WEATHERING THE STORM: IMPROVING HURRICANE RESILIENCY THROUGH RESEARCH

FIELD HEARING

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENT

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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C O N T E N T S

July 22, 2019

WEATHERING THE STORM: IMPROVING HURRICANE RESILIENCY THROUGH RESEARCH

MONDAY, JULY 22, 2019

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENVIRONMENT,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 3:14 p.m., at Houston Community College, West Loop Campus Auditorium, 5601 West Loop South, Houston, Texas 77081, Hon. Lizzie Fletcher [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
SUBCOMMITTEE ON ENVIRONMENT
U.S. HOUSE OF REPRESENTATIVES
HEARING CHARTER

"Weathering the Storm: Improving Hurricane Resiliency through Research"

Monday July 22, 2019
3:00 p.m. CDT

Houston Community College, West Loop Campus, Auditorium
5601 West Loop South, Houston, TX 77081

PURPOSE

The purpose of the hearing is to understand the state of current hurricane and coastal resilience research in the U.S., and to identify knowledge gaps and improvements to current research efforts. This will also be an opportunity to discuss what steps coastal communities like Houston, are, or should be, taking to prepare for, and rebound from, hurricane impacts such as high winds, heavy rains, and storm surge.

WITNESSES

- **Dr. Louis W. Uccellini,** Assistant Administrator for Weather Services, National Oceanic and Atmospheric Administration (NOAA), and Director, National Weather Service (NWS)
- **Dr. Hanadi Rifai, P.E.,** John and Rebecca Moores Professor; Director, Environmental Engineering Graduate Program; Associate Dean Research and Facilities, Director of Hurricane Resilience Research Institute (HuRRI), University of Houston
- **Ms. Emily Grover-Kopec,** Director of Insurance Practice, One Concern, Inc.
- **Mr. Jim Blackburn,** Co-Director, Severe Storm Prediction, Education & Evacuation from Disasters (SSPEED) Center; Professor, Department of Civil and Environmental Engineering, Rice University

OVERARCHING QUESTIONS

- What is the current state of hurricane research?
- How can we improve our understanding and prediction of hurricane impacts, namely, heavy precipitation, storm surge, and high winds?
- What can we do to mitigate hurricane impacts?
- How can coastal communities build resilience to hurricanes and their associated impacts?
- What improvements can be made to research on hurricane impacts and coastal resilience?

BACKGROUND

The National Hurricane Center

The National Hurricane Center (NHC), a division within the National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS), was formed in 1956.[1] It is responsible for forecasting tropical cyclones in the Atlantic Ocean and the eastern Pacific Ocean. The NHC issues estimates of the path or track of a tropical cyclone, its intensity, the size and structure of the storm, storm surge, rainfall, and presence of tornadoes. The NHC also provides hurricane watches, warnings and public advisories; which are released with increasing frequency as a tropical storm strengthens and advances toward the U.S. coastline.[2]

To create a hurricane forecast, the NHC coordinates observations, modeling and computing capabilities, and communication systems from across the line offices[3] at NOAA. Evidence to support the forecast begins as observations from satellites, aircraft, ships, buoys, and radar, which track Atlantic hurricanes from the moment they form.[4] NOAA's Geostationary Operational Environmental Satellites (GOES) provide remote sensing data as the storms cross the Atlantic. The *Hurricane Hunters (*NOAA and U.S. Air Force aircraft), as well as the National Aeronautics and Space Administration (NASA) unmanned aircraft the Global Hawk, fly directly into the center of the storms to collect additional data. Land-based observations are taken by terrestrial radars and the Automated Surface Observations System (ASOS).[5]

The NHC uses these data to build an understanding of the state of the atmosphere, and through mathematical calculations, the models generate the hurricane forecasts.[6] When the NHC issues its forecast, local NWS Weather Forecast Offices use the information to deliver their own forecasts, which take into consideration local conditions.

Hurricane Research

The NHC engages with NOAA's intramural hurricane research and development programs such as the Atlantic Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD), the Joint Hurricane Testbed, and the Hurricane Forecast Improvement Project (HFIP).

The Hurricane Research Division (HRD) conducts research to advance the understanding and prediction of hurricanes and other tropical weather. HRD's research uses computer models, academic theorizing, and observations, particularly from research aircraft that collect data from the inner structure and surrounding environment of hurricanes.[7] NOAA's Joint Hurricane Testbed (JHT) was established in 2001 in conjunction with the US Weather Research Program (USWRP), to facilitate the transfer of tropical storm research into operations. The program has successfully contributed advances to hurricane forecasting; most of the 62 projects funded in its

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[1] The National Hurricane Center. The National Hurricane Center – Past, Present, and Future. February 15, 1990. https://www.nhc.noaa.gov/pdf/NHC_Past_Present_Future_1990.pdf

[2] Congressional Research Service. The National Hurricane Center and Forecasting Hurricanes: 2017 Overview and 2018 Outlook. August 23, 2018. https://fas.org/sgp/crs/misc/R45264.pdf

[3] NOAA Line Offices: Office of Marine & Aviation Operations (OMAO), Marine Fisheries Service (NMFS), National Ocean Service (NOS), Office of Oceanic and Atmospheric Research (OAR), National Environmental Satellite, Data, and Information Service (NESDIS)

[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] NOAA, Atlantic Oceanographic & Meteorological Laboratory: Hurricane Research Division https://www.aoml.noaa.gov/hrd/

first decade were implemented operationally, including work on dynamical modeling, statistical modeling, observations, improved satellite and aircraft observations, model post-processing, and forecaster efficiency and quality control.[8]

The National Science Board (NSB), which provides oversight to the National Science Foundation (NSF), established the Task Force on Hurricane Science and Engineering (Task Force) in 2005 to assess U.S capacity to mitigate the effects of, and respond to, hurricanes. In 2007, The Task Force recommended the creation of a national hurricane research initiative that would coordinate federal agencies in interdisciplinary research to expand the understanding of hurricanes and identify effective strategies for dealing with them.[9] In response to the recommendations outlined in the NSB report and others,[10] NOAA established the Hurricane Forecasting Improvement Project (HFIP) in 2009, which is managed by the HRD.[11] It met its five-year goal to reduce track and intensity errors by 20 percent from the 2009 average.[12]

In the last decade, major disasters have prompted additional federal investments for hurricane research and improvements to hurricane forecasting. The Disaster Relief Appropriations Act of 2013, known as the Sandy Supplemental, provided $74.8 million to NOAA's Office of Oceanic and Atmospheric Research (OAR) for research to improve observing systems, global modeling, localized predictions, as well as funds to acquire high performance computing capacity. The research included both intramural research and extramural grants.[13] Following the active 2017 hurricane season, the Disaster Supplemental passed in 2018 provided $400 million for NOAA, with $50 million dedicated to improving forecasting capabilities to protect life and property in the face of future hurricanes.[14]

The Weather Forecasting and Improvement Act of 2017 required the HFIP to report to Congress on their research, development and technology transfer activity to achieve three focus areas: "1) improving the prediction of rapid intensification and track of hurricanes, 2) improving the forecast and communication of storm surges from hurricanes, and 3) incorporating risk communication research to create more effective watch and warning projects."[15] HFIP submitted

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[8] American Meteorological Society. The Joint Hurricane Testbed: Its first Decade of Tropical Cyclone Research-to-Operations Activities Reviewed. March 2012. https://www.jstor.org/stable/26218649?seq=1#page_scan_tab_contents

[9] National Science Board. Hurricane Warning: The Critical Need for a National Hurricane Research Initiative. January 12, 2007. https://www.nsf.gov/nsb/publications/2007/hurricane/initiative.pdf

[10] NOAA, through its Science Advisory Board (SAB), established a Hurricane Intensity Research Working Group (HIRWG), which released recommendations for improving hurricane intensity forecasts in 2006 (NOAA SAB. Hurricane Intensity Research Working Group Majority Report. 2006. ftp://ftp.oar.noaa.gov/SAB/sab/Reports/HIRWG_final73.pdf). In addition, the Office of the Federal Coordinator of Meteorological Services (OFCM) released a 2007 report in calling for a federal investment of $70-85 million annually over the next 10 years for tropical cyclone research and development, transition of research to operations, and operational high performance computing (OFCM. Interagency Strategic Research Plan for Tropical Cyclones - The Way Ahead, FCM-P36-2007. 2007. https://www.amazon.com/Interagency-Strategic-Research-Tropical-Cyclones-ebook/dp/B01IC0ZIWW)

[11] Hurricane Research Division Webpage - https://www.aoml.noaa.gov/hrd/about_hrd/hfip_cra.html

[12] NOAA. Hurricane Forecast Improvement Project Years Five to Ten Strategic Plan. 2014. http://www.hfip.org/documents/HFIP_StrategicPlan_Yrs5-10_Nov05_2014_Update.pdf

[13] NOAA, Office of Oceanic and Atmospheric Research. "NOAA Research Program Overview: Sandy Supplemental." https://research.noaa.gov/sites/oar/Documents/oarProgramOverview_SandySupplemental_CC.pdf

[14] Miami Herald. NOAA gets $400 million in disaster funds in latest spending bill. February 12, 2018. https://miamiherald.typepad.com/nakedpolitics/2018/02/noaa-gets-400-million-in-disaster-funds-in-latest-spending-bill.html

[15] P.L. 115-25

this report to Congress on May 28, 2019. It outlined specific goals that the next generation of HFIP must meet to make progress on the focus areas:[16]

- Reduce numerical forecast guidance errors, including during rapid intensification, by 50 percent from 2017;
- Produce seven-day forecast guidance that is similar to the 2017 five-day forecast guidance;
- Improve guidance on pre-formation disturbances, including genesis timing, and track and intensity forecasts, by 20 percent from 2017; and
- Improve hazard guidance and risk communication, based on social and behavioral science, to modernize the Tropical Cyclone product suite

To reach these goals, HFIP plans to advance an operational Hurricane Analysis and Forecast System (HAFS), improve probabilistic guidance, enhance communications of risk and uncertainty, support dedicated high performance computing allocation, and enhance research to operations (R2O).[17] In addition to NOAA, the National Science Foundation (NSF) also provides extramural grants for hurricane research through its Engineering (ENG), Geosciences (GEO), and Social, Behavioral, and Economic Sciences (SBE) Directorates.[18] Following Hurricane Harvey, NSF awarded $5.3 million in grants to study the effects of hurricanes.[19]

Hurricane Forecasting

The NHC issues estimates of the path or track of a tropical cyclone, its intensity, the size and structure of the storm, storm surge, rainfall, and presence of tornadoes. Track forecasts help predict where on the coastal U.S. a hurricane will make landfall. The accuracy of NHC's hurricane track forecasts has improved significantly since the 1960s due to investments on both the research and operational side of hurricane forecasting. For example, federal efforts have reduced errors in track and intensity forecasts, and extended reliable forecasts from three to five days.[20] Advanced satellites, and other data collection instruments, have contributed to those improvements, as have better forecasting models and advances in computing capabilities.

NOAA is continuing to improve predictions of hurricane intensity (highest sustained wind speeds, over the course of a storm's life), storm size and structure, rainfall, flooding, and storm surge (abnormal rise of water over the predicted tide due to a storm).[21] Intensity forecasts are particularly important as storms are predicted to more rapidly intensify with a changing climate.[22] Predictions of rainfall and storm surge are also important because the majority of casualties from hurricanes are caused by flooding. Further, some studies show that the amount of

[16] NOAA. Report to Congress Hurricane Forecast Improvement Program. May 28, 2019. (not yet released to the public)
[17] Ibid.
[18] National Science Foundation. FY 2020 Budget Request to Congress. March 18, 2019. https://www.nsf.gov/about/budget/fy2020/pdf/fy2020budget.pdf
[19] NSF, "NSF awards $5.3 million in 59 grants to study effects of recent hurricanes," October 10, 2017, https://www.nsf.gov/news/news_summ.jsp?cntn_id=243293
[20] Congressional Research Service. The National Hurricane Center and Forecasting Hurricanes: 2017 Overview and 2018 Outlook. August 23, 2018. https://fas.org/sgp/crs/misc/R45264.pdf
[21] National Hurricane Center Webpage: Storm Surge Overview. https://www.nhc.noaa.gov/surge/
[22] Kieran T. Bhatia, Gabriel A. Vecchi, Thomas R. Knutson, Hiroyuki Murakami, James Kossin, Keith W. Dixon & Carolyn E. Whitlock. *Recent increases in tropical cyclone intensification rates.* Nature Communications. Volume 10, Article number: 635. 2019. https://www.nature.com/articles/s41467-019-08471-z

rainfall may not be related to the intensity of the hurricane.[23] Given this, the NWS developed a Storm Surge Forecast that is separate from its track and intensity forecasts. The first operational storm surge forecasts were issued during Hurricane Harvey in 2017, which had no deaths related to storm surge.[24]

Coastal Resilience

Coastal resilience can be defined as building the ability of coastal communities, infrastructure, and resources to withstand, and recover from, human and naturally occurring hazardous events such as hurricanes, coastal storms, and flooding, rather than just reacting to impacts.[25,26] With 39% of Americans living in coastal counties, building coastal resilience is a key factor in protecting lives and retaining the homes, businesses, and civic institutions that support these communities.[27]

Tropical cyclones alone have caused $927.5 billion in total damages since 1980; this accounts for the majority of the damage of all 246 weather-related disasters in this time period with an average cost of $22 billion per event.[28] The rainfall, intensity, and frequency of hurricanes is likely to increase globally due to climate change. Given the likely human contributions to rising sea levels, higher levels of coastal inundation are also expected when hurricanes do occur.[29]

Much of the current public infrastructure was designed and built using historic flood and rainfall data. This design approach, which includes risk assessment of infrastructure, assumes that the frequency and intensity of these weather events do not change significantly over time.[30] Since climate change is leading to increased precipitation and flooding associated with tropical cyclones and other weather events, current infrastructure was not designed to withstand these levels of repeated impacts. Designing or updating infrastructure to incorporate resilience can help mitigate future disaster and recovery costs. The National Institute of Building Sciences found that every $1 invested in resilience can save $4-$11 in future disaster costs.[31]

Building coastal resilience will depend not only on improvements to forecasting hurricanes and their impacts, such as rainfall and storm surge, but also on understanding the future climate and weather patterns and utilizing that information to guide infrastructure design and development. Forecast improvements can also help inform decision-makers and emergency managers in coastal communities on what to expect during a hurricane, and how they can prepare their communities.

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[23] Congressional Research Service. Forecasting Hurricanes: Role of the National Hurricane Center. July 11, 2019. https://aquadoc.typepad.com/files/crs_infocus_hurricane_center_11july2019.pdf

[24] National Hurricane Center. Hurricane Harvey. May 9, 2018. https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf

[25] Texas General Land Office, "Texas Coastal Resiliency Master Plan", March 2019, https://coastalstudy.texas.gov/resources/files/2019-coastal-master-plan.pdf

[26] NOAA, National Ocean Service, "What is resilience?" accessed here: https://oceanservice.noaa.gov/facts/resilience.html

[27] NOAA. National Ocean Service, "What percentage of the American population lives near the coast?" https://oceanservice.noaa.gov/facts/population.html, 6/25/18.

[28] NOAA, https://coast.noaa.gov/states/fast-facts/weather-disasters.html

[29] NOAA, "Global Warming and Hurricanes: An Overview of Current Research Results," Geophysical Fluid Dynamics Laboratory, July 3, 2019. https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

[30] USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[31] National Institute of Building Sciences, Natural Hazard Mitigation Saves: 2017 Interim Report, https://www.nibs.org/page/mitigationsaves

NOAA Coastal Resilience Grants

NOAA's Coastal Resilience Grants Program provides competitive grants to fund projects in coastal communities to help them prepare for, and recover from, extreme weather events. The Coastal Resilience Grants Program partners with nonprofit and regional organizations.[32] The demand for these grants has exceeded the number of projects that are funded each year. Since 2015, grant applicants have requested approximately $327 million in federal funds. In this time period, NOAA has funded projects totaling $35.8 million with an additional $22.3 million in matching funds.[33] In May 2018, the National Fish and Wildlife Foundation (NFWF) established the National Coastal Resilience Fund to restore and enhance natural coastal infrastructure to protect coastal communities from natural events. The initial round of funding of about $29 million for 35 grants was provided by NFWF, NOAA, Shell Oil Company, and TransRe. The program leveraged matching grants totaling $38 million.[34]

Additional Reading

Blake, Eric S. and Zelinsky, David A., "Tropical Cyclone Report: Hurricane Harvey," National Hurricane Center, May 9, 2018, https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf

[32] NOAA, "NOAA Coastal Resilience Grants Program," https://coast.noaa.gov/resilience-grant/

[33] NOAA, "Coastal Resilience Grants for Coastal Communities," https://www.coast.noaa.gov/data/resilience/factsheet-resilience-grants.pdf

[34] NFWF, "National Coastal Resilience 2018 Grant Slate," https://www.nfwf.org/coastalresilience/Documents/2018grantslate.pdf

Chairwoman FLETCHER. This hearing will come to order. Without objection, the Chair is authorized to declare recess at any time.

The Chair would like to request unanimous consent for Ms. Garcia and Ms. Jackson Lee to participate in today's hearing. Without objection.

Good afternoon, and welcome to today's hearing entitled, "Weathering the Storm: Improving Hurricane Resiliency through Research." This hearing will follow the format that is standard for the Committee's Science, Space, and Technology hearings on Capitol Hill. First, I will give a 5-minute statement on the topic of the hearing. Then Dr. Babin, the senior-most minority Member on the Environment Subcommittee in attendance here today, will have 5 minutes to give an opening statement. After that, we will hear 5 minutes of oral testimony from each of our expert witnesses. Then, starting with myself, each Member will have 5 minutes to question the panel. We will alternate back and forth between Democratic and Republican Committee Members. If there is time, we will hold a second round of questions.

Thank you for joining us at today's Subcommittee on Environment field hearing. I would like to welcome our panel of witnesses that includes two fellow Houstonians, Dr. Rifai and Mr. Blackburn.

I'm glad we're able to hold this hearing in Houston today, and I'm so pleased to welcome our witnesses and my colleagues here in Houston. I thank Chairwoman Johnson, who will be joining us shortly, for making this field hearing possible.

Here in Houston, we know the devastating effects that hurricanes can bring, and we know the importance of preparing. As a young girl, I was just a few blocks from where we're sitting today in the house I grew up in when Hurricane Alicia came through Houston and the eye of the storm passing right over our heads.

In the years since, we have seen many storms here and across the Gulf Coast. We know them by name: Rita, Ike, Harvey. In fact, Texas is particularly vulnerable to hurricanes. The Texas General Land Office has found that in the last 14 years every coastal county in Texas has received at least one hurricane disaster declaration.

In 2017, Hurricane Harvey rewrote the continental U.S. record for rainfall from a tropical cyclone. It was the second-costliest hurricane in United States history behind only Hurricane Katrina. At least 68 people died, as we know all too well in this community, from the direct effects of the storm, and it left an estimated $125 billion worth of damage in its wake. We are still recovering.

We have watched in recent days as Hurricane Barry made its way to the coast, predicted to dump 1 to 2 feet of rainwater across Louisiana with storm surges along the Mississippi River. Fortunately, the effects were not as severe as expected, but we know that will not always be the case.

The science is clear: Hurricanes are becoming more frequent and more intense. That means more storms like Harvey. And with that knowledge it's time to expand the conversation beyond just improving weather forecasts so that communities can prepare for and recover from severe storms.

The National Oceanic and Atmospheric Administration, or NOAA, defines coastal resilience as, quote, "building the ability of

a community to bounce back after hazardous events such as hurricanes, coastal storms, and flooding rather than simply reacting to impacts." I know that my constituents and Americans across the country want the Federal Government to do more than simply react to storms.

Investing in research can facilitate the development of evidence-based policies that address how our environment is changing and how this change will affect society. We need not only a better understanding of the conditions that generate hurricanes but also an understanding of how to adapt our natural and manmade structures to better withstand more frequent and intense tropical storms.

Today's advancements in hurricane forecasting would not be possible without Federal investments at agencies like NOAA. The National Hurricane Center, part of NOAA's National Weather Service (NWS), works closely with research partners and with the broader research community to develop products and services that ultimately lead to more accurate forecasts. Given the success of these Federal investments in improving hurricane research and forecasting, it is now time we expand our focus to building coastal resilience to hurricanes we have gotten much better at predicting.

While hurricane forecasts have improved tremendously, we still need to continue to improve our forecasts and to better understand what to expect during hurricane season in both the short and long term. Hurricane forecasts help us understand the new normal we are facing, informing research needed to develop resilience to increasingly extreme hurricanes. This means broad investments into interdisciplinary research that can address tough problems. That is why we are here today.

I look forward to hearing from our expert panel how the Science, Space, and Technology Committee can best support interdisciplinary research needed to help coastal communities like Houston build resilience to hurricanes.

[The prepared statement of Chairwoman Fletcher follows:]

Good afternoon, and welcome to the Subcommittee on Environment's field hearing on hurricane and coastal resilience research.

I am glad we are able to hold this hearing in Houston today, and I am pleased to welcome our witnesses, including two Houstonians, Dr. Rifai and Mr. Blackburn, and my colleagues. I thank Chairwoman Johnson for making this field hearing possible.

Here in Houston, we know the devastation hurricanes can bring-and we know the importance of preparing. As a young girl, I was just a few blocks from where we sit today, in the house I grew up in, when Hurricane Alicia came through Houston-the eye of the storm passing right overhead. And in the years since, we have seen many storms, here and across the Gulf Coast. We know them by them by name: Rita. Ike. Harvey.

In fact, Texas is particularly vulnerable. The Texas General Land Office has found that in the last fourteen years, every coastal county in Texas received at least one hurricane disaster declaration. In 2017, Hurricane Harvey rewrote the continental U.S. record for total rainfall from a tropical cyclone. It was the second-costliest hurricane in U.S. history, behind only Hurricane Katrina. At least 68 people died from the direct effects of the storm, and it left an estimated $125 billion of damage in its wake. We are still recovering.

We have watched in recent days as Hurricane Barry made its way to the coast, predicted to dump one to two feet of rainwater across Louisiana, with storm surges along the Mississippi River. Fortunately, the effects were not as severe as expected. But we know that will not always will be the case.

The science is clear: Hurricanes are becoming more frequent and more intense. That means more storms like Harvey. And with that knowledge, it is time to expand

the conversation beyond just improving weather forecasts, so that communities can prepare for *and* recover from severe storms.

The National Oceanic and Atmospheric Administration, or NOAA, defines coastal resilience as "building the ability of a community to 'bounce back' after hazardous events such as hurricanes, coastal storms, and flooding - rather than simply reacting to impacts." I know that my constituents, and Americans across the country, want the federal government to do more than simply react to hurricane impacts.

Investing in research can facilitate the development of evidence-based policies that address how our environment is changing and how this change will affect society. We need not only a better understanding of the conditions that generate hurricanes, but also an understanding of how to adapt our natural and man-made structures to better withstand more frequent and intense tropical storms.

Today's advancements in hurricane forecasting would not be possible without federal investments at agencies like NOAA. The National Hurricane Center, part of NOAA's National Weather Service, works closely with research partners within the Agency, such as the Office of Oceanic and Atmospheric Research, and with the broader research community, to develop products and services that ultimately lead to more accurate forecasts. Given the success of these federal investments in improving hurricane research and forecasting, it is now time we expand our focus to building coastal resilience to the hurricanes we have gotten much better at predicting.

While hurricane forecasts have improved tremendously, we still need to continue to improve our hurricane forecasts, and to better understand what to expect during hurricane season in both the short- and long-term. Hurricane forecasts help us understand the new normal we are facing, informing research needed to develop resilience to increasingly extreme hurricanes. This means broad investments into interdisciplinary research that can address tough problems. That is why we are here today.

I look forward to hearing from our expert panel how the Science, Space, and Technology Committee can best support interdisciplinary research needed to help coastal communities like Houston build resilience to hurricanes.

Chairwoman FLETCHER. Before I recognize Dr. Babin, I would also like to enter into the record a letter from Marie Lynn Miranda, Director of the Children's Environmental Health Initiative at Rice University, on behalf of the Hurricane Harvey Registry. The registry is an ongoing research effort at Rice that collects health, location, and exposure information for people along the Texas Gulf Coast. I commend the researchers at Rice for seeing a need to systematically track and identify short- and long-term health and housing impacts of this horrific storm on our community. This information can be used for ongoing efforts, as well as for future disaster response efforts. Without objection, so ordered.

I will now recognize Dr. Babin for an opening statement.

Mr. BABIN. Thank you. Thank you, Madam Chair. I really appreciate you having this hearing. I want to welcome our panel of experts, looking forward to hearing what you have to say, and also for those who came to hear what we have to say.

As a lifelong resident of southeast Texas, a witness to many storms over the years. The very first one I remember was Hurricane Audrey in 1957, which had about 400 casualties in Louisiana, just over the line from where we lived in Beaumont. So this could not be a more fitting place and fitting location.

And less than 2 years ago, Hurricane Harvey made landfall in Texas and left a staggering amount of damage in its wake. As has already been said, it's second only to Katrina. Eighty-eight lives were lost. The National Hurricane Center estimated that more than $125 billion in damages occurred due to the hurricane and subsequent flooding. Nearly 40,000 people were forced out of their homes and into shelters. Over 200,000 homes were damaged, many outside the 100-year floodplain.

I can continue citing statistics, but the point remains that Harvey was absolutely a devastating event for the residents of my district and surrounding communities. I represent nine counties basically from Houston over to Louisiana, and all nine counties were federally declared disasters.

If we need a reminder of the impacts of severe weather, Hurricane Barry struck Louisiana just last week, dropping 15 inches of rain in a period of hours. And though the Atlantic hurricane season began on June the 1st, we saw last year that many of the most devastating hurricanes did not make landfall until August or September.

Earlier today, this Committee had the opportunity to tour the National Weather Service office near Galveston, which was on the very frontline of Harvey, and were able to hear firsthand about the innovative forecasting techniques utilized to determine the paths of hurricanes.

This Committee has played a critical role in the development of weather forecasting, and I'm proud to serve on it. In April 2017, President Trump signed the *Weather Research and Forecasting Innovation Act*, legislation that was drafted by Ranking Member Frank Lucas from Oklahoma.

It sounds like some weather out there right now, doesn't it?

Among the provisions included was section 104, which directed NOAA to improve hurricane forecasting by improving the prediction of rapid intensification and the track of hurricanes to include the forecast and communication of storm surges from hurricanes to improve communication of these very grave threats. We will hear about NOAA's ongoing efforts to implement these provisions and what other steps this Committee can take to improve hurricane forecasting this Congress, the 116th.

Knowing what will happen is only half of the battle. In addition to understanding the patterns of behavior of hurricanes, we will also hear today about how we can better allocate our research priorities in order for communities to be more resilient when a severe hurricane makes landfall.

As many in this room have experienced in the last couple of years, we saw homes, businesses, roads, dams, even Federal Government facilities such as the Johnson Space Center, which I represent, were unprepared for the damaging effects of Harvey. Houstonians are strong, and they're resilient. And as we've seen in the recovery over the last 2 years, they are tough folks that live here. We have an obligation to ensure that the residents of Houston and other communities across the country can have greater certainty that they will know just how strong a hurricane will be and feel certain that they live in a resilient community.

I want to thank our panel of witnesses today again for sharing your expertise with us. I'm very proud to be sitting up here with our Houston delegation members. And I would yield back, Madam Chair.

[The prepared statement of Mr. Babin follows:]

Thank you for holding this hearing, Chairwoman Fletcher.

This hearing could not take place in a more fitting location. Less than two years ago, Hurricane Harvey made landfall in Texas. Harvey left a staggering amount of damage in its wake. Eighty-eight lives were lost. The National Hurricane Center estimated more than $125 billion in damages occurred due to the hurricane and sub-

sequent flooding. Over 200,000 homes, many outside of the 100-year flood plain, were damaged, forcing nearly 40,000 people into temporary shelters. I could continue citing statistics, but the point remains that Harvey was a devastating event for the residents of my district and surrounding communities.

