ON GLOBAL WARMING: A CENTER OF GRAVITY ANALYSIS OF ATLANTIC BASIN TROPICAL CYCLONES

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ABSTRACT

ON GLOBAL WARMING: A CENTER OF GRAVITY ANALYSIS OF ATLANTIC BASIN TROPICAL CYCLONES, by Major Ian P. Kent, 115 pages.

The United States military faces several important near-term threats including a potentially unstable Europe and Korean peninsula. While geographic combatant commanders around the world focus on state and non-state actors, they must also understand the "threat multiplier" of global climate change. Particularly, United States Northern Command, already faces the threat of large-scale destruction on the homeland. This threat takes the form not as a terrorist group or foreign army but as an extreme weather event, a hurricane. This incredible force of nature has demonstrated destructiveness many times over in our history and is expected to be further compounded by global climate change. With rising sea levels, increased sea surface temperatures, and a warmer atmosphere, tropical cyclones are forecasted to become more intense. The response following hurricane strikes will likely overwhelm local and state agencies requiring Title 10, or federal forces to respond more often. This will require United States Northern Command to adapt its strategy for the next 50 years meet this threat.

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ACRONYMS

COG	Center of Gravity
DoD	Department of Defense
DSCA	Defense Support of Civil Authorities
FAR	Fifth Assessment Report
FEMA	Federal Emergency Management Agency
IPCC	Intergovernmental Panel on Climate Change
JP	Joint Publication
JTF	Joint Task Force
RCP	Representative Concentration Pathway
TC	Tropical Cyclone
TCP	Tropical Cyclone Precipitation
U.S.	United States
USGCRP	United States Global Change Research Program
USNORTHCOM	United States Northern Command

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CHAPTER 1

INTRODUCTION

A hurricane is the strongest type of tropical cyclone (TC) existing in the Atlantic Basin and is one of the most powerful forces of nature on the planet. Comprised of a counter-clockwise rotating system of thunderstorms in a low-pressure air mass, these storms create high winds from 74 to 156 miles per hour or greater, generate intense rainfall, and produce powerful storm surge (National Oceanic and Atmospheric Administration 1999, 2). A typical hurricane produces the equivalent energy release of detonating a 10-megaton nuclear warhead every 20 minutes (University Corporation for Atmospheric Research 2013). Proof of the magnitude of destruction were witnessed in numerous incidents of hurricane strikes on the United States (U.S.). Between 1851 and 2010 a total of 284 hurricanes made landfall on the U.S. Homeland, with 96 designated as major hurricanes, those Category 3 or stronger (winds of 110 miles per hour or greater). These types of storms contain an immense amount of power, on the order of 3 x 10^{12} watts, or three million watts (Emmanuel 1999, 107). Investigating only the 30 costliest storms between 1851 to 2017 and accounting for inflation, an estimated total of $891 billion in damages was created. Total deaths caused by storms producing 25 deaths or more between the same range resulted in over 21,000 lives lost (Blake, Landsea, and Gibney 2011, 7-9). With these impressive figures in mind, it is imperative to analyze historical examples to better understand the impact of these storms, the extent of corresponding relief efforts, and the policy that informs them.

The deadliest hurricane to strike the United States occurred on September 8, 1900 in Galveston, Texas. This Category 4 storm struck the 40,000 person city and caused between 6,000 and 12,000 deaths, equal to one in every six inhabitants losing their lives (Rubin 2012, 17). The high death toll was mostly due to the limited warning systems at the time and the relatively clear skies the day before the impending storm. This false sense of security thwarted evacuation effort. The most fatal force during the storm, a 15.5-foot storm surge, caused the seas to rise as much as four feet in just four seconds at one point. This violent storm surge swept through the city preying on those who remained and destroyed countless homes (Rubin 2012, 18). Though this devastating cyclone initiated the twentieth century, it certainly was not the last.

