Written Testimony of

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Understanding, Forecasting, and Communicating Extreme Weather in a Changing Climate

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Clarity on Extreme Weather-Climate Change Attribution, Messaging, and Steps Forward

Key Takeaway Points

Your constituents, my fellow citizens, and my two kids feel the impacts of extreme weather in their lives and "kitchen table" issues. It's not about polar bears or the year 2080.

- Attribution studies affirm that the influence of climate change is found in contemporary extreme weather events affecting the United States.
- Extreme weather events impact people, infrastructure and processes more than "average" events. Our agricultural, energy, water, transportation, public health, and national security institutions are at risk, and this ultimately affects American households and beyond. We must message the risks and impacts with such context in mind rather than using distant and abstract concepts.
- Robust science and technology resources must be sustained at local to federal levels.
- We must keep a close eye on the well-being of vulnerable populations and disparities in climate resiliency.

Introduction

I would like to thank Chairwoman Eddie Bernice Johnson and her colleagues on the Science, Space, and Technology Committee for an opportunity to share my thoughts and expertise on contemporary extreme weather and its context within a changing climate. In 2013, I sat before the Senate Environment and Public Works Committee on a similar topic.[1] Two key messages that I delivered to the Committee at that time were:

- Climate change is increasing the probability of extreme events, and in some cases may be strengthening their intensity or increasing their frequency (i.e. we are loading the dice towards more Sandy or blizzard type storms)

- There is strong evidence that increases in some types of extremes are linked to human-induced climate change, notably extreme heat, coastal flooding, and heavy downpours.

For other types of extremes, such as tornadoes, current evidence is much more limited

Since 2013, there is nothing that I would change about those statements except amplifying and affirming them with greater vigor.

While in elementary school, I did a science project called "Can A 6th Grader Predict The Weather?" As a child, I was in awe of the weather but naively never understood that it could fundamentally alter the lives of families, disrupt our economy, take human lives, or threaten national security. I was just a boy from Canton, Georgia making weather instruments from things around the house and charting local weather patterns. That passion for the weather set the course for my educational and professional career. However, the blinders of youthful naivety are gone. Extreme weather within a changing climate is one of the most pressing concerns of this generation and those to come. From my lens as a scientist, professor, and the former president of the American Meteorological Society (AMS), I would like to discuss extreme weather attribution, messaging, and pathways forward.

Contemporary Extreme Weather Within the Context of Climate Change

Earlier this month, talented colleagues at the National Hurricane Center and National Weather Service monitored Hurricane Dorian. Dorian was a human tragedy for parts of the Bahamas because it stalled in that region as a major hurricane with powerful winds, storm surge, and multiple feet of rainfall.[2] Dorian eventually paralleled the U.S. coast as forecasted and created challenges for the East Coast of the United States. Dorian joins Michael, Harvey, and Maria as billions dollar+ weather events that took the lives of people. Their names will be retired, and people will ask how they are connected to climate change. These storms certainly

exhibited characteristics of processes reported in the scientific literature: Rapid intensification[3], stalling[4], and higher sea levels within storm surges[5]. However, the process of extreme weather attribution must be carefully considered without hype, speculation, and social media debates.

Many of these same questions are posed about recent heat waves, fires in Alaska, flooding, and drought activity impacting agricultural lands. In 2016, I served as a co-author on a study conducted by The National Academies of Sciences, Engineering, and Medicine[6] called "Attribution of Extreme Weather Events in the Context of Climate Change." A key finding from the report is that scientific studies are able to provide some degree of attribution with moderate to high confidence for certain weather events (Figure 1). I should caution that it is irresponsible to link singular events to climate change with the "ill-posed" question, "Was that hurricane, flood, or drought caused by climate change?" However, confidence is growing that the fingerprint of climate change is firmly seen in extreme temperature events (e.g. extreme heat and lack of extreme cold events). Attribution of extreme rainfall, hydrological drought, and hurricanes are found in the moderate confidence category. There is little to no confidence in attribution of tornadic storms or Nor'easter-Mid-latitude cyclone type storms.