If we need a reminder of the impacts of severe weather, Hurricane Barry struck Louisiana last week, dropping 15 inches of rain in a period of hours. Though the Atlantic Hurricane season began on June 1st, we saw last year that many of the most devastating hurricanes did not make landfall until August and September.

Earlier today, members of this committee had the opportunity to tour the National Weather Service office near Galveston, which was one of the first cities to be devastated by Harvey. We had the opportunity to hear first hand about the innovative forecasting techniques utilized to determine the paths of hurricanes.

This committee has played a critical role in the development of weather forecasting. In April 2017, President Trump signed into law the *Weather Research and Forecasting Innovation Act*- legislation drafted by Ranking Member Lucas. Among the provisions included was section 104, which directed NOAA to enhance hurricane forecasting by improving the prediction of rapid intensification and track of hurricanes, the forecast and communication of storm surges from hurricanes, and the communication of these threats. We will hear about NOAA's ongoing efforts to implement these provisions and what other steps this committee can take during this Congress to improve hurricane forecasting.

Knowing what will happen is only half the battle. In addition to understanding the patterns of behavior of hurricanes, we will hear today about how we can better allocate our research priorities in order for communities to be more resilient when a severe hurricane makes landfall. As many in this room saw a couple of years ago, homes, businesses, roads, dams, and even federal government facilities, such as Johnson Space Center, were unprepared for the damaging effects of Harvey.

Houstonians are strong and resilient, as we've seen in the recovery from Hurricane Harvey over the last two years. We have an obligation to ensure that the residents of Houston, along with other communities across the country, can have greater certainty that they will know how strong a hurricane will be, and feel confident that they live in resilient communities.

I want to thank our panel of witnesses today for sharing their expertise with us. Thank you, Chairwoman Fletcher. I yield back.

Chairwoman FLETCHER. Thank you, Dr. Babin.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

[The prepared statement of Chairwoman Johnson follows:]

Good afternoon and thank you, Chair Fletcher, for convening this important hearing on how we can improve hurricane resilience research. I am excited to hear how we can help coastal communities like Houston become more resilient to the increasingly frequent and intense storms we are already seeing.

As Chair Fletcher mentioned, the Texas coast is no stranger to hazardous weather. Hurricane damage is primarily caused by their high winds, heavy precipitation, and storm surge. These hurricane impacts can be devastating, especially to the estimated six million Texans that NOAA has estimated live along our over 3,000 miles of shoreline. Storm surge, and the waves caused by hurricanes, are the largest potential threats to life and property in coastal areas. Texan cities like Houston are on the forefront of dealing with these impacts, along with inland flooding caused by heavy precipitation, as we saw with Harvey.

Hurricane forecasts have improved tremendously in recent years. Many of the operational forecasting products developed by the National Hurricane center within NOAA's National Weather Service can be attributed to federally funded research. The Weather Service's partnerships with hurricane research programs, both within NOAA and extramurally, have played a huge role in improving the accuracy of hurricane models and forecasts.

I look forward to hearing from Dr. Uccellini, about the successes of the National Hurricane Center, and future opportunities for Congress to support initiatives within NOAA that can continue to improve hurricane forecasts.

Along with many of my fellow colleagues from Texas here today, I serve on the Transportation and Infrastructure Committee. It is becoming clear that the way our current infrastructure was designed decades ago, cannot withstand the coming impacts of a changing climate. Better understanding our future climate through improved weather forecasts and long-term climate predictions is critical to developing more resilient coastal infrastructure.

Just as hurricane forecasts have improved due in part to federal research investments in weather forecasting and modeling, there is opportunity for Congress to bolster research into coastal resiliency solutions. Conversations like the one we are having today with federal agencies, academic researchers, and resilience-focused businesses, can provide recommendations that will inform decision-makers on how to move forward.

I am glad we have two Houstonians on this panel who are actively collaborating across disciplines and institutions in the Houston area, and beyond, to leverage a wide-range of expertise. I can guarantee that there is no one more dedicated to developing innovative solutions for building coastal resilience than those who have seen the devastation these storms can cause first-hand. I hope today's discussion brings us one step closer to finding these solutions.

Thank you, and I yield back the balance of my time.

Chairwoman FLETCHER. At this time, I would like to introduce our witnesses. Our first witness from NOAA, Dr. Louis Uccellini, serves as the Assistant Administrator for Weather Services, and the Director of the National Weather Service. Prior to this position, he served as the Director of the National Centers for Environmental Protection, NCEP, for 14 years where he directed the operations at nine NCEP centers. Before that, Dr. Uccellini has been the Director of the National Weather Service's Office of Meteorology, Chief of the National Weather Service's Meteorological Operations Division, and section head for the Mesoscale Analysis and Modeling Section at the Goddard Space Flight Center's Laboratory for Atmospheres. Dr. Uccellini received his Ph.D., master's, and bachelor of science degrees in meteorology from the University of Wisconsin Madison.

Our second witness, Dr. Hanadi Rifai, is the John and Rebecca Moores Professor, and Director of Hurricane Resilience Research Institute, or HuRRI, at the University of Houston. HuRRI is a national center uniting a coalition of coastal universities to promote U.S. coastal resiliency through research and educational programs. Dr. Rifai's research focuses on groundwater flow modeling, risk assessment, hydrology, hazardous waste, and urban stormwater quality. She authored three widely used computer models for the decomposition of organic matter by microorganisms. She also co-directs the Severe Storm Prevention, Education, and Evaluation from Disaster, SSPEED, Center, with another of our panelists, Mr. Jim Blackburn. Dr. Rifai received both her Ph.D. and M.S. in environmental engineering from Rice University and received her B.S. in civil engineering from American University of Beirut in Beirut, Lebanon.

Our third witness is Ms. Emily Grover-Kopec. She serves as the Director of Insurance Practice at One Concern and has more than 15 years of experience in catastrophe modeling and climate analytics primarily for use by the insurance industry. Prior to joining One Concern, Ms. Grover-Kopec spent 12 years at Risk Management Solutions as a vice president where she focused on analytics for the flood peril in the United States. Ms. Grover-Kopec holds a B.S. degree in atmospheric, oceanic, and space sciences from the University of Michigan and an M.S. degree in meteorology from Penn State University.

Our last witness, Mr. Jim Blackburn, is the Co-Director of the Severe Storm Prevention, Education, and Evacuation from Disaster, SSPEED, Center, at Rice University, where he's also a Professor in the Department of Civil and Environmental Engineering.

In his work at the SSPEED Center, Mr. Blackburn uses simulations of hurricanes to improve the lead time for warnings of storm impacts and researches effective mitigation and coastal resiliency strategies for Houston that can be extrapolated to other communities. The SSPEED Center is recognized as the Gulf Coast's top university-based resource for research and education related to protection strategies for severe storm flooding and hurricane-related surge.

Mr. Blackburn is also a practicing environmental lawyer with the Blackburn & Carter law firm in Houston and a Rice faculty scholar at the Baker Institute. Mr. Blackburn received a B.A. in history and a J.D. from the University of Texas at Austin, as well as an M.S. in environmental science from Rice University.

We will begin with Dr. Uccellini.

TESTIMONY OF DR. LOUIS W. UCCELLINI, ASSISTANT ADMINISTRATOR FOR WEATHER SERVICES, NOAA; AND DIRECTOR, NWS

Dr. UCCELLINI. Good afternoon, Chair Fletcher and Members of the Committee. I am Louis Uccellini, Director of NOAA's National Weather Service. It is my honor to testify before you today on the state of hurricane forecasting in the United States.

Hurricane track forecast accuracy has improved tremendously over the past 2 decades. Storm track forecast errors have decreased every decade since records began, but we've accelerated that improvement since the mid-90s. And new records are set almost every year. Our 48-hour forecast improved from an era of over 300 miles in the 1960s to only 85 miles today. The 5-day forecast is better now than the 1-day forecast was in the 1960s. Our current experimental 7-day forecasts are as accurate as the day-3 forecasts were 25 years ago.

More recently, intensity prediction has also improved by about 25 percent over the past 5 years. Improved forecasts have many contributing factors, including improved models and the experience and skill of our forecasters. There are three contributing components to improved America weather prediction: Increased supercomputing capacity; assimilating global observations of the atmosphere, oceans, and land; and, three, improving the increasingly complex models themselves.

With respect to improving the models, the global forecast system model improvements—that's the American model—the introduction of ensemble forecasts, and the Hurricane Weather Research and Forecasting model all represent significant steps forward in our numerical prediction of hurricane structure, intensity, and track.

The research and development for the Hurricane Weather Research and Forecasting model—and we refer to that as HWRF—is a joint effort between NOAA and academic partners as part of the Hurricane Forecast Improvement Project. This advancement, which began under the U.S. Weather Research Program, highlights the importance of research and operational entities working together to more rapidly transfer promising research techniques into operations. These programs also accelerated the track forecast improvements that we've seen over the last 2 decades.

The *Weather Research and Forecasting Innovation Act* that was noted earlier addresses NOAA's critical mission areas, including improvements to the Hurricane Forecast Improvement Program, spanning improved modeling, computing capacity, and working with the private and academic sectors to obtain the best possible data and to further research on hurricane behavior to improve the numerical weather prediction of—and especially to improve the numerical weather prediction of rapid intensification.

As an example of the important role of our forecasters, the hurricane forecasters at the National Hurricane Center apply their experience and knowledge about hurricanes to computer models and other inputs to make forecasts that, on average, are more accurate than every individual computer model prediction. These improvements in NOAA's hurricane forecasts have helped emergency managers make better, timely, focused, and accurate community preparation and evacuation decisions and are responsible in part for the decreasing impacts that we see of these storms at landfall.

Ninety percent of fatalities from tropical weather systems are due to water. These water fatalities are either from storm surge or from inland flooding. The impact from storm surge can reach up to 100 miles inland along major rivers and tributaries. To reduce the storm surge impacts, we now issue storm surge products—watches, warnings, and inundation maps—for the public, for emergency managers, and for others. We believe these products have led to better decisions—are the main reasons for the recent reduction in the number of storm-surge fatalities from major landfalling storms in 2017 and 2018.

Heavy rains from tropical systems can lead to extreme inland flooding, sometimes hundreds of miles inland and away from the center of the storm and days after the storm makes landfall. We have demonstrated increased skill with our precipitation forecasts, but that is not enough. For Hurricane Harvey, we predicted over 50 inches of rain and historic catastrophic flooding days before it occurred. While meteorologists knew the flooding would be catastrophic, we needed to map and communicate those impacts.

Given the predicted magnitude of Harvey, we accelerated what we called the first use of our experimental flood inundation mapping information that was under development at the National Water Center. These maps identified areas that would flood and, just as importantly, areas that would remain dry for staging and for shelters. These inundation maps clearly improved our ability to communicate the potential flood impacts related to the historic 50-plus-inch rainfall amounts.

Intensity forecasts have improved, especially in the extended time periods. Strengthening or weakening trends are often captured by the models, and recent improvement in the HWRF model showed great promises to predict rapid intensification and the extent of these trends. The goals of the Hurricane Forecast Improvement Program are to improve the track and intensity forecast accuracy by another 50 percent over the next 10 years, to extend high accuracy forecast from 5 to 7 days in advance, and to further integrate social and behavioral sciences into new products.

Through our newly provided impact-based decision support services authorized in the 2017 *Weather Act*, we are better connected

than ever to decisions being made across the entire spectrum of emergency managers at the local, State, regional, and national levels, and to the public. Effective communication about storms provided through these new products, outreach, and education efforts to increase the attention on the individual impacts from wind and water hazards that could occur in each community and to focus on these winds, tornadoes, storm surge, inland flooding, and ocean waves and rip currents will all lead to lessen the impact of these storms.

In conclusion, NOAA and the weather enterprise have made significant strides in the accuracy of hurricane forecasts, but we must continue to improve these forecasts, including a focus on the social and behavioral sciences to better understand people's reaction to the information.

Thank you for this opportunity to appear before you today. I look forward to answering any questions you may have.

[The prepared statement of Dr. Uccellini follows:]

Dr. Louis Uccellini
Assistant Administrator for Weather Services and
Director of the National Weather Service,
National Oceanic and Atmospheric Administration,
U.S. Department of Commerce

Testimony to the
Environment Subcommittee of the
Committee on Science, Space, and Technology
United States House of Representatives

Field Hearing: Weathering the Storm. Improving Hurricane Resiliency through Research
July 22, 2019

Good morning Chairwoman Fletcher, Ranking Member Marshall, and Members of the Subcommittee. I am Dr. Louis Uccellini, Director of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS). Within the NWS, NOAA's National Hurricane Center (NHC) issues the official forecast for all Atlantic and eastern Pacific tropical cyclones (hurricanes, tropical storms and tropical depressions) and their precursors. It is my honor to testify before you today on the state of the United States hurricane forecasting capability; our efforts to improve our understanding and prediction of hurricane impacts from storm surge, heavy precipitation, and high winds; and what hurricane research focus areas are needed to improve prediction.

I come before you today to report that hurricane forecasting accuracy has improved tremendously over the past two decades. The NHC track (storm location) forecast errors have decreased every decade since forecast accuracy records were established in the 1960's, and NHC has set new records almost every year. For perspective, the average two-day Atlantic forecast location error was reduced from around 300 miles (approximately 260 nautical miles (n mi), see Fig. 1) in the 1960s to near 85 miles in the 2010s. The five-day forecast for storm location is now better than the day-and-a-half forecast was in the 1970s. There has also been about a 25 percent reduction of intensity errors at day five in 2010-2018 as compared with 2000-2009.

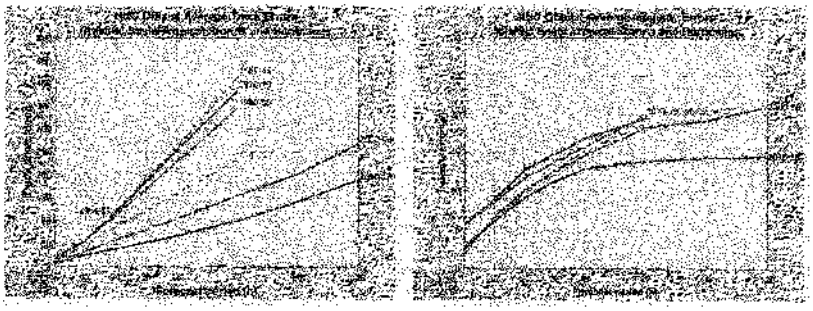

Figure 1. NHC Atlantic hurricane and tropical storm track and intensity forecast errors

These improvements in NOAA's hurricane forecasts have helped emergency managers make more timely, focused, and accurate community preparation and evacuation decisions (see Figure 2). The increasing accuracy of our forecasts is from improvements in weather prediction models, access to high quality global data, and our skilled forecasters. The NWS Environmental Modeling Center (EMC), NOAA's Office of Oceanic and Atmospheric Research (OAR), and our partners in government and academia developed these models. Also contributing are advances in our ability to measure the atmospheric and ocean conditions from satellites and NOAA hurricane hunter aircraft that are used to collect observations for the models, and running these ever-increasingly complex models on the latest supercomputers. These high-resolution models, and multiple "ensembles" of the models, provide our forecasters with the guidance they need to make accurate predictions. Official hurricane forecasts are made by NHC's "hurricane specialists." These forecasters apply their experience and knowledge about the hurricane, the computer models and other inputs to make forecasts that, on average, are more accurate than every individual computer model prediction.

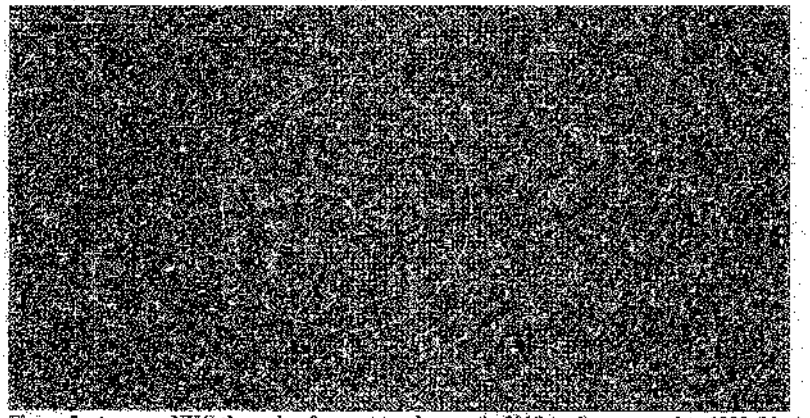

Figure 2. Average NHC three-day forecast track error in 2018 (red) compared to 1990 (blue).

The Hurricane Challenge and NOAA's Recent Advances in Hurricane Products and Services

The U.S. Gulf and east coasts, adjacent inland areas, and U.S. territories have experienced many devastating hurricanes and tropical storms over the years, causing enormous damage and loss of life. Looking back at U.S. hurricane history, about 90 percent of fatalities directly attributable to the forces of tropical weather systems are due to water, not wind. These water fatalities are either from storm surge or from inland flooding. Storm surge incidents accounted for about half of the deaths attributed to

water. Storm surge from individual hurricanes has taken thousands of lives in this country, and it remains one of, if not the greatest, threats for large loss of life in a single-day event.

To reduce storm surge impacts, during the past few years NWS began implementing new storm surge products. These include watches and warnings specifically for storm surge. The NWS also introduced potential inundation maps to provide the public, emergency managers, and others with more information specific about storm surge and inundation. These enhancements have helped emergency management officials with coastal evacuations. This year, the NHC is extending the storm surge watch and warning capability to Puerto Rico and the U.S. Virgin Islands.

For storm surge, small changes in the hurricane structure, size, and forward speed can make a big difference on the ground in terms of impacts. For example, a 30 mile change in track could mean the difference in a particular location between a few feet of storm surge versus water rising to over 10 feet deep (see Figure 3).

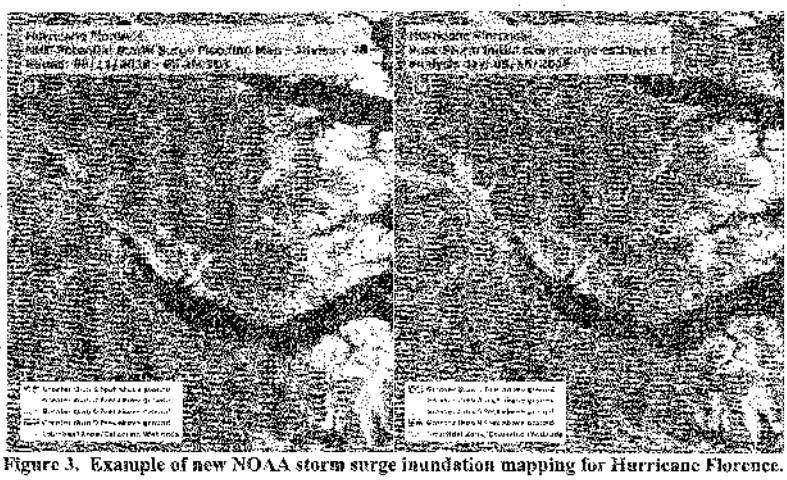

Figure 3. Example of new NOAA storm surge inundation mapping for Hurricane Florence. (a) shows the NWS storm surge forecast available publicly while (b) shows the post-storm analysis of what occurred.

Beyond storm surge accounting for about half of the number of deaths, freshwater floods from excessive rain are responsible for another quarter of the casualties. These floods can occur as much as hundreds of miles inland and away from the center of the storm, and days after the storm makes landfall.

Over the past two hurricane seasons, we have demonstrated increased skill on precipitations forecasting. For Hurricane Harvey, the NWS predicted over 40 inches of rain and historic catastrophic flooding two

days before it occurred. Forecast amounts were increased to over 50 inches as the event unfolded, particularly in the Houston area. Historic flooding with totals of 50-60 inches of rainfall were observed. Forecasting these amounts of rainfall that far in advance was unprecedented. The NWS communicated those predictions to the emergency management community and that led to their proactive actions, even to close the City of Houston on Saturday ahead of the heaviest rains. Our private sector partners, both in the media and private weather companies, also helped communicate the impacts of this forecast for record rainfall and flooding.

At our new National Water Center, NOAA is developing inundation mapping graphics that will better convey the extent of the flooding and, just as importantly, which areas will not flood. This experimental tool was used last year during Hurricane Florence. Florence was another slow-moving hurricane that dumped record rainfall—over 40 inches in North Carolina. Five days before landfall the NWS accurately predicted huge rainfall amounts, over 20 inches, and refined our forecasts to over 40 inches about three days before landfall (see Figure 4). We are working to improve rainfall inundation mapping so the public can better understand how deep the water will be from inland and river flooding from excessive rain. While deaths directly attributable to storm surge have decreased markedly, people continue to perish due to flooding..

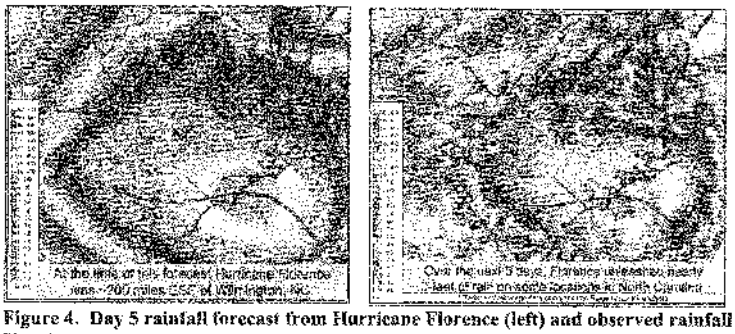

Figure 4. Day 5 rainfall forecast from Hurricane Florence (left) and observed rainfall from Hurricane Florence (right).

Giving accurate hazard information as far in advance as possible of a storm is crucial. While some hurricanes, like Florence, form far from land and give residents many days to prepare, that is not always the case. Hurricane Michael, for example, came ashore at Category 5 intensity just a few days after forming. To extend lead time, NHC has recently implemented the capability to issue its full product suite, including "warnings," prior to the formation of a tropical cyclone. This has enabled preparations to begin earlier, which is especially important for storms that form close to the U.S. coast. In fact, this new service has added 15 hours, on average, of lead time over the last two years for those storms like Harvey and Michael that formed close to the coast.

To help decision makers prepare, NOAA also implemented a very helpful and popular "time-of-arrival" graphic in the past few years. It depicts the time when tropical storm force winds could begin at a location, signifying the time when outside preparedness activities can be too dangerous to conduct. This

timing information is important because there are critical decision points in advance of a storm when preparations must be completed.

The new storm surge and time of arrival products account for and can convey forecast uncertainty. For example, the time of arrival products provide emergency managers with a range of times when tropical storm conditions could begin based on the underlying forecast uncertainty. Future products will continue to provide uncertainty information using past forecast errors and output from ensemble modeling systems.

Forecast accuracy is not the only hurricane challenge. Effective communication about storms is also critical. An important strategy in our operational communications, development of new products and warnings, and outreach and education efforts, is to increase attention on the individual impacts from wind and water hazards that could occur in each community—namely winds, tornadoes, storm surge, inland flooding, and ocean waves and rip currents. The storm surge watches and warnings are an example of one new hazard-specific information.

Hurricanes and tropical storms are not only coastal event. In fact, the highest storm surge measured in Hurricane Florence was 100 miles inland from the Atlantic coastline where river channels narrow and water collects. The most deadly aspects of hurricanes, storm surge and inland rain, are highly dependent on the size, structure, and forward speed of the storm, not just the wind category. In fact, over the past 10 years, Category 1 hurricanes have produced around $100 billion in damage and killed more than 150 people in the United States. There is no such thing as a "just a" Category 1 hurricane or "just a" tropical storm; it is about the impacts of these storms.

Certain parts of the country have gone years without experiencing a major hurricane. NOAA is working to help these communities prepare for a hurricane that may impact their community. The introduction of new hurricane storm surge products and warnings increased public and partner focus on preparing in advance for that hazard. To adequately prepare, the public needs to recognize that overall hurricane activity has almost no relationship to hurricane impacts in any one community. "It only takes one." One of the best examples is 1992 that was overall a below-average year for the number of hurricanes in the Atlantic, with only one "major" hurricane forming. But, that one was Andrew, which struck South Florida as a Category 5, the most intense rating on the Saffir-Simpson hurricane wind rating scale and caused catastrophic damage when it moved across the southern portion of the state.

While U.S. hurricane related deaths have gone down by about two-thirds, much work remains to reduce further the loss of life from tropical cyclones. NOAA's public outreach messaging is not only about the hurricane hazards themselves, but also about what people should be doing to get ready, starting well in advance of the next hurricane, and about resiliency in the face of the hazards that could occur where they live

Hurricane Science and Technology

As noted earlier, there has been tremendous progress made in hurricane prediction. The new supercomputers for which Congress appropriated funds have allowed us to run more complex, sophisticated and accurate forecast models, including the new Hurricane Weather Research and Forecast (HWRF) model. The HWRF model represents a significant step forward in our prediction of hurricane

structure and intensity. The research and development has been a joint effort between NOAA, primarily NWS and OAR, and academic partners as part of the Hurricane Forecast Improvement Project (HFIP). This advancement highlights the importance of the research and operational entities working hand-in-hand to transfer promising research techniques into operations. Improvements in NOAA's hurricane prediction will continue to follow the guidelines outlined in the Weather Act. The Weather Act expands NOAA's critical mission areas, including improvements through HFIP—improved modeling and computing capacity, working with the private and academic sectors to obtain the best possible data, further research on hurricane behavior to better predict rapid intensification.

Another joint effort between NWS and OAR, the Joint Hurricane Testbed (JHT), is a virtual environment for cutting-edge technology testing and demonstration funded by the U.S. Weather Research Program (USWRP). The JHT connects the tropical cyclone research community with forecast operations. Since its inception, nearly 20 years ago, the JHT has supported nearly 100 projects, averaging around 10 at a time, and demonstrated great success by transferring about two-thirds of the projects into NWS operations, resulting in improved NOAA services for the public. This year, the current six JHT research and development projects will be completed. NOAA plans to fund three JHT projects during the program's next round, beginning later this year.

Intensity forecasts have improved, but not as much as the track forecasts. The NHC now usually can capture the trend of strengthening or weakening, but we need to learn more through the research community to better predict the extent of these trends. "Rapid Intensification" remains a particularly difficult phenomenon to predict accurately. There are still parameters we need to understand better to improve those forecasts. Understanding storm structure and the upper atmosphere contributions, including how storms react to moderate amounts of environmental wind "shear," will help us better predict their roles in the intensity challenge.

HFIP is a multi-year, multi-million dollar effort to improve hurricane forecasts, and it can be largely credited with the advances in forecasting noted over the past decade. NOAA met the five-year HFIP goal to reduce hurricane forecast track and intensity errors by 20 percent. Recent HFIP-funded enhancements that have been made to the operational HWRF have made it our best-performing intensity model over the 2013-2018 period. HFIP is also supporting promising work to help identify and adjust for biases in the primary track and intensity models. In addition, HFIP supported the development of the new time of arrival product, and will continue to support new product development and evaluation. HFIP's current ambitious goals are to improve track and intensity forecast accuracy by another 50 percent over the next 10 years, to extend high-accuracy forecasts from five to seven days, and to further infuse social and behavioral science into the product development process.

NOAA's flagship operational weather model—the Global Forecast System (GFS)—is undergoing a significant upgrade to include a new dynamical core called the Finite-Volume Cubed-Sphere (FV3). This upgrade will drive numerical weather prediction into the future with improved forecasts of the jet stream and associated weather, tropical cyclone intensity and five-day track forecasts, as well as precipitation forecasts across the U.S. and worldwide. NOAA's FY20 Budget request includes $15 million for the Earth Prediction Innovation Center (EPIC) to advance a community weather model that is accessible by the public. EPIC leverages partnerships to accelerate advances designed to meet NOAA's operational forecast mission to protect life and property and improve economic growth.

