H.R. 2227- STRENGTHENING THE RESILIENCY OF OUR NATION ON THE GROUND ACT

AN ENVIRONMENTAL AND SCIENTIFIC ASSESSMENT

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EXECUTIVE SUMMARY

Extreme weather is a national problem that causes devastation to communities across the United States. In the past 30 years, extreme weather events, which include hurricanes, floods, tornadoes, droughts, extreme heat and extreme cold, have claimed the lives of 16,232 individuals and resulted in more than $880 billion in damages. Furthermore, the frequency and intensity of some of these events are expected to increase in the future. This nationwide problem merits a nationwide response. H.R. 2227, the Strengthening the Resiliency of our Nation On The Ground Act ("STRONG Act" or "the Act") seeks to build resiliency to extreme weather events through the development of a National Extreme Weather Resilience Action Plan ("the Plan"). In order to establish a coordinated strategy for disaster mitigation, the Plan will incorporate the input of diverse stakeholders and integrate existing resilience efforts across all levels of government. It is estimated that every dollar spent on mitigation solutions, which include predictive models and resilient infrastructure, saves $4 in future losses. Scientific uncertainties regarding the nature of extreme weather events and the efficacy of certain solutions can be managed through effective monitoring of resiliency programs. The development of a comprehensive response to extreme weather events will save lives and ensure the welfare of communities throughout the country.

BACKGROUND

Extreme weather affects every region of the United States. Extreme weather events include severe and unseasonable weather, hurricanes, floods, tornadoes and other windstorms, drought, extreme heat and extreme cold (Peters, 2015). These events have significant impacts on human health, property, infrastructure and economic productivity. Recovery from individual events can take years depending on their specific intensity and duration.

HUMAN HEALTH IMPACTS

The most severe health implication of these events is individual loss of life. The 196 billion-dollar weather disasters that occurred between 1980 and 2016 resulted in the deaths of 9,517 individuals in the United States (NOAA, n.d.-l). Additionally, the National Oceanic and Atmospheric Administration (NOAA) estimates that since 1986, at least 16,232 people have died as a result of severe weather, including events not specifically outlined in the STRONG Act (NOAA, n.d.-m).

These events can also cause physical and mental health problems, in both the short and long-term. A Community Advisory Group study of New Orleans metropolitan area residents in the aftermath of Hurricane Katrina found that nearly 50% of pre-hurricane residents had anxiety mood disorders 5 months after the storm, while 30% suffered from post-traumatic stress disorder (PTSD) (Kessler et al., 2008).

ECONOMIC IMPACTS

Extreme weather can also have significant economic impacts. In the past 30 years, the United States experienced more than 130 weather-related disasters that each incurred losses of $1 billion or more. The total standardized losses over this period were greater than $880 billion (Peters, 2015). Over each of the past 8 years, extreme weather events resulted in at least $10 billion in damages annually (Kuhne, 2016). It is estimated that the total annual cost of hurricanes and other storms could rise to a projected $35 billion over the next 15 years (Gordon, 2014).

CURRENT POLICY

The United States does not currently have a national plan to prepare for and respond to extreme weather events. The resilience-building efforts of individual agencies, such as the Federal Emergency Management Agency (FEMA), United States Department of Agriculture (USDA), Army Corps of Engineers, and NOAA, are loosely coordinated. Furthermore, resilience efforts have yet to be integrated into a cohesive national framework. As identified by the Government Accountability Office, these factors can lead to confusion at the local level (U.S. Government Accountability Office, 2015).

JOPLIN, MO & THE EFFECT OF EXTREME WEATHER DISASTER ON COMMUNITIES AND INDIVIDUALS

On May 22, 2011, the deadliest tornado in United States history touched down in Joplin, Missouri with wind speeds of over 200 mph. The tornado was catastrophic to the community, as it killed 160 people, caused more than 1,000 injuries, and resulted in $2.6 billion in infrastructure damage.

Reports depicting the aftermath of the tornado all describe similar, tragic scenes of homes stripped down to their foundations, cars toppled, and trees uprooted. Following the storm, numerous volunteers and organizations traveled to the scene to help, but even two years after the disaster, many members of the community were still without homes. Further, individuals who could not afford to rent or relocate sometimes resorted to living in the dilapidated structures that were once their homes (Shenolikar, 2016). Construction costs for rebuilding totaled $1.6 billion.

Additionally, rebuilding required 1.5 million hours of labor. Another lasting effect from the storm was the deterioration of residents' mental health. A study conducted on the mental health of residents after the tornado found that PTSD and depression were prevalent both 6 months and 2.5 years following the storm. Further, these effects were worse for those in lower socioeconomic classes (Houston et al., 2015).

Now, more than five years after the devastating tornado, the city of Joplin is mostly rebuilt. While lessons were learned and scientific mitigation techniques (such as the advanced warning system) have been updated, the lives lost, social impact, and economic toll of the tornado serve as evidence of the disastrous impacts of extreme weather events.

