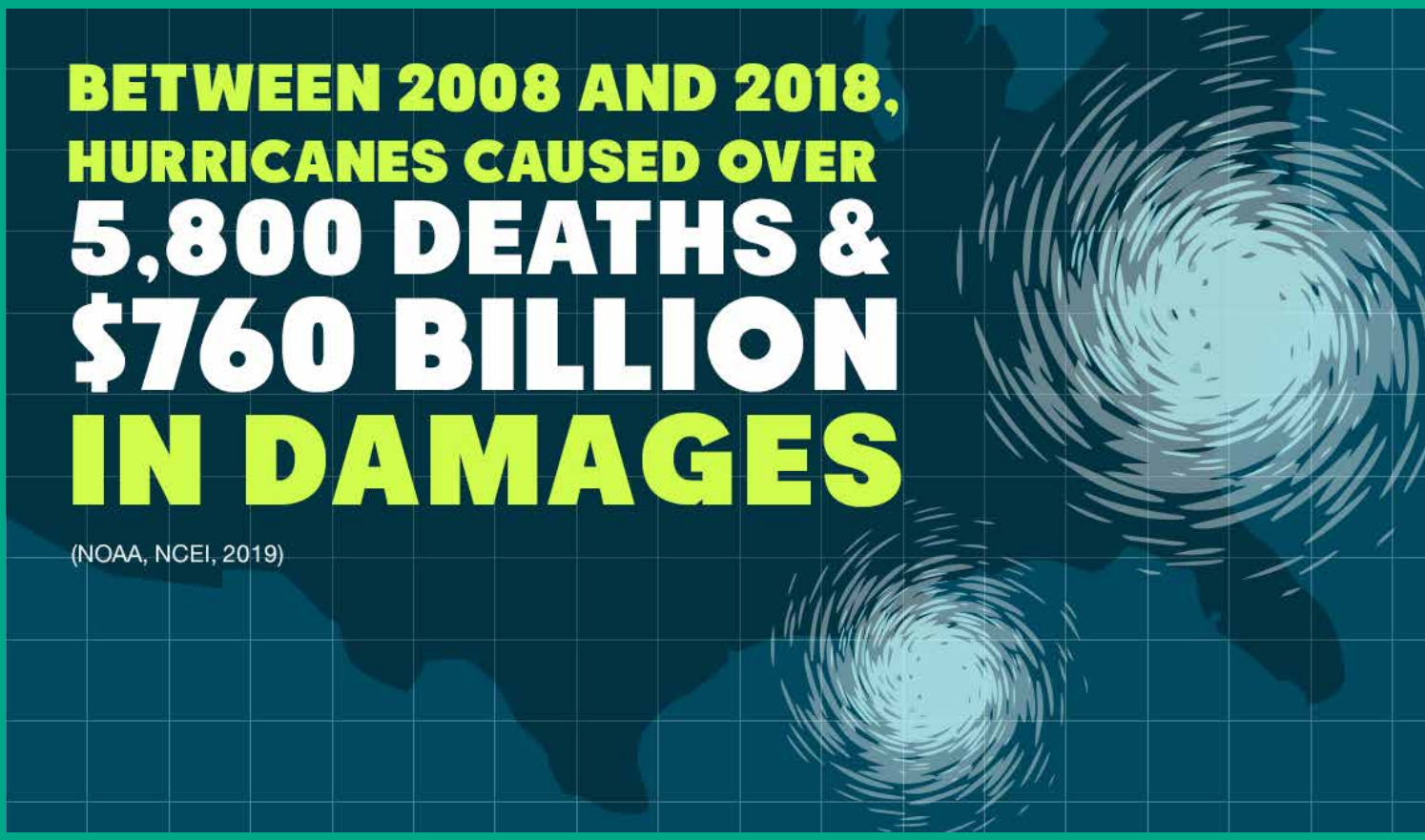
HURRICANES

AFTER THE STORM, DIFFICULT DECISIONS

In July 2019, nearly 2 years after Hurricane Harvey crashed ashore near Rockport, Texas, Elvia Escobar is still repairing her home. Compared with other areas, her neighborhood escaped much of the flooding caused by the estimated 34 trillion gallons of rain Harvey dumped across Texas and Louisiana.[13] But Escobar stripped off wallpaper and paneling inside her home anyway, exposing the framework and insulation. Her neighbors didn't understand what she was doing. "Unlike the community, I am fully aware of the consequences of having mold in our house," Escobar explains. "So I demolished some of the walls in my house; I made sure it was all sprayed with a solution against mold. Now the house doesn't look very pretty, but at least it's clean from mold."