Hurricane forecast operations continue to rely on aircraft reconnaissance. The NOAA Gulfstream-IV (G-IV) and two Lockheed WP-3D (P-3) Orions are part of NOAA's fleet of highly specialized research and operational aircraft. These aircraft are operated, managed and maintained by NOAA's Office of Marine and Aviation Operations (OMAO), based in Lakeland, Florida. The G-IV flies at high altitudes around and ahead of a tropical cyclone, gathering critical data that depict the atmospheric steering flow, and those data feed into and result in improved accuracy from hurricane forecast models. The P-3s are NOAA's hurricane research and reconnaissance aircraft flying into the eye of the storm. These versatile turboprop aircraft are equipped with an unprecedented variety of scientific instrumentation, radars and recording systems for both in-situ and remote sensing measurements of the storm and its environment. These two aircraft have led NOAA's continuing effort to monitor and study hurricanes. Additionally, ten WC-130J aircraft are configured specially for hurricane reconnaissance, and operated by the U.S. Air Force Reserve from the 53rd Weather Reconnaissance Squadron, 403rd Wing, located at Keesler Air Force Base in Biloxi, Mississippi. When flying a hurricane mission, military air crews fly directly through the eye of the storm several times each flight. Both the NOAA and USAF aircraft collect data and transmit them in near real time by satellite directly to EMC to be incorporated into the forecast models, and to NHC, so forecasters can analyze and predict changes to the hurricane's path and strength. The men and women of NOAA's Aircraft Operations Center and the U.S. Air Force are heroes who fly into and around hurricanes to give us the critical data we need to forecast the storms and warn the nation.

These aircraft data are key. For example, last year was the first year NOAA's P-3 aircraft flew into hurricanes in the Central Pacific. The model forecast track for Hurricane Lane was erratic at best until data from NOAA flights were incorporated into the models. The computer forecasts then gave NOAA forecasters confidence that Lane would make a sharp left turn, as they had been predicting.

NOAA anticipates data from new Unmanned System (UxS) technologies will contribute significantly to improving the understanding of tropical cyclone processes and ultimately to improvements in track and intensity predictions. NOAA is working with the private sector and other federal agencies to identify, evaluate, and transfer to operations innovative and cost-effective UxS capabilities that meet NOAA's observing requirements, and help form a comprehensive observing strategy for the future. In the recent past, unmanned aerial systems (UASs) have improved hurricane observations. In the 2017 hurricane season, NOAA joined with NASA to fly the unmanned NASA Global Hawk ahead of and above Hurricanes Franklin and Harvey, launching dropsondes that collected data to be assimilated into the operational GFS model and HWRF. That year marked the first time that Global Hawk dropsondes were assimilated in real-time into the GFS model. In 2016 scientists also launched six small "Coyote" drones from a NOAA P-3 Hurricane Hunter during Hurricane Maria to collect unique data from within the eyewall in the lower part of the storm, where the hurricane gains strength from the ocean and it is very dangerous for manned aircraft to fly. The low-level observations of wind speed, wind direction, atmospheric pressure, temperature, moisture, and sea-surface temperature provide more detail on hurricane strengthening than dropsondes that record a single point of data at any one level. These observations can provide information needed to improve intensity predictions. The FY20 President's Budget includes an increase of $4 million for a new operational program for unmanned systems within OMAO. A centralized, NOAA-wide UxS program will more efficiently manage and standardize acquisition and procedures for use of UxS. NOAA will leverage labs and programs within all of its line offices that have extensive experience in unmanned systems research and development to create a more organized and cost-effective corporate operation in OMAO.

NOAA researchers partnered with NOAA/National Ocean Survey integrated Ocean Observing System regions to deploy autonomous underwater gliders to better understand how the upper ocean contributes to hurricane intensity. These gliders collect information in the Atlantic Warm Pool, an area of the ocean commonly associated with hurricane development and intensification. Hurricanes Harvey, Irma, Jose, and Maria passed directly over, or very close to the gliders, providing valuable information to NOAA researchers and forecasters. The ocean data collected by the gliders totaled over 4,000 temperature and salinity profiles. Correct representation of ocean conditions during a hurricane has been shown to significantly reduce the error in intensity forecasts.

Data from satellites are a critical component of NOAA's observation network. Satellites provide more than 95 percent of the data assimilated into NOAA's operational numerical weather prediction (NWP) models of which over 80 percent are from polar-orbiting satellites. NOAA has managed the operation of polar-orbiting operational environmental satellites (POES) since 1966 and geostationary operational environmental satellites (GOES) since 1974. NOAA also uses complementary satellite data from other collaborating national and international space agencies, either in joint mission like the JASON ocean altimetry series and Metop satellites in which NOAA is a partner, or NASA Earth Observing System, Japan's Global Change Observation Mission-Water 1 and Himawari, and Europe's Meteosat missions where NOAA is a key data user. Over the decades, these systems have supported weather and environmental monitoring programs that users in the U.S. and around the world rely on for accurate data and imagery.

NOAA's POES provide full global coverage for a broad range of weather and environmental applications. These satellites are crucial for NOAA's operational three to seven-day weather forecasts and are used to initialize the NWP models because they can uniquely measure the vertical profiles of temperature and moisture. The high resolution sounders on NOAA-20, the Cross-track Infrared Sounder (CrIS), and Advanced Technology Microwave Sounder (ATMS) have been instrumental in providing significant improvements to NOAA's weather forecasts. The European Metop satellite constellation, also provides observations that NOAA assimilates into its operational numerical weather prediction models.

Data, imagery, and products from NOAA's GOES satellites are vital for observing and tracking tropical cyclones and their precursor disturbances, which leads to more timely, accurate, and actionable warnings. This past winter GOES-17 in the GOES West position joined GOES-16 in the GOES East position as the current NOAA operational geostationary satellite constellation. These are two of four satellites in the GOES-R Series and users are excited about the technological advances of these new GOES satellites, which includes improvements to the spatial, temporal, and spectral resolutions of existing data for Earth monitoring and new observations, such as lightning data. The resolution of GOES visible satellite images have improved to around a quarter of a mile, and forecasters can see images (pictures) every minute. The one-minute images allow us to better observe the early stages of tropical cyclone formation and learn on a scale that has not before been available to us. The imagery is helping us better understand eye-wall reformation, which is critical to understanding the intensity fluctuations that hurricanes undergo. New satellite-based lightning data from GOES are showing promise for better anticipating rapid intensification. Data from partner missions are also becoming increasingly important for characterizing surface winds, sea state, and inferring ocean heat content. Data from geostationary and polar orbiting satellites also provide products that are used by our forecasters to

detect areas of flooding from the larger perspective. These products and imagery also assist with post-event recovery and damage assessments.

NOAA Enhances Communities' Coastal Resilience

NOAA's National Ocean Service (NOS) provides science-based products and services to reduce impacts of extreme weather, respond to emergent issues, and support long term resilience.

During the 2018 hurricane season, NOAA partnered with the U.S. Navy in an effort utilizing autonomous underwater gliders for the improved understanding and forecasting of the ocean's impact on Hurricane intensity. The Navy transferred 10 gliders to NOAA for deployment in the Caribbean and made data from an additional 20 gliders available to researchers in the Gulf of Mexico. NOAA is working with the Navy to identify partnership opportunities for the 2019 hurricane season.

NOS provides a suite of services and expertise to help communities anticipate the impacts of storm surge and other coastal hazards. StormQuicklook provides near real-time ocean and weather conditions during major coastal storms and will be incorporated into the soon-to-be released Coastal Inundation Dashboard. NOS partners in the Integrated Ocean Observing System to deploy autonomous vehicles and other sensors to improve storm forecasts. The Digital Coast, a web-based resource of data, tools, and trainings, offers hundreds of state-of-the-art products, from authoritative data sets to interactive mapping tools for more informed coastal planning. For example, in preparation for Hurricanes Harvey, Irma, and Maria, these tools were used to provide the elevation models and sea level rise data needed to develop storm surge forecast maps.

After a storm passes, NOS has a number of services that make the immediate emergency response more effective. Our navigation response teams conduct surveys that are essential to reopening ports and waterways to commerce and shipments of fuel and other emergency supplies. The National Geodetic Survey conducts aerial surveys to assess damage and prioritize response actions, such as when chemical spills or storm debris are posing a continuing threat to life, property, and natural resources. The NOAA Office of Response and Restoration works with the U.S. Coast Guard (USCG) and other incident responders to ensure that response actions protect sensitive natural and cultural resources that are at risk.

During disasters in recent years, impacted states and territories have requested federal assistance to mitigate the oil and hazardous substance threat posed by thousands of displaced vessels. NOAA's Office of Response and Restoration has supported this effort through information management support, providing initial classification of debris through remote sensing data, and providing support in environmental protection and compliance associated with vessel removal activities. For example, after Hurricane Irma hit Florida, NOAA's Marine Debris Program Regional Coordinators reviewed all planned USCG vessel removal operations throughout the state. In cases in which vessel removals could potentially harm natural or cultural resources, NOAA coordinated with specialists in the field to ensure best management practices were followed, to document impacts, and to keep the USCG Incident Command informed. In addition, NOS also trains over 2000 state, local and federal responders each year, in courses such as Science of Coastal Natural Disasters and Science of Oil Spills, to ensure that they are well-equipped with the knowledge to make critical decisions.

NOAA is also a key contributor to FEMA's Daily Operations Brief, providing response and recovery officials with critical information before, during, and after disasters.

Puerto Rico greatly relies on its coastal protection from coral reefs for the safety of human life, property, and commerce. Through participation in the National Disaster Recovery Framework, NOAA received a direct Mission Assignment from FEMA in 2018 totaling $895 thousand to support a request from the Commonwealth for coral reef damage assessment, emergency restoration, and long-term recovery planning following Hurricanes Maria and Irma. Mission Assignments are work orders, with or without reimbursement, issued by FEMA to other federal agencies directing the completion of a task in response to a Stafford Act event. Two teams of scientists worked to evaluate the damage to coral reefs around the archipelago of Puerto Rico. One team quantified the extent of reef damage while the second team reattached at-risk coral colonies to prevent their death and to help rebuild the reef structure. NOAA continues to support planning of long-term restoration activities.

NOAA supplemental funding is tracked by FEMA's Program Management Office (PMO), an effort by the interagency Recovery Support Function Leadership Group (RSFLG) to track and display on a public-facing website (https://recovery.fema.gov/) all supplemental funding, which Congress allocated after the historic 2017 Hurricane Season.

NOAA participated in the development of "An Economic and Disaster Recovery Plan for Puerto Rico", known as the Governor's Plan for "Transformation and Innovation in the Wake of Devastation," and helped develop Courses of Action for the Natural and Cultural Resources Recovery Support Function.

The Coastal Zone Management Act (CZMA) provides the framework for NOAA's partnership with states and territories for collaborating on resilience efforts. Through this voluntary partnership, NOAA provides financial incentives and technical assistance to states and communities to develop and implement policies and plans for coastal hazards, such as flooding, erosion, sea-level rise, and changes in Great Lakes levels. For example, the Texas General Land Office, supported in part by NOS funding, developed the Texas Coastal Resiliency Master Plan. NOS funding also supports on-the-ground resilience actions that protect coastal communities. For example, outside of Houston, Texas, NOS supported the conversion of an abandoned golf course into a wetland and greenspace to absorb floodwaters. During Hurricane Harvey, approximately 200 homes in that neighborhood were protected from flood waters, and when the project is complete, up to 3,000 homes will be protected.

National Coastal Resilience Fund
The National Coastal Resilience Fund is a partnership between NOAA and the National Fish and Wildlife Foundation (NFWF) that funds projects that increase the resilience of coastal communities while enhancing fish and wildlife habitat. In 2019, the fund will invest up to $29 million in the restoration or expansion of natural coastal structures to help absorb the impacts of hurricanes and floods and protect coastal communities.

Research on Coastal Resilience
NOS's Ecological Effects of Sea Level Rise (EESLR) Program assesses the vulnerability of natural ecosystems, evaluates the potential for natural structures (e.g., barrier islands, wetlands, etc.) to reduce coastal inundation, and develops best practices for the inclusion of ecosystems in coastal protection

strategies. In many cases, fostering natural coastal features provides a cost-effective alternative to rigid hardened structures.

Conclusion

NOAA and the weather enterprise have made significant strides in the accuracy of hurricane forecasts and have shown the importance of developing products to better communicate the potential impacts from tropical systems and hurricanes. Effective communication products and accurate forecasts are both essential to further our effort to become a weather-ready nation.

Thank you for the opportunity to appear before you today. I look forward to answering any questions you may have.

NATIONAL WEATHER SERVICE

Dr. Louis W. Uccellini

National Weather Service Organization

National Program

Dr. Louis W. Uccellini
Assistant Administrator for Weather Services
National Oceanic and Atmospheric Administration (NOAA),
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Dr. Louis W. Uccellini is the National Oceanic and Atmospheric Administration's Assistant Administrator for Weather Services, and Director of the National Weather Service. In this role, he is responsible for the day-to-day civilian weather operations for the United States, its territories, adjacent waters, and ocean areas.

Prior to this position, he served as the Director of the National Center for Environmental Prediction (NCEP) for 14 years. He was responsible for directing and planning the science, technology, and operations related to NCEP's nine centers: Central Operations, Environmental Modeling Center, Ocean Prediction Center, Hydrometeorological Prediction Center, Climate Prediction Center, all in Camp Springs, MD; the National Hurricane Center in Miami, FL; Storm Prediction Center in Norman, OK; Space Weather Prediction Center in Boulder, CO; and the Aviation Weather Center in Kansas City, MO. With his leadership, the 13 year effort to plan, develop and build the new NOAA Center for Weather and Climate Prediction (the NCWCP Building) at the University of Maryland M Squared Research Center was completed, as was the implementation of a Seamless Suite of Models from the S2S to Mesoscale modeling systems based on the principle of multi model ensembles.

Dr. Uccellini was the Director of the National Weather Service's Office of Meteorology from 1994 to 1998. Chief of the National Weather Service's Meteorological Operations Division from 1992 to 1994, and section head for the Mesoscale Analysis and Modeling Section at the Goddard Space Flight Center's Laboratory for Atmospheres from 1978 to 1989.

Dr. Uccellini received his Ph.D. (1977), Master (1972) and Bachelor of Science (1971) degrees in meteorology from the University of Wisconsin-Madison. He has published more than 70+ peer-reviewed articles and chapters in books on subjects including analysis of severe weather outbreaks, snowstorms, gravity waves, jet streaks, cyclones, and the use of satellite data in analysis and modeling applications and more recently the basis for the Joint Center for Satellite Data Assimilation, the WMO based Grand Challenge for Seamless Prediction and the Restructuring of the NWS to Build a Weather Ready Nation. He is the co-author of a widely acclaimed, long-lasting American Meteorological Society (AMS) monograph Northeast Snowstorms, published in 2004, and authored chapters in the 1990 AMS publication Extratropical Cyclones, the 1999 AMS publication The Life Cycles of Extratropical Cyclones, and the 2003 AMS publication Synoptic Dynamic Meteorology and Weather Analysis and Forecasting.

Dr. Uccellini is the Permanent US Representative at the World Meteorological Organization, and has served on many national and international research and field experiment programs. He has received many awards in recognition of his research and operational achievements including the Maryland Academy of Sciences Distinguished Young Scientist Award (1981), the NASA Medal for Exceptional Scientific Achievement (1985), the AMS's prestigious Clarence Leroy Meisinger Award (1986), the Cleveland Abbe Award (2016), and the National Weather Association's Research Achievement Awards for Significant Contributions to Operational Meteorology (1996). He was elected as President of the AMS in 2012- 2013 and served as its Chief Editor of Weather and Forecasting from 1988 1992. In 2004 he received the U.S. Presidential Meritorious Executive Rank Award and in 2005 he received the U.S. Presidential Distinguished Rank Award.

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Chairwoman FLETCHER. Thank you. Thank you, Dr. Uccellini. I'm learning we need to sit very closely to the microphones.

We will now hear from Dr. Rifai.

TESTIMONY OF DR. HANADI RIFAI,
JOHN AND REBECCA MOORES PROFESSOR,
ENVIRONMENTAL ENGINEERING GRADUATE PROGRAM;
AND DIRECTOR OF HURRICANE
RESILIENCE RESEARCH INSTITUTE,
UNIVERSITY OF HOUSTON

Dr. RIFAI. Chair Fletcher, Members of the Committee, I appreciate the opportunity to testify before you here today. My name is Hanadi Rifai, and I am John and Rebecca Moores Professor of Environmental Engineering and Director of the Hurricane Resilience Research Institute, or HuRRI, at the University of Houston. I organized my testimony today into three sections highlighting the past, the present, and the future of my hurricane and coastal research. I'll start with the past.

My journey with hurricanes and severe storms dates back to Hurricane Katrina in 2005. At the time, we in Houston felt New Orleans' pain profoundly. A group of us, faculty from Houston and Louisiana, met to discuss what could be done, and that was the seed that germinated the Severe Storm Prediction, Education, and Evacuation from Disaster, or SSPEED, Center. It was difficult then to secure research funding for the center, and it remains difficult now to do the same.

My work with SSPEED focused on Houston's industrial infrastructure and its vulnerability to natural hazards. The industries along the Houston Ship Channel produce, store, and transport chemicals and petrochemicals. And in times of natural hazards, the processing units, storage, and transportation facilities, including the Port of Houston, are vulnerable to storm surge, wind, rainfall, and high-channel flows. There are upwards of 4,100 storage tanks in the Houston Ship Channel, and they are full with various types of chemicals and petrochemicals, and the tanks themselves have various shapes and sizes.

Our research at SSPEED developed the first-of-its-kind predictive model. The model quantifies economic losses in the Houston Ship Channel that would be incurred due to varying storm surge heights at the individual facility level and for the entire Houston Ship Channel. With this model, we call it FEDERAP, we predicted catastrophic losses exceeding $70 billion at 25 foot surge just from the Houston Ship Channel and the Port of Houston alone.

Other related and critical research that we undertook in the SSPEED Center involved a closer look at the environmental impacts associated with surge protection and building gates and barriers across parts of the Galveston Bay system. We have developed relatively short- and long-term models of bay water quality looking at temperatures and salinities when such mitigation measures are implemented that can be used to inform surge protection systems design and implementation. Much more effort, however, is needed to further develop these models into robust predictive platforms that can elucidate the—incorporate changes in sediment regimes,

flood flows in the San Jacinto and Trinity Rivers, the timing of the flood flows, drought cycles, climate change, and sea-level rise. But importantly, we must maintain the delicate balance of the Galveston Bay system between its freshwater inflows and its healthy interaction with the Gulf Coast.

It brings me to the present. As we embark on our recovery journey in Houston after Harvey, the affinity we felt with Louisiana in 2005 expanded. We now were looking at the entire Gulf Coast because of the severity of the 2017 hurricane season and its disastrous outcomes for all of us from Texas to Florida.

In forming HuRRI, we aimed to catalyze innovation. We're looking at six dimensions of resilience. We call them MAPPER. These include mitigation, assessment, prediction, protection, education, and recovery. The main goal of our institute is to change the paradigm from waiting and paying for hurricanes to anticipating and accommodating them to save lives and reduce damages and costs associated with natural disasters.

At present, HuRRI faculty are undertaking 12 collaborative projects that span hurricane flood modeling, sensor development, resilient power systems, mental and physical health during hurricanes, and public policies associated with hurricanes and severe storms.

In my own research program and with the National Science Foundation grant and seed grant from the College of Engineering at the university, I mobilized my research team immediately after Harvey, and we began to assess the environmental damages and the chemical and biological hazards that may have been released during Harvey from environmental and industrial infrastructure. We sampled water and sediment quality many, many times over a 1-year period to assess the resiliency of our waterways, our natural water systems, and Galveston Bay. The results were astounding. It was evident that our waterways have become rivers of brown, carrying with them a chemical and biological mix of pollutants onto land, into homes, and into waterways and sensitive ecological systems.

The overall impact on Galveston Bay is yet to be fully quantified and understood. In addition to near zero salinities for an extended period of time, the system experienced extensive sediment deposition and erosion, pollutant loads containing organics, metals, and pathogenic organisms.

While the full impact of Hurricane Harvey remains unknown, what is clearly apparent, however, is that much research is needed on how to soften the impact from environmental and industrial infrastructure failures. This knowledge gap has never been more greater or glaring to us as we observe the uneven distribution of these impacts amongst Houston's communities. We determined that while flooding was universally inclusive, human health effects were not equivalently borne by our communities. We found a disturbing pattern of their prevalence in areas with a high percentage of concentrated disadvantage populations.

This brings me to the future, which is what we're all about, I hope, here. Harvey is not your typical storm for Houston by any stretch of the imagination. What the climate experts, however, are telling us is that storms like Harvey are the new normal and that

in the future, hurricanes and severe storms will be more frequent, more intense, they will linger around longer, and they will move slower. These factors, when taken together, do not portend a bright future for our region. Houston, until Harvey, was still implementing Tropical Storm Allison recovery projects. In that last 15-year period, we've had multiple severe storms and a hurricane.

Confronting the recent rise in disaster losses locally is a defining challenge for Houston as we aim to be both resilient and smart. The good news is we do have scientific and engineering foundations that can reduce the toll on humans, economic, environmental, and infrastructure losses from extreme events. However, investments in research must be made to build our society's capacity to reduce and manage risk and create resilient and prosperous communities that are not just well-prepared but socially just.

My analogy and justification for increased research funding for hurricanes and coastal resilience stems from observing the benefits derived from directing funding toward research from penalties after the Deepwater Horizon disaster. Obviously, we cannot penalize Mother Nature for hurricanes and severe storms. On the contrary, we need to respect her power and accommodate it. And this can only be accomplished with research and funding for research on how to best achieve hurricane and coastal resilience. There is much to be learned on how to harden the physical infrastructure, how to soften the environmental impacts, how to understand the ramifications of transitioning to the new NOAA Atlas 14 storm on flooding, infrastructure, and communities, and even greater need is to understand future climate projections, sea-level rise, and their impacts on our region.

Research should guide our decisionmaking into mitigation and remedies. Do we elevate homes? Should we expand buyouts? Do we build tunnels beneath Houston? Do we expand conveyance with our bayous? Do we build more detention capacity or more reservoirs? Better yet, do we need to research nature-based solutions and the possibility of recharging our depleted aquifers with floodwaters? We also need to research and develop strategies for rapid response during and after extreme events to protect people and ecosystems, especially human health.

As academic institutions, our educational mission cannot be understated. Funding would be needed to integrate knowledge, training, research methodologies, and findings into existing and new curricula across disciplines to create a well-trained hazard and disaster mitigation workforce. Importantly, we need to leverage the power of data, data analytics, machine learning (ML), artificial intelligence (AI), and emerging and enabling technologies in and hurricane protection. We have made significant advances and coordinated declarations of disaster, disaster response, and evacuations. This is the right time to begin to anticipate and accommodate extreme events and focus on recovery and resiliency.

One of the most important steps we should take—and admittedly, I am somewhat biased in my passion toward research, science, engineering, and technology—is to provide continuous and sustained support for research and research centers such as SSPEED and HuRRI. We have missions and visions that transcend

day-to-day living and are forward-thinking and forward-looking engines of innovation and creativity.

In conclusion, I greatly appreciate the effort of this Committee to support hurricane and coastal resilience research that keeps Houston and America safe, secure, and globally competitive and assures constituencies a high quality of life, health, and prosperity. I'd be glad to answer any questions you may have.

[The prepared statement of Dr. Rifai follows:]

Testimony of
Hanadi Rifai
Director, Hurricane Resilience Research Institute (HuRRI)

Before the Subcommittee on Environment of the
House Committee on Science, Space, and Technology
Hearing: "Weathering the Storm: Improving Hurricane Resiliency through Research"

July 22, 2019

Chairwoman Fletcher, Ranking Member Roger Marshall and Members of the Subcommittee, I appreciate the opportunity to testify before you here today. My name is Hanadi Rifai; I am John and Rebecca Moores Professor of Environmental Engineering and Director of the Hurricane Resilience Research Institute (HuRRI) at the University of Houston.

I have organized my testimony into three sections highlighting the past, the present and the future of my hurricane and coastal research. I use this framework to summarize the lessons learned and identify the improvements needed to current research efforts and the knowledge gaps that remain. I conclude my testimony with a call-to-action and make the case for increased funding for research as a low risk but incredibly high rewards investment strategy towards coastal resilience and empowerment of coastal communities like Houston to be better prepared for high winds, storm surge, and heavy rain.

The Past

My research journey with hurricanes and severe storms dates back to Hurricane Katrina in 2005, at the time, Houston felt New Orleans's pain profoundly. A group of us (faculty) from Houston and Louisiana met to discuss what could be done and that was the seed that germinated the Severe Storm, Prediction, Education, and Evacuation from Disaster (SSPEED) Center. It was difficult then to secure research funding for the Center and it remains difficult now to do the same. Centers such as SSPEED and HuRRI are very critical for our nation's safety, security and resiliency. In SSPEED and HuRRI, our work has been interdisciplinary, fundamental, transformational, and responsive to societal needs before, during and after hurricanes and severe storms. While SSPEED has focused mainly on the Houston-Galveston region, HuRRI is aimed at our entire 3rd coast, the Gulf of Mexico and its coastal communities and their challenges.

My work with SSPEED focused on Houston's industrial infrastructure and its vulnerability to natural hazards. This focus stemmed from my significant involvement in the U. S. Environmental Protection Agency's (EPA) Galveston Bay National Estuary Program (GBNEP) that culminated in a novel and unique non-point source study for the Galveston Bay region[1] and in the development of the Galveston Bay Plan[2]. I currently serve on the Galveston Bay Council, a coordinating body of the Galveston Bay Estuary Program (GBEP) created and appointed in 1995

by the Texas Natural Resource Conservation Commission (TNRCC now known as the Texas Commission on Environmental Quality or TCEQ). The Council is charged with providing a forum for stakeholder involvement and ensuring stakeholder commitment towards implementation of the Galveston Bay Plan. I represent Major Universities on the Council.

Houston's industries are concentrated along the 50-mile Houston Ship Channel (HSC), stretching from the Gulf of Mexico to Houston and Harris County, Texas. The Channel is home to more than 200 chemical and petrochemical facilities (Figure 1). Along with the Port of Houston that moves almost 300 million tons of cargo annually and is one of the largest ports in the world, the HSC is credited with fostering the growth and prosperity of the entire State of Texas. With this economic opportunity and prosperity, however, comes vulnerability. The industries along the channel produce, store, and transport chemicals and petrochemicals and in times of natural hazards, their processing units and storage and transportation facilities, including the Port of Houston, are vulnerable to storm surge, wind, rainfall and high channel flows. There are upwards of 4,100 storage tanks in the HSC region of various types and shapes containing a variety of chemicals and petrochemicals at any given time (Figures 2 and 3). These tanks can experience failure due to uplift pressures, for example, that would transport an impacted tank with the flowing water thereby increasing the potential for breaching it and spilling its contents.

Our research in SSPEED developed the first of its kind predictive model that quantified economic losses in the HSC that would be incurred due to varying storm surge heights at the individual facility level and for the entire Channel region. With this Facility Economic Damage and Environmental Release Planning or FEDERAP model, we predicted catastrophic losses exceeding 70 billion dollars for 25 ft surge[3] in the HSC and Port of Houston. It is important to note that FEDERAP integrates a storm surge predictive model (ADCIRC+SWAN)[4] with an in-stream water and sediment quality model (EFDC)[5] to generate scenarios of inundation and storm surge using Hurricane Ike as a model hurricane with varying strengths and landfall locations. The generated scenarios are overlain on ground-based topography and satellite imagery and merged with a detailed Hurricane Vulnerability GeoDataBase (HVGDB) that includes economic productivity data and environmental vulnerabilities in addition to infrastructure at risk for each scenario for each facility (see for example Figure 4). More recently, we developed probabilities of failure for each storage tank at each facility for Hurricane Harvey and demonstrated the utility of this modeling by comparing the projected probabilities to the actual failures that occurred during Harvey (Figure 5).

Such detailed information and integrated models did not exist at the time when we first developed them in my research team but they are instrumental tools and resources for enhancing resiliency in our region and other industrialized regions along the Gulf Coast that are so critical for our nation's economy. Such models and tools need to be further developed and enhanced and broadened to include other infrastructure and services and to model a future with potentially more frequent, stronger, slower storm systems, and rising sea levels.