EXTREME WEATHER FORMATION

HURRICANES

Hurricanes are formed when water evaporates from tropical oceans heated to at least 80°F through a depth of approximately 150 feet below the surface. The rising air reduces the quantity of air at the ocean's surface, resulting in a low-pressure zone that draws in the surrounding air, generating wind (NOAA, n.d.-d). The Earth's rotation causes the wind currents to spin, while clouds form as the warm moist air rises and then cools. With favorable conditions, the winds around the storm's center increase in speed, further lowering the pressure at the center and generating higher wind speeds. Tropical storms with wind speeds of 74 miles per hour or more are considered hurricanes although individual storms can reach 200 miles per (NOAA, 2014). As hurricanes make landfall, they lose the moisture and heat that power their convection cycles and begin to dissipate (see Figure 1).

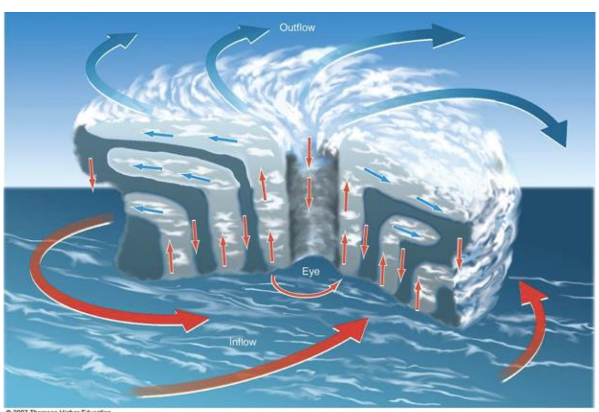

Figure 1. Convection cycles forming a hurricane

INLAND AND COASTAL FLOODING

Freshwater flooding is the result of excessive precipitation or excessive melting of snow or ice (American Planning Association, n.d.). Excessive precipitation is exacerbated by high temperatures, which encourage greater evaporation and atmospheric humidity. This moisture-rich air ultimately condenses within clouds and generates rainfall (National Science Foundation, 2015). Precipitation or snowmelt feeds into rivers, but when the rivers are unable to accommodate the incoming quantity of water, the water floods into the surrounding area.

Coastal flooding is usually caused by storm surges and elevated sea levels. Reasons for sea level rise include the melting of glaciers and land ice, as well as the thermal expansion of the ocean as it warms (NOAA, 2014). During storms, higher sea levels increase the negative impacts of storm surges (NOAA, 2014).Mitigating factors include topography, permeability of the surrounding land, and flood infrastructure (see Figure 2).

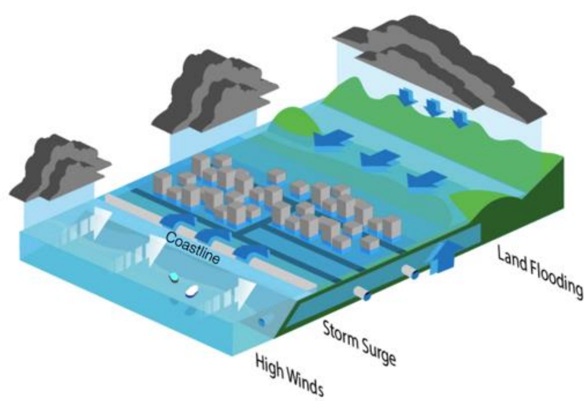

Figure 2. Storm surge and flooding patterns

TORNADOES

Tornadoes are violent storms that extend between the Earth and clouds. They form when warm, humid air collides with cool, dry air, creating a convection cycle (see Figure 3). Tornadoes and other windstorms depend heavily on the location of jet streams, which are high-speed air currents found in the upper atmosphere. The jet streams in the northern and southern parts of the United States are especially important to tornado formation in the U.S. because they allow for the collision of warm and cool air, often at very high speeds (NOAA, 2016a).

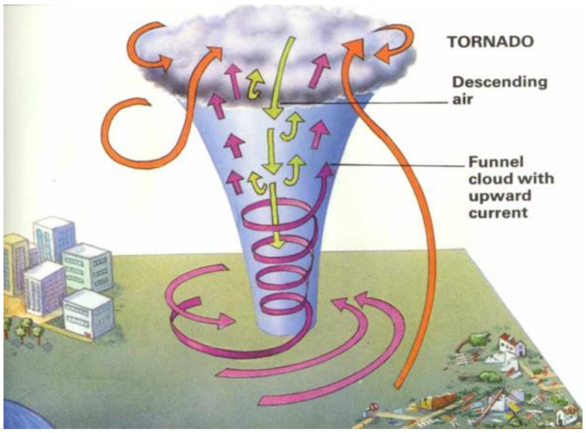

Figure 3. Tornado formation by high speed air currents

EXTREME HEAT

A heat wave is a prolonged period of abnormal or excessive heat, most often in very humid conditions. The magnitude and impacts of a heat wave depend on the ratio of temperature to humidity. Extreme heat events can occur anywhere in the United States and are primarily driven by high humidity and temperatures. Areas that receive direct sunlight are more susceptible, but topography and atmospheric circulation control the overall energy balance of a region. Extreme heat events are increasingly associated with droughts (Mazdiyasni & AghaKouchak, 2015).