Escobar is a construction worker who is originally from Mexico, and a volunteer trainer with the Fe y Justicia (Faith and Justice) Worker Center (FJWC) in Houston, Texas. In her role with FJWC, Escobar delivered health and safety trainings to her construction peers. This was when she learned about the immediate and long-term health consequences of flooding. However, many in the construction community still lacked access to this information and basic safety equipment. Following Harvey, FJWC organizers Kendra Baldazo-Tudon and Chris Wager Saldívar helped survey construction day laborers in Houston. Of the 361 surveyed workers entering hurricane-affected sites, 85% had received no training on the risks of mold or how to work safely in contaminated water, 32% lacked access to gloves, and 61% lacked access to a respirator.[14] Without proper training and personal protective equipment (PPE), many of these same workers were already reporting health impacts such as difficulty breathing (27%), skin rashes (28%), recurring headaches (35%), and eye infections (40%).[14]

FJWC strives to educate and advocate for Houston workers. As Harvey approached, they braced for a different kind of impact than most Texans. "It's common knowledge among worker centers that after hurricanes and other natural disasters, labor violations are more frequent," explains Wager Saldívar. The negative health and legal impacts for workers following Hurricanes Katrina and Sandy were well documented,[15,16] and already in the 4 weeks following Harvey's landfall over one quarter (26%) of surveyed day laborers reported wage theft to FJWC, with the total amount of unpaid wages exceeding $20,000.[14] Wager Saldívar says of the weeks following Harvey, "We had a difficult decision to make. Do we put our energy into health and safety or wage theft and other legal issues? Ultimately, we went with health and safety."

FROM HEALTH RESEARCH TO HURRICANE RECOVERY

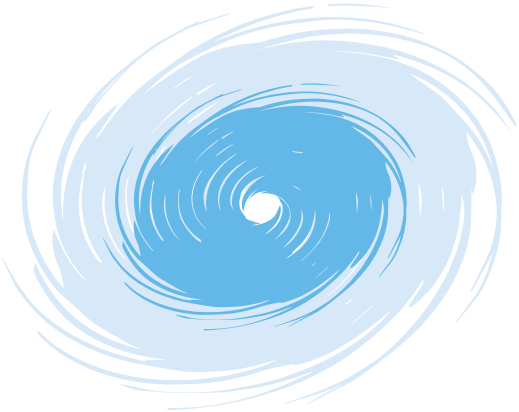
Like Escobar, Houston resident and public health researcher Janelle Rios has not yet completed the repairs to the home she and her husband were in the process of renovating when Harvey hit. Rios has a habit of classifying the various tropical storms and hurricanes that she has weathered during her decades of living in the state as either rain events or wind events. "Harvey," she says, "was a biblical rain event. It was raining so hard for 3 days solid. We just watched the water rise and rise and rise." On the third day, Rios convinced her husband to canoe to their home. They could hear helicopters above as they paddled, and they were dismayed to find that they could row right into their kitchen.

Also like Escobar, Rios was aware of the risks of living in and cleaning up flooded homes and buildings. Rios is a faculty associate at UTHealth School of Public Health and a co–principal investigator at the Texas-Utah Consortium for Hazardous Waste Worker Education and Training (Texas-Utah Consortium), a research and training facility funded by the National Institute of Environmental Health Sciences (NIEHS). Her research focuses on environmental health risks to workers. Working with her colleagues at the Texas-Utah Consortium, Rios began to do what she could for cleanup workers in the Houston area.

Baldazo-Tudon explains that the Texas-Utah Consortium was one of many partners that teamed with FJWC following Harvey to address the need for more safety trainings and PPE for day laborers. These partners collaborated to provide training workshops aimed at educating peer trainers, like Escobar, who could relay the information to their fellow workers on construction sites. Ultimately, 785 peer trainers received health and safety trainings in the 6 months between December 2017 and May 2018, according to the FJWC.

The Texas-Utah Consortium also played a key role in obtaining protective equipment for workers. Rios spearheaded efforts to reallocate funds for the purchase and distribution of 1,000 N95 respirators, which are designed to filter out mold spores and other hazardous particulates that might be present in a building that has been filled with water for several days.[17] She and her colleagues at the Texas-Utah Consortium trained workers on the use of respirators, as well as how to recognize common health risks like heat stress. Rios also distributed informational booklets in English and Spanish and Tyvek suits and leather gloves to protect those who would rebuild the city.