Other related and critical research that we undertook in the SSPEED Center involved a close look at the environmental impacts associated with surge protection and building gates and barriers across parts of the Galveston Bay System. The Bay is an incredibly productive and critical resource for our region and one of the few estuaries around the country that still has its oysters and a vibrant fisheries and coastal tourism economy. The Bay is heavily dependent on freshwater inflows and a healthy interaction with the Gulf of Mexico that creates a delicate balance for its productive ecosystems. Construction of barriers, dikes, and the like to mitigate storm surge needs to be carefully evaluated and studied to ensure that this delicate balance is not disrupted or harmed. We have developed relatively short-term and long-term models of bay water quality looking at temperatures and salinities when such mitigation measures are implemented that can be used to inform surge protection systems design and implementation. Much more effort is needed, however, to further develop these models into robust predictive platforms that can further elucidate and incorporate the changes in sediment regimes, flood flows in the San Jacinto and Trinity Rivers and their relative timing, drought cycles, climate change, and sea level rise.

The present

As we embarked on our recovery journey in Houston after Harvey, the affinity we felt with Louisiana in 2005 expanded to include the entire Gulf Coast because of the severity of the 2017 hurricane season and its disastrous outcomes that were felt from Texas to Florida. This fueled our resolve to create another broader research entity to serve as a gateway to resiliency of the entire Gulf Coast and a framework to transfer and exchange ideas and lessons learned among its diverse coastal communities.

HuRRI is a collaborative institute encompassing six founding member universities that include: the University of Houston, Texas Tech University, The University of Texas Tyler, Louisiana State University, the University of Miami, and the University of Florida. In forming HuRRI in 2017 after Hurricane Harvey, we aimed to catalyze innovation in six dimensions of resilience: Mitigation, Assessment, Prediction, Protection, Education and Recovery or MAPPER dimensions. The main goal of the Institute is to change the paradigm from *wait-and-pay* to *anticipate-and-accommodate* to save lives and reduce damage and costs associated with natural disasters. HuRRI goes beyond the physical impacts of wind, surge and rain to infrastructure and their mitigation and takes a close look at cascading consequences and compounding disasters, environmental hazards, and human health post disasters, among other areas of research. At present, and with seed grant funding from the founding members of the Institute, HuRRI faculty are undertaking 12 collaborative research projects that span hurricane and flood modeling, sensor development, resilient power systems, mental and physical health during hurricanes, and public policies associated with hurricanes and severe storms (see Table 1 for a complete list).

In my own research program and with a National Science Foundation (NSF) RAPID grant (RAPID grants support research that has a severe urgency) and seed-grant funding from the Cullen College of Engineering at UH, I was able to mobilize my research team immediately after Harvey and begin to assess the environmental damages and the chemical and biological hazards that

may have been released during Harvey from environmental and industrial infrastructure. Water and wastewater facilities, septic tanks, landfills, storm water networks, hazardous waste and Superfund sites, referred to collectively as environmental infrastructure, are all potential hazards to community health in extreme events because of releases, spills and leaks, and failures in their systems. Inundation of wastewater systems, for instance, releases of untreated wastewater and sludge into communities or inundation with floodwaters; all introduce a new ecosystem for pathogenic fungal and bacterial growth, and foster vector-borne diseases especially in low-income neighborhoods. Examples include antibiotic resistant staph infections, flesh-eating bacteria, and diarrheal disease, as well as West Nile, dengue, chikungunya, and zika that are spread by mosquitoes. Contaminated water can spread the organisms causing typhoid and cholera; tetanus, gas gangrene, allergies, asthma and immunological reactions; all are concerns that have affected communities in recent disasters.

We sampled water and sediment quality multiple times over a 1-year period in an effort to assess the resiliency of our waterways, natural water systems, and Galveston Bay. The results[6] were an astounding call-to-action; it was evident that our waterways had become Rivers of Brown (see Figure 6) carrying with them a chemical and biological mix of pollutants onto land, homes, and into waterways and sensitive ecological systems. As time went by, waterways within watersheds that have little to no anthropogenic activities recovered relatively quickly within a day or two after the storm, whereas other natural water systems that are urbanized and with a relatively significant anthropogenic footprint within them had varying degrees of recovery that in some cases persisted beyond six months after Harvey. Buffalo Bayou, for example that had received discharged flood flows from the Addicks and Barker reservoirs in addition to the storm flows from its watersheds, was among the most impacted. In addition to depressed oxygen levels for an extended period of time and significant erosion of its banks, Buffalo Bayou waters became unnaturally acidic due to the water released from the reservoirs (Figures 7 and 8).The long-term impact of these stresses and shocks to Buffalo Bayou are largely unknown.

Similarly, the overall impact on Galveston Bay is yet to be fully quantified and understood. In addition to near zero salinities for an extended period of time, the system experienced extensive sediment deposition and sediment grain-size shifts (silt percentages in the sediment grain size distribution profile increased up to 4-fold at some locations) and extensive pollutant loads containing organics, metals and pathogenic organisms. We saw in our data after Harvey effects down at the microbial level in the system where the microorganisms in Bay sediment reflected the flood flows and the pollutant loads within them. For example, Cyanobacteria, a toxic organism commonly found in freshwater lakes were found at considerably higher levels near the mouth of the San Jacinto River (SJR) than other sampled locations. The source of Cyanobacteria, while not confirmed, could be from the freshwater that was released from Lake Houston into the San Jacinto River during Hurricane Harvey. The impact that the shift in microbial communities within the Galveston Bay system in response to Harvey will have in the long-term on the Bay has yet to be assessed but more research is needed to understand the role that microbial communities play as sentinels of bay and ecosystem health and community exposure to pollutants post disaster.

While the full impact of Hurricane Harvey remains unknown, what is clearly apparent, however, is that much research is needed on how to soften the impact from environmental and industrial infrastructure failures. This knowledge gap has never been greater or more glaring to us as we observed the uneven distribution of these impacts amongst Houston's communities. The NSF RAPID funding allowed us to develop relatively simple geospatial flood prediction models and mapped databases of environmental infrastructure facilities that included wastewater, landfills, superfund sites, and hazardous waste sites and their locations relative to communities and the 100-year and 500-year flood zones in addition to detailed information about spills and leaks from this infrastructure and industrial facilities during Harvey. Figure 9, for example, illustrates our geospatial model prediction compared to an actual aerial image taken for the same wastewater plant after Harvey. Such models are very valuable especially for decision makers since they rely on relatively simple data inputs and can be overlaid on mapped infrastructure and population data as we did in our research to understand the full impact of flooding, and the relationships and interactions between infrastructure and people, a dimension of resilience that is oft ignored but deserves further research and study.

Using the aforementioned geospatial model and associated databases, we determined that while flooding was universally inclusive, human health effects were not equivalently borne by our communities. Houston has a relatively high proportion of concentrated-disadvantage communities that are spread in a north-east-south moon-shaped ring around its central core. Concentrated-disadvantage is defined in our work using 5 measures of disadvantage (Figure 10): (i) % female head of household, (ii) % below poverty line, (iii) % on public assistance, (iv) % unemployed, and (v) % below 18 years of age. In evaluating the distribution of environmental facilities and industrial hazards and the spills, leaks, and releases during Hurricane Harvey, we found a disturbing pattern of their prevalence in areas with a higher percentage of concentrated-disadvantage populations (Figures 11 and 12). This pattern also manifested itself in vector borne diseases as we evaluated the positive responses to Arbovirus (group of viruses transmitted by mosquitoes, in this case the data in the figure are for West Nile) within our communities (Figure 13). In addition, and in an effort to define resiliency of environmental infrastructure, we found many causes for concern, numerous facilities were located within floodplains, others had a history of flooding and significant down-time after severe events, and yet other facilities that are intended to manage solid and hazardous waste had failures and became themselves sources of pollution during Harvey.

Of note is our work with the San Jacinto River waste pits site that was designated a Superfund site after our investigation into the presence and levels of polychlorinated dibenzo-dioxins (PCDDs), polychlorinated dibenzo-furans (PCDFs), and polychlorinated biphenyls (PCBs) in the Houston Ship Channel, the San Jacinto River and Galveston Bay that began in 2002 and continues to the present with numerous sampling campaigns throughout this time period. A remedial cap emplaced over the waste pits experienced failure during Harvey. My research team has collected sediment and tissue samples after Harvey to assess the potential impact from releases that may have occurred due to cap failure. The study is currently underway.

The Future

Harvey is not a typical storm for Houston by any stretch of the imagination and its departure from prior severe storms and hurricanes can be observed by comparing Harvey rainfall depths with those from the most recent extreme events in Houston as shown in Figure 14. What the climate experts are telling us, however, is that storms like Harvey are the *new normal* and that in the future, hurricanes and severe storms will be more frequent, more intense, linger around longer, and move slower. These factors, when taken together do not portend a bright future for our region. Houston, until Harvey, was still implementing Tropical Storm Allison Recovery Projects. We have had multiple severe storms and one hurricane in the 15 year period since Allison and before Harvey. *Confronting this recent rise in disaster losses locally is a defining challenge for Houston as we aim to be both resilient and smart. The good news is that there are scientific and engineering foundations that can reduce the human, economic, environmental, and infrastructure losses from extreme events, however, investments in research must be made to build our society's capacity to reduce and/or manage risks and create resilient and prosperous communities that are well prepared and socially just.*

My analogy and justification for increased research funding for hurricanes and coastal resilience stems from observing the benefits derived from directing funding towards research from penalties after the Deep Water Horizon disaster. Obviously, we cannot penalize Mother Nature for hurricanes and severe storms; on the contrary, we need to respect her power and accommodate it and this can only be accomplished with research and funding for research on how to best achieve hurricane and coastal resilience. There is much to be learned on how to harden the physical infrastructure and how to soften environmental impacts. Much research is needed to understand the ramifications of transitioning to the new NOAA Atlas 14 storm on flooding, infrastructure and communities. An even greater need is to understand future climate projections, sea level rise, and their impacts on our region. We need to evaluate and define the risk level that we as a community are willing to accept and what is the cost that we have to bear to achieve protection that is commensurate with our chosen risk level.

Research should guide our decision making into mitigation and remedies; do we elevate homes and where and how much? Should we expand buyouts and how does that affect community integrity and viability? Do we build tunnels beneath Houston to convey the water to the Gulf of Mexico or expand conveyance within our existing bayous and creeks and what impacts would that have on water quality and human health? Do we build more detention capacity or more reservoirs and where and how and what benefits would be derived? Better yet, we need to research nature-based solutions and what risk reduction they can afford us. We also need to keep an open mind and research and debate holistically the possibility of recharging our depleted aquifers with floodwaters. We need to research ways to reduce vulnerabilities in our infrastructure and systems whether they are water systems, storm sewers, sanitary, solid waste, power, health services, and public health systems and so on.

We also need to research and develop strategies for rapid response during and after extreme events to protect people and ecosystems especially human health. We need to research the best strategies to engage communities and empower them with a culture of preparedness and

resilience. We need to address disparities that still exist in disaster outcomes in different communities. As academic institutions, our educational mission cannot be understated. Funding would be needed to integrate knowledge and training and research methodologies and findings into existing and new curricula across disciplines to create a well-trained hazard and disaster mitigation workforce.

Importantly, we need to leverage the power of data, data analytics, machine learning, artificial intelligence, and emerging and enabling technologies such as drones, swarms, Underwater Unmanned Vehicles (UUVs) and Unmanned Aerial Vehicles (UAVs), new water and wind resistant materials and construction technologies, barrier technologies, and sensors and flood warning systems that can go a long way towards addressing vexing challenges with hurricanes and severe storms that prevent human access due to dangerous conditions. We need to continue developing and expanding the suite of predictive models for our region across the board in flooding, storm surge, pollution, mitigation, economic impacts, and transmission of infectious disease, among others. We also need to leverage our human capital and collective mental capacities and rely on citizen science, social media, and the myriad of motivated volunteer corps to engage in being part of the solution. But funding is needed to undertake this research and more.

There are many steps that coastal communities like Houston have taken and should take to prepare for hurricane impacts such as high winds, heavy rains or storm surge. We have made significant advances in coordinated declarations of disaster, disaster response and evacuations, yet many of our evacuation routes remain subject to flooding. It is the right time to begin to *anticipate and accommodate* extreme events and focus on recovery and resiliency. We need to expand our flood warning and flood alert systems in every neighborhood, and provide adequate sheltering options and capacities. We have to research supply chains to ensure supplies of food, water, energy, and basic necessities. We need to research resilient approaches to address the mountains of solid waste and discarded building materials after floods that are a significant hazard to human and ecosystem health because of their components. We need to build redundancies in our hazard mitigation planning to alleviate potential catastrophes such as the Arkema Plant toxic release during Harvey. We need to integrate hazard mitigation planning into every aspect of our society and future development plans and policies. It goes without saying that we need to build surge protection systems and address infrastructure resiliency to high winds and flooding. However, while we continue to emphasize resiliency in our economy, critical infrastructure, our built and natural environment, we must expand our focus to include people especially concentrated-disadvantage communities, their health and well-being.

One of the most important steps we should take, and admittedly, I am somewhat biased in my passion towards research, science, engineering and technology, is to provide continuous and sustained support for research and research centers such as SSPEED and HuRRI; they have missions and visions that transcend day-to-day living and are forward-thinking and forward-looking engines of innovation and creativity. Research on hurricanes and coastal resilience plays a very significant role for our community locally and for other similarly challenged communities nationally and globally. Research centers such as SSPEED and HuRRI focus attention on

important societal questions and needs, are nonpartisan, and can respond quickly to the continually changing landscape of our society and train the next generation of natural hazard mitigation workforce. They have access to incredible resources that can be brought to bear on hurricanes and coastal resiliency. In HuRRI, for instance, we have a great resource in the NSF funded National Center for Airborne Laser and Mapping (NCALM) that can mobilize at any time to provide on-demand research-grade accurate LiDAR data (Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to generate three-dimensional information about the surface characteristics of the Earth), and data on impacts after a hurricane or severe storm as well as detailed data on landscape and topography change over time. We can integrate these data into our predictive models and continuously update model predictions and the uncertainties inherent in them and provide near-real time predictive capabilities. Research Centers such as SSPEED and HuRRI, in addition to their research-focused missions, provide a forum for engagement, debate, and discussion that is, otherwise, not readily available or accessible for communities, decision-makers, policy developers, stakeholders, and other entities.

In conclusion, I greatly appreciate the effort of this committee to support hurricane and coastal resilience research that keeps Houston and America safe, secure, and globally competitive and assure its constituencies a high quality of life, health and prosperity.

I will be glad to answer any questions you may have.

References cited

1. Newell, C. J., H. S. Rifai, and P. B. Bedient, *Characterization of Non-Point Sources and Loadings to Galveston Bay*, Galveston Bay National Estuary Program (GBNEP-15), Clear Lake, Houston, 33 pp., 1992.
2. McFarlane, R. W., C. J. Newell, H. S. Rifai, P. B. Bedient, and F. S. Shipley, The State of the Bay, A Characterization of the Galveston Bay Ecosystem, A publication of the Galveston Bay National Estuary Program, 1994.
3. Burleson, D. W., H. S. Rifai, J. K. Proft, C. N. Dawson, P. B. Bedient, Vulnerability of an Industrial Corridor in Texas to Storm Surge, *Natural Hazards*, 77(2): 1183-1203, 2015.
4. Dietrich, J. C., S. Tanaka, J. J. Westerink, C. N. Dawson, R. A. Luettich, Jr., M. Zijlema, L. H. Holthuijsen, J. M. Smith, L. G. Westerink and H. J. Westerink, Performance of the Unstructured-Mesh, SWAN+ADCIRC Model in Computing Hurricane Waves and Surge, *Journal of Scientific Computing* 52(2): 468-497, 2012.
5. Hamrick, J. M. *A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects*. Special report in applied marine science and ocean engineering ; no. 317.. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/VSTT6C , 1992.
6. Kiaghadi, A., and H. S. Rifai, Physical and Chemical Quality of Floodwaters in Houston Following Hurricane Harvey, *Environ. Sci. Technol.*, 5 (39): 4832-4840, 2019.

Table 1. List of research projects underway in HuRRI

1. Identification and assessment of chemical hazards during hurricanes and flooding
2. Towards data-driven hurricane modeling using Unmanned Aerial Vehicles (UAV)-deployed subsurface sensors
3. Hurricane Harvey: experiences, recovery and future policies
4. Wireless carbon nanofiber aggregate sensor system for real-time water level monitoring and flood warning
5. HuRRI-Composites: Resilient coastal communities using advanced construction materials and systems
6. Hurricane evacuation harnessing connected and automated vehicles
7. Understanding hurricane response resilience across mental and physical health: consideration of individual-level and community-level factors
8. Complex dynamics modeling and mitigation of power transmission system under extreme hurricanes and storm surges
9. The aftermath of hurricanes: pathways to resilience and recovery among college students
10. An integrated framework for grid resiliency in disaster recovery through smart control of residential and community level distributed energy resources
11. Predictive tools for large precipitating storms in coastal Texas and Louisiana
12. A comprehensive analysis and assessment of portable fuel cell-solar hybrid power system to provide energy resilience

Supporting Figures

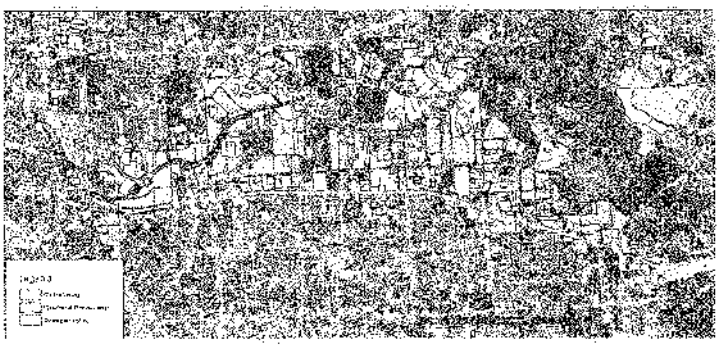


Figure 1. Illustration of Houston Ship Channel facilities categorized by type (oil refining in orange, chemical processing in magenta and storage in light yellow)

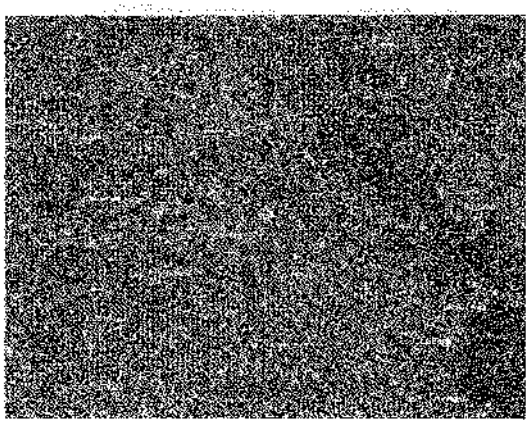
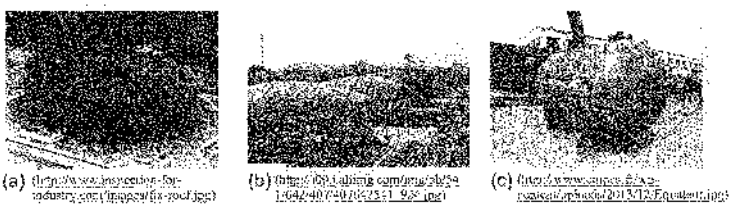


Figure 2. Schematic illustrating the more than 4,100 chemical and petrochemical storage tanks in the Houston Ship Channel region



(a) (b) (c)

Figure 3. Examples of tank types modeled in FEDERAP (a) Floating-top vertical tank (b) Fixed-top vertical tank (c) Horizontal tank (FEDERAP – Facility Economic Damage and Environmental Release Planning Model)

Figure 4. Aerial view of a facility in the Houston Ship Channel illustrating vulnerable infrastructure (the red lines show the boundaries of the different land parcels within the facility)

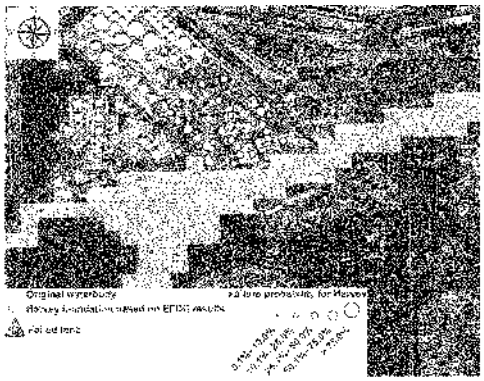


Figure 5. An aerial view that illustrates the modeled-probability of storage tank failure during Harvey at an industrial facility. The red triangle shows the tank that actually failed and had a significant release during Harvey

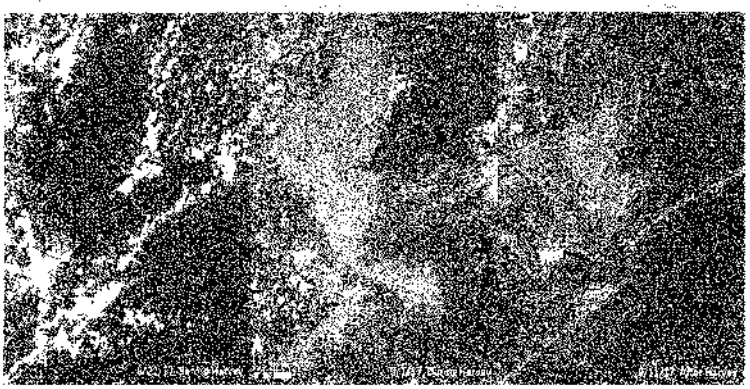


Figure 6. Satellite imagery showing Rivers of Brown before, during, and after Hurricane Harvey in the Houston area and Galveston Bay (the dates from left to right are August 22nd, September 1st and September 11 in 2017; Harvey made landfall in Texas on August 25, 2017)

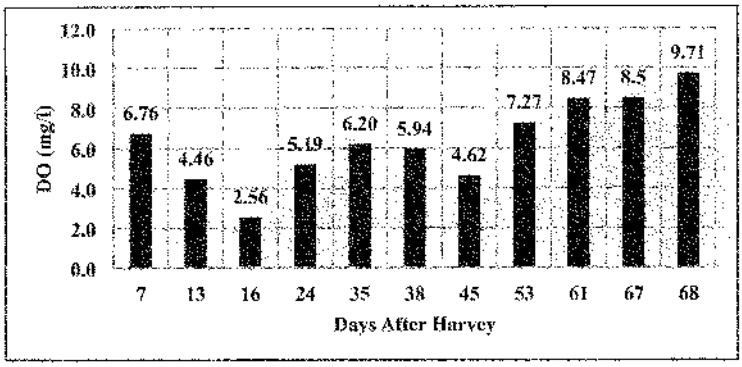


Figure 7. Dissolved oxygen levels in Buffalo Bayou downstream of the Barker Reservoir between 1 week and more than 2 months after Harvey. Depressed oxygen levels as shown on day 16 are outside the historical range for dissolved oxygen measurements in Buffalo Bayou and in general, are not considered supportive of biota and other living forms in the bayou

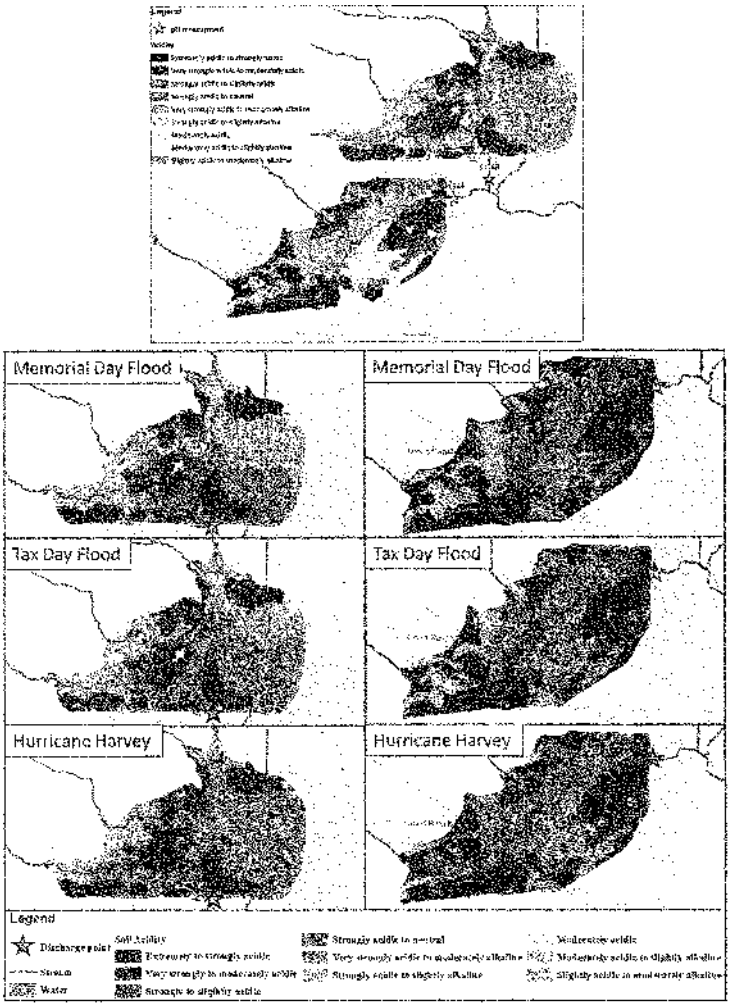


Figure 8. The soils of the Addicks and Barker Reservoirs are naturally acidic. With their historic flood levels experienced during Harvey, water within the reservoirs became unnaturally acidic (Barker reservoir is shown on the left and Addicks on the right)

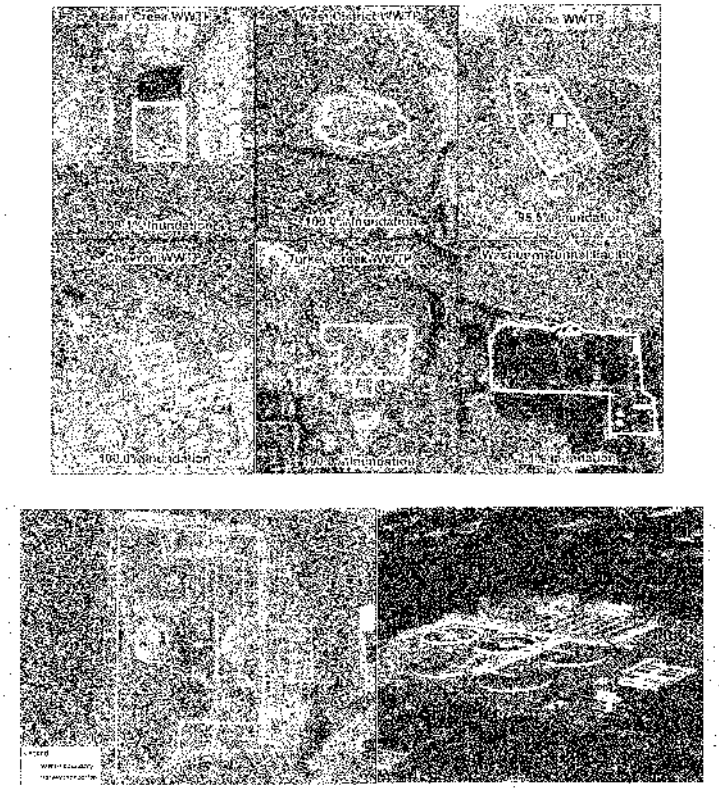


Figure 9. Illustrations of the modeled extent of flooding from geospatial modeling of wastewater treatment plants after Harvey (select facilities shown in the top figures). The bottom images compare the modeled flooding during Harvey on the left to an actual photograph taken during Harvey on the right for the Turkey Creek wastewater treatment plant