DROUGHTS

Droughts are periods of abnormally dry conditions that generate water shortages (USGS, n.d.). Areas that are drier tend to be on the leeward, or downwind, side of a mountain range. Moisture-filled clouds form on the windward, or upwind, side of mountains. Clouds release their stored precipitation on the windward side of mountains in order to become sufficiently light to migrate to the leeward side. The cloud then has little remaining moisture, leaving the leeward side arid (Siler, Roe, & Durran, 2012). Mismanagement of water can exacerbate drought (Drye & 2014, 2014).

EXTREME COLD

Extreme cold stems from a shift of the jet streams to lower latitudes during winter. Jet streams follow boundaries between hot and cold air fronts and are typically stronger in the winter because of the greater temperature differential between these fronts.. Other variables such as air pressure further affect jet stream location. Arctic oscillation occurs when air pressure is low at arctic latitudes and elevated at mid-latitudes, which creates a strong jet stream. When the pressure differential between these two regions lessens, the jet stream weakens and undulates, simultaneously permitting warm air to penetrate further north than is typical (e.g., Northern Canada) and cold air to reach much further south (e.g., the Midwestern and Northeastern United States) (Kug et al., 2015).

THE LEGISLATIVE SOLUTION

The STRONG Act's legislative solution to the problem of extreme weather events is threefold: the creation a cohesive national plan for building resilience to extreme weather; improvement of communication and information sharing among stakeholders; and optimization of existing federal resources as part of these efforts (Peters, 2015). The Act does not directly address the causes of these events, and instead focuses on mitigating their impacts.

UNIFIED STRATEGIC VISION

A National Extreme Weather Resilience Action Plan would establish a national strategic vision and framework for resilience planning. A 2015 report by the Government Accountability Office found that while many agencies are engaged in resilience planning in some way, there is no significant coordination among them (U.S. Government Accountability Office, 2015). This creates opportunities for redundant or even contradictory actions by the agencies.

The National Plan outlined in the STRONG Act would build upon existing federal processes to improve coordination at the federal, state, tribal and local levels. It would improve economic analytical capacity, provide tools and support to private and non-profit stakeholders, and promote public-private partnerships for resiliency-building. Several states have formulated resilience policy frameworks integrating these principles (see The Safeguarding California Plan of 2014).

Creating uniform systems and strategies across the federal government is critical for protecting the United States from these events.

IMPROVED INFORMATION SHARING

Much of the science surrounding extreme weather events is complex and difficult to understand. However, misunderstanding the causes of these events, or not having the most up to date predictive models, increases community vulnerability (Knapp & Sudhalker, 2014). Additionally, knowledge of best practices for building resilience may not be widely understood by local policymakers. The STRONG Act requires the creation of an online portal for the sharing of resilience-related information, including the latest scientific data and predictive models, guidance documents, and financing opportunities. Much of this information is already located in various online databases but compiling it into one website will make it more accessible to state and local policymakers, businesses and the public.

OPTIMIZATION OF EXISTING FUNDING

In support of the above efforts, the bill requires the Director of the Office of Science and Technology Policy to ensure that existing funding resources are being utilized properly to prepare communities for extreme weather events. The act does not authorize additional funding for these activities and is instead focused on improving the use of existing funding through greater coordination and resource utilization. Additionally, as part of the National Plan, communities are encouraged to seek out private partnerships to leverage their funding.

THE SAFEGUARDING CALIFORNIA PLAN OF 2014

The Safeguarding California Plan of 2014 provides policy guidance for decision-making at the state and local levels to prepare for climate-related risks. Its overarching purpose is to minimize economic and social losses through mitigation and adaptation efforts. This plan is a useful model for the National Plan because it addresses a wide variety of extreme weather events, including extreme heat, drought and flooding, and it incorporates many of the same mitigation and coordination strategies outlined in the STRONG Act. Components of the National Plan include cooperative projects across state and local governments, the protection of vulnerable populations, and assessments of future losses from extreme weather risks. The Act also calls for the utilization of existing resources and programs, data analysis and communication of extreme weather risk to all stakeholders, and gap and overlap analyses of existing efforts, as outlined above.

A number of municipal governments in California have established and overseen smart grids. The Safeguarding California Plan proposes that these smart grids be replicated across the entire state. The plan also aims to identify California's most vulnerable populations and ensure that these groups have access to information, services and resources to respond to extreme weather. In addition, it provides for assessments of predicted economic losses from extreme weather events. These assessments include gap analyses examining where existing municipal or local initiatives are lacking in resiliency preparedness. As part of the plan's framework, the Business and Utilities Operation Center (BUOC) serves as a critical hub for emergency response and addresses the needs of impacted communities by organizing and leveraging private sector resources. Private sector and non-governmental organizations involved in the BUOC have agreements with the government to provide support during times of crisis (Natural Resources Agency, 2014). These ideas, outlined in the California plan can be scaled up to a federal level and incorporated into the STRONG Act's National Extreme Weather Resilience Action Plan.