The American Meteorological Society recently weighed in on Attribution in its Information Statement on Climate Change[7]:

> *"Heavy precipitation (e.g., maximum daily precipitation in consecutive 5-year segments) has increased in both intensity and frequency since 1900, especially in the eastern half of the United States and notably in the Northeast. Areas that receive limited precipitation, sometimes called drylands, are increasing in area. The combination of warmer temperature and reduced precipitation in some regions has increased the risk of drought and drought-related impacts. There is evidence that wildfire seasons are increasing*

globally and areas where wildfires occur are expanding…The number and intensity of Atlantic hurricanes have both increased since the early 1980s, but much of this increase may be due to natural variability of the atmosphere and ocean. Furthermore, there is little trend or even a decrease in hurricane activity in other ocean basins, so the global trend, if there is one, is not clear. There is evidence that ocean warming is providing more energy to make hurricanes more intense….There is no sign of an increase in the most violent U.S. tornadoes (those rated EF4 or EF5 on the Enhanced Fujita Scale). However, there is evidence that annual U.S. tornado activity has become more variable since the 1970s, with larger tornado outbreaks separated by longer periods of below-average tornado frequency."

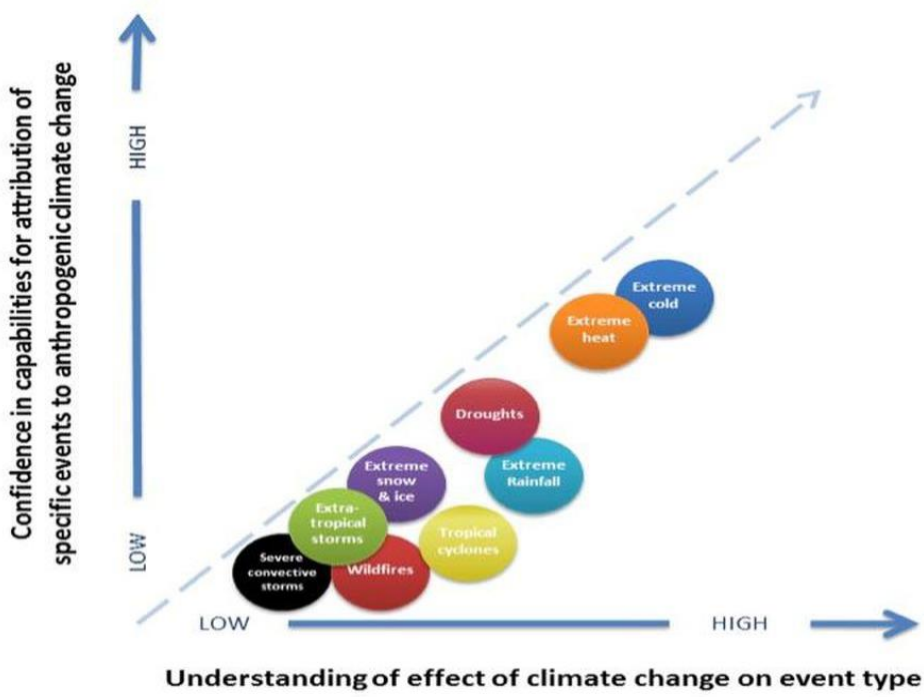

Fig. 1 Confidence, based on current literature, in extreme weather linkages to climate change (NAS, 2016).

Our methodology for confidence in the National Academies study relied on sound physical principles, consistent observational evidence, and the ability for numerical models to reproduce the event. These "three legs of the stool" served as the benchmarks in our review of studies and scientific methodologies. Many events ranked lower on the confidence scale may ultimately end up higher as the science evolves. There is emerging literature that may increase our confidence going forward. For example, the best consensus on hurricanes and climate change points to less frequent but stronger storms. However, emerging studies find that hurricanes are stalling more frequently as we witnessed with Imelda (2019), Harvey (2017), Dorian (2019), and Florence (2018).