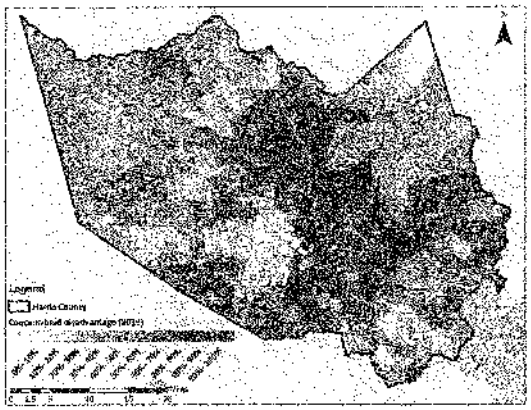


Figure 10. Concentrated-disadvantage communities in Houston form a north-east-south moon-shaped ring around the City's core (Concentrated-disadvantage is defined using 5 measures of disadvantage: (i) % female head of household, (ii) % below poverty line, (iii) % on public assistance, (iv) % unemployed, and (v) % below 18 years of age)

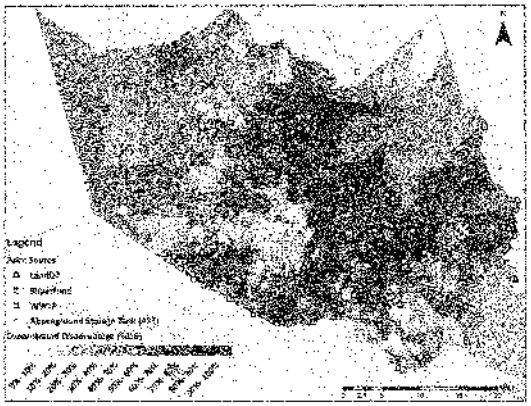


Figure 11. Concentrated-disadvantage communities in Houston bear the brunt of potential failures in environmental and industrial infrastructure associated with extreme events (WWTP – waste water treatment plant)

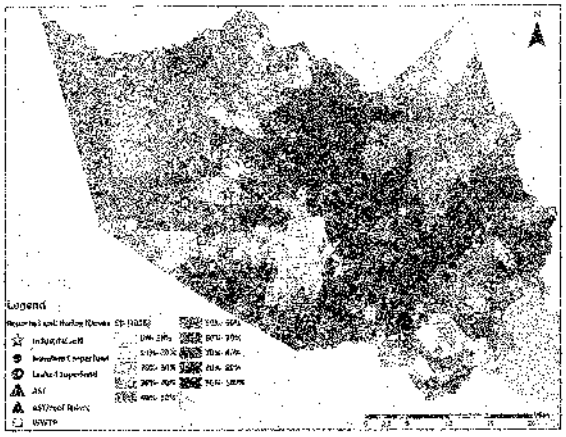


Figure 12. Actual spills and leaks reported during Harvey were almost all located within areas with significant concentrated-disadvantage populations (AST – above ground storage tank, WWTP – waste water treatment plant)

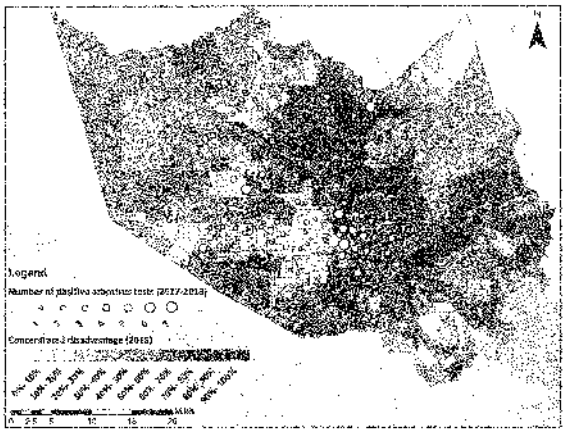


Figure 13. Mosquitoes with positive Arbovirus (group of viruses transmitted by mosquitoes, in this case the illustration shows West Nile) within areas with significant concentrated-disadvantage populations (Arbovirus data from Harris County Public Health)

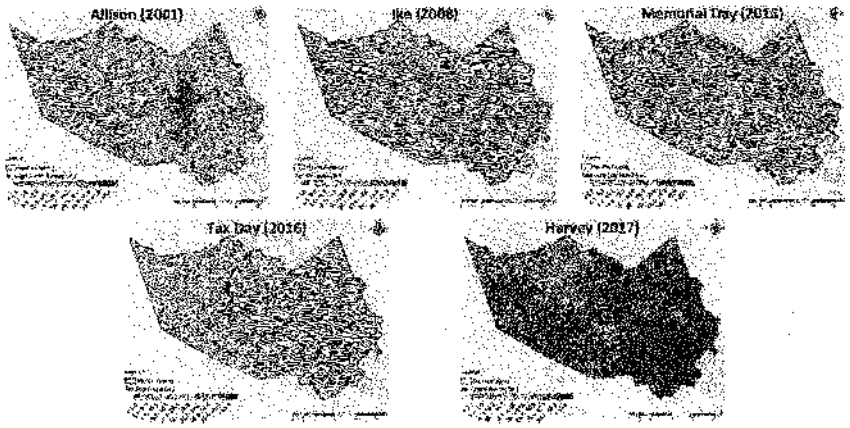


Figure 14. Rainfall depths for the most significant recent hurricanes and severe storms in Harris County in Texas (the scale ranges from greens that start at < 2 inches to dark blue colors that are > 40 inches of rainfall)

Hanadi S. Rifai
Biographical sketch

Dr. Hanadi S. Rifai is John and Rebecca Moores Professor of Environmental Engineering and Director of the Hurricane Resilience Research Institute (HuRRI) at the University of Houston. She also serves as Associate Dean for Research and Facilities in the Cullen College of Engineering and is Director of the Environmental Engineering Graduate Program at UH. Dr. Rifai is a Council Member of the Galveston Bay Council representing Major Universities on the Council. Dr. Rifai graduated with her Masters and PhD from Rice University and has been a Professor at the University of Houston for over 20 years. Her current research interests are focused on hurricanes and coastal resilience including research related to hardening infrastructure, softening environmental impacts, and addressing disparities in disaster outcomes in different communities in Houston and along the Gulf Coast.

Chairwoman FLETCHER. Thank you, Dr. Rifai. Ms. Grover-Kopec.

TESTIMONY OF EMILY GROVER-KOPEC,
DIRECTOR OF INSURANCE PRACTICE, ONE CONCERN, INC.

Ms. GROVER-KOPEC. Thank you, Chair Fletcher, Chairwoman Johnson, distinguished Members of the Committee, for holding this important hearing and for giving me the privilege of providing a private-sector perspective. And thank you to the Committee staff, who have been a pleasure to work with in preparing for this hearing. It is an honor to address the Committee regarding the importance of creating resiliency through scientific R&D (research and development) in a city that knows firsthand the importance of a more resilient future and to do so in my current capacity directing the insurance practice at One Concern, a benevolent artificial intelligence company.

At One Concern, our mission is to prepare communities to save lives and economic livelihoods through action before, during, and after natural disasters. My testimony today focuses on using R&D in AI and natural hazard sciences to predict disaster damage, aid officials during all phases of emergency management, and drive informed decisions that create resilient systems and financial tools.

One Concern's work would not be possible without the R&D performed and funded by the U.S. Government and at universities around the country. We are developing technology to minimize the impact of disasters like the flooding Houston experienced during Hurricane Harvey, as well as earthquakes and wildfires. Our AI platform removes the elements of human bias and insufficient data in times of crisis, providing objective situational awareness in near real time to drive informed response.

Machine learning and AI sit at the core of these analytics, helping to unlock new ways of understanding how complex disciplines interact. And these mathematical algorithms leverage several fields of scientific study, including hydrodynamic and hydrological-coupled science, structural engineering, fluid mechanics, seismic and atmospheric sciences.

A specific example of One Concern's unique research efforts is our platform's application for active flood events that provides a high-resolution understanding of impending flood inundation based on forecasted precipitation generated by the National Weather Service. The solution's AI-driven approach allows it to correct and adjust during the event, thereby addressing the core complexity associated with modeling floods: Their dynamic nature.

Decisions around evacuations in large metro areas like Houston can be informed by technologies like ours that provide a granular view of an impacted area at a block level up to 5 days out from a flooding event. This provides an understanding of which populations face the greatest risk and, through our continued R&D process, will allow first responders to understand the impact of mitigated actions. This level of situational intelligence could potentially change outcomes by informing targeted evacuations and mitigation to divert floodwater away from people and critical infrastructure. We are also working with jurisdictions to implement our flood risk R&D toward other proactive preparedness efforts, allowing emergency personnel to create better plans for a disaster.

R&D such as One Concern's could have even more impact through pre-disaster mitigation. We believe it is important that policy and infrastructure planning intended to improve resiliency should be equitable, should focus in on mitigation overall societal risk rather than mitigating purely the greatest financial risk, the latter of which tends to show bias toward the most affluent.

Our data and models assess the baseline resilience of the entire community, including how natural hazards impact structures, as well as critical infrastructure. Our R&D, therefore, would be well-positioned to drive equitable and informed decisions around overall societal resilience.

In addition to effective mitigation, preparedness, response, and access to insurance to support a community's recovery plays a critical role in resilience to disasters such as hurricanes and their associated flooding. One Concern's current R&D efforts include assessing the risk to a business' physical structure, as well as its access to power, water, roads, and bridges. This provides a transparent view of a business' overall resilience, which will enable an expansion of insurance and resilience finance tools. We seek to partner with businesses and insurers to support the development of new insurance products that will help businesses, their communities, and the economy to recover. Ultimately, this helps transfer risk from taxpayers to the private sector.

In closing, I would like to again thank Chairwoman and the Committee for inviting me to share One Concern's ongoing R&D efforts to create a more resilient future. Thank you.

[The prepared statement of Ms. Grover-Kopec follows:]

Written Testimony of
Emily Grover-Kopec, M.S.
Director of the Insurance Practice, One Concern, Inc.

Submitted to the
House Committee on Science, Space, and Technology's
Subcommittee on Environment

"Weathering the Storm: Improving Hurricane Resiliency through Research"
July 22, 2019
Houston Field Hearing

Thank you, Chairwoman Fletcher, Ranking Member Marshall, and distinguished Members of the Committee for holding this important hearing today and for giving me the privilege of providing a private sector perspective. It is an honor to be here to address the importance of creating resiliency through scientific research and development (R&D) in a city that knows firsthand the importance of the realization of a more resilient future.

I thank this committee for its efforts to shine a national spotlight on the topic of resiliency and for facilitating a national discussion on how, as a nation, we should be creating more resilient communities. Research conducted across multiple sectors is fundamental to increasing our ability to withstand and recover from natural disasters of all kinds. This research drives innovation in academia, as represented by my esteemed colleagues testifying with me today, in government, as demonstrated by the lifesaving work of the National Hurricane Center, and in the private sector in large multinational corporations as well as at start-ups, such as One Concern.

It is my great pleasure to appear before you today in my current capacity directing the Insurance Practice at One Concern, a benevolent artificial intelligence (AI) company

based in Menlo Park, California. We are a company dedicated to saving lives and livelihoods. That mission is rooted in our founder's first-hand experience of living through both earthquake and flood disasters, and our team's personal dedication to building long-term planetary-scale resilience.

At One Concern, our mission is to work with policy makers, emergency management officials, first responders, and the private sector, to prepare communities to save lives and economic livelihoods before, during and after natural disasters, through the use of benevolent artificial intelligence, community action, and resilience. Our Executive Team and Advisors notably includes Craig Fugate, the former Administrator of FEMA from 2009 to 2017, who serves today as our Chief Emergency Management Officer, retired General David Petreaus, the former Director of the Central Intelligence Agency, retired Ambassador to Japan, John Roos, who served during the Fukushima tsunami nuclear reactor crisis, and Judith Rodin, former President of the Rockefeller Foundation and founder of their100 Resilient Cities Project.

My testimony today focuses on using research and development in artificial intelligence, machine learning, and natural hazard sciences to:

- predict disaster damage;
- aid emergency responders in the preparation, response, and recovery phases of natural disasters; and
- ultimately drive informed decisions that create resilient systems and enable financial tools to better prepare communities and the private sector for such events.

One Concern's work would not be possible without the R&D being performed by the U.S. government and at universities around the country, including the work our co-founders conducted while graduate students at Stanford University and active collaborations with leading academic institutions such as the University of Michigan and Texas A&M University. With the growing threat and impact of climate change on natural disasters, such as hurricanes, our ongoing research and development efforts, including collaboration with public and private universities, are more critical than ever for Houston, the State of Texas, our nation, and communities around the globe.

Since 1970, the number of disasters worldwide has more than quadrupled to around 400 per year (based on United Nations' disaster monitoring system). In the last 40 years natural disasters have caused more than 3.3 million deaths and $2.3 trillion in economic damages. Complicating this reality is our increasingly urban population - by 2030, 60

percent of the world's population will live in cities - a trend seen here in Houston as it has been one of the fastest growing U.S. cities in recent years.

As Members of the Committee know well, the State of Texas and the City of Houston are at significant risk from hurricanes, severe storms, and flooding. The impacts of urbanization were felt here in Houston when Hurricane Harvey hit in August 2017, causing the second costliest storm in U.S. history ($125 billion) over one of the most densely populated areas of the Gulf Coast and the fourth most populous city in the United States (2017 data). According to the federal government, Harvey's eight day tropical cyclone rainfall was the largest amount of rainwater recorded in the contential United States from one storm. More than 60 inches fell in various locations, more than 15 inches above the average annual amounts of rainfall for eastern Texas and the Texas coast. Harvey was directly responsible for at least 68 deaths in Texas, over half of which were in Harris County and the Houston metro area. In Houston proper, 204,000 homes and apartments were flooded. Almost 80,000 homes were inundated with 18 inches of water and 23,000 homes had more than five feet of floodwater. Roughly three quarters of these damaged homes were outside of the mapped floodplains.

At One Concern, we are developing technology to minimize the impact of floods like that during Hurricane Harvey, as well as earthquakes, and wildfires. Our benevolent AI platform removes the elements of human bias and insufficient data in times of crisis, providing innovative situational awareness in real-time to drive informed response. Our cloud-based platform enables decision-makers to act quickly to protect the maximum number of lives and property. Every prediction on the map in One Concern's solutions is carefully validated across hundreds of data points. In the background sit powerful, state-of-the-art complex mathematical algorithms across several fields of scientific study including structural engineering, hydrodynamic and hydrological coupled science, fluid mechanics, seismic and atmospheric sciences, and other subjects.

Machine learning and artificial intelligence sit at the core of these innovative analytics, helping to unlock new ways of understanding the manner in which complex disciplines interact. One Concern's research and development enables us to solve some of the most challenging problems in resilience to natural disasters, including devastating and life threatening flooding and storm surge caused by hurricanes.

Traditional hazard models rely on either high-resolution asset-level data not readily available at scale or low-resolution uni-dimensional data more widely available but lacking in detail. The former requires extensive pre-disaster data collection—making it computationally expensive to estimate damage during a disaster—while the latter

provides only aggregated impact estimates that are too coarse to be actionable. Given these constraints, existing hazard models provide a broad analysis with limited accuracy, resolution and actionable insights. This limited view of the modeled hazard hinders the ability of public safety and elected leaders to make targeted and timely decisions in an accurate manner for life-saving and life-safety activities such as alerts and warnings, evacuations, logistics management, and mitigation.

Houston's appropriate hesitancy to evacuate millions of people in the potential hazard zone could be a situation of the past as technologies like ours provide a granular view of an impacted area up to five days out from the flooding event. One Concern, through our R&D, has eliminated the data, modelling, and computational constraints of traditional hazard models that to date have only been able to provide a "big red (or blue) blob" of impact. We are able to create enhanced situational awareness, provide an understanding at the block level of which populations face the greatest risk and, through our continued R&D process, will allow first responders to visualize and understand the impact of mitigative actions. This level of situational intelligence could potentially change outcomes by informing targeted evacuations, engineering the flood and diverting flood water away from people and critical infrastructure.

One Concern's models gather asset-level data from various public and proprietary sources in a scalable process along with impact data from previous disasters and then implements data-driven machine learning models that require no user inputs and can output impacts at high spatial resolution. Additionally, One Concern's solutions are being developed with the capability to gather real-time hazard data such as water levels (e.g., river/stream/ocean gauges), user-reported damage reports, temperature and wind patterns from satellites, and weather conditions and forecasts to generate highly accurate localized impacts that can be updated continually as more information becomes available. Through our ongoing R&D efforts, One Concern is creating dynamic models for disaster impact analysis that combine physical sciences with machine learning techniques. As a result, One Concern's solutions create, distribute, and visualize critically valuable data during a disaster; not to merely visualize static data.

R&D in Action: Modeling Flood Events

A specific example of One Concern's unique research efforts is our platform application for active flood events. As demonstrated in Hurricane Harvey, flooding from storm surge and rainfall create a dangerous and deadly situation. A 2014 National Hurricane Center report found that during the Atlantic tropical hurricanes and storms from 1963 to 2012, 88 percent of deaths in the United States were from drowning created by storm

surge, rainfall flooding, high surf, and deaths just offshore (within 50 nautical miles of the coast).

Existing geographic information system (GIS)-based solutions show the weather forecast, location of rivers and locations of buildings on the same map; however, One Concern creates models to estimate how precipitation from the weather forecast will increase water flow in rivers, and how river flow will breach banks and inundate surrounding areas. Our R&D efforts are solving the shortcomings of existing hazard analysis and GIS-based tools by applying the combination of natural phenomena sciences and artificial intelligence to the process of impact assessments from hazards.

For example, immediately before and during a flood, our platform combines hundreds of forecast data points with real-world sensor and gauge data. It then combines that data with a coupled hydrodynamic and hydrological prediction and natural environment factors through a proprietary machine learning algorithm to estimate damage in near real time. This provides a highly accurate, high resolution understanding of the impending flood inundation, associated impacts, and a real-time situational awareness. The solution empowers leaders and stakeholders with accurate information to understand how to mitigate against, prepare for, respond to or recover from flood events

This modeling approach addresses the core complexity associated with modeling natural disasters - their dynamic nature. By definition, natural disasters are extreme events and cause permanent deformations in the physical environment. Buildings and infrastructure are weakened or partially damaged. Rivers will change course or combine, stream banks will reorganize, and debris will change water depth and direction. If the model output is based on static data, as is the case in conventional live hazard models, the model is very far from ground truth at any point in time. Using AI, One Concern's solutions are developed to not just change their model live, but their underlying data as well. This ensures that leaders and planners are provided with accurate and reliable predictions during all phases of the disaster life cycle.

While informed decision-making during an event is paramount, the resilience of a community is typically enhanced most efficiently through proactive preparedness, planning and mitigation. Emergency managers and their partner stakeholders within the entire community invest their time and limited funding to plan, train and exercise before the next disaster. At One Concern, we are working with jurisdictions to put our R&D into action by implementing our flood risk preparedness module to allow emergency personnel to plan within the framework of highly accurate simulated disaster scenarios.

By providing realistic impact predictions, One Concern's preparedness solution will ensure that plans developed before the disaster are usable and effective.

Creating Resilience

To create true resilience, more research and development needs to be done across an entire ecosystem. One Concern is tackling this challenge. We are endeavoring to create a holistic picture of hazard risk to business and communities that identifies vulnerabilities to critical infrastructure and external dependencies, such as access to electricity and water. Analyses of how floods, fires, and earthquakes have direct structural impact to assets and indirect impact to critical dependencies, we are providing a more complete understanding of a community's baseline resilience. One Concern's R&D efforts allow a community or business to assess and mitigate risk with a more precise picture of how that action will benefit people, assets, and infrastructure. This enables a jurisdiction or a company to develop and enact mitigation plans before a disaster strikes. Local officials are better able to identify at-risk parts of the population and/or community, providing a more complete picture for disaster planning and management, enabling resilience and thus a quicker recovery when disaster strikes.

It is important that policy and infrastructure planning that is intended to improve resiliency be equitable and that it focus on mitigating overall societal risk, rather than mitigating just the greatest financial risk. One Concern's data represents the entirety of our communities, not just that of those most affluent, and is therefore well positioned to drive equitable and informed decisions around overall societal resilience.

Current systems for measuring resilience are narrowly scoped looking at a single or few factors rather than the cascading dependencies within a system that impacts how a jurisdiction or organization functions. In addition, they are not very granular, and do not permit, a side-by-side comparison of a place or a company, and are typically only calculated periodically. One Concern and our partners are developing a forward-looking, granular, objective rating for enterprises, and then governments, to estimate the impact from a variety of hazards on: businesses; critical infrastructure and supply chains and their related dependencies; communities; and economies.

Current metrics also tend to focus on current risk rather than future potential risk, and tend to be qualitative rather than objective in their analysis. Through our ongoing R&D, One Concern considers the cascading effects of disasters within the complex networks of jurisdictions and organizations. We are creating metrics that a jurisdiction could measure how resilient their critical infrastructure and lifeline dependencies of power,

water and wastewater, communications, transportation, healthcare and food system are and how well they would fare in a natural disaster.

Effective mitigation, preparedness and response play a critical role in how a community's resilience to natural disasters such as hurricanes and associated flooding, but another key element is the access to insurance to support the community's recovery. One Concern's intent is that our innovative modeling provides a comprehensive view of a business' resilience to enable an expansion of insurance and resilience finance. Currently, there are gaps in society's ability to understand the risk to businesses from disasters beyond its physical structure. The ability for a business to operate after a disaster is not just dependent on that structure, but also its access to power, water, customers, employees and supply chain. We seek to partner with businesses and insurers to provide a transparent assessment of that risk and support the development of new business interruption insurance products that will help businesses, their communities, and the economy to recover after a disaster event.

One Concern's platform provides unprecedented situational awareness of floods, earthquakes and wildfires and actionable insights for decision-makers, allowing our partners take an integrated approach to building lasting resilience. We leverage critical research in AI, hazard science, and weather. Through our ongoing R&D, we integrate AI, machine learning, and deep learning with expertise on natural science phenomena, emergency management, and our clients' institutional knowledge. By doing so, we enable our partner jurisdictions and companies to improve the robustness of their approach and the speed at which they are able to achieve success as defined by them. Ultimately, One Concern will enable resilience that strengthens communities, protects people, places and assets, and rewards smarter infrastructure investments.

In closing, I would like to thank Chairwoman Fletcher and the Committee for inviting me here today to share One Concern's ongoing research and development efforts to create a more resilient future.

Emily Grover-Kopec

Emily Grover-Kopec serves as the Director of the Insurance Practice at One Concern and has more than 15 years of experience in catastrophe modeling and climate analytics with a primary focus on applications within the insurance industry. Prior to joining One Concern, Ms. Grover-Kopec spent 12 years at Risk Management Solutions (RMS). Most recently, she was Vice President of Modeling Solutions at RMS and focused on analytics for the flood peril in the United States. Ms. Grover-Kopec also brings experience from Columbia University's International Research Institute for Climate and Society (IRI). Her work at the IRI concentrated on monitoring climate impacts and mitigating climate risk in developing countries. Ms. Grover-Kopec holds a B.S. degree in Atmospheric, Oceanic and Space Sciences from the University of Michigan and a M.S. degree in meteorology from Penn State University.

Chairwoman FLETCHER. Thank you. Mr. Blackburn?

TESTIMONY OF JIM BLACKBURN,
CO-DIRECTOR, SEVERE STORM PREDICTION, EDUCATION AND EVACUATION FROM DISASTERS CENTER; AND PROFESSOR, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING, RICE UNIVERSITY

Mr. BLACKBURN. Good afternoon, Chair Fletcher, Members of the Committee. I'm pleased to be here today to discuss resilience and research in my capacity as Co-Director of the Severe Storm Center at Rice, the SSPEED Center. In our work at the SSPEED Center, we were fortunate to be funded by a private foundation, the Houston Endowment, and we were able to use the latest and best cutting-edge methods to address flooding from coastal surge and from inland rainfall. We were allowed to make mistakes and find new ways forward. I would like to share with you what we've learned from that experience.

Three implementable concepts have come from this research. First, we've developed a structural solution along the Houston Ship Channel called the Galveston Bay Park plan, a plan to protect the Houston Ship Channel industries and the west side of Galveston Bay from a 25-foot surge. This Park plan is compatible with the coastal spine project of the Corps of Engineers, and the park plan is being developed alongside the proposed widening of the Houston Ship Channel, working with stakeholders such as the Port of Houston Authority.

Second, an economic solution—the Texas Coastal Exchange—is now a standalone nonprofit that will make grants to landowners for storing flood waters and carbon dioxide in their soil.

And third, the proposed Lone Star Coastal National Recreation Area focuses on enhancing ecotourism and economy that is flood-resilient. Our research has convinced us that flooding is the biggest threat to the economic future of the Houston region, period. There are 2.2 million barrels of refining capacity, 200-plus chemical plants, and 800,000 people that are unprotected from hurricane surge along the Houston Ship Channel and the west side of Galveston Bay. The loss of these plants represents a legitimate threat to national security. This is what keeps me up at night.

In our work at SSPEED Center, we found that a lack of adequate procedures and practices to integrate hydrology, climate, economy, ecology, and social considerations. They just simply don't exist. Current engineering and political science methodologies are antiquated. Our floodplain maps are wrong and understate the risk. In many ways, our current thinking about flooding is obsolete. We are not going to control storms like Harvey. We can learn to live with them. Big rains are coming, and we must make room for the water. We need a better understanding about the intersection of engineering and the storms of the future.

Our climate has been, is, and will be changing. We must understand these changes to develop realistic engineering solutions. We need innovative urban design thinking for our cities. Our creativity needs to be jumpstarted. We are mired currently in 20th-century

thinking facing 21st-century problems. We need economic methodologies that work with our engineering solutions.

There's likely not enough Federal money to solve all the flooding problems in the coastal United States. Therefore, we need to research and understand how the private sector can participate in funding these solutions. We're committed to finding private-sector funding for the $3–$6 billion that the Galveston Bay Park Plan requires. We need research about how insurance and investment funds and other private capital sources can become a major part of our flood solutions not only here but throughout the United States.

We need a better understanding of risk. What is a reasonable hurricane surge in the future with a hotter Gulf of Mexico? What is a reasonable rainfall to plan for in 2025 or 2030? What level of risk is acceptable? Our engineering solutions are designed to last at least 50 years if not more, including highways, buildings, landfills, and hazardous waste sites. What we are building today must be functioning in 2040, in 2070. That will not occur with our current tools.

Successfully addressing flooding is fundamental to succeeding as a region in the 21st century. It is the threat to the future of Houston. For the first time in 40-plus years, I am hearing the word fear used in conjunction with rainfall. And it is clear that national security is implicated. Why don't we think about flooding like President Kennedy thought about the space program back in 1962 when he spoke at Rice Stadium? We shouldn't undertake flood research because it's easy but because it is hard, because that challenge is one that we're willing to accept and one which we intend to win.

Please consider forming a national flood-related research effort with a space-program mentality. We actually put astronauts on the moon with our research. Let's actually solve our flooding problems. Such a flooding program should focus upon practical applied research perhaps along the lines of the old National Science Foundation Research Applied to National Needs program. Such a program could be a major step in solving the severe storm flooding problem that threatens our national security in ways far beyond any other domestic and perhaps international problem.

We can do this. We must do this. Thank you very much.

[The prepared statement of Mr. Blackburn follows:]

"Weathering the Storm: Improving Hurricane Resiliency Through Research"
Hearing before the Subcommittee on the Environment of the House Committee on Science, Space and Technology
Testimony of Jim Blackburn, SSPEED Center, Rice University
July 22, 2019

1. Overview of the Interdisciplinary work we do at SSPEED Center

The Severe Storm Prediction, Education and Evacuation from Disaster (SSPEED) Center is an interdisciplinary research entity formed at Rice University in 2007 that is dedicated to researching hurricanes and severe rainfall events. Our focus has been on hurricane surge and large rain events; we are not focused on wind damage at this time. The SSPEED Center brings in researchers not only from around the Rice campus but from several other universities, including the University of Houston, the University of Texas, Louisiana State University and Texas A&M University, as well as private consultants as needed. The Center includes engineers, architects, environmental scientists, economists and legal and political science researchers. Most of the funding for the SSPEED Center's research has come from private sources, such as the Houston Endowment; thus, our research has been primarily focused on flooding issues in the Houston area. We have been working on addressing urban flooding problems in Houston, especially since Hurricane Harvey (2017), and have been working on coastal resilience issues since Hurricane Ike (2008). We have published over 50 peer-reviewed papers since 2010 regarding various aspects of our research, and the SSPEED Center has hosted conferences, workshops and

seminars to bring in experts from around the world to collaborate and help provide a better understanding of the issues and potential solutions.