Rios still hasn't moved into her house, but she insists she is one of the lucky ones. She and her family had shelter during the storm; they continue to have a permanent place to live; and they had access to the services they needed both before the storm and in the ongoing recovery period. For Escobar and many other vulnerable Houstonians...



...THE IMPACTS FROM HARVEY ARE STILL UNFOLDING. "MOST PEOPLE DIDN'T THINK IT WAS THAT DANGEROUS TO GO BACK INTO THE HOUSE," SAYS ESCOBAR. "THERE IS STILL NOT A GREAT AWARENESS IN THE COMMUNITY ABOUT THE HEALTH CONSEQUENCES FROM HARVEY."

When asked about the continuing impacts to workers, Baldazo-Tudon and Wager Saldívar say they're still trying to figure this out. "As a nonscientist, you don't really know what to look out for in terms of the long-term effects," explains Wager Saldívar. "We could really use more scientists looking at that." At least one NIEHS-funded study is currently tracking Harvey's long-term health impacts on nearly 200 Texans living in homes flooded during the storm, as part of NIEHS's disaster research response priorities.[18,19] The hope is that Wager Saldívar and Baldazo-Tudon, and all those working to keep flood-impacted individuals healthy, will get answers soon.

SCIENCE SAVES LIVES

With the sole exception of Hurricane Katrina, no weather event on record has ever caused as much damage in the United States as Hurricane Harvey.[10] However, hurricanes themselves are nothing new to the residents of the south central and southeastern United States. Between 2000 and 2018, hurricanes caused more than 5,800 deaths and $760 billion in damages.[10] Fortunately, the efforts of Rios and organizations like the FJWC were also not unique. This is only one example of how scientists and engineers work alongside public safety officials, community leaders, and first responders during all stages of extreme weather events, from preparation to addressing the aftermath.

CLIMATE SCIENCE AND THE ECONOMY:
THE BOTTOM LINE

The current scientific consensus predicts that hurricane maximum wind speeds and precipitation rates will increase with projected climate change.[9] Change has already started; some studies indicate that human-caused climate change has contributed to the observed increase in North Atlantic hurricane intensity since the 1970s.[9] For Hurricane Harvey, in particular, multiple modeling studies suggest that human-driven climate change increased the likelihood of the observed extreme precipitation accumulations from the storm.[9] One study found that warmer sea surface temperatures, caused by carbon dioxide (CO2) accumulation in the atmosphere, increased the highest amounts of total rainfall by at least 19%, with a best estimate being 38%.[38] A second study found that the 3-day rainfall was 15% more intense than predicted by a warmer atmosphere holding more moisture alone.[39] In both studies, human-driven factors were estimated to increase the likelihood of the observed extreme rainfall during Harvey by 3–3.5 times.[38,39]

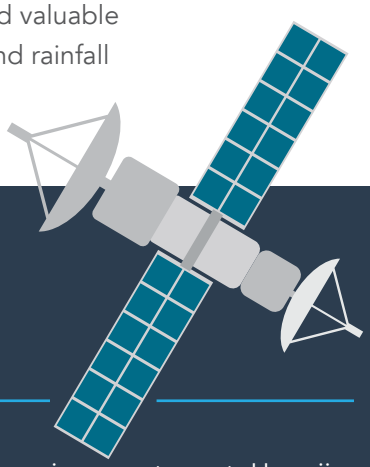
The Congressional Budget Office (CBO) estimates that hurricane wind and flooding damage will cost the U.S. economy $54 billion annually under current conditions, an amount greater than the individual gross domestic products of Montana, South Dakota, Wyoming, or Vermont.[40,41] Given climate predictions, however, it is likely that future costs from hurricane damages will exceed the CBO's current estimates.

HURRICANE WIND AND FLOODING DAMAGE WILL COST THE U.S. ECONOMY

$54 BILLION

ANNUALLY UNDER CURRENT CONDITIONS

The day before Harvey made landfall, 23 August 2017, the National Hurricane Center (NHC) issued its first hurricane watch tracking the storm.[20] Meteorologists at NHC and the National Weather Service (NWS) worked around the clock to predict where Harvey would make landfall. In near-real time, they pored over updated imagery from a weather satellite known as GOES-16, a satellite developed and launched by NASA and the National Oceanic and Atmospheric Administration (NOAA). GOES-16 is just one of multiple satellites operated by NASA and NOAA that first spotted the tropical wave off the coast of Africa that later developed into Harvey. Satellites provide forecasters at NWS data to feed into sets of equations, collectively called models, and create forecasts. NOAA's weather prediction models, such as the Global Forecast System, provided valuable predictions of the storm's path and rainfall days in advance.[21]