TECHNICAL SOLUTIONS

WARNING SYSTEMS AND PREDICTIVE MODELING

The National Weather Service (NWS), United States Geological Survey (USGS) and NOAA serve as the primary agencies for weather-related data collection and modeling. An array of tools including satellites, buoys and radar systems are employed to detect extreme weather events, alert the public of imminent threats and produce long-term predictive models (NOAA, n.d.-j). The collected data is available to the public for independent research. Warning systems can greatly minimize loss of life and property damage, while models track weather trends and can inform policy decisions and resource planning.

NOAA's NEXRAD or Next-Generation Radar is a widely utilized data collection tool and can characterize different storms from their unique precipitation patterns (see Figure 5). This network of 160 nationwide installations emits radio waves that are deflected by atmospheric precipitation. Based on the motion and amount of precipitation, NEXRAD can detect storms forming within a distance of 155 miles and characterize their behavior (NOAA, n.d.-h).

HURRICANES AND COASTAL FLOODING

The NWS National Hurricane Center (NHC) combines satellite, buoy and NEXRAD data to monitor incoming storms and alert the public to differing levels of risk through watches and warnings relating to tropical storms, hurricanes or high winds, often with several days of advance warning (NOAA, n.d.-e). In addition to tracking storm development, the NHC predicts associated surges and coastal flooding, which are responsible for much of the social and economic costs of these events. The NHC and U.S. Air Force synthesize information on storm behavior to model historical trends in hurricane frequency, intensity and range to better protect the public from these events (NOAA, n.d.-e).

INLAND FLOODING

The NWS River Forecast Center uses NEXRAD precipitation data and snow/ice melt data to produce flash flood warnings. These warnings provide an average advance notice of 54 minutes (NOAA, n.d.-b). NOAA, NWS and USGS researchers further collaborate to produce statistical flood models incorporating information on river stage, historical storm intensity, floodplain topography, and other relevant flooding factors to identify at-risk populations (NOAA, n.d.-a) (see Figure 4).

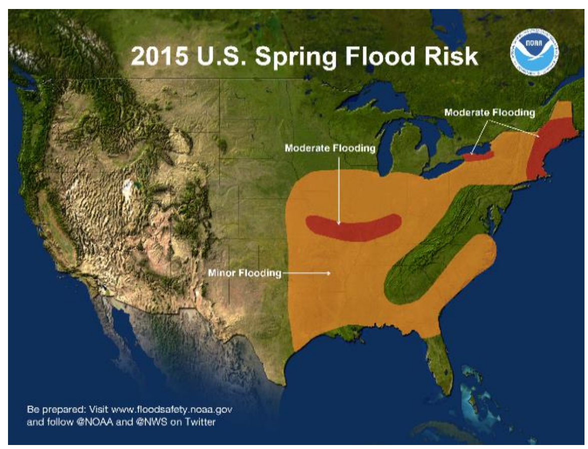

Figure 4. Spring flood risk map published by NOAA

TORNADOES

NEXRAD detects patterns called tornadic vortex signatures approximately 20 minutes before tornado touchdown with 75% accuracy. This tool has increased average tornado warning times to 13 minutes, and decreased annual tornado injuries and fatalities by 40% and 45%, respectively (NOAA, n.d.-b). The NWS Storm Prediction Center combines NEXRAD data and public input to create the public database SeverePlot. SeverePlot incorporates Geographic Information System (GIS) imagery to analyze the temporal trends of tornado patterns since 1950 (NOAA, n.d.-j).

Figure 5. NEXRAD installation in California

EXTREME COLD

The NWS Winter Storm Warning system tracks ice and snow accumulation and issues a public warning of an extreme cold event within 36 hours of its occurrence (NOAA, n.d.-c). Warning criteria depend on geographic averages and are lower for the Southern United States, where extreme cold weather is less common. NOAA's Winter Weather Prediction Center produces two daily forecasts from September through May and populates the National Snow and Ice Data Center database. This database helps predict extreme cold events based on historical trends, sea ice melting anomalies and jet stream oscillation. (NOAA, n.d.-i).

EXTREME HEAT AND DROUGHT

NWS issues excessive heat outlooks, watches and warnings with increasing degrees of certainty and immediacy. Current predictive models allow the forecasting of extreme heat events up to 7 days in advance (NOAA, n.d.-g). The publically available NWS Heat Index, combines temperature and relative humidity data to calculate the apparent temperature and its associated risk to humans (NOAA, n.d.-f).