2. How We Can Build Resilience to Storm Impacts

Building resilience to adverse impacts from surge and rain events is a very difficult issue. First, one has to define resilience, which I consider to be the ability to withstand impacts, being not only to absorb but also recover, to "spring back into shape". In SSPEED Center's initial work after Hurricane Ike, we were all struck by the difference between the impact of Ike's surge on human development near Galveston on the Bolivar Peninsula , which was devastated, as compared to the adjacent natural marsh and prairie ecosystems, which were inundated up to twenty miles inland and recovered relatively quickly.

These natural systems are resilient because they have evolved to survive and rebound from inundation. We made an early decision that from a non-structural flood damage reduction standpoint, we needed to encourage economic solutions that recognized the value of our coastal marshes and prairies because on the Texas coast, regulation to protect these areas is not likely to happen. We believed that if we could create monetary benefits from maintaining, enhancing or creating such resilient land uses, then we would be heading in the right direction. These economic solutions will be discussed further in Sections 3 and 4 below.

Second, a point of resilience relating to "living with water" evolved from Hurricane Harvey as well as many earlier large rain events

in the Houston region. I doubt that any city in the world can "control" the flooding generated by a Harvey-like storm that dumped 40 to 50 inches of rain in 4 days. We can, however, minimize the damage from such storms by making more room for water in our communities. In Houston, we have tried to limit the expanse of our channels and bayou flood plains to maximize development immediately adjacent to them. Over time, this has proven to be unwise; we will need to move back development from the water's edge, providing more room for the water and letting the bayous flood along their physical floodplains. The Dutch, who many consider to be the best flood protection thinkers in the world, have made a similar decision to "make room for the river" in their more recent projects. Flood water must be treated differently than in the past. We cannot banish it. We simply must expand the area "dedicated to water". That will generate land use consequences that are discussed in Section 4 below.

Third, for us here in Houston to become resilient, we must address coastal surge flooding in the Houston-Galveston area, which threatens the largest refining and chemical complex in the United States. The 2.2 million barrels of refining capacity and 200+ chemical plants on the west side of Galveston Bay are very much at risk from the large storms we are starting to see. This infrastructure represents 13% of U.S. refining capacity and almost 27% of the jet fuel capacity of the United States. This is a bona fide national security issue not adequately addressed by current methodologies (see Section 4), and this critical infrastructure is not going to be able to just move from harm's way. The industrial complex along the Houston Ship Channel and Galveston Bay has to be protected with structural solutions if it is going to survive the next several decades. Just as important is the need to protect the

approximate 800,000 people living adjacent to the western shoreline of Galveston Bay, many of whom work at these plants. The western bay area potentially inundated by storm surge from a weak Category 4 hurricane (also known as FEMA Storm 36) is shown in Figure 1.

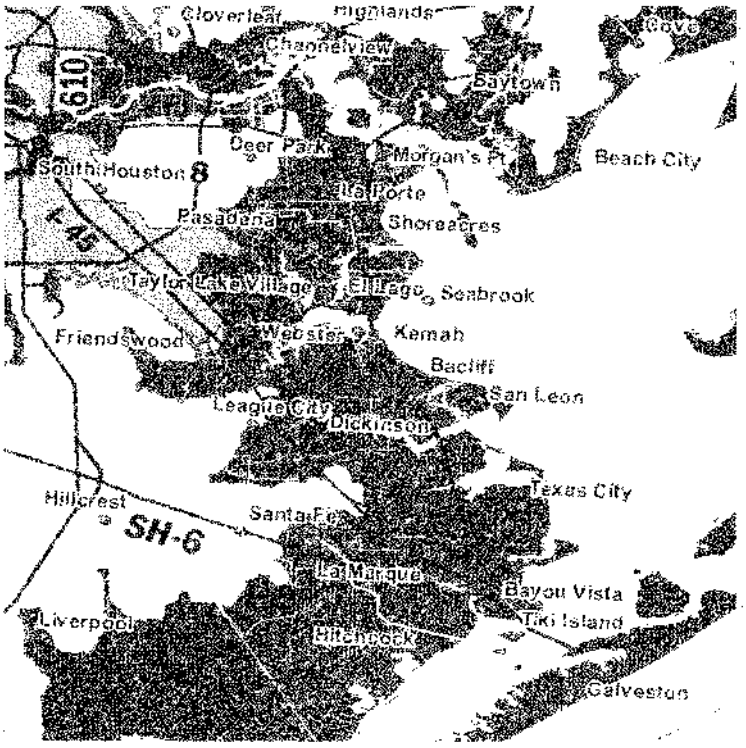


Figure 1. The projected inundated area (in purple) from a weak Cat 4 (FEMA Storm 36) coming ashore at the worst location for Houston. (Computer modeling from SSPEED Center; graphic by Christina Walsh for the author.)

Such a hurricane's storm surge would inundate the area shown in purple , including the western bay cities that are identified and the refining and chemical complexes up the Houston Ship Channel (top center), the Bayport complex (north of Taylor Lake Village and El Lago) and the Texas City industrial complex. Areas shown in yellow are the portions of incorporated cities not flooded by this surge, the pink area is that part of the City of Houston also not flooded by this surge and the light grey is unincorporated areas not flooded by this surge.

In the case of the Houston Ship Channel (a federal navigation project), non-federal action may generate surge protection to a greater level than federal action will provide, an important piece of the resilience puzzle that is related to both the characterization of the risk and the flexibility of our evaluation tools. To this end, the SSPEED Center has proposed the Galveston Bay Park Plan, an in-bay surge protection system that is compatible with and supplemental to the Coastal Spine barrier recently proposed by the U.S. Army Corps of Engineers. Further discussion of this issue is set out in Sections 3 and 4 of this presentation.

Fourth, for humans to be resilient, we need vision, information and action. Vision includes mimicking nature where possible, "living with water" and protecting critical infrastructure and people from the big storms of the future. Good information is imperative to making sound decisions, yet it is lacking, if not absent, at least in the Houston region regarding issues such as the size of rain events and hurricanes in the future, flood detection and warning and public awareness and education. We often seem to skip this step of good information and go directly to "action", and that is a major resilience-related mistake from my perspective.

3. How to Mitigate these Storm Impacts

In order to mitigate the potential impacts from storm surge and heavy rains, a community should first develop a realistic vision for the future, then create and disseminate high quality information about those risks and solutions, and finally take specific action as quickly as possible given that some of these solutions may take a decade or more to implement.

Vision is important. We need to "see" a pathway forward. That pathway has to include an image of what it means to "live with water", particularly in our coastal areas and in major cities adjacent to river systems. But a realistic vision needs realistic information in order for us to understand how much water we need to plan for. Our lack of vision is only compounded by our failure to recognize that rainfall events are getting larger and more frequent, as evidenced by the chart below compiled by the Harris County Flood Control District (see Figure 2). The maximum rainfalls for various durations of time from four recent storms affecting the Houston area reveal our lack of understanding of our risks when they are compared to what meteorologists call the 100-year and 500-year rainfall amounts in Houston for these same durations. The 100-year and 500-year rainfall events (typically based on a 24-hour storm duration) are those utilized in the current 100-year floodplain maps from the Federal Emergency Management Agency (FEMA), including those we have here for the Houston area.

Likewise, Hurricanes Harvey, Irma and Maria, all from 2017, are among the most severe that we have experienced. We need to foresee these extreme events in the future and have an approach to our

development patterns that can accommodate these storms in areas such as the undeveloped land adjacent to the coast and in our floodplains, and an approach that can repel these waters for areas around our existing critical infrastructure and communities, perhaps creating a metaphor of the yin and yang of flood protection in the future.

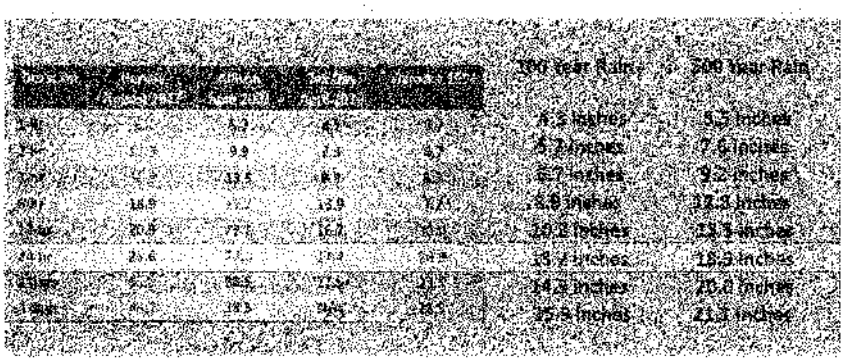


Figure 2. Maximum Rainfall Amounts from Recent Storms affecting the Houston area compared to the FEMA 100-year and 500-year storm events. (Rainfall reports are from Jeff Lindner, Harris County Flood Control District.)

Information is the second key component to flood damage mitigation. We need the best possible understanding of the size and severity of our future storms. We cannot depend on the statistics of the past when we are seeing storm characteristics changing before us. When Tropical Storm Allison hit in 2001 with extraordinary rainfall amounts, our flood control district captioned their report "Off The Charts", with some considering Allison to be a 10,000-year event. And then came the 2015 and 2016 Memorial Day, Tax Day and Halloween flood events, also very large rainfalls, followed by Harvey in 2017 which

went even further off the rainfall charts. Similarly, Hurricane Ike in 2008 had an unusually large wind field for "Category 2" level wind speeds, and thus exceeded projected storm surges for such a hurricane, causing the National Weather Service to add a surge estimate to the longstanding use of wind speed-based categories that is also based on wind field size. Unfortunately, future prediction of increasing hurricane statistics does not currently exist and will be further discussed in Section 4.

Action is needed in several areas. We must protect the critical infrastructure of the Houston Ship Channel, the Bayport Industrial complex and Texas City. The Coastal Spine that has been proposed by the U.S. Army Corps of Engineers is part of a coastal defense system for the Galveston Bay area, but that system, while certainly helpful, does not adequately protect these three refining and chemical centers and the nearby local communities from the larger storm events of the future and the surge generated within Galveston Bay behind the Coastal Spine. To address this situation, the SSPEED Center has developed an in-bay barrier system called the Galveston Bay Park Plan, a concept that combines the future widening of the Houston Ship Channel with additional flood protection by converting the dredged material into the building material for the in-bay barrier. That concept is shown in Figure 3.

Figure 3. The proposed Galveston Bay Park Plan (shown in the center of the image of Galveston Bay). Image from SSPEED Center by Rogers Partners.

This structural flood protection project will be constructed to a height of 25 feet above sea level and will utilize dredge material generated by the future widening of the Houston Ship Channel. Small craft navigation and water circulation gates are indicated by the five red lines and the red circle indicates the location of the deep-water navigation gate for tankers and container vessels. The green area is

beneficial use upland and marshland construction, and the created land mass is proposed for various human recreational activities.

In order to construct this project, a permit application is proposed to be submitted to the Corps of Engineers on behalf of one or more governmental entities. At this time, ongoing discussions are occurring with stakeholders such as the Port of Houston to determine their willingness to participate in this permit application to construct this project which has been determined by the Corps of Engineers to be compatible with their Coastal Spine proposal. This 25-foot in-bay barrier will require construction of various components, such as a levee, several gate structures including a major navigation gate, and raising the Texas City flood protection levee to 25 feet. It is anticipated that elements of the Coastal Spine, such as the newly proposed dune construction and back-side levee around the City of Galveston, could be proposed for early implementation by the Corps, while the type of structure for the large gate system across the Bolivar Roads pass connecting the bay with the Gulf is being reconsidered and redesigned to make it perform much better from an environmental impact standpoint. I want to commend the Corps for looking into making these modifications in their plan and look forward to working with them in the future as we attempt to implement these two project components of this regional surge protection system.

There are many other actions that need to take place in order to make the Houston area more resilient to major flood events. For example, the Addicks and Barker federal dams are two of the best flood control investments ever made in Houston, yet about ten years ago, the U.S. Army Corps of Engineers identified them as being 2 of the Corps' 6 dams nationally that were in danger of "catastrophic failure". This is a serious dam safety issue, with hundreds of thousands of human lives at

risk; this issue should have been immediately addressed back in 2009 when it was first discovered. While a portion of the various dam safety issues have been addressed, the disastrous flooding both upstream and downstream of those dams during Harvey (2017) re-enforced the need to address the remainder of the dam safety issues at these dams sooner rather than later.

We also need to move forward more quickly with the federally authorized projects on White Oak, Brays and Hunting Bayous, and Clear Creek, as Harvey also reminded us of their need. And while that does appear to be happening, it is worth noting that even though these actions will improve the current flooding situation, they will not adequately address the flooding problem because their design is outdated because the level of protection they were designed to deliver will be much lower due to our recently increased rainfall standards as set out in NOAA Atlas 14. Perhaps most importantly, we must understand the long-term implications of these increasing rainfall numbers and develop a better methodology to analyze them than is currently in place.

It is also important to have non-structural alternatives to complement these structural alternatives. Non-structural alternatives generally serve to incorporate more natural measures to reduce damage rather than to provide physical protection. In the work we have completed at the SSPEED Center, we focused on developing economic solutions that will pay landowners to keep their land natural and to even create economic development that is – by its nature – resilient. In this regard, two important options have been created – the Texas Coastal Exchange and the proposed Lone Star Coastal National Recreation Area.

The Texas Coastal Exchange has been developed as a private, non-profit organization that is focused on coastal protection and carbon sequestration. Initially, TCX will focus upon the areas of the Upper Texas coast, that are at or below elevation 20 feet which would make them subject to coastal surge flooding. In these areas, TCX is contacting landowners of marshes, coastal prairies and bottomland hardwoods that are, or could be, sequestering carbon dioxide. TCX is proposing to make grants to these landowners to protect their private lands and its carbon storage capacity and create a financial incentive to increase that potential over time. To obtain funding for these grants, TCX is offering the public of the Texas coast and the world the opportunity to donate an amount of money equivalent to the size of their carbon footprint based on the estimated value of that footprint. However, this is not a formal offset system, but rather a contribution to protect the various ecological services of the Texas coast, including flood storage, water supply enhancement, fish and wildlife enhancement and carbon sequestration. In this manner, landowners will receive income for protecting our coastal future, while storing floodwaters, among other things.

The second concept called the proposed Lone Star Coastal National Recreation Area (LSCNRA) involves working with the various owners of conservation lands along the upper Texas coast to better utilize these preserved areas to generate eco-tourism and economic development that is compatible with flooding. The upper Texas coast has hundreds of thousands of acres of national wildlife refuge land, state wildlife management areas, state parks, Corps of Engineers lands, county and city parks and non-governmental organization lands. These lands represent a national ecological resource that has significant

potential for eco-tourism, but there is literally little to no infrastructure or collaboration to support such tourism. To this end, non-governmental and civic organizations and local, state and federal agencies are working together in collaboration with the Lone Star Coastal Alliance. Through this collaboration, the Texas coast is on the verge of becoming a nationally and internationally known recreation venue, having an economic use that does not need extensive physical infrastructure, but rather utilizes nature and local business and talent, making it much more resilient to hurricane surge flooding.

The area of focus for these two non-structural projects is shown in Figure 4. The high-risk surge zone that is the initial focus of the Texas Coastal Exchange is shown in darker green and the conserved lands of the Texas coast that might participate in the Recreation Area are shown in lighter green. Together, these two projects will initiate a different type of economic development that will be much more resilient to hurricane surge, and it is being done by the private sector.

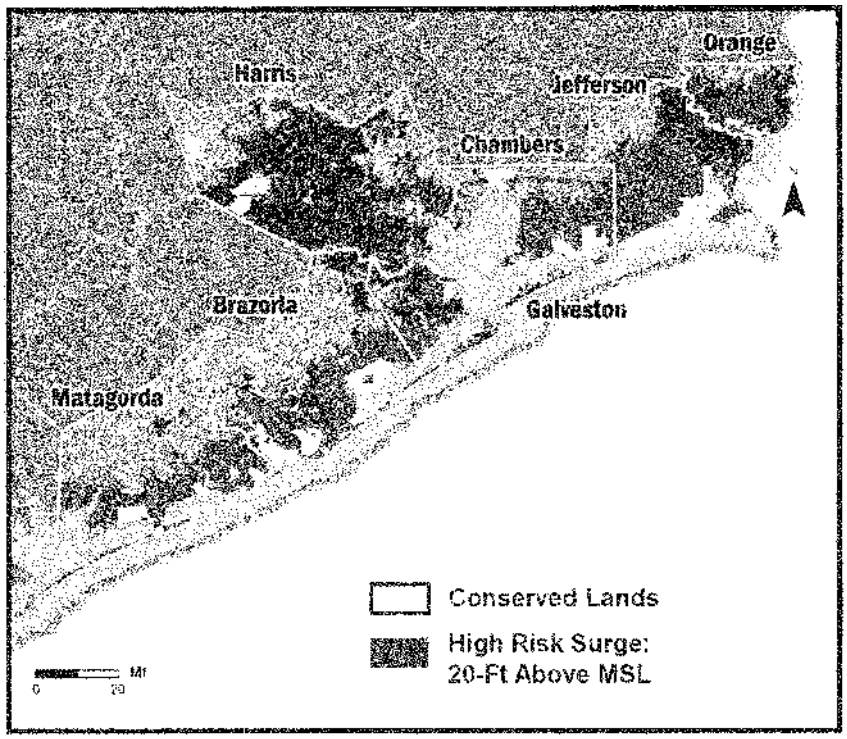


Figure 4. Seven-County Focus Area of SSPEED's Non-structural Flood Damage Reduction Projects. Image by Christina Walsh for the author.

4. How to Improve Hurricane and Coastal Resilience Research

There is a major role for hurricane-related research going forward in the United States and particularly along our coastal areas. Many of the tools we are using today are ill-suited to the storms that we are facing

today – storms much larger and more frequent than previously considered – storms that can destroy an entire industrial complex.

First and most importantly, we need to update our thinking on acceptable levels of risk, risk evaluation, risk avoidance and risk protection relative to flooding. Our storms are getting larger and more frequent. The statistics prove this, and NOAA's recently published Atlas 14 chronicles the fact. The methodologies currently used by engineers and governmental entities rely on past occurrences and past records that do not appropriately account for today's climate conditions. This research should involve a combination of statistical, economic and engineering research done in an interdisciplinary fashion rather than in silos. Our approach to project design for rainfall and surge flooding should be reconsidered and redone because these old methodologies are leading to solutions that are obsolete upon arrival.

Houston is a good example of an area having experienced multiple storm events, each considered as having greater than 500-year or 1,000-year frequency of occurrence, with all occurring within the last 20 years. It is not that solutions based on past determinations of the 100-year flood are not useful; they are. However, these studies and projects are not providing honest information to decision-makers and to the public about the residual risk once these projects are in place and about the need for multiple solutions, including difficult decisions such as buying out flood-prone housing which may be our most effective solution over time. Here, statisticians should be combined with sociologists and engineers and planners and governmental officials to determine risk and the appropriate related reaction that will have long term benefits.

From a climate-related standpoint, we need better projections of future rainfall events and future hurricanes and storm surge. Implicit in this call for research on future storms is that it requires acknowledging the fact that the climate is changing, and not for the better. Forget about why the climate is changing for the moment. The important point is that the climate is changing, and we cannot continue to ignore this fact in our research and in our project design.

In this regard, one serious concern is the potential for the overlap of major rainfall flooding with a major surge event as well. To date, the biggest rainfall events (Harvey, Allison and Claudette) in the Houston-Galveston area were tropical storms that did not produce large surges in our area. Going forward, we need to better understand the potential risk of both surge and rainfall flooding occurring simultaneously. Similarly, in New Orleans, the Mississippi River has been near flood stage for months due to unprecedented upstream rainfall. What is the potential for a surge event occurring while the Mississippi is at bank-full, a situation that has not occurred historically?

From a methodological standpoint, the Corps of Engineers is restricted by Standards and Principles, the rules that guide project decision-making. National Economic Development (NED) calculations are not sufficiently flexible to allow national-security related infrastructure to be protected against these future larger storms. Nuclear power plants, considered as "critical infrastructure", are provided with a much higher level of flood protection than the nation's refining and chemical manufacturing centers. Instead, under Corps procedures, more than one hundred hypothetical storms are averaged to determine the best economic decision for flood protection of these centers rather than protecting them against a certain sized or

recurrence-interval storm. This method can lead to major investment in undersized facilities, thereby failing to achieve either realistic protection or wise economic expenditure.

As stated in the text, the current floodplain maps for Harris County – and much of Texas – are obsolete and in the process of being updated. However, these changes will be based on statistics from decades ago through 2017. These new maps do not look at more recent events going forward, and thus will also be obsolete on arrival. With new methodologies for rainfall prediction, our maps could be anticipatory rather than lagging. This is important not only for the location of homes but also for the protection of hazardous waste treatment, storage and disposal facilities, municipal landfills and the appropriate construction of roads and highways. The infrastructure of the future is dependent upon getting the rainfall (and surge) used for planning and design calculations to be reflective of more recent events and the reality of our changing climate.

Similar reconsideration needs to occur with regard to coastal surge flooding. Current floodplain maps do not accurately depict the future risk of surge flooding. The larger storms of the future will send larger surge events into our coastal areas. We must anticipate this surge and provide high quality information as one of the first steps in developing the best damage prevention measures.

From a social standpoint, the issue of equity in flood protection is an important research topic. The National Economic Development (NED) methodology identified above focuses almost entirely upon economic benefits of a project being greater than the project costs. By such a focus on dollar benefits, a project might qualify for construction in a wealthy part of the community and might not qualify in a lower

income area, even if more people and homes would be benefitted in the lower income area. In this way, discriminatory patterns of federal investment can occur even though unintended. We believe that this situation has occurred in the Greens Bayou area in Houston, the second most populous watershed and among the lowest income areas. It has not qualified in the past for major federally-funded, structural flood protection. The better integration of social concerns into project selection methods is another important research area. Here, policy researchers should be united with sociologists and engineers to find new pathways.

Similarly, research is needed into the pairing of home buy-out programs with the provision of replacement housing. Buy-outs are likely to emerge as a major alternative throughout the Houston-Galveston region if not the United States. We simply will not be able to protect all of our current housing inventory from the storms of the future. Buy-outs are quick and very effective at removing people from harm's way. However, particularly in lower income areas, affordable replacement housing is usually lacking. These two issues must be linked, particularly in lower income areas. Here, architecture and urban planning research should be combined with sociologists and engineers to provide interdisciplinary guidance. In doing so, beneficial use can be provided in the abandoned areas with essential public places such as parks and nature preserves that are compatible with flooding.

From a slightly different perspective, it is important that we maintain and protect undeveloped coastal lands because they are resilient. Here, economic research into the dollar value of these natural lands like coastal wetlands, coastal prairies and coastal forests should be supported, particularly from the perspective of developing markets

for the ecological services provided by these lands. In Texas, much of this land is private property and many of the landowners wish to continue ranching. We should support economic and ecological research into increasing "cash-flow" to these coastal landowners, particularly in the development of a viable carbon dioxide transaction system that works for United States landowners. Similarly, research might be undertaken into diversion of some of the $20 billion in agricultural subsidies to ecological service payments for ranchers and coastal landowners who maintain natural ecosystems to the benefit of us all.

In the discussion above, attention has been focused on specific research areas. However, there is a need for general research into one major topic. We, as a country, need to learn to "live with water". Over recent human history, our settlement patterns have been based upon banishing water from our developed areas through engineering – through channels, underground conduits, dams and reservoirs. And while this infrastructure is very important, the rains of the future cannot be "controlled". No city in the world could have controlled the rainfall from Hurricane Harvey. It is more reasonable to think in terms of "managing" the rainfall from Harvey. However, that means that our concepts of development and developed areas must change a bit, particularly along the coastal areas of the United States.

Living with water involves dedicating a certain amount of land area to water – it means setting floodplains aside for flood waters. It means understanding how much land is required to accommodate the storms of the future. This research combines all of the elements identified above - statistics and risk assessment, hydrology, climatology,

engineering, architecture and urban design, economics, sociology - into a coherent concept of urban design for the future.

In summary, research is needed in the following areas:

(1) Acceptable levels of risk, risk evaluation, risk avoidance and risk protection relative to flooding and flood damage reduction projects;

(2) Better projections of future rainfall events, hurricanes and storm surges, in recognition of climate change;

(3) Potential for major rainfall-related flooding being combined with major surge flooding;

(4) Equity in flood protection, with integration of social concerns into project selection;

(5) Integrating home buy-out programs with provisions for replacement housing;

(6) Economic valuation of our natural, undeveloped coastal lands, including the development of markets for the ecological services they provide; and

(7) Learning to "live with water".

Thank you for inviting this testimony. If you need further information, please contact Jim Blackburn at blackbur@rice.edu.

Jim Blackburn Bio

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Jim Blackburn is an environmental lawyer and planner. He is a Professor in the Practice of Environmental Law in the Civil and Environmental Engineering Department where he teaches environmental law and sustainable design at Rice University. He is co-director of the Severe Storm Prevention, Education and Evacuation from Disaster (SSPEED) Center at Rice, a faculty scholar at the Baker Institute and Director of the undergraduate minor in energy and water sustainability. Blackburn set aside environmental litigation to concentrate on research and teaching and expand his planning practice through his firm, Sustainable Planning and Design. He has authored two books published by Texas A&M Press – *The Book of Texas Bays* in 2004 and *A Texan Plan for the Texas Coast* in 2017. He has co-authored two books that are collections of poems and artwork with artist Isabelle Scurry Chapman, titled *Birds: A Book of Verse and Vision* (2009) and *Hill Country Birds and Waters: Art and Poems* (2019). Blackburn received the Distinguished Alumni Laureate Award from Rice University in 2018, the Good Egg Award from the International Crane Foundation for litigation to protect the endangered whooping crane in 2015, the Barbara C. Jordan Community Advocate Award from Texas Southern University in 2007 and the Robert Eckhardt Lifetime Coastal Achievement Award from the General Land Office of the State of Texas in 1998, among others. Also active in civic affairs, Blackburn founded the Bayou City Initiative (BCI), a Houston-based NGO focused on community recovery and long-term flood protection post Harvey. He continues to serve on the boards of the Matagorda Bay Foundation, the Texas Coastal Exchange and the Aransas Project, three NGOs committed to protecting the Texas coast.

Chairwoman FLETCHER. Thank you, Mr. Blackburn.

So at this point we will begin our first round of questions. We will begin with the Committee Members of the Science, Space, and Technology Committee, and then we will turn to our colleagues from our Houston delegation to ask questions as well. With time permitting, we will have two rounds of questions.

And for those of my colleagues—since we are in a field hearing, it's a little bit different than our setup that we're used to in Washington. But we each will have 5 minutes to ask questions of any of the witnesses on the panel, and I would remind my colleagues that the timer is right at the base of the stairs of the 5 minutes. And the lights will light up, and the witnesses should be able to see it as well to know if we're coming close to time.

So with that, I will recognize myself for 5 minutes. My first question is directed to Dr. Uccellini. In the face of changing climate, Dr. Uccellini, what role can the Weather Service play not only in a short-term weather forecasting and predictions but also in long-term climate predictions? And, as we think about those challenges facing the coast, can you tell us what extent the Weather Service is currently engaging with stakeholders in the coastal resilience and infrastructure community on these particular issues?

Dr. UCCELLINI. OK. So a number of questions there. With respect to the changing climate and its impacts along the coast, the principal impact has to do with the rising sea levels. With the warming ocean, the sea levels will rise for two principal reasons. One is the expanding volume of the water that's heated, and the melting ice that we see over the globe is certainly having its contributions to the rising sea level as well.

We—now, we have to accommodate that background—changing background state into storm surge and potential impacts of intense storms, whether they be hurricanes or extratropical storms as well. So we do that—that's part of the short-term aspect is recognizing that background state is changing, and we need to account for it with respect to our watches and warnings.

