURADO. I think that we need to allow for a lot of flexibility in terms of where we reinvest and how we reinvest. We need to ensure that we are building for future conditions in terms of the design approach. But there will be areas where it will become increasingly evident that it would be beneficial to not replace infrastructure in the same area, maybe utilize that land for storage and buffer the storm surge, and alternatives to allow densification in other areas that may not be as exposed.

Senator WHITEHOUSE. Agreed.

My time is now expired, and you have all had a long morning. So let me follow Chairman Carper's lead and close out the hearing.

The housekeeping rule before we adjourn is that Senators must submit questions for the record by close of business Wednesday, November 15th. And we will compile those questions and send them to the witnesses, and we urge that you reply by Wednesday, December 6th. It is a pain in the neck to have to chase you, so we hope we can get, if there are questions for the record, timely and punctual responses.

I thank you all for your presence here. And with that, the hearing is adjourned.

[Whereupon, at 11:53 a.m., the hearing was adjourned.]

[Additional material submitted for the record follows:]


What *can't* extreme event attribution tell us?
NOAA says:
It can't tell us whether global warming 'caused' a specific event. When most people ask if something caused something else—did global warming cause the Louisiana floods?—they want a yes or no answer. But with global warming and extreme events, it's not a yes/no question.
Instead, it's always a question of whether global warming added to the existing mix of ingredients that already make extreme weather happen. Global warming may be a cause for an event, but not the cause—at least not yet.
NOAA: "Extreme event attribution: the climate versus weather blame game" published by Rebecca Lindsey, December 15, 2016
Climate.gov

ENERGY AND CLIMATE CLIMATE IMPACTS NATURAL HAZARDS AND DISASTERS CLIMATE AND WEATHER

Turning Down the Temperature on Extreme Claims About Extreme Weather

A genre of studies has emerged that purports to blame large portions of extreme weather impacts on climate change—but these studies make one big basic error.

AUG 21, 2023 PRINT SHARE SUBSCRIE

Editor's note: The Liberal Patriot *and* The Breakthrough Institute *are pleased to present the inaugural piece in our new collaborative series "The Climate Report" looking at the science and reporting behind*

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We've all seen the headlines:

"At Least 1,500 Britons Have Died Due to Climate Change-Related Heatwaves in Last 20 Years," reads one from activist group Global Citizen. "Climate change toll from two droughts tops $800m," reads another from the New Zealand outlet *Stuff*, "Climate crisis to blame for $67bn of Hurricane Harvey damage—study," reads a third from *The Guardian*.

These headlines not only purport to quantify the contribution of climate change to extreme weather, they take the additional step of assigning impacts—dollars or lives lost—to climate chang They are also all founded on studies that themselves rest on a fundamental conceptual error that systematically inflates these costs.

This error, which I delve into in a recent peer-reviewed article, has to do with a miscategorization of weather and climate phenomena as discrete, countable events—yes-or-no, on-or-off occurrences—rather than recognizing the reality that extreme weather and climate changes are on a continuum of intensity.

The most straightforward way of thinking about how climate change affects the weather is to consider how it affects the intensity of that weather—not the overall number of extreme weather events. The remarkably extreme rainfall associated with Hurricane Harvey in the Houston area, for example, was probably made between eight to twenty percent more intense by climate change. Further modeling indicates that the increased rainfall amounted to an additional $13 billion in flood damage, or about 14 percent of the total $90 billion cost of the storm.

That's a lot. But it's five times smaller than the $67 billion—or three-quarters of the total cost—that *The Guardian* headline says can be blamed on climate change.

The smaller number based on changes in rainfall intensity is the correct way to think about the influence of climate change, and the larger number is incorrect because it is based on the erroneou notion that rainfall amounts can be thought of as discrete, countable "events." Put another way, climate change doesn't create storms like Hurricane Harvey—but it does make them more intense on the margins.

—for example, it is endorsed by the authoritative Intergovernmental Panel on Climate Change (IPCC) in their Sixth Assessment Report. Here's the key passage in the original *Nature* article:

If...past greenhouse-gas emissions have increased the risk of a flood tenfold, and that flood occurs, then we can attribute...90 percent of any damage to those past emissions.

At first glance, this sounds logical—which is perhaps why it has survived for so long. But the devil is in the details, and this logic does not survive scrutiny when you delve into the details.

To get technical for a moment, this method uses something called the "fraction of attributable risk" that purports to quantify the *proportion* of an extreme weather or climate "event" attributable to climate change. When you see a headline that says a heatwave would have been impossible without climate change, for instance, it's saying that the fraction of attributable risk was 100 percent.