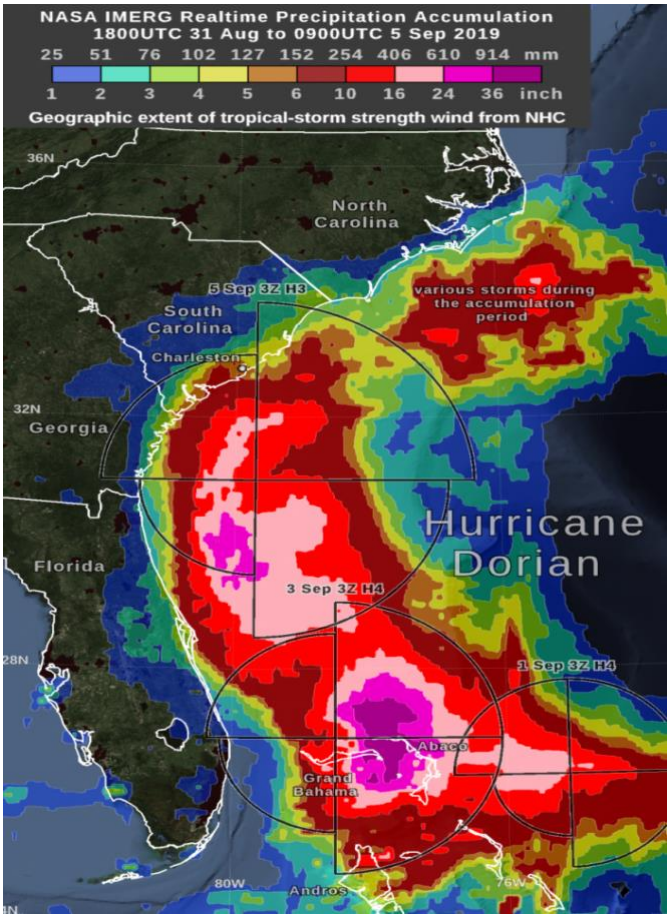

Fig. 2 Rainfall footprint of Hurricane Dorian (2019) as measured by NASA satellite-based instrumentation associated with the Global Precipitation Measurement Mission (GPM).

Indeed, climate changes naturally and always has. I assure you that every climate scientist of significance understands this fact. It is often amusing when people remind degreed scientists of this fact in the mall, at dinner or on social media. It is not an "either/or" proposition. It is an "and" proposition. Grass grows naturally, but it grows very differently when soil is fertilized. Our climate is being fertilized by increasing levels of greenhouse gases (GHGs) in our atmosphere, and I want to be crystal clear here that GHGs are the dominant source for warming.[8] Suspended particulates (aerosols)[9] and land use changes[10] related to deforestation, urbanization, and agriculture also play important roles in changes being observed from local to global scale. All aspects of the Earth's system, including weather, are responding. For example, NOAA recently updated what constitutes a 100 or 1000 year event in Texas because of changes in rainfall intensity.[11] This will have implications on the National Flood Insurance Program and infrastructure design.