With respect to, you know, research into the changing climate, the Weather Service has responsibilities for predicting out to the sub-seasonal to seasonal range. And what we're doing today that we weren't doing 15 years ago is using dynamic climate models to improve or attempt to improve those forecasts that are used for water resource management, et cetera. We're seeing success in the temperature forecast. We're actually seeing challenges with precipitation forecast, and that's probably going to be the biggest challenge that we—that we'll face.

We work with the climate community in these models by running them every day and in some cases like in our models we run four times a day. We are testing the fidelity of the algorithms that are then used by the research community in the global change arena. So our effort is to continue to improve those models both from a dynamic and from a physical perspective. And then we put those results back to the—to those researchers within government, within the academic community, on the—these model changes.

So, you know, that's basically what we're working with both from a short-term and long-term perspective.

Chairwoman FLETCHER. Thank you, Dr. Uccellini. And my next question is to the other panelists, if any of you all could talk about how the National Weather Service products and services, which are particularly useful in your research or where there might be additional areas where you would like to see opportunities for weather research for your purposes.

Dr. RIFAI. So we use the products extensively, and we are very much dependent on a lot of the data that's generated. Obviously, the precipitation information, the climate change, the sea-level rise. I think it's going to be hard for us in the research community to keep up with change, so that's something to think about.

In Houston, we're designing or have designed for 12.5-inch storm. The new Atlas could be anywhere from 16 to 18 inches. Experts tell us hydrologists such as myself, that our capacity in our bayous is no more than 6 to 8 inches in a 24-hour period, so we've got a big disconnect to live up to, and that's really the biggest challenge is this gap between what we're getting from NOAA to what really needs to be done and is being done at the—in the trenches so to speak.

Chairwoman FLETCHER. Thank you.

Mr. BLACKBURN. Do you want to say something?

Ms. GROVER-KOPEC. Yes, briefly.

Mr. BLACKBURN. Go ahead.

Ms. GROVER-KOPEC. Yes. We also make extensive use of National Weather Service products. So I mentioned that we use the quantified precipitation forecast for our flood modeling for live events, and we're trying to actually extend our technology as the Weather Service does the same, right? So there's a lot of work and funding going into the MRMS project from out of the National Severe Storm Laboratory. That's Multi-Radar/Multi-Sensor project, sort of the next step in understanding quantified precipitation as it falls. And we'll be utilizing that data and working it into our technology as well. We also utilize some of the weather observations into our wildfire monitoring to understand live events for wildfires as well.

Chairwoman FLETCHER. Thank you.

Ms. GROVER-KOPEC. Yes.

Chairwoman FLETCHER. Mr. Blackburn briefly.

Mr. BLACKBURN. I'd just like to add that we make extensive use of what we have access to. It would be nice to see that work expanded in the sense of not only looking for what has happened in the past up to 2017, which is what NOAA Atlas 14 does, but begin to get projections of where we see these storms going in the future because that's what's really important to me because we're building stuff now, like I said, that's going to last for 50 years. And we need to know what that climate looks like going forward, and we don't really have the tools at all that will help us make those decisions. And I think that's an area for serious research. Thank you.

Chairwoman FLETCHER. Thank you, Mr. Blackburn. And I have now exceeded my time, so I will yield back. And I will recognize Dr. Babin for 5 minutes.

Mr. BABIN. Thank you very much. I just lost 4 seconds there. OK. All right. To the panel——

Dr. RIFAI. I'm glad you can see it.

Mr. BABIN. Can each of you, very briefly if you would, identify for us the areas where you believe this Committee can best focus on the research or moving forward both for weather forecasting and developing resilient communities? And we'll start with you, Mr. Blackburn. And try to keep it as brief as possible.

Mr. BLACKBURN. Well, briefly, urgency. I think there is an urgency about addressing and really elevating this flooding problem to the—I think the national security issue that it is. And I think you could help with your abilities to focus us as a Nation on that issue. And I think a lot of the rest of it will follow.

Mr. BABIN. I could not agree more because I represent oil refining and chemical facilities in my district than anywhere else in the country.

Mr. BLACKBURN. Yes, sir.

Mr. BABIN. And after Ike, the gasoline price spiked throughout the country, and so I appreciate that answer. Ms. Grover-Kopec.

Ms. GROVER-KOPEC. Actually, I think through action demonstrated by this hearing is being open to new technologies like AI and ML. There's broad understanding of its potential across the board not just for disaster resiliency, and congressional committees have put some good funding into resilient projects. And having those projects being open-minded to including new technologies to demonstrate the efficacy and accuracy of those products would be a great way——

Mr. BABIN. OK.

Ms. GROVER-KOPEC [continuing]. To implement them.

Mr. BABIN. Thank you.

Ms. GROVER-KOPEC. Yes.

Mr. BABIN. Doctor?

Dr. RIFAI. So in the big scheme of things we're heavily weighted on built environment and on infrastructure. We've paid a lot of attention to that, not so much on people. I think we need to bring both in the balance and start thinking about how people interact with their natural and built environment and their infrastructure.

Mr. BABIN. Excellent.

Dr. RIFAI. To me, that's very important.

Mr. BABIN. Excellent. Dr. Uccellini?

Dr. UCCELLINI. Yes, thank you for the opportunity to answer this question. First of all, the extensiveness of the effort that's actually involved, technology through science and any related applications.

Support of the *Weather Act*, this is probably the most foundational law that's been enacted that I know of that will have a direct impact on our ability to serve and people to react.

Understand that it's from a spectrum from observations forecast to decisionmaking, so it's the importance not only of the physical sciences but the social sciences. We have to have both to move forward.

Mr. BABIN. OK. Yes, thank you. Excellent.

And, Mr. Blackburn, much of your research is focused on resilience. Lack of resilient infrastructure was clearly an issue when Hurricane Harvey made landfall in August 2017. As we seek to prepare for future severe weather events, how do you differentiate the roles of different levels of government? What role should the

Federal Government play in helping communities to improve resilience to these types of weather events?

Mr. BLACKBURN. Well, I think all levels of government have to play in this, and I think the Federal Government historically has been a funder, a major source of funding. I would tell you that what I would like to see the Federal Government do is to reevaluate the methodologies they use to evaluate funding. I think there is a lot that can be done there.

Our local government has stepped up with a $2.5 billion Flood Control bond issued in Harris County. The State of Texas has begun to get involved, and they were the last to get involved, and they were missing for a long time. But I'm happy to see that they're involved. All three have to be involved. I would say that a lot of the lead could come from the local government, but I think the Federal Government has always been the rudder, and think it will continue to be the rudder that will guide us. I would just like to see your methodologies updated. Thank you.

Mr. BABIN. Thank you as well. I'd also like to reiterate not only do I have the petrochemical plants, but I also have Port of Houston. And it was shut down. And so it was an acute feeling of helplessness when we——

Mr. BLACKBURN. I understand. We're working on that, and——

Mr. BABIN. Yes.

Mr. BLACKBURN [continuing]. We'll be back in touch with you on that.

Mr. BABIN. You bet. Dr. Uccellini, Hurricane Sandy struck New Jersey and New York October 2012, causing tremendous damage. What lessons were you able to take from forecasting Hurricane Sandy to the forecast for Harvey, and what lessons did you learn from Harvey, and how will you be able to apply those to future hurricane forecasts?

Dr. UCCELLINI. Well, Hurricane Sandy and Hurricane Harvey had similar traits and that is that they were highly unusual in terms of their track and the duration. I would say that from a forecasting perspective and a very difficult what we call predictable—predictability issue with respect to Sandy, that the forecasters did a remarkable job in predicting and communicating uncertainty.

What we learned from Sandy, however, is the connectivity with decisionmakers across the government spectrum—local, State, to Federal—and it's been since Sandy that we've really adopted that into our strategic goal of building a weather-ready Nation and providing what we call now impact-based decision support services, which is also authorized by the *Weather Act*. And what this means is that we have to practice, practice, practice, practice, practice before an event, well before an event, establish the trust with these decisionmakers. And that's—I think was a test of us in Harvey and up and down the Texas coast.

I'll point out that with the new satellite that was launched and our co-location with the emergency managers who we know each other really well, there were some tremendous decisions made during Harvey up and down the Texas coast, including where the eye wall crossed the coast and firemen went out in the eye itself—that never would have happened before—and saved over 200 lives. So we learned our lesson there.

What we know for now is that we can't rest on past laurels. We scrub every event to learn what to do for the next event. And we're always in the process of doing that.

Mr. BABIN. Thank you very much, and I yield back. My time is expired.

Chairwoman FLETCHER. Thank you. Thank you, Dr. Babin.

Mr. BABIN. Yes, ma'am.

Chairwoman FLETCHER. I will now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you, Madam Chair. And since I'm going to be leaving for an airplane here shortly, do I get 10 minutes now? I'm just asking.

It's a great event you're holding here, and we really appreciate that. I do have a lot of questions. And I will be here for round two.

Dr. Uccellini—am I saying that right—we got to tour the National Weather Service this morning, and you did a fab job down off of Highway 646 in Galveston County, which happens to be in my district. Hurricane Harvey, for many of you all who may or may not know, we were ground zero for flooding. I represent all three coastal counties starting at the Louisiana border. I got Jefferson County, then I've got Galveston County, then I have the southern half of Brazoria County. So for us it was a huge event.

I got to drive all three counties during that time, as I told you all earlier today. I have an F-350 1-ton truck 4-wheel-drive. I'm from Texas after all. It sets up about knee-high, and I can go through water that most cars would never dream of. I got to watch you all in action, I've got to watch Jefferson County Emergency Management Center in action, and I got to watch Brazoria County Emergency Management Center in action. So I got up close and personal to watch this in real time what we were going through.

So this is a very timely hearing, Congresswoman Fletcher. Again, I applaud you for holding it.

This stuff is huge and very, very important to the Texas Gulf Coast. Dr. Babin is right. He may have more refineries than I do, but we actually manufacture about 65 percent of the Nation's jet fuel in my district, about 20 percent of the Nation's gasoline east of the Rockies. And when you take the—in my district. Now, that's without the Port of Houston. Jump up and grab that port, it's almost 85 percent of the Nation's gasoline, almost 60—jet fuel rather, and almost 45 percent of the gasoline. It is huge, about 6 million people in the collective area.

I noticed that you talked about 800,000 people up and down the Ship Channel, but I would say let's expand that to all the families and the homes and the jobs that it represents, so that this is a huge issue for us to tackle.

Well, all that to say that being a Member of the Science Committee, we are actually working on now a new type of supercomputing. You've probably heard about it. And my question is, are you interacting with any of the national labs on quantum computing?

Dr. UCCELLINI. The research component of NOAA certainly is, and as we work our way toward the next generation of computing over the next 10 years, we are actually—well, NOAA and especially the Weather Service is what's been designated as an implementing agency. So we are certainly working with the research community

within the government and outside the government on this next-generation compute, and we stand ready to be able to run on those computers and test out the new technology.

Mr. WEBER. Well, thank you for that. You said in one of your question and answers with one of the Members that you are running tests on algorithms. And if I understand correctly, quantum computing helps us run tests on algorithms. And maybe this is a question for the lady from the AI community.

Dr. UCCELLINI. Right.

Mr. WEBER. Just super, super fast. Do you know if that's the case? Quantum computing—I'm sorry, your name is——

Ms. GROVER-KOPEC. That's OK.

Mr. WEBER. Dr. Grover-Kopec. Am I saying that right?

Ms. GROVER-KOPEC. It is, yes. I will defer—we are not using it, but I think it's more attuned to the scale of work that the Weather Service——

Mr. WEBER. Right.

Ms. GROVER-KOPEC [continuing]. That NOAA is doing.

Mr. WEBER. Now, you did mention in your testimony that you want to take the human element out of it as much as possible. You want this artificial intelligence to be making—and obviously, they can make decisions quicker than any of us can generally speaking. But I will tell you, based on what I said earlier, I made all three of those counties—for about a solid week and a half I was on the ground in all of the emergency management centers. I was in many of the shelters and watching this in real time unfold. The Brazos Port River and the San Bernard River come to the southern Brazoria County, and my district director and I were over there day 1, and we said it's only a matter time before everything downstream is flooded. So we watched that very closely.

I have to say, especially the Weather Service, who is embedded with the emergency management center over there in Galveston County, the people that were making those decisions were making it based on families and houses and neighborhoods and yes, industry, and yes, the ability to produce and manufacture gasoline, diesel jet fuel. You can go right—refined chemicals. You can go right down the list. So if we come in with artificial intelligence, are we going to be able to do that in such a way, Ms. Grover-Kopec, that will help those people to interface with those local officials?

Ms. GROVER-KOPEC. I think that's exactly the point, right? So maybe just to clarify my comment and then respond, some common hesitancy around machine learning is that there's inherent bias in the data. And so my point is in creating models in the data that we collect, we're doing so in a way to avoid that bias.

But in terms of actually using the modeling to respond to events, we're absolutely on the same page. So, for example, the products that we put out for our live events actually allows a jurisdiction to look to see where the most vulnerable communities are, where are the hospitals, where are the nursing homes, where are the schools so that they can respond appropriately and have the human element of response in the decisionmaking, not in the analytics. If that make sense?

Mr. WEBER. OK. Well, I'm over my time. I appreciate that. Thank you, Madam Chair. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Weber. I will now recognize Mr. Olson for 5 minutes.

Mr. OLSON. Thank you, Chairwoman Fletcher, and thank you so much for your hard work to make this very important field hearing happen. And welcome to our four witnesses. A special welcome to Dr. Uccellini. One of your alumni from your alma mater, a guy named J.J. Watt, showed what Houston Strong means during Hurricane Harvey. That man by himself, our star football player, promised to raise $250,000 for our citizens here in Houston. He stopped at about $338 million. That is Houston Strong. That is J.J. Watt. Thank you, Wisconsin, for giving us such a hero.

As you all know, damage from hurricane comes from mostly two sources, a storm surge—a wall of water—and heavy, heavy rainfall. Hurricane Ike in 2008 had a wicked storm surge wherein above the sea wall built after the Galveston hurricane in 1900 ricocheted off the older part of Galveston Bay, came back, hit Galveston without protection, and I saw all the damage that happened because of Hurricane Ike. And that was just a category-2 storm.

Harvey was not a storm surge, at least not for us. Some parts of my district got 5 feet of rain in less than 2 days. In fact, it got so bad, as the Chairwoman knows, there are two reservoirs near Kinney, Texas. One is called Barker, one is called Addicks. They've never been open to stop an overflow of the levees, of the dams. They had to open those gates early, in the middle of the night. It flooded 600 homes, the subdivision called Canyon Gate. Those people woke up homeless.

And so there's all sorts of solutions. We've talked about a third reservoir up there with Barker and Addicks. We've talked about a tunnel coming from Kinney down through Texas City, La Marque to Galveston Bay. We've talked about the coastal spine.

But my question is, in your opinion, all of you, and starting from the left to the right with you, Mr. Blackburn, in your opinion, how should we be investing our limited resources? How do we balance things between storm surge, rain in an environment where, coming from D.C., our funds are very limited? As you know, right now, we're facing a $21 trillion national debt, and that's going to go up this week. So without a boatload of money coming from D.C., how can we fight to make sure we're resistant in the future—prevention?

Mr. BLACKBURN. Well, that's a tough one. And I appreciate you asking that.

Mr. OLSON. That's why I'm here.

Mr. BLACKBURN. I understand that. I appreciate you asking the question. A couple of thoughts on that. First of all, I think we've got to find more sources of money than just the Federal Government. We've got to—I mean, I mentioned the fact about trying to figure out how to bring other sources of money to this. There's all sorts of creative bond concepts that are out there. They're not being implemented. I don't know why. I think this is one of the things we're about to find out a lot more about.

But I would just say, one, trying to increase the pool of money that is available ought to be a priority, and I think the private sector is a place to look and find that support.

Second, I think that there needs to be prioritization of a number—I think you've got to split between storm surge and between rainfall flooding. They're both big issues. They're both huge issues. I would tell you the surge flooding is perhaps the more violent of the two. I think you've got a greater chance of loss of life. I think you've got a lot of—a better chance of major industrial damage and a huge environmental release. And I think that just on that scale surge demands a lot of attention. And we forget it a lot because it seems like we have a 100-year rain here all the time, but it—we don't have a 100-year surge very often. But I would split that between the two. Thank you.

Mr. OLSON. Ms. Grover-Kopec?

Ms. GROVER-KOPEC. I actually—I might turn the question on its head a bit. Rather than focusing on diverting research toward one aspect of a peril versus another, rainfall flooding versus surge, I would look at what makes the community more resilient regardless of where that water is coming from. And it won't surprise you that I'll say insurance. Take up for insurance among private citizens for flood is incredibly low, and we know that a significant amount of the loss that was seen in Harvey was outside of the NFIP (National Flood Insurance Program) take-up.

So to Dr. Rifai's comments around social behavior, there's actually research in trying to guide the positive decisionmaking to get people to purchase that insurance, and having the products there available to them I actually think would be a good start.

Mr. OLSON. Well, darn, you're ready for Congress with that answer.

Dr. Rifai, your comments?

Dr. RIFAI. So, very simply, I would second the motion and say we really need to incentivize resilience. Instead of paying us for damages, make us do it better. And when we do it better, it doesn't break.

Mr. OLSON. Dr. Uccellini?

Dr. UCCELLINI. Well, thank you. I was actually—from a water resource management perspective, I can't offer engineering advice because I'm not an engineer, all right, and I don't know the—but we do know that if communities are ready and responsive to these extreme events, they tend to be more resilient. So a comment was made earlier about Barry wasn't as impactful as expected. Maybe it's the result of—that the community really had 5 to 10 days to become ready and responsive to the forecast.

I suggest that if you even look at Harvey versus the 1900 storm, there was no situational awareness of exactly where that storm was or when it was coming in and over 6,000 lives were lost. We'll never know how many lives were actually lost here. Eighty-eight lives lost is a terrible—that's a terrible statistic, but it could have been a lot worse if we didn't have this investment in what we're doing.

So to address the issues that you're talking to will take a lot of effort in terms of becoming ready and responsive to increased resiliency. I would offer that, you know, we focus on the prediction aspect of that and working in partnership with the local communities to make that happen.

Mr. OLSON. Thank you. My time is expired. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Olson. I'll now recognize Ms. Jackson Lee for 5 minutes.

Ms. JACKSON LEE. Thank you, Madam Chair. And let me thank Congresswoman Fletcher for a very significant, timely, and I would offer to say crucial hearing as we are on the precipice of the beginning of probably one of the more intense times of our hurricane season, which would be August really through into the fall.

And I can imagine that we are certainly looking to the question of resilience, resilience I believe being one of the most important responses to the devastation of flooding and hurricanes.

And I think people are also what is important because today, I was—it was brought to my attention of a 75-year-old who is still living in a trailer on her property, pursuant to Hurricane Harvey. That means that throughout our respective districts there are people who are still struggling to be resilient and to overcome the devastation of Hurricane Harvey, 51 trillion gallons of water, which I think we have not seen in this region for the time of our hurricanes, separating from the Galveston hurricane in the early 1900s.

So I thank the witnesses for their presentation, and I have a series of quick questions. I do want to make the point, however, about NOAA and its importance and the Hurricane Research Division, that NOAA is continuing to improve predictions of hurricane intensity, high and sustained wind speeds over the course of a storm's life, storm size, structure, rainfall, and flooding, and storm surge, all of the elements that we ran into—run into with respect to floods and hurricanes.

So quickly to Ms. Grover-Kopec, you mentioned that when we mitigate risk, it should be all over. It shouldn't be in just high-income areas or high-cost areas. Can you just expand on that very briefly?

Ms. GROVER-KOPEC. Sure. I just—it's—it's just—we're a very mission-driven organization and feel that resiliency is our mission and that it should be aimed at benefiting an entire community and all that contribute and live in the community. And typically, with current analytics that are used, purely the financial output is used, which is absolutely important. But we've actually been developing technology that allows you to look at the expense of the community that's impacted, the number of people, the number of homes, which might not necessarily equate to just the financial risk. So the financial element is purely important. We just advocate for taking a more broad view.

Ms. JACKSON LEE. It gives a fair shake to older neighborhoods, senior citizens——

Ms. GROVER-KOPEC. Exactly.

Ms. JACKSON LEE [continuing]. Who are living in different conditions——

Ms. GROVER-KOPEC. Exactly.

Ms. JACKSON LEE [continuing]. Than some of our newer neighborhoods. But then it does not eliminate them because you're talking about all over——

Ms. GROVER-KOPEC. Exactly.

Ms. JACKSON LEE [continuing]. Which I think is extremely important.

Mr. Blackburn, let me thank you for your long service on these issues. How important is our understanding and acceptance of this phenomenon of climate change in our continued research and funding by the Federal Government on this research dealing with hurricanes?

Mr. BLACKBURN. I think it's incredibly important. The rainfall amounts are changing. The data show us that. I think that we've lost a lot of time arguing about this issue. I think just here in the community person after person will tell you that they're seeing a larger rainstorm than we've ever seen in the past, and the data support that. So I would say it's very, very important.

Ms. JACKSON LEE. So we need to focus our time understanding how impactful climate change is and using Federal resources, which you indicated were very important——

Mr. BLACKBURN. Yes, absolutely. And looking to the future. I mean, what none of us have a clue about is what is it going to look like in 5, 10, 20 years. Those are the issues that are most important from my perspective.

Ms. JACKSON LEE. Ms. Rifai, would you explain—thank you—the importance of having a well-trained workforce? I think you mentioned that. And then my final question would be to Mr. Uccellini to mention the use of social media in your work going forward.

Dr. RIFAI. So I think it's very important to educate our generations into this very severe challenge that we have, which is dealing with natural hazards. We really must inculcate it in every student, in every curriculum in every university, community college, high school. Schoolchildren, they are the future, and this is a problem that we're leaving them that they have to deal with. So I feel very strongly that this should be really integrated in everything so that not some of us are prepared, but all of us are prepared today and tomorrow.

Ms. JACKSON LEE. Thank you. Doctor?

Dr. UCCELLINI. Yes, thank you for your question. I like to think of it in terms of the use of all media to get the information out. Social media is becoming increasingly important in interacting with groups of people who reassure each other that this is the real deal and they better take action, so we see that happening. We also get important information from the social media as the event is unfolding, which we can then factor into continually refining our messages during the event. So whether it's communicating outward or communicating in, the whole range of social media is being employed to keep track of exactly what's going on. Thank you.

Ms. JACKSON LEE. Thank you. Madam Chair, let me thank you very much for your courtesies, and I ask to be excused with other matters in my district. And I'd like to thank the Houston Community College for their hospitality. And I see that our Chairwoman is here. I certainly want to welcome her, as I know that you will. But thank you very much for having this a very, very crucial hearing.

Chairwoman FLETCHER. Thank you very much. And yes, I would like to recognize and acknowledge our Chairwoman of the Science, Space, and Technology Committee, Chairwoman Eddie Bernice Johnson, who has joined us from Dallas, delayed by a little bit of weather getting down here. But we are so grateful to Chairwoman

Johnson for her leadership of this Committee, of really bringing together a bipartisan Committee, working together in a bipartisan way with the Ranking Member and serving as a great example to all of us, and for making it possible for us to hold this field hearing in Houston today.

So thank you so much, Chairwoman Johnson, for joining us, and you are now recognized for your questions for 5 minutes. Thank you.

Chairwoman JOHNSON. Thank you very much. And let me apologize for being late. I'm coming from Dallas. I started out at 10 this morning to get here. I had no control over what happened. Just blame the airline.

Let me thank our Subcommittee Chair, Mrs. Fletcher, for taking on the leadership of having this hearing. I was delighted to support her and say welcome to the other distinguished Members of the Committee and our visiting Members as well.

I knew this would be a very important hearing because of where you're located and because of the weather that we are all experiencing. We know very well that we are dealing with this weather change. And it's not a debate. The debate is what can we do to see if we can relieve ourselves of some of the outcomes.

Let me welcome our witnesses and thank you so very much for being here.

We know that we are dealing with a hotter, wetter atmosphere due to increased greenhouse gas emissions and increasing rainfall during typical cyclones. According to the Fourth National Climate Assessment, Hurricane Harvey rewrote the continental U.S. record for total rainfall from a tropical cyclone. It has been estimated that the climate change increased rainfall 38 percent during Harvey, and accordingly, Houston experienced record-breaking floods in the years between 2015 and 2017. I know full well that is not a pleasant experience.

Now, Dr. Blackburn, thank you so much for being here. As extreme rainfall and flooding intensifies in the Houston area due to a changing climate, what research has been done on improving the resiliency of roads and infrastructure?

Mr. BLACKBURN. In terms of the roads and infrastructure specifically, I would say that they are—in a way are among our more vulnerable infrastructure that we have. Unfortunately, they were built at a time before much of the information that we have now is—was well-known, so many of them are below the current 100-year floodplain and maybe below the—and certainly will be below the 100-year floodplain once it's readjusted with the NOAA Atlas 14 data.

So we—I would tell you that roads are extremely vulnerable. I think our chemical plants and our refining infrastructure are also incredibly vulnerable. So right now, I would say we are a very vulnerable community to both rainfall flooding and surge flooding unfortunately.

Chairwoman JOHNSON. Thank you very much. Dr. Rifai, we know we've had a great deal of damage. I also serve on the Transportation Committee, and I've been asking for research for resilience now for several years. And before we can get all of it done, we are in great need of the outcome. What are some of the mecha-

nisms for information-sharing among cities and emergency managers regarding successful strategies for resilience?

Dr. RIFAI. So there's a lot of data that we could use from them, and if we had access to this information, the idea is to put that type of knowledge in with the information from the weather and the predictions and in with the information from the sophisticated AI and algorithms and also from—excuse me—the data that we collect on anticipated damages, weaknesses, vulnerabilities, and fragilities in the system. So it does take all kinds of information to put together a system whereby we can make decisions and make improvements in our systems.

Chairwoman JOHNSON. Thank you. Dr. Uccellini, to your knowledge, how equipped are forecasters and emergency managers quick to respond to rapid hurricane intensity changes?

Dr. UCCELLINI. Yes, we have a very strong partnership. In fact, we call it a core partner with the emergency management community at every level of government as we've developed—or—our strategic or realizing our strategic goal of building a weather-ready Nation. We have to be in partnership with the folks who are on the ground and making decisions. And whether we are co-located with them, as we are here, whether we surge our resources to embed in the emergency management community during an event, or whether we're working through the social media outlets to—or direct communications, we keep them up-to-date on the situational awareness and whether it's in the forecast mode or during the actual events. So these rapid changes that we're seeing are well-communicated with them.

And, as I answered before with respect to the changing climate, we have to calibrate our forecasts accordingly for things like storm surge or coastal flooding conditions based on sea-level rise, for example. So all of this is worked into our ongoing practice with them and actually during the event.

Chairwoman JOHNSON. Thank you very much. Let me just say that we just are celebrating the 50th anniversary of Apollo, Houston is very familiar with, and many people don't equate often that research with the outcomes of which we are working with today, all of the weather forecasting and all that. It's been such a tremendous 50 years of findings, but we still need additional information.

It is clear that we have gained by having access to that information because we're saving a lot more lives with the projections and the predictions. We're trying now to make sure we can save some properties as well.

I want to express to all of you just how important this is to our Committee's research and direction. All of us here that are on the Committee are very concerned about what we can do and do it in a fairly rapid manner to see if we can improve from where we are. And we are bipartisan, as you can tell, and I don't know that I could say that any Member on this Committee is doubting whether or not we are going to look out for as much as we can to try to prevent more property loss in all of this weather change.

Let me thank Mrs. Fletcher, and I will yield.

Chairwoman FLETCHER. Thank you very much, Chairwoman Johnson. I will now recognize Ms. Garcia for 5 minutes.

Ms. GARCIA. Thank you, Madam Chair, and I, too, want to thank you for bringing this field hearing to Houston. And, Chairwoman, thank you for all the support that you gave Representative Fletcher to make sure that we could do this because, as you said, this is a very critical topic, and all of us must work together not only as Members of Congress but together with all the other local governments.

And I do want to acknowledge that Council Member Stardig is here, and I know I've worked with her on some of these issue. And our former County Judge Eckels, who also is known for knowing these issues like the back of his hand, so thank you for doing that.