The U.S. Drought Monitor combines climactic, hydrologic and soil condition measurements from NOAA, the U.S. Department of Agriculture and the National Drought Mitigation Center to predict drought likelihood and severity. NOAA's Drought Risk Atlas analyzes long-term trends, incorporating El Niño Southern Oscillation (ENSO) data and comparing drought severity to historical levels (U.S. Drought Monitor, n.d.)

INFRASTRUCTURE SOLUTIONS

HURRICANES AND COASTAL FLOODING

Green infrastructure, including the maintenance of riverine ecosystems, coastal estuaries and floodplains, plays an important role in mitigating the physical impacts of hurricanes. These ecosystems retain water, prevent storm surges from reaching further inland, and aid in the flood draining process when storm surges reach urban areas; they can also function as wind barriers and reduce the impacts of hurricanes' high wind speeds (Glick, Kostyack, Pittman, & Briceno, 2014). Built infrastructure, such as floodwalls, levees and dry-proofed construction techniques, helps divert water from at-risk communities and serves as a crucial component to effective hurricane resilience planning (Army Corps of Engineers, 2013).

INLAND FLOODING

Mitigation techniques vary depending on the scale of flooding. Floodwalls, natural riverbanks or barriers typically suffice to stem flooding from small rivers, whereas dams and levees are employed for larger rivers with greater stream flow (FEMA, n.d.). These solutions control and store runoff water during a flood event and protect downstream floodplains (see Figure 6).

Figure 4. Maintenance of wetlands in Florida to prevent damage from coastal flooding

TORNADOES

Wind-resistant construction, including the incorporation of techniques such as structural bracing and connection point reinforcement, is critical to maintaining infrastructural integrity in the event of extreme winds (Texas Tech University National Wind Institute, n.d.). FEMA also encourages the construction of safe rooms in affected areas to reduce the fatal impacts of high-category tornadoes (FEMA, 2014).

EXTREME COLD

Extreme cold events place great stress on energy distribution systems, leading to power outages (Mirzatuny, 2014). This can be avoided through fuel source diversification (including the integration of renewable energies) and increased grid storage efficiency. Building insulation further serves to reduce energy demand and shield populations from hazardous outdoor weather conditions (Urban Green Council, n.d.).

EXTREME HEAT AND DROUGHT

While extreme heat events occur nationwide, their effects are exacerbated in cities as a result of the urban heat island effect. The urban heat island effect is a phenomenon that keeps temperatures abnormally high in cities in the evenings, due to high population density and low albedo. As with extreme cold, building insulation reduces demands on urban energy grids, while greater incorporation of heat-tolerant materials in bridges, roads and other infrastructure can reduce service disruptions. Strategically located cooling centers help prevent deaths during extreme heat events, while expanding green areas through the proliferation of green rooftops and cool pavements can reduce the formation of heat islands in the long-term (US EPA, n.d.).

Drought mitigation revolves around water management efficiency, achieved by constructing new reservoirs, identifying secondary water sources, and establishing water usage and storage regulations. Dams can release stored water to relieve drought conditions (Macfie & Blanchard, 2016), and recycled water (both from wastewater and graywater) is an emerging tool for water conservation (American Planning Association, n.d.). Finally, certain agricultural practices, including allowing fields to lie fallow until the drought is over and planting on the stubble of the previous year's crops, can further help the soil retain moisture (California Department of Water Resources & California Department of Agriculture, 2009)

THE U.S. ARMY CORPS OF ENGINEERS' RESILIENCE INITIATIVE

The U.S. Army Corps of Engineers' Resilience Initiative can serve as a model for optimizing existing federal resources in support of resiliency efforts within communities. Established in March 2015, the Initiative seeks to improve the resiliency of communities across the United States to extreme weather events by sharing and encouraging the adoption of the latest resiliency standards and criteria, including building codes, with local decision-makers. It also ensures that the Corps incorporates the most current risk-informed decision-making practices into its projects and operations (U.S. Army Corps of Engineers, n.d.).

Many aspects of this Initiative merit replication on a larger scale as part of the National Plan. A key component of resilience planning outlined in the Initiative is ensuring that buildings and structures maintain their primary function during a naturally-occurring or manmade disruption (U.S. Army Corps of Engineers, n.d.). The June 2016 West Virginia flooding event clearly highlights the importance of this goal. During this event, the Corps closed three of its dams to prevent additional water from flowing downstream toward towns and cities. This prevented additional loss of life and property damage. The Corps had recently completed a construction project strengthening the Bluestone dam on the New River near Hinton, West Virginia, ensuring that it would be able to maintain its functions during even the most extreme flooding (Davis, 2016). The National Plan would require all federal agencies to incorporate resilience into their policies and to coordinate with local entities on resilience efforts. The U.S. Army Corps of Engineers' Resilience Initiative provides an example of how such actions can be taken utilizing existing resources and funding.

UNCERTAINTIES AND CONTROVERSIES

Technological improvements and historical databases have advanced our understanding of the drivers and impacts of these extreme weather events. Nevertheless, scientific uncertainties and controversies persist at three levels of analysis: extreme weather lifecycles, predictive models and infrastructure solutions.