TECHNOLOGY:
THE EYES ABOVE

The GOES series satellites fly in "geostationary orbit," revolving around the Earth at a speed matching the planet's rotation, which allows the satellites to remain in a fixed position relative to the Earth's surface. Launched in 2016, GOES-16 monitors central and eastern North America, South America, and the Atlantic Ocean from 22,300 miles above the Earth's surface, about 10 times the distance between New York City and Las Vegas.[42] Its counterpart, GOES-17, monitors the North American west coast, Hawaii, and the Pacific Ocean.[42] Both GOES-16 and GOES-17 scan the Earth 5 times faster than their predecessors, as often as every 30 seconds, and at 4 times higher resolution.[42]

In addition to geostationary satellites, the majority (85%) of the information used in weather forecasts comes from polar-orbiting satellites, which circle the Earth 14 times a day, traveling from pole to pole.[43]

During Harvey, satellite images and the related forecasts developed by NWS were distributed in near-real time through the Emergency Managers Weather Information Network, allowing emergency managers and public safety officials to access information rapidly and take action.[20] Almost a decade of social science funded by the National Science Foundation (NSF) and NOAA informed how NWS forecasters shared information with emergency manager partners and their television counterparts.[22]

EFFECTIVE COMMUNICATION WAS ESSENTIAL FOR THE PUBLIC TO UNDERSTAND THE RISK, BELIEVE THE MESSAGE, AND KNOW WHAT ACTION TO TAKE.[22]

Ultimately more than 1 million Texas residents evacuated in advance of Hurricane Harvey.[20]

SCIENTISTS AT THE SCENE

Unlike humans in the path of a storm, buildings cannot evacuate.

Data collected by researchers after disasters can help us understand how to construct buildings, roads, bridges, and other pieces of critical infrastructure so that they can withstand future events. The Geotechnical Extreme Events Reconnaissance (GEER) Association, funded by NSF, which began decades ago as an ad hoc group of engineers and engineering geologists who self-assembled to survey damages and collect perishable data after large earthquakes, now deploys volunteers to other extreme events like hurricanes.[23]

NATIONAL SECURITY:

HURRICANES AS A THREAT

Within just 1 month in 2018, hurricanes caused an estimated $6.6 billion in damages to military installations.[44] In late September 2018, Hurricane Florence damaged Camp Lejeune and other Marine Corps facilities in North Carolina; a preliminary estimate placed the repair costs at $3.6 billion.[44] Just a few weeks later, in October, Hurricane Michael hit Tyndall Air Force Base in Florida. The repairs were estimated to require $3 billion and more than 5 years to complete.[44]

HURRICANES CAUSED AN ESTIMATED $6.6 BILLION IN DAMAGES TO MILITARY INSTALLATIONS

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Nina Stark, an associate professor in the Department of Civil and Environmental Engineering at Virginia Tech, was a coleader of GEER's Hurricane Harvey response team. Stark, who studies soil erosion processes, along with members of her team flew to San Antonio a few days after Harvey made landfall. Following the path of the storm, Stark and her team worked with colleagues from local universities like Texas A&M and the University of Texas along with the USACE, municipalities, and local community organizations to record the extent of erosion immediately after the storm, before any natural backfilling or cleanup took place.

By being at the scene so quickly after Harvey had passed through southeastern Texas, Stark observed that erosion around some bridge pilings was deeper than she expected based on current scientific models of erosion processes. Stark suspects that this occurred because current models are based on data collected much longer after storms when new sediment has already begun to fill the holes left by erosion. The resulting research could affect models that predict when bridges will fail, or even the way bridges are designed. Stark emphasizes,

"IT'S REALLY IMPORTANT TO UNDERSTAND THE PROCESSES IN ORDER TO PREDICT WHAT WE HAVE TO PREPARE FOR IN THE FUTURE–TO MAKE SURE THAT EVENTS MAY BE LESS DEVASTATING BECAUSE WE'RE BETTER PREPARED AND MORE RESILIENT."