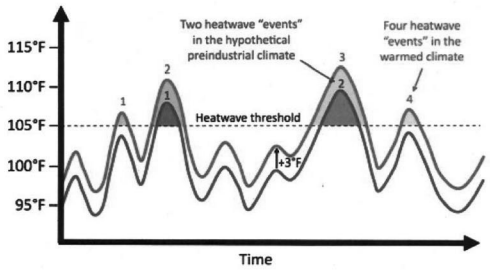
This concept was borrowed from epidemiology, and the general idea is to quantify how a change in conditions affects the risk of a certain outcome. The fraction of attributable risk can quantify how exposure to a particular chemical affects the risk of contracting cancer, for example. If exposure to the chemical doubles the risk of cancer and an exposed individual contracts cancer, then half of the risk of contracting of cancer can be attributed to that exposure.

The genre of climate studies in question makes an analogous calculation on extreme weather "events." But these studies take the further step of assigning impacts like economic damages or deaths to climate change by simply multiplying observed consequences by a calculated fraction of attributable risk. So, for Hurricane Harvey, these studies calculated that the fraction of attributable risk was 75 percent, and therefore about $67 billion out of $90 billion in storm damage could be blamed on climate change.

Ultimately, however, this calculation is wrong because the weather and climate phenomena in question—like rainfall amounts, flood depths, drought measures, and temperature values—are *not* properly conceived of as discrete binary "events" like contracting cancer. In order to shoehorn these phenomena into this framework, researchers use arbitrary thresholds (e.g., crossing some rainfall total, temperature, or drought index) to define countable events.

Let's break down how this works with an example.

3°F cooler preindustrial climate.



When certain meteorological factors come together, temperatures far above normal—say 20°F abov normal—might occur. But we can see that climate change would only be responsible for the additional 3°F. Of course, a strong heatwave can also be responsible for plenty of negative effects—damage to GDP, deleterious health outcomes, reduced crop yields, and so on—but only those *additional* effects associated with the *additional* 3°F could plausibly be blamed on climate change.

But the genre of studies in question neglects this obvious fact and instead define countable "events as the crossing of a particular temperature value. In this hypothetical example, the heatwave threshold is defined as 105°F (black dotted line). Using that definition of a heatwave, a researcher can claim that the *number* (or frequency or probability) of heatwaves has *doubled* in the warmed climate (four versus two). Then the researcher can go on to claim that the *impacts* from heatwaves *have also doubled,* and thus half of all impacts can be blamed on climate change!

This calculation would only be correct if there were zero impacts for temperatures below the heatwave threshold and constant impacts for temperatures above the heatwave threshold, as if flipping a switch. But that's obviously false: impacts scale with temperature, not the number of times an arbitrary threshold is crossed. Quantifying these impacts as a function of intensity is much more difficult to do practically, but as we saw with the Hurricane Harvey example a proper calculation will almost certainly be substantially lower than those calculated with an erroneous method. What's more, comparing the contemporary climate to the preindustrial climate is not particularly relevant because society today is better conceived of as being adapted to the contemporary climate than to the climate of the 1800s.

99th percentile of over 20 million research outputs tracked in terms of online attention. It was cite prominently (five times) in the latest IPCC Report and was promoted on social media by high-profil climate communicators, endorsed by a climate scientist on *Time*'s 100 most influential people list, and was the basis for sensationalist headlines like the one above in *The Guardian*.

This widespread misreporting of climate impacts matters because it undermines trust in climate science—and because it can be used to support policies that are ultimately unjustified.

The authors of the Harvey study also explicitly argue that their work has political implications by, for example, informing lawsuits. They contend their study demonstrates that traditional estimates of the social costs of carbon are severely underestimated, and their work should motivate stricter greenhouse gas emissions reductions in a cost-benefit framework that takes into account both the costs of emissions reductions and the benefits of reduced climate change. These inflated costs of climate change will thus justify overreactive policies like blanket bans on all new natural gas projects in low-income countries—policies that can do more harm than good.

Overall, then, these studies take the notion that climate change is responsible for the *entirety of an event* and make it mathematically explicit. But this same erroneous notion is implicit in all framin of extreme weather that discuss changes in frequency, likelihood, or probability: the entirety of any single extreme weather event is blamed on climate change even though the vast majority of its measurable intensity would have been there *even without climate change*. That leaves the public and policymakers with the impression that climate change is responsible for a much higher portion of extreme weather and its impacts than it actually is.