EXTREME WEATHER LIFECYCLES

Several facets of the formation, behavior and dissipation of extreme weather phenomena defy scientific consensus, complicating the ability of the NWS to issue accurate weather forecasts and warnings. While not explicitly mentioned in the bill, climate change is a notable driver of this uncertainty, as the effect of rising temperatures on these events is not yet fully understood.

HURRICANES, COASTAL FLOODING AND INLAND FLOODING

Hurricane behavior is influenced by warm oceanic currents, which vary in location, depth and strength over time. These currents, including the Gulf of Mexico's Loop Current (see Figure 7), provide an injection of heat and moisture that affects hurricane intensity (Gyory, Mariano, & Ryan, n.d.). Climate change further complicates hurricane behavior. NOAA computer models predict a significant increase in hurricane intensity by the end of the 21st century as a result of warming atmospheric temperatures. However, no correlation has been found between climate change and hurricane frequency (NOAA, 2015a).

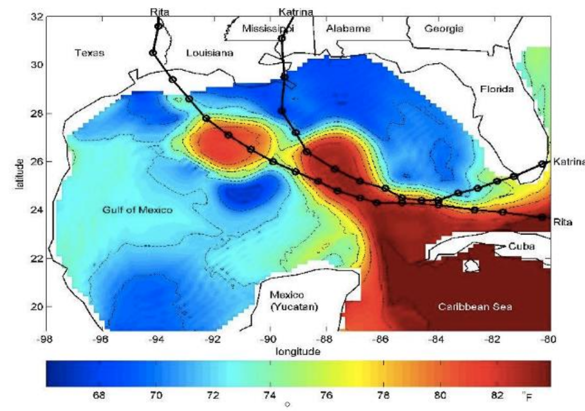

Figure 5. Loop current which was responsible for intensifying Hurricane Katrina

TORNADOES

Tornadoes remain particularly unpredictable, and little of their behavior is fully understood. Ideal weather conditions within a thunderstorm do not always produce tornadoes, while tornadoes can form under imperfect conditions. Furthermore, certain thunderstorm processes, such as cold outflows, can serve as both deterrents and drivers of tornado dissipation (NOAA, 2016b). Climate change is an additional source of uncertainty. NOAA models suggest that rising temperatures will affect several drivers of severe thunderstorms, including atmospheric instability and wind shear, in opposing ways.

EXTREME HEAT AND COLD

Temperature and moisture vary significantly at small scales, as demonstrated by the significant impacts of the urban heat island effect on local conditions in cities. The temperatures felt by city residents can vary on a block-by-block basis due to differing infrastructure density, composition and albedo, limiting public warnings and forecasts that assume heterogeneity of actual surface temperatures (Climate Central, 2014).

Scientists further remain uncertain as to how climate change may affect the jet streams that drive extreme cold events. The Intergovernmental Panel on Climate Change predicts that climate change will shift the jet streams poleward and shrink the polar vortex, while NOAA expects the jet stream maintain its current position, but become wavier and more variable (see Figures 8 and 9). Jet stream behavior will have a significant impact on the occurrence of many extreme weather events, including extreme heat and cold (Overland, Francis, Hanna, & Wang, 2012).

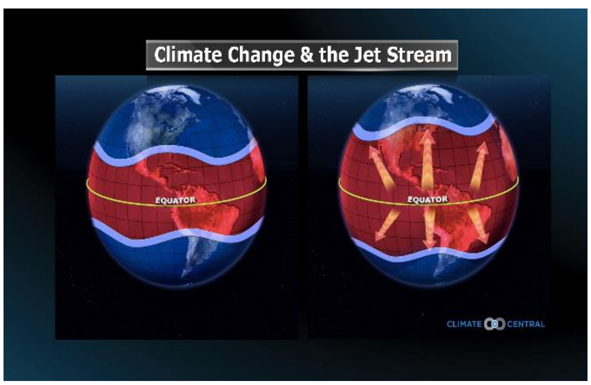

Figure 6. IPCC's projection of change in Jetstream due to climate change

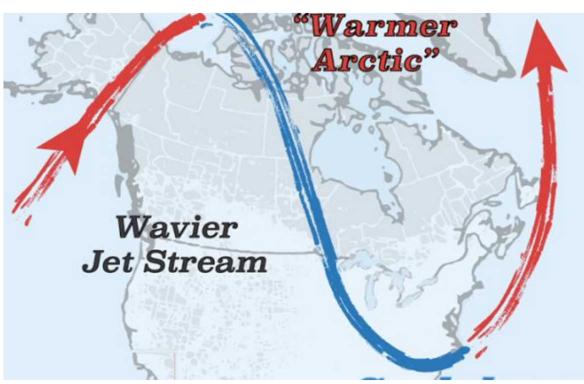

Figure 7. NOAA's projection of change in Jetstream due to climate change

VARIABILITY IN PREDICTIVE MODELS

Our lack of understanding of the drivers of extreme weather behavior and the potential impacts of climate change can make short and long-term modeling of these events difficult and imprecise. In some cases, our ability to predict the occurrence and general track of a storm is limited to a few hours or minutes (NOAA, n.d.-k). Even generally well-understood storms, like hurricanes, are not immune to model imprecision (see Hurricane Sandy & Predictive Modeling). Models analyze atmospheric and oceanic conditions and storm physics, to predict a storm's pathway. These models weigh conditions differently, resulting in certain models outperforming others (Johnson, 2012) . Unforeseen weather conditions can shift a storm away from its expected pathway.