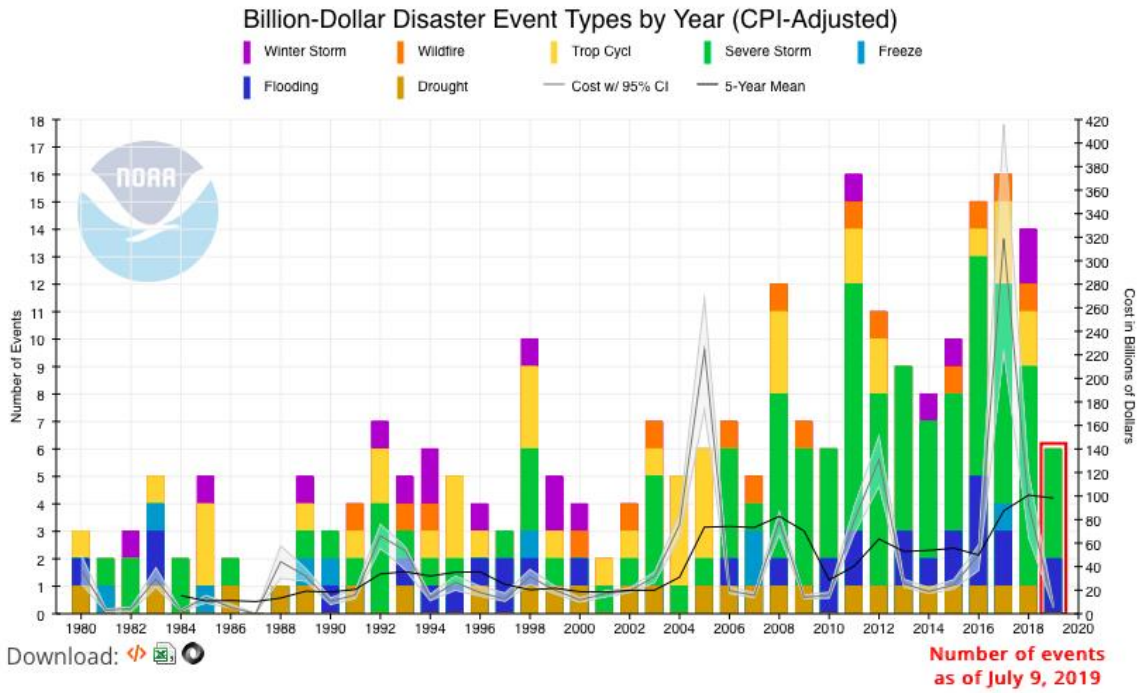

Fig. 3 Trends in billion-dollar disasters (Source: NOAA-NCEI).

Messaging Emergencies in the Extreme Weather-Climate Change Connections

In 2018, there were 39 billion-dollar+ disasters. According to the annual report of Aon, a leading insurance broker, insured dollars totaled $90 billion, which is the fourth highest inflation-adjusted number of such events on record.[12] Of those events, the United States tallied 16 of them, the most of any country and second-highest on record according to Dr. Jeff Masters.[13] The U.S. experienced 20 billion-dollar+ weather disasters in 2017. As a reference, there were only 28 billion dollar events within the entire decade of the 1980s according to data from the National Oceanic and Atmospheric Administration and NBC News.[14] Trends certainly indicate an uptick in both weather disasters (Figure 3) and infrastructure[15]. This suggests that the United States faces amplified and compounded risks from extreme weather, population pressures, and wealth.

At a time in which national emergencies are being discussed in Washington, D.C., I argue that climate change has reached the level of a national emergency or crisis. It is imperative that we speak on the topic in such terms rather than distant or abstract references that may not resonate with the average U.S. citizen. I like polar bears and butterflies, but climate messaging must firmly be anchored in how extreme events affect our water supply, public health, infrastructure, energy systems, food supply, and national security.

In 2018, Hurricane Michael devastated my home state of Georgia, and my heart ached for the hard-working families whose pecans, peanuts, bell peppers, and cotton were lost.[16] As tragic as the losses were for my state, it is important that we connect the dots for people that when they go shopping for peanut butter or t-shirts they may feel the impact of that extreme weather event

in their personal budgets. The 2018 National Climate Assessment report warned that climate change could have a significant negative impact on the U.S. economy and its Gross Domestic Product.[17]

My approach to communicating the climate crisis to the public, stakeholders, and policymakers is to utilize analogies, familiar stories, and common language. I recently served on a panel with former Georgia Congressman Lindsay Thomas. During his remarks, the former Congressman cited a scripture from the same text that I read:

> *All streams flow into the sea, yet the sea is never full. To the place the streams come from, there they return again.* -- ***Ecclesiastes 1:7 (New International Version)***

This text perfectly captures the hydrological or water cycle that most of us learned about in 4th grade. It is a cycle in perfect harmony and balance until human intervention started to disrupt it. More intensive downpours associated with climate-enhanced moisture availability, sustained downpours and melting snowpacks are overwhelming flood protection and stormwater management systems. The Environmental Protection Agency website discussion[18] from 2017 warned:

> *"In many areas, climate change is likely to increase water demand while shrinking water supplies. This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers. In some areas, water shortages will be less of a problem than increases in runoff, flooding, or sea level rise. These effects can reduce the quality of water and can damage the infrastructure that we use to transport and deliver water."*

Water availability and infrastructure resiliency are issues that would seem immune from partisan ideology. Water is essential to life and doesn't understand the concept of "liberal" or "conservative."

I am a climate scientist, but I am a husband, father, and community citizen like other Americans. We care about our children, their health, and our great nation. The graphs, charts, and jargon can be a distraction. The climate emergency affecting families is real and must be conveyed in relatable terms.

Some Ideas To Move Forward

I am a scientist trained to understand how our atmosphere works and how to predict its changes. My expertise does not lie in the 2, 4 or 6 year political cycles that you have to think about. However, I am grateful for this opportunity to serve my country through my expertise. I would like to offer the following ideas as steps forward:

1. **Keep scientific observation and modeling capacity robust**.

Diverse observations are essential when meteorologists are diagnosing the atmospheric and oceanic conditions that may lead to rapid intensification of a hurricane or sustained flooding. NOAA, NASA, and other satellite datasets are critical for diagnosing extreme weather in real-time, but these datasets are also assimilated into our numerical weather prediction models. Denial studies have shown, for example, that the forecast for Hurricane Sandy would have been terrible if satellite datasets were left out of the models.[19] I chair NASA's Earth Science Advisory Committee. NASA along with federal, international, and private partners continue to provide vital Earth system observations of Earth. NASA is currently implementing the Decadal Survey plan recommended by the National Academies. The agency has initiated several studies and

issued calls to the community in support of ensuring that vital observations of the weather-climate system continue and are advanced.[20]

NOAA and the National Center for Atmospheric Research (NCAR) recently signed agreements to establish, according to a federally issued press release[21], "*a new partnership to design a common modeling infrastructure (EPIC) that will be transparent and easy to access and use by public and private researchers, including academia and industry. By leveraging efficiencies and synergies, reducing duplication of effort, and creating shared model repositories, future research advances will more quickly benefit the public through better weather and climate forecasts."* Challenges with rainfall forecasts in Tropical Depression Imelda in Texas (2019) and rapid intensity changes observed with Hurricane Michael (2018) affirm the need for the EPIC framework. I believe EPIC is a positive step to ensure a more nimble and responsive U.S. weather model capability as we keep pace with or attempt to surpass other global modeling efforts.

To improve extreme weather prediction in the 5 to 14 day time window, we must also aggressively maintain our high performance computing and data assimilation resources. Such capacity will also improve emerging sub-seasonal to seasonal forecasting capabilities critical to agricultural, energy, and other applied needs. We need the fastest supercomputers available to accommodate this generation's volume of observational data and computational codes needed to advance our predictive capabilities. We know what is needed. We just need the continued support.

Advances in small or cube satellite technologies and precision instrumentation aboard research aircraft at NASA and NOAA enable nimble and efficient measurements required to address specific aspects of extreme weather prediction. For example, hurricane track forecasts

have steadily improved in recent decades while intensity forecasts have lagged behind.[22] Scientific interrogation of the processes within the eyewall of hurricanes and beneath the surface will likely move us forward.