In September 1944, just months after the invasion of Normandy, France, a Category 4 hurricane dubbed the "Great Atlantic Hurricane" struck the east coast of the United States. During its fury, the magnitude of energy and destructive force of this storm was made apparent. With winds as high as 130 miles per hour at the eye and hurricane force winds (74 miles per hour and higher) blowing over 600 miles in diameter, it was responsible for sinking three U.S. Navy and one U.S. Coast Guard vessel causing 344 sailors to be lost at sea (Sumner 1944, 189). Overshadowed by combat operations in Europe and Japan, this storm depleted critical combat power while the U.S. conducted a two-front world war. Landfall damage included over $100 million with 46 people killed along the coast (Sumner 1944, 188). The lack of modern infrastructure contributed to the death and destruction caused by this storm, as shipping lanes provided the bulk of reporting of inbound tropical cyclones at the time. However, this year proved to be instrumental in further advancements in this regard.

The genesis of aircraft reconnaissance missions of hurricanes occurred in 1944 to better warn and inform coastal residents of these formidable systems. As the predecessors of the modern day “Hurricane Hunters”, these units provided critical information on the metrics of the storm and its location and direction. However, due to limitations in the aircraft’s range, tropical cyclones originating and existing east of latitude 55 degrees west were rarely identified (Landsea 2007, 199). Not until the advent of the polar orbiting satellite in 1966, with the launching of ESSA-1, did the ability to take daily photographs of tropical cyclones exist (McAdie et al. 2009, 12). Despite the advent of new technology, however, the threat of landfalling tropical cyclones in the United States and the resultant damage and death was not entirely removed.

In 1969, during the height of the Vietnam War and just three years following the successful launch of ESSA-1, Hurricane Camille slammed into the gulf shores of Mississippi and Louisiana. As the second of only three Category 5 storms to ever strike the U.S. mainland, the storm unleashed incredible power. It was so forceful, in fact, that it physically destroyed the wind-measuring instruments, but estimates top out at over 200 miles per hour (Hearn 2004, 88). Coupled with these ferocious winds was an incredible storm surge of over 28 feet (Zebrowski and Howard 2005, 128). The affected area stood little chance to prevent itself from being impacted from these two consuming forces of nature. 68 square miles were destroyed in Harris County and 172 lives were lost. In response to this expansive disaster were16,500 Department of Defense (DoD) service members who came to the aid of overwhelmed local and state authorities. However, the creation of an entity to coordinate the disaster relief efforts of several different agencies would take decades to evolve.

On January 12, 1950, the Federal Relief Act was signed into law by then President Truman, with the ostensible motive to assist in response to a nuclear attack

(Rubin 2012, 84). This act allowed the federal government to support civil authorities during natural disaster relief efforts and provided more timely support to local and state authorities following such catastrophic events. This formation helped lead to the creation of the Office of Emergency Planning in 1961 that served as a precursor to the Federal Emergency Management Agency (FEMA), which was later signed in to law by President Carter in 1979. Furthermore, the ability of the federal government to improve response to natural disasters was greatly enhanced with the Robert T. Stafford Disaster Relief Act. This act enabled the President of the United States to declare a state of emergency with or without state governor concurrence. It also authorized the President to use the DoD for "emergency work" for up to 10 days without a state of emergency declaration (Wombell 2009, 14).

Finally, in August 1992, FEMA was put to the test during relief efforts following Hurricane Andrew, a Category 5 hurricane that struck Miami Dade County. Andrew was only one of three Category 5 storms to ever hit the U.S. Homeland between 1851 and 2010 (Blake, Landsea, and Gibney 2011, 15). The devastation caused by the massive release of the storm's energy killed 60 people, caused extensive damage in a 200-square mile area, leveled 80,000 homes, and created 250,000 internally displaced persons. This epic amount of destruction overwhelmed local and state entities as well as FEMA, who requested federal assistance. This came in the form of more than 22,000 federal military troops (Wombell 2009, 14).

Joint Task Force (JTF) Andrew was established, including elements from both the 82nd Airborne Division and the 10th Mountain Division from Fort Bragg, North Carolina and Fort Drum, New York respectively. These two elements were further organized into

Task Force All-American (82nd Airborne Division) with an area of operations to the north of the affected area and Task Force Mountain (10th Mountain Division) to the south (Joint Task Force Andrew 1992, 6). These elements were responsible for power generation, debris clean up, restoring essential services, medical treatment, and search and rescue operations. This storm created a massive amount of damage and death while committing vast combat power within the US military, but also potentially affected combat readiness for deployments to other national security issues. 1st Battalion, 22nd Infantry Regiment of the 10th Mountain Division, for example, deployed and returned from their disaster relief efforts only to be given a deployment order two months later to support Operation Restore Hope in Somalia (Wombell 2009, 214).