And most of you on the panel I've run across before because, like many here at the table, I've been through Katrina and Rita and all of them. You know, I remember Tropical Storm Allison. I mean, that was not a surge event. It was just a hell of a lot of water. And that was probably the first time we experienced something like that to a great degree here in Houston. So we've been through a lot together.

And my questions are really going to be to Ms. Rifai. You know, you say in your testimony on page 2 that it is important to note that we'd be exceeding $70 billion for a 25-foot surge. What was the surge in Ike?

Dr. RIFAI. I'm sorry?

Ms. GARCIA. Do you recall what the surge was during Ike?

Dr. RIFAI. So the scenario we analyzed resulted in a 25-foot surge.

Ms. GARCIA. Well, I know what you analyzed, but do you recall what it was for Ike?

Dr. RIFAI. Oh, for Ike it was 14, and so——

Ms. GARCIA. Fourteen.

Dr. RIFAI [continuing]. With the—at the——

Ms. GARCIA. So another 11 and we could have suffered $70 billion. How much did we suffer after Ike?

Dr. RIFAI. Well, it was a few billion dollars. It wasn't 70. But the idea is Ike, as has been mentioned earlier, is really not the big storm per se. So if you were to take Ike and increase its wind or its strength by 30 percent, you would end up with 25-foot surge. And that basically would be very disastrous for Houston not just from infrastructure losses but from its economic viability essentially.

Ms. GARCIA. Right. And earlier, you said that it's important that we kind of weigh infrastructure and people——

Dr. RIFAI. Exactly

Ms. GARCIA [continuing]. And I always keep it real simple, especially when I was County Commissioner, to make sure people understood where we were. I always say that it's the three P's. It's protecting people, the plants—and I mean industry—I don't mean their pretty ivies—and of course the port. And port, I don't just mean Port of Houston but the entire, you know, 26 miles of the Houston Ship Channel. Would you agree with that, keeping it simple?

Dr. RIFAI. Exactly.

Ms. GARCIA. Right.

Dr. RIFAI. But——

Ms. GARCIA. And then I was really intrigued with your figure—I think it's 12 on page 17. And I apologize to the audience if you don't have the handouts. But you mentioned the number of tanks, but you mentioned that only one has actually had a spill and—concentrated, but the spill was—it—significant concentrated disadvantaged populations.

Dr. RIFAI. So actually the figure that you are referring to shows at this one facility there was one tank that failed during Harvey——

Ms. GARCIA. Right.

Dr. RIFAI [continuing]. But in fact in figure 12 you will see that there were many other failures across the city.

Ms. GARCIA. Right.

Dr. RIFAI. And most of these failures are in these zones that have concentrated disadvantage. In our work, we define concentrated disadvantage, looking at five different measures of disadvantage, one being younger than 18, one being female head of household, one is the amount of money that you make in your household, and so on. So when you look at these five factors, that's the mapping of the community and what it looks like with regard to disadvantage and——

Ms. GARCIA. So is it too simple to say that most leaks have occurred and impacted the concentrated disadvantaged populations the most in our area?

Dr. RIFAI. OK.

Ms. GARCIA. OK means yes? Or would you say it another way?

Dr. RIFAI. Well, I mean, we see more impact in areas that have concentrated disadvantage. That's where the industries are, that's where most of the release is. Even when you look at the infrastructure like wastewater plants and hazardous waste sites, Superfund sites, they're all located in disadvantaged—concentrated disadvantaged communities. And so when you have a release, especially when people don't have the means to leave, they're sheltering in place, they really have no way to get out of the situation they're in, and on top of that they have to deal with these biological and chemical hazards, that all—are all around them.

Ms. GARCIA. I ask as I still remember the words at the first briefing that—I was a State Senator at the time that the State did before Harvey hit, and they said places that have never flooded before will this time. And, unfortunately, a lot of these disadvantaged areas—and many of which are in my district—sort of always get hit. I mean, I always say that Harvey was like the guy who's lost and doesn't want to stop and ask for directions because it wandered—Harvey wandered everywhere.

So I guess my concern and my final question to you would be would you say then that the greater impact is usually to the disadvantaged populations?

Dr. RIFAI. I'm sorry, the greater impact?

Ms. GARCIA. Impact, negative impact, financial impact, losing their homes.

Dr. RIFAI. Yes.

Ms. GARCIA. Because, as you see, most people here are probably homeowners. I don't know how many people here are from indus-

try. But I just want to make sure that when we talk about these issues that we always talk about people first.

Dr. RIFAI. Absolutely.

Ms. GARCIA. Thank you.

Dr. RIFAI. I couldn't agree with you more.

Ms. GARCIA. Thank you.

Chairwoman FLETCHER. Thank you, Ms. Garcia.

Thank you all for your very thoughtful questions. Thank you for your wonderful answers. We're going to begin our second round of follow-up questions where the remaining Committee Members will have up to 5 minutes to ask some follow-up questions. They may not take the whole 5 minutes, but we definitely want to follow up on a couple of things.

And certainly we've talked a lot about Harvey and the impacts of Harvey. And I think there are lessons there that we can all take. Certainly, I think in response to some questions from Mr. Olson, Mr. Blackburn, I want to ask you a quick follow-up. I know Mr. Olson talked about particularly the flooding of Harvey and the Canyon Gate subdivision, which I think just the record will reflect is upstream of the Barker Reservoir. And of course that is a very important concern, the upstream flooding, as well as downstream.

But one of the things you mentioned in response to that question, Mr. Blackburn, was that there are a lot of creative concepts that aren't being implemented, and I was wondering if you could give us some examples of some of those creative ideas that could be implemented here and elsewhere because, of course, the work on this Committee applies across the Gulf Coast and across the United States. But if you could just give us some examples of some of those creative ideas, I think that could be helpful.

Mr. BLACKBURN. I mean, would that be—are you asking specifically to Addicks and Barker or more generally?

Chairwoman FLETCHER. No, more generally.

Mr. BLACKBURN. OK. I think from a creativity standpoint, the—I've mentioned one, getting the private sector more involved from a financial side. I think looking hard at the methodologies and perhaps releasing some of the Federal agencies from some of the binding methodologies that they have that are kind of tying their hands in how they respond, the benefit-cost analysis process is something that I would ask you to take a look at. I think it was done at a time for good reasons, but it may not be appropriate for now.

From a creative standpoint, I would also look at frankly, how we're—you know, the role of flood insurance and really buyout. I would tell you that if you want to get really creative, let's combine housing strategies with buyout strategies so that when we talk about buyouts, there are going to be homes available for people to move into, linking things that have not been linked before.

And I concur with all of the focus on the equity issue. It has to be in the middle of that discussion and oftentimes has not been for various reasons I think related to methodologies.

Chairwoman FLETCHER. And would you include natural infrastructure as part of that creative approach?

Mr. BLACKBURN. Absolutely. We've worked real hard with natural infrastructure and particularly trying to work with landowners to keep them on their lands so that those lands can flood

and not generate a lot of damage. A lot of ranchers want to stay on their lands. We need to find ways to get money to them, and we're working on that with our Texas coastal exchange.

Chairwoman FLETCHER. Terrific. And I have one more question for the full panel. We've talked a little bit about some of the funding challenges, the Federal Government's historical role as a funder, but there's encouragement of getting more involved, especially in the research. But could you identify for us any of the research gaps that you have found in your work that could be addressed with Federal funding?

And likewise, are there suggestions of things where funding isn't really the issue, but there's some collaboration or collective effort that you could share with us would be helpful that we should know about?

Mr. BLACKBURN. Is that to me or to others?

Chairwoman FLETCHER. That's to everyone. Maybe if each of you want to give a quick answer to that, and then we'll move on.

Dr. UCCELLINI. Well, you know, I can't talk about funding, so what I will say is whether it's the Federal Government, within the Federal Government, or among the government partners, there's got to be I think more attention paid to how we can leverage each other. And that also applies not only nationally but internationally, so we certainly on the science side are always working with the international community to try to advance our predictive capabilities, for example.

I see one of the biggest gaps, again, as we are now—it's relatively new that we're actually going beyond the forecast and warning to try to affect decisionmaking across the whole. And what we're finding is—and what's now being reported in literature is trying—a better understanding of the changing risk preference of people as an event is coming on them. And this is this link between physical and social science. And if there's a gap anywhere, it's cementing that linkage between those two sciences——

Chairwoman FLETCHER. Thank you.

Dr. UCCELLINI [continuing]. Science categories.

Chairwoman FLETCHER. Thank you. Dr. Rifai?

Dr. RIFAI. Sure. So, for me, I will focus on a couple of key points. One is the ability to basically have research-informed decisionmaking. We have a lot of tough decisions, and they're all costly. And it's not an infinite pot of money, as has been mentioned several times. So for us to make those tough decisions, we really need to fund research into what would—what can we buy most for the limited resources that we have.

The second point that I would like to make is in our country in the U.S. our monitoring grid, our observation grid is really ancient and old. It doesn't give us all the information that we need, whether it be the rainfall gauges or water quality systems, any type of LIDAR (light detection and ranging) or satellite imagery or boots-on-the-ground-type data collection. I think it would behoove us to invest in upgrading that entire network to where we have data on the fly, real time, and people can make informed decisions.

We'd like to be like NOAA. We'd like to be like the communities that have access to AI and machine learning and be able to take that data in real time and tell communities stay, leave, get out,

you're at risk, this is what's going to happen, and provide this type of information at great detail.

Chairwoman FLETCHER. Thank you. Ms. Grover-Kopec?

Ms. GROVER-KOPEC. I would echo the comments that Dr. Uccellini and Dr. Rifai said. The thing I would add actually is a non-funding option is supportive of public-private partnerships. There are plenty of private enterprises who, both because it's good for their business and because they care about their communities that they operate in, are open-minded to partner with our municipalities, our State and Federal local governments, and supporting that would be extremely helpful.

Chairwoman FLETCHER. Terrific. Thank you. Mr. Blackburn, any——

Mr. BLACKBURN. No, I have nothing to add.

Chairwoman FLETCHER. OK. Thank you very much. Well, I will yield back my time, and I will recognize Mr. Babin for 5 minutes.

Mr. BABIN. Thank you, Madam Chair. Just a couple questions. Dr. Uccellini, how has the *Weather Act* passed by this Committee 2 years ago, helped you improve weather forecasting to date? And another follow-up after that.

Dr. UCCELLINI. Well, with the separate categories—and I could go through each one. With the observations, we depend on global observations. Satellite data is extremely important to everything we do, as an example. The commercial aspect of that where—which is being tested now, is something that we need to look at because, clearly, the government can't assume all the risk anymore with billion-dollar systems, so this is something that we are looking forward to actually working and adopting observations from any source, as long as those observations meet our standards.

On Titles 2 and 3 is the research improvement of the models, and there's a major effort ongoing to create our linkages to the university community. It's titled EPIC as—and the Administration has been fully behind that, and our management team, leadership team, and NOAA is certainly pushing to work that. They're focused on seasonal and sub-seasonal. There's been increased money redirected toward that area, which is important for us because we have to know that climate background, you know, in that time range as we improve our forecasts.

And then, of course, on Title 4, we have building a weather-ready Nation, increasing IDSS (Impact-based Decision Support Services), and we've really embraced that's to move forward. And title 5 is the tsunami program, and we're certainly making progress there as well.

So it just teed up all of these efforts and brought a focus on very high-priority items that we're certainly working to address now the advances which we presume we'll be getting from all these efforts.

Mr. BABIN. You did mention EPIC.

Dr. UCCELLINI. Yes.

Mr. BABIN. That was my follow-up question, so you took care of that one. So we will——

Dr. UCCELLINI. That's Earth Prediction Innovation Center.

Mr. BABIN. That's right.

Dr. UCCELLINI. Right.

Mr. BABIN. Earth Prediction Innovation Center, better known as EPIC. And you kind of alluded to it, but how is the National Weather Service—how are you going to be able to utilize EPIC in forecasting hurricane development and tracking in the future? Sorry about that.

Dr. UCCELLINI. We need—we absolutely need to have better ties to the entire research community, not just those researchers——

Mr. BABIN. Right.

Dr. UCCELLINI [continuing]. Within NOAA but the entire research community, academic community especially. And this center is designed to be able to work with them in design, in the actual research, and then assuring that the research is done within a framework that will allow for an accelerated research to operations. And that's one of the key areas that we're really focused on is accelerating those changes into our operational system. So we're pretty excited about it. We've worked with the academic community in the past. What we're doing here is to broaden that scope and to ensure that there's a faster return on investment in partnership with that community.

Mr. BABIN. OK. Thank you very much. And then my second and last question was for Ms. Grover-Kopec. Thank you for being here today and sharing the private sector's perspective on developing more efficient disaster response strategies. In your written testimony, you explain how One Concern's work is made possible by research sponsored by the Federal Government. Can you explain how you utilize your company's work to assist communities like Houston in planning for the next weather disaster? We'd be very interested in it.

Ms. GROVER-KOPEC. Sure, yes. Well, I'll be honest with you. So most of the implementation that we've done on this technology has been earthquake-focused, so most of the examples I can cite would be focused on the West Coast and seismic risk, so we have some good work going with the city of Seattle, as well as American Family Insurance as an example of the public-private partnership that we're talking about.

On the climate-related risk more related to kind of the hurricane risk that Houston sees here, we started to implement our flood product in the State of Arizona in the Nogales Wash, and we soon will be doing that with the State of Pennsylvania around Williamsport and the city of Pittsburgh. And so the intent there is it's the city managers, it's emergency responders, and those emergency management officials in those jurisdictions——

Mr. BABIN. Right.

Ms. GROVER-KOPEC [continuing]. Using the live event products to respond.

Mr. BABIN. The amazing thing is—you know, you were talking about tsunamis a while ago. When you have a 25-foot storm surge like we had in Hurricane Ike, basically it's a tsunami with wind, and so we get a double whammy on that deal, so——

Ms. GROVER-KOPEC. Yes.

Mr. BABIN [continuing]. I'll yield back, Madam Chair. Thank you very much.

Chairwoman FLETCHER. Thank you, Mr. Babin. I will now recognize Mr. Weber for 5 minutes.

Mr. WEBER. Thank you, Madam Chair. I'd just like to say for the public that's here, thank you for being here and for paying attention and caring enough to come out and spend your time.

I make a note of optimism. You're seeing this very hearing for the very reason that you're here, to make sure that your government is on top of things and wanting to make things better and safer, protect people, families, you know, houses, and of course industry as much as possible because that means jobs.

The science is getting better. There's much money needed for research. I think hopefully you're getting a sense of that from up here. And so take heart because I look for good things to happen.

Dr. Uccellini, for you, we had this discussion when we toured the National Weather Service this morning, which of course is in my district in League City. And my district has the dubious distinction of having the two largest rainfall records in United States history. Tropical storm Claudette, in 1979, dropped about 43 inches of rain overnight in a 24-year period in Alvin, Texas. And then of course, as you know, Harvey dropped about 61 inches in Jefferson County, drainage district number 7, a little longer timeframe but still it was the new rainfall record.

And so you were very gracious with your time this morning, Dr. Uccellini. How many National Weather Service centers are in the United States?

Dr. UCCELLINI. We have nine operational centers today. We have a 10th center, which is—will approach initial operation capability—that's the water center in Alabama—by September 30. So we'll have 10, and they cover a spectrum from space weather to ocean predictions, so we have centers focused on what I call a domain space of the sun to the sea. And for those in the audience who don't think space weather is important, if you use GPS, it's important. So—as an—or if your plane is using it, it's important, too. So we have 10 centers.

Mr. WEBER. Well, thank you for that. And we are very, very fortunate and blessed that we have one local. And as you all——

Dr. UCCELLINI. Oh, wait a minute, I'm sorry. We have 122 local forecast offices, so you have that local forecast office.

Mr. WEBER. Right, but you know, in Texas, things are bigger and better, and we want more centers in Texas. I'm just saying. And so we are very, very fortunate to have that. Now, we had a discussion with Galveston County, Judge Mark Henry, and he was there to kick us off. And he mentioned that the Federal Government, the National Weather Center, did not just barge in to the emergency management center there, but they asked if they could come in and partner with Galveston County. And of course the emergency management center, the Commissioners said of course you can, you're welcome, please come. And then Judge Mark Henry said, you know, you came as a volunteer, but now you're hostage; you can't leave.

And you all laid out a scenario that worked for Hurricane Harvey, which was so astounding because you had emergency management personnel there on the ground, you were dealing with Texas Emergency Management Coordinator, you were dealing with Harris County. Would you describe for the panel and for the people here exactly why that worked so well being in close proximity?

Dr. UCCELLINI. So it's the development of the trust that—between the forecasters who—we'll always have uncertainty in a forecast. We can ever produce a perfect forecast. So yet there were incredible decisions that have to be made 5, 6, 7 days in advance to even start the process. So they have to go through the practicing with us through this developing relationship our sense of certainty and uncertainty as we approach this event and gets to a key decision point in which they need to act.

So—and you mentioned the rainfall records. The one difference between the two of them is we predicted the second one, right? And even that, making that prediction, I contend that if we didn't have that trust built in, I'm not sure people would have believed our forecast of over 50 inches of rain. So it's that trust factor through practice, practice, practice that's essential to making this work.

Mr. WEBER. Right. And I appreciate that. And for the panelists and the audience, there were people who stayed there how many days in a row?

Dr. UCCELLINI. Geez, I get——

Mr. WEBER. Six, eight, 10 days——

Dr. UCCELLINI. Yes, it was in the 5-, 6-, 7-day range.

Mr. WEBER. Right.

Dr. UCCELLINI. And this facility was incredible in terms of not only colocations but they had showers——

Mr. WEBER. Right.

Dr. UCCELLINI [continuing]. So, as was pointed out today, that's really essential for keeping that trusted relationship working through days 5 and 6.

Mr. WEBER. One of the comments made was that the showers weren't for him, it was for his coworkers, so—anyway, thank you for that and your service. And I just want the community to take heart because good strides and good steps are being made.

And, Madam Chairwoman, I appreciate you, and I'm going to yield back.

Chairwoman FLETCHER. Thank you, Mr. Weber. I'll now recognize Mr. Olson for 5 minutes.

Mr. OLSON. I thank the Chair again. And my second round of questions starts out with you, Ms. Grover-Kopec, about the National Flood Insurance Program. As you know, there's a philosopher who said the definition of insanity is doing the same thing over and over and over expecting different results. I submit the FIP is a great example of that working in our Federal Government. Right now, it's in debt about $21 billion last year. It increased all the floods we had in the Midwest, what's going to happen to hurricane season. We don't know what's going to happen. It's going bankrupt.

My former colleague, the Chairman of Financial Services Jeb Hensarling, tried to pass a bill. He knew the private sector could adequately address the costs and risks of most floods probably 90 percent or more with the public sector covering the—sort of the big issues. He thought that'd be more viable, lower cost, better service. And so what do you think about the private sector taking up a big chunk of flood insurance? Is that viable, will save money, more responsive, or should we just keep marching down with the current NFIP?

Ms. GROVER-KOPEC. My own personal opinion is I think it is viable, though will probably not happen overnight. I do think some of the changes that FEMA (Federal Emergency Management Agency) made over the last year around the governance of NFIP in those policies helps considerably. For example, the ability of homeowners to use a private policy if they have a federally backed mortgage instead of an NFIP policy, assuming those are comparable, that's an example of a really concrete move that they've made in the right direction. And once those policies—they're seeing some stability in opening up that arena to the private sector, as well as openness on the regulatory front at the State level. I think you'll see insurers step in as—it's a growth opportunity for them, and they would like to cover that risk, assuming they understand it well.

Mr. OLSON. So say we create that environment, this will actually work, the private sector take a big chunk of what NFIP is doing right now. Is that——

Ms. GROVER-KOPEC. If they understand the risk——

Mr. OLSON. Yes, all the—yes.

Ms. GROVER-KOPEC [continuing]. And the regulatory environment allows it, yes.

Mr. OLSON. Work to go.

But the second round of questions is for you again, ma'am, and maybe for you, Dr. Rifai. It's about AI. And I'm the co-Chairman of the House AI Caucus, along with Chair McNerney from California. And we all know what AI is going to do for the future, I mean, especially during natural disasters. It will give us real-time information on unpassable roads, powerlines that are down, trees are down, status of hospitals. For example, Memorial Hermann Sugar Land shut down because of the floods of the Brazos River during Hurricane Harvey.

And also AI never forgets a situation. Who here remembers Tropical Storm Claudette? Not many hands. That storm set a record. That tropical storm dropped 42 inches of rain on Alvin, Texas, in less than 24 hours. That record stood until last year. Something happened in Hawaii.

So my question is, how can AI—both of you—solve some of these problems, get this thing turned on and manage it, all these issues with biases, there's things out there, but what do you think about AI in the future? How can we help at the Federal Government make this thing a reality?

Dr. RIFAI. So there's so much data out there and so much knowledge, and it's really hard for the human brain to get their arms around it, so we need machines to help us sort through the information and detect patterns. And then by detecting these patterns, we can make better decisions. So if you ask me, we need to make maybe 10,000 computer simulations. Even with the fastest computers, there's no way I and my research group or any other entity by themselves can sort through all those results and give you the probability that a given scenario is going to happen. AI, machine learning helps with all of that. It's done really quickly. And while I'm not in quantum computing, I can buy into AI and machine learning; quantum computing is going to take us a little bit longer to get that done.

Ms. GROVER-KOPEC. I just want to comment. That answer is spot on. And the thing I would add is that modeling approach allows us to not be so biased by history, right? If you take what Dr. Rifai just said and the ability to look at potential future scenarios in a dynamic and a quick manner, it allows to remove the bias of history. History is important, but we need to be able to account for the future view as well.

Dr. UCCELLINI. And if I may, within the forecast process itself, there's a tremendous amount of information in the observations, in the models that we can extract and use not only for supporting decisionmaking—and I contend or believe that AI or cognitive computing is going to be really important in assisting in decisionmaking, but it also helps us extract the information that could improve our forecast and help pinpoint warnings as well. So we are very actively engaged in this and have been. There's been—there was artificial intelligence work that started in the 1990s, so this is something that we're actually looking toward to help our jobs as well.

Mr. OLSON. Mr. Blackburn, I'll give you your Rice-style farewell. I yield back.

Chairwoman FLETCHER. Thank you, Mr. Olson.

And before we bring our hearing to a close, I really want to echo the comments of all of my colleagues. I'm so grateful to have with us in attendance today some of our elected officials and leaders on this issue, of course Houston City Council Member Stardig, former Harris County Judge Eckels. And Russ Poppe from Harris County Flood Control was here but I don't see him anymore—and our community for coming out to this hearing to listen to these important issues. It really underscores the importance of the work that our witnesses are doing and the work that is before this Committee and the work that we need to do from where we sit in Washington.

So I really want to thank all of our witnesses for their time. I want to thank the community for coming out.

The record for this hearing will remain open for 2 weeks for additional statements from the Members or for any additional questions the Committee may want to ask of the witnesses.

And with that, the witnesses are excused, and the hearing is now adjourned.

[Whereupon, at 5:08 p.m., the Subcommittee was adjourned.]

Appendix I

Additional Material for the Record

LETTER SUBMITTED BY REPRESENTATIVE LIZZIE FLETCHER

Marie Lynn Miranda, Ph.D.
Professor of Statistics
Director, Children's Environmental
Health Initiative

July 18, 2019

The Honorable Lizzie Fletcher
Chairwoman
Subcommittee on Environment
1429 Longworth House Office Building
Washington, DC 20515

The Honorable Roger Marshall
Ranking Member
Subcommittee on Environment
312 Cannon House Office Building
Washington, DC 20515

Dear Chairwoman Fletcher and Ranking Member Marshall:

Please accept the following statement for the record regarding the Subcommittee's July 22 field hearing titled "Weathering the Storm: Improving Hurricane Resiliency through Research."

As we are in the midst of another hurricane season and as Houstonians approach the two year anniversary of Hurricane Harvey's historic deluge of the city, the Subcommittee's selection of the Texas Gulf Coast for this hearing is especially appropriate.

You will undoubtedly hear a great deal regarding how much remains to be done in terms of Harvey recovery. You will also hear a great deal regarding the applied research being conducted on improved engineering and prediction for future storms (flood planning, infrastructure, mitigation, retention, and weather/climate modeling). We will also provide you with information on an innovative and ongoing research effort at Rice University – the Hurricane Harvey Registry – born in the days immediately following the storm and providing critical insights and support to local, state, and federal partners by engaging the people of the region impacted by Harvey.

The Registry is a project that collects health, location, and exposure information from people along the Texas Gulf Coast—both those affected and those who feel they were not affected by the storm. It offers a much-needed, systematic way to identify and track the storm's short- and long-term health and housing impacts, providing vital information to inform ongoing recovery and planning for future disasters. This information is not only beneficial for Houston, it can also inform disaster planning in other areas of the country. In order to maximize the benefits of the Registry, a large number of registrants--necessitating substantial public outreach – is needed.

The Registry team continues to engage the public through social media and local organizing efforts, including community events and partnerships with news outlets and organizations helping the region recover, learn, and prepare for the next storm. Active participation with the Registry is ongoing and

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available for everyone in the Harvey-impacted region. Residents can take the survey online through, harveyregistry.rice.edu, or fill out a paper copy of the survey.

The Registry's health-related questions cover both the physical and mental aspects of health. Physical health is crucial, of course, because healthcare providers in Houston have indicated an increase in invasive mold illness since Harvey – especially among people who are immunocompromised, including cancer patients and organ transplant recipients. Because many occupied homes still need significant repair from floodwater intrusion, exposure to mold will continue to produce health problems.

The Registry also assess mental health impacts from the storm and ongoing recovery, an issue increasingly recognized as critically important in the aftermath of natural disasters. Immediately after Harvey, approximately 250 people at the George R. Brown Convention Center mega-shelter required emergency mental health assistance. Even now, nearly two years later, many people continue to report mental health issues. As shown in the Registry's first report, intrusive or unintended thoughts are among the most frequently mentioned. Rain – especially storms that produce flooding – continues to be a trigger for some people who were deeply impacted by Harvey. This information is critical for recovery and planning efforts locally, regionally, and nationally, just as much as being able to gather and report information from respondents regarding their physical health.

In terms of scope, since launching in April 2018, the Registry has collected data from more than 19,000 registrants, capturing the living environments of over 57,000 residents across the Harvey impacted region. The data collected through the Registry gives our partners valuable new insight into the effects of the storm on the well-being of their residents and neighbors. Information about where people stayed after they were dislocated, how long they were out of their homes, and the health effects they experienced are shaping response programs that will play a vital role in responding to future storms.

For Registry collaborators, the data has helped refine community outreach and engagement strategies to reach and enroll community members in need across our region's incredibly diverse communities—both in terms of socio-economics and cultures. For example, the Houston Health Department implemented English and Spanish paper surveys at Neighborhood Restoration Centers and various community events, removing digital barriers to participation. They also created a wealth of video content for the Registry's marketing campaign, leveraging social media to reach thousands of Texans who may not be regular consumers of traditional broadcast or print media.

Since its inception, the Registry has been a collaborative effort of Rice University's Children's Environmental Health Initiative (CEHI) and Kinder Institute for Urban Research (KIUR) in partnership with the Houston Health Department, Harris County Public Health, Chambers County, Fort Bend County, Montgomery County, Victoria County Emergency Management, and the Environmental Defense Fund (EDF). The Registry has been supported through funding from the Cullen Trust for Healthcare, the Environmental Defense Fund, and the National Institutes of Health. The Registry tracks health and housing impacts in the community, informs targeted interventions, then supports our growing group of partners. The strong ties among Registry collaborators mean that local, state,

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and federally funded investments in this research go even further toward improving our regional and national resilience.

Thank you again for this opportunity to share information on the Registry with the Subcommittee on Environment. We stand ready to share registry findings with subcommittee members or answer any questions that may be relevant to your work. Please direct any questions to Nathan Cook, Rice University's director of government relations at nathan.l.cook@rice.edu or 713-348-6237, or Marie Lynn Miranda, Professor of Statistics and director of the Children's Environmental Health Initiative at mlm@rice.edu.

Sincerely,

Marie Lynn Miranda
Professor of Statistics
Director, Children's Environmental Health Initiative

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