If we want the public to regain trust in science and for climate policy decisions to be made on the most accurate information, the relationship between climate change and extreme weather must b quantified and communicated with much more accuracy.

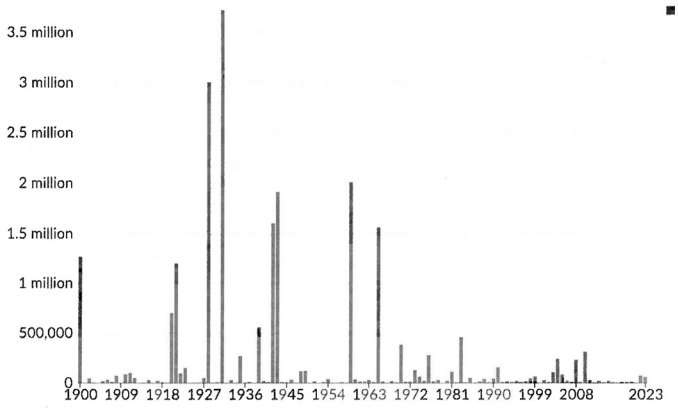
Patrick Brown

Patrick is a Co-Director of the Climate and Energy Team at The Breakthrough Institute and is also an adjunct faculty member (lecturer) in the Energy Policy and Climate Program at Johns Hopkins University.

Number of deaths from disasters

Disasters include all geophysical, meteorological and climate events including earthquakes, volcanic activity, landslides, drought, wildfires, storms, and flooding.

Our World in Data



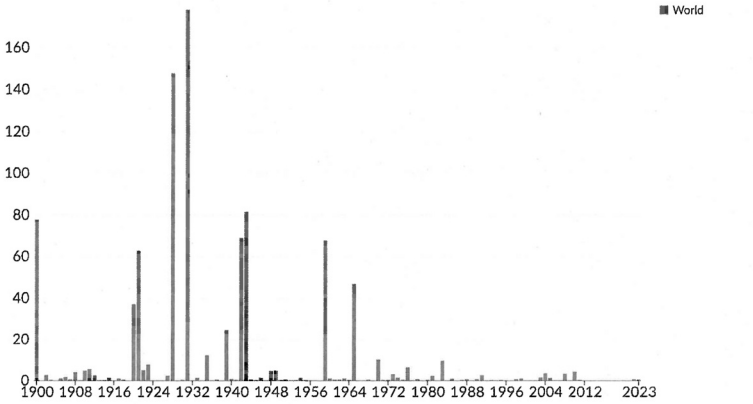
Data source:

Note: Data includes disasters recorded up to September 2023.

Death rate from disasters

Death rates are measured as the number of deaths per 100,000. Disasters include all geophysical, meteorological and climate events including earthquakes, volcanic activity, landslides, drought, wildfires, storms, and flooding.

Our World in Data



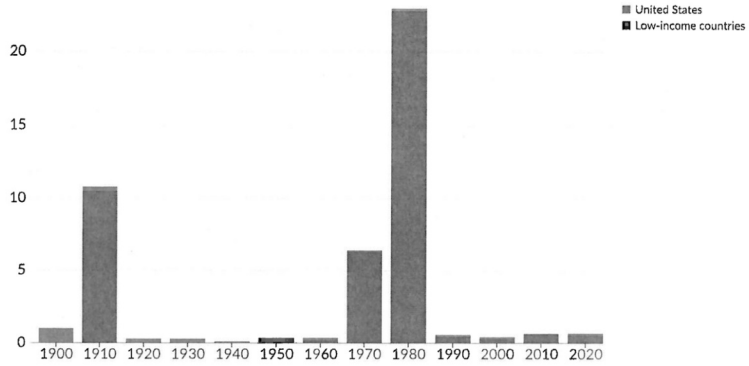
Data source:

Note: Data includes disasters recorded up to September 2023.

Decadal average: Annual death rate from disasters

Our World in Data

Death rates are measured as the number of deaths per 100,000. Decadal figures are measured as the annual average over the subsequent ten-year period. Disasters include all geophysical, meteorological and climate events including earthquakes, volcanic activity, landslides, drought, wildfires, storms, and flooding.



Data source:

Note: Decadal figures are measured as the annual average over the subsequent ten-year period. This means figures for '1900' represent the average from 1900 to 1909; '1910' is the average from 1910 to 1919 etc. Data includes disasters recorded up to September 2023.