Furthermore, models may rely on assumptions or built-in biases as a result of remaining scientific uncertainties. Computer models have traditionally underestimated the likelihood of extreme heat events, in part because the factors behind the formation of high-pressure systems are not yet fully understood (McKinnon, Rhines, Tingley, & Huybers, 2016). The differing predictions and accuracies of extreme weather models make preparing for these events difficult and poses problems for resilience planning.

INFRASTRUCTURE SOLUTION EFFICACY

Uncertainty in the science of storm behavior and predictive model variability fuel further uncertainty and controversy regarding the best infrastructure solutions to certain extreme weather events. This uncertainty can result from disagreements over the most appropriate way to build resilience to a certain event, or from a lack of understanding of how outside factors could impact the effectiveness of the solution. Controversy can also arise when infrastructure solutions have negative impacts on the surrounding ecosystems and human populations. The following examples demonstrate the different levels of uncertainty surrounding infrastructure solutions.

TORNADOES

The effectiveness of tornado-resistant infrastructure depends largely on proximity to the storm, and the strength of the storm. As previously discussed, there aspects of tornado behavior cannot currently be predicted with great accuracy. For most buildings, wind-proofing (e.g., reinforced roofing and siding) may be effective in reducing tornado damage (Roach, n.d.). However, for houses in the immediate path of a tornado, or in the vicinity of Category 4 or 5 tornadoes, wind-proofing will likely not suffice in reducing loss of life or economic costs. While not actively discouraging wind-proofing, FEMA suggests that the construction of safe rooms and the proliferation of shelters may provide the best protection from tornadoes (FEMA, 2014). The appropriate resilience solution therefore depends on unforeseeable storm characteristics and therefore is subject to a great deal of uncertainty.

INLAND FLOODING

Dams are often utilized to control the flow of water. However, flooding can still occur when a dam is present because of a number of factors outside of the control of the dam. A dam can only control the water that is behind it. However, a river can have a number of supporting tributaries, and precipitation can fall downstream of the dam. Uncertainty may exist surrounding the best place to locate a dam, as well as over whether a dam is the most appropriate solution for a given area (see Figure 10). Additionally, as dams age, maintenance is required to maintain their reliability. Even with the best maintenance, dams can fail.

Figure 8. Glen Canyon Dam in Colorado as an example of an inefficient dam such as high rates of evaporation and infiltration decreasing its capacity to hold water

Controversy surrounds the building of dams because of their impact on local and downstream ecosystems, which can include ecosystem degradation and increased probabilities of rockslides. Dams are also often associated with the decline and disappearance of native fish populations, which can in turn benefit the proliferation of invasive species. Downstream ecosystem degradation can result in the loss of ecosystem services and increase local community vulnerability (Climate Central, 2014).

HURRICANE SANDY - PREDICTIVE MODELING AS A HURRICANE PREPAREDNESS TOOL

Hurricane forecasting models rely on mathematical equations meant to compute the behavior of weather. These models account for myriad weather variables, and often take hours to calculate on even the fastest supercomputers. Global forecasting models incorporate data sets from across the planet, while other models incorporate data from only a select region (Masters, n.d.). On October 22, 2012, the storm that would become Hurricane Sandy formed in the Caribbean Sea. It made landfall in Jamaica, Cuba and the Bahamas, and then moved northward across the Atlantic Ocean. The earliest predictions of Hurricane Sandy's landfall on the Northeast coast of the United States were made approximately 8 – 9 days prior to landfall and were made by the European Centre for Medium-Range Weather Forecasting (ECMWF). At that time, the American Global Forecast System (GFS) model projected the storm would remain over the Atlantic until it dissipated. The GFS model did not forecast landfall until four days prior to the storm reaching land (Halverson & Rabenhorst, 2013).