To that end, GEER leaders recruited Tracy Kijewski-Correa, an associate professor of civil engineering and global affairs at the University of Notre Dame, for the Hurricane Harvey mission. GEER had coordinated many extreme event responses before, but never one that included structural engineers. Surveying the damage after hurricanes like Harvey can help structural engineers learn how to build back communities stronger by making homes better able to withstand hurricane-force winds and storm surges. Kijewski-Correa assembled a team of engineers to survey residential building damage. They deployed in multiple teams, including one team mapping the extent of storm surge inundation, multiple teams walking door to door to assess damage due to wind and storm surge, and one creating 3-D maps of storm damage across entire neighborhoods.[24]

Stark, Kijewski-Correa, and all the participants in these efforts were volunteers, and all the data they collected are freely available.[25,26,27,28,29] Surveys for domestic events like Harvey cost GEER about $19,000 to complete; an engineering firm would charge an estimated $170,000 for the same response.[30] The data generated by these federally funded surveys therefore cost only about 11 cents on the dollar. But the true return on investment is invaluable when considering the lives and homes saved through changes to construction practices informed by the results of the surveys.

AN EYE ON THE FUTURE

Harvey is just one example of how hurricanes devastate communities.

SCIENTISTS ARE WORKING TIRELESSLY PAST THE INITIAL STAGES OF RECOVERY TO IMPROVE FUTURE FORECASTS AND LEARN HOW TO PREPARE AND RECOVER FASTER IN THE FACE OF DISASTER.

The 2017 hurricane season demonstrated the need for structural engineers like Kijewski-Correa to formalize their response to extreme events. She has since received NSF funding to create a coordinated Structural Extreme Events Reconnaissance (StEER) Network. NSF also supported the creation of a central "node," the Natural Hazards Reconnaissance Facility, to organize the response of extreme event reconnaissance between organizations like StEER and GEER. This facility is based at the University of Washington and successfully coordinated responses to Hurricanes Michael and Florence in the 2018 hurricane season, among other events.[31]

Hurricane forecast models are continually improving based on our understanding of the physical processes that drive weather patterns. After Hurricane Sandy in 2012, Congress passed a funding bill providing $15 million for improved computing capacity and research to strengthen hurricane forecasting.[32] With this investment, NOAA scientists developed the Next Generation Global Prediction System (NGGPS) model. Preliminary results are promising; during the 2017 hurricane season, a prototype of NGGPS predicted hurricane paths better than the existing U.S. and European models.[33]

ECONOMY:

VALUE OF WEATHER FORECASTS

Americans surveyed about the economic value of accurate weather forecasts are willing to pay approximately $285 per year per household to ensure that they have this information at their fingertips.[45] This is equivalent to $31.5 billion in benefits to the American public from weather forecasting, and a benefit-to-cost ratio of 6.2:1, given the $5.1 billion annually spent by both the federal government and the private sector on weather forecasts and supporting operations.[45]

The NGGPS model is useful for storm and general weather forecasting, but NOAA also develops models specifically to predict hurricanes through the Hurricane Forecast Improvement Program (HFIP). Between 2008 and 2016, models created through HFIP decreased intensity and hurricane track forecast error by 20%–25% for 1- to 5-day forecasts.[34] A 2004 study estimated the value of a 50% improvement in the 48-hour hurricane forecast to the oil and gas industries alone at $15 million, more than twice the operating budget of the National Hurricane Center[35,36]

NOAA-developed models also support the work of Federal Emergency Management Agency (FEMA) insurance agents seeking to distribute insurance claim funding by type of damage. The 2012 Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act asked NOAA to produce models that could predict after a home is leveled to its foundation whether the damage was caused by wind, wave action, or storm surge.[37] To fulfill this ask, NOAA scientists are working on developing models that can create these hindcasts at the level of an individual house.[33]

SCIENCE CANNOT PROTECT US FROM ALL EXTREME WEATHER IMPACTS, BUT AS WE SAW IN THE CASE OF HURRICANE HARVEY, IT CAN HELP US AVOID CATASTROPHE.

Collectively, the United States needs to ensure that communities across the country facing all varieties of extreme weather—from hurricanes to wildfires to tornadoes and landslides—have the resources and information they need to best prepare and recover in the face of disaster.

SUMMARY

Hurricanes are a costly, deadly problem for our nation. Between 2000 and 2018, hurricanes caused over 5,800 deaths and $760 billion in damages.

Cleaning up after a disaster is a team effort. Science funded by federal agencies and institutes brings together volunteer scientists and engineers from across the country to rapidly respond to disaster situations, collecting data to help us build back better and stronger, and providing evidence-based trainings to keep workers safe.

Knowing when and where a hurricane is going to make landfall, and the predicted intensity of rain and wind, helps keep people safe. The federal agencies NOAA and NASA team up to provide the satellites and modeling capabilities needed to improve lead time for an informed and adequate response by emergency managers.

Disasters like hurricanes are not going away and are predicted to intensify, but scientists, inside and outside federal agencies, working in partnership with affected communities, are advancing their understanding of and ability to predict and respond to this type of extreme weather.