It is also important that we find a compromise on the use of the electromagnetic spectrum used for telecommunications and weather so that vital observations assimilated into weather prediction models are not degraded.[23] The efficacy of modern day weather models is highly dependent upon temperature, water vapor, and other satellite-derived fields.

As important as the technology of extreme weather forecasting is to the enterprise, it is clear that a "good forecast" easily becomes a "bad forecast" if people are not consuming, understanding or acting upon the information. Investments in social sciences (psychology, communication, sociology, equity studies, economics) at the intersection of extreme weather will hopefully help prevent tragedies that could be avoided. As we move toward a Weather Ready Nation, science increasingly plays a role as a decision support service with regard to how use-inspired research initiates, O2R, and how to frame forecasts for utility services, state and municipal governments, emergency management, water management, public health, and so forth.

2. Learn from Best Practices In Regional or Stakeholder Efforts

In Georgia, through the support of the Ray C. Anderson Foundation, I am participating in a unique consortium called the Georgia Climate Project.[24] The effort was called out by the 2018 National Climate Assessment as a potential best practice to be replicated in other states and jurisdictions. Our goals are: (a) Synthesizing what is known and analyzing what is not in order to improve understanding of climate impacts and solutions in Georgia, (b) Fostering a constructive, nonpartisan discussion about how climate change affects Georgia and what can be done about it, (c) Working with partners to enable Georgians to take practical steps to respond to climate

change and its impacts, and (d) Bringing together experts working to understand and act on climate. We will host the Georgia Climate Conference in November to assess where these efforts are and to move forward. While such regional actions can move the needle on science and policy, they do not replace the vital federal role in providing observational platforms, models, research grants, policy and international diplomacy.

3. Understand risk, vulnerability, and resiliency.

A common question that I often receive is "So what do we do about climate change and extreme weather?" Mitigation strategies centered on reducing carbon emissions have been the dominant themes along with adaptation strategies. My focus is increasingly on aspects of risk, vulnerability, and resiliency. I am particularly concerned about the "Extreme Weather-Climate Gap." Disparities in income, social status, and other factors that lead to marginalized groups mean that hurricanes, floods, or heat waves have disproportionately adverse impacts on certain populations. Such vulnerable populations have elevated risks in terms of health, resiliency, and economic well-being when facing extreme weather events.[25]

This is clearly apparent when you look at a cross section of how communities recovered after Hurricane Katrina and Harvey, respectively. The other aspects of resiliency involve urban and rural infrastructure. AT&T, for example has been a leader in its efforts to address climate resiliency, in part because they understand their own vulnerabilities.[26] The U.S. Navy is constantly thinking about resiliency as its facilities struggle with sea level rise and a generation of more intense hurricanes.[27] More locally, major cities and small, rural towns face degradation to transportation, water-delivery, and agricultural systems. The Institute for Resilient Infrastructure Systems (IRIS) at the University of Georgia, of which I am a part of, is starting to

think about such issues but will require adequate resources to think about such challenges in innovative ways.[28]

Concluding Thoughts

In summary, anthropogenic climate change superimposed onto the naturally varying climate system has created an era of extreme weather events foreseen by past studies in the scientific literature. Climate scientists, in most cases, typically try to be measured with messaging and objective in their analyses . However, the climate system itself is sounding the alarms with the current generation of heat waves, floods, and storms.

- Attribution studies affirm that the influence of climate change is found in contemporary extreme weather events affecting the United States. They will continue to advance to better understand the connections between climate change and extreme weather events with the goal of improving predictive capability and building in resiliency to our societal frameworks.
- Extreme weather events impact people, infrastructure and processes more than "average" events. Our agricultural, energy, water, transportation, public health, and national security institutions are at risk, and this ultimately affects American households and beyond. We must message the risks and impacts with such context in mind rather than distant and abstract concepts.
- Robust science and technology resources must be sustained at local to federal levels.
- We must keep a close eye on the well-being of vulnerable populations and disparities in climate resiliency.

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