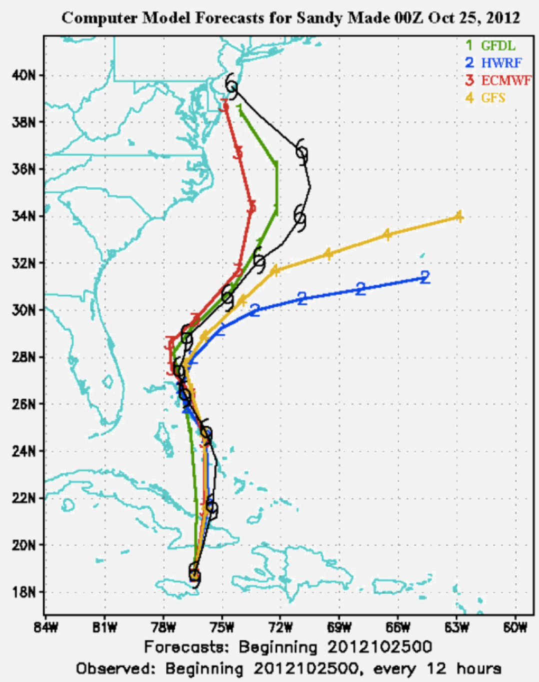

Figure 11. Forecasts for Hurricane Sandy pathway

When comparing the salient differences between the European and U.S. models, three key points stand out: data simulation, computing power, and physical variables analyzed. The European models used multi-dimensional data analysis on a global scale, while U.S. models incorporated data from fewer geographical locations. Furthermore, the European models are run on systems with greater computing power than the U.S. systems, which allowed for higher resolution forecasts (Kwon, 2015). Finally, the European models better incorporated relevant physical variables, such as "cumulus parameterization", in their computations. A 2014 study found that enhanced analysis of this variable would have greatly improved the GFS model's Hurricane Sandy predictions (Bassill, 2014). Following Hurricane Sandy, NOAA announced a plan for significant upgrades to the existing GFS system, such as incorporation of more variables, increased computing time and higher resolution. The Director of the National Weather Service stated that the upgrade would provide for "more accurate and consistent forecasts required to build a Weather Ready Nation."

MEASURING SUCCESS

The goal of the STRONG Act is to improve local and national resilience to extreme weather in order to reduce the human health and economic impacts of these events. The exact measures of success will be determined by the Director of the Office of Science and Technology Policy, who is responsible for the implementation of this Act (Peters, 2015). However, FEMA assessments of the efficacy of their ongoing resilience and emergency management efforts could serve as an appropriate blueprint. FEMA utilizes a standardized benefit-cost analysis approach, with a minimum benefit-cost threshold of 1.0, to evaluate the validity of their proposed grants prior to implementation (FEMA, "Benefit-Cost Analysis").

A 2005 FEMA-derived study indicated a 4:1 benefit-cost ratio for mitigation efforts across all extreme weather events, suggesting that every $1 spent on disaster mitigation would yield future cost savings of $4. At this ratio, the United States could have saved $660 billion over the past 30 years through adequate investment in disaster mitigation (The Multihazard Mitigation Council of the National Institute of Building Sciences).

Individual resilience initiatives will each have project-specific outputs by which to track progress (see: Freeport, NY & FEMA Flood Mitigation). The ultimate measure of success for resilience planning, however, is the reduction in loss of life, injuries and economic damages. Increased coordination of existing resilience efforts and the development of a national plan will help achieve this outcome, saving lives and protecting populations from the worst impacts of extreme weather events. Planning for the future will help to avert catastrophes like Joplin, Missouri, and bolster the strength of communities across the United States

FREEPORT, NY AND FEMA FLOOD MITIGATION GRANTS

The town of Freeport, New York serves as a case study for measuring the success of hurricane and flooding mitigation techniques. Freeport was built on low wetlands. The town frequently experienced flooding, particularly during high tides and storm surges. As a result of Freeport's regular flooding and increasing population, the town was provided with six FEMA hazard mitigation grants between 1997 and 2002. The mitigation grants included money for home elevation projects.

A 2005 study conducted by the Multihazard Mitigation Council of the National Institute of Building Sciences quantitatively demonstrated the success of the mitigation grants. According to the study, prior to the mitigation grants, FEMA honored a total of 1,448 flood insurance claims valued at $10.1 million in Freeport. After the FEMA grants to elevate private houses in the community, it was found that the participating homes had increased property values, and no additional flood insurance claims were issued (FEMA, 2016).

ACRONYMS

BUOC	Business and Utilities Operation Center
CEH	Centre for Ecology & Hydrology
ENSO	El Nino/Southern Oscillation
FEMA	Federal Emergency Management Agency
GAO	U.S. Government Accountability Office
GIS	Geographic Information System
ICLEI	International Centre for Local Environmental Initiatives
IL	Illinois State
MO	Missouri State
NEXRAD	Next Generation Weather Radar
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NOAA-FFEWSRG	National Oceanic and Atmospheric Administration-Flash Flood Early Warning System Reference Guide
NOAA-SPC	National Oceanic and Atmospheric Administration-Storm Prediction Center
NSF	National Science Foundation
NWS	National Weather Service
NY	New York State
SCWA	The Sonoma County Water Agency
STRONG Act	Strengthening the Resiliency of Our Nation on the Ground Act
USD	United States Department Of Agriculture
USGS	United States Geological Survey

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