Once again, in August of 2005, another Joint Task Force was formed to conduct defense support to civil authorities following Hurricane Katrina. In a similar fashion to Hurricane Andrew, JTF Katrina was established to assist an overwhelmed FEMA. Katrina was responsible for 1,833 deaths, $108 billion dollars in damage (2005 dollars) and committed massive amounts of combat power with over 72,000 Army Soldiers (Active, Reserve, National Guard), Sailors, and Airmen conducting the largest disaster relief effort in U.S. history (Medlin, Ball, and Beeler 2016). Included in this number was over 20,000 federal, or Title 10, forces that complemented the 50,000 National Guard soldiers already committed to the response (Government Accountability Office 2006, 21).

Major General William B. Caldwell, then Commander of the 82nd Airborne Division, was informed by Lieutenant General Russel L. Honore that his job was "to fix the airport and fix New Orleans" with four subordinate tasks. The first was to save lives, second to restore airport operations to continue evacuation efforts, third to provide humanitarian assistance, and fourth to assess what the most critical needs were. With this initial guidance and mission statement 3rd Brigade of the 82nd Airborne Division conducted search and rescue efforts and provided security by patrolling the city while 1st Battalion, 319th Airborne Field Artillery Regiment restored airport procedures and evacuated over 9,000 personnel. Additionally, 13th Corps Support Command from Fort Hood, Texas also took over logistics operations when FEMA asked for additional assistance (Berthelot 2010). Though United States Northern Command responded twice during the 2005 season for both Hurricane Katrina and the subsequent Hurricane Rita landfall on the Texas-Louisiana border, the command would respond many more times in the future.

More recently, in August and September of 2017, elements under USNORTHCOM responded to three hurricane relief operations near simultaneously. Hurricane Harvey relief efforts were underway following its Category 4 landfall on August 25, 2017, in Texas when Hurricane Irma developed into a follow-on Category 4 hurricane and struck southern Florida just over two weeks later. Nearly a week following Irma's landfall in Florida, Category 4 Hurricane Maria devastated the U.S. territory of Puerto Rico and Virgin Islands. Significant combat power from the U.S. Army, U.S. Air Force, and U.S. Navy assembled into a Joint Task Force and was committed from USNORTHCOM to each of these closely sequenced hurricane strikes.

During Harvey, alongside the 10,000 Soldiers of the Texas National Guard, a vast amount of response assets from the Department of Defense also came to assist relief efforts. This included 87 helicopters, four C-130 Hercules to deliver much needed supplies into the state. 100 high-water vehicles were then used to distribute these supplies through the extensively flooded areas. Two naval vessels, an amphibious ship (the *USS Kearsarge*), and a docking ship (*USS Oak Hill*), with several hundred Marines of the 26th Marine Expeditionary Unit aboard with MV-22 tilt rotor Osprey aircraft also contributed to relief operations (Klare 2017). Over 3,000 active-duty forces were also sent to Texas to assist the large contingent of National Guard soldiers in relief efforts (USNORTHCOM 2017b, App C). To coordinate the response in an area of widespread devastation without a working communications network, an E-3A AWACS (Airborne Warning and Control System) was employed to manage operations from the air (Klare 2017). This was but the first of three Category 4 hurricanes to make landfall in the United States or its territories.

Hurricane Maria, making landfall as a Category 4 hurricane in Puerto Rico on September 20, 2017, was the tenth strongest hurricane on record and caused deaths and massive destruction to property and the island's power grid. The DoD, having already committed to relief operations in Texas and Florida, began operations to synchronize actions and integrate forces with FEMA and National Guard units to provide disaster response in Puerto Rico. With USNORTHCOM in the lead of the DoD's disaster response effort there, the aggregation of assets, capabilities, and leadership again proved similar to a JTF created for a contingency operation within the range of military operations.

Lieutenant General Jeff Buchanan was charged with this significant undertaking and commanded a complement of military assets that would rival that for an invasion of a small Caribbean nation (Klare 2017). His position and rank were equivalent to the Joint Task Force Commander who is tasked to defeat the Islamic State in Iraq and al-Sham (ISIS) and speaks volumes to the weight of responsibility DoD places on disaster relief operations. Support from the DoD came through the land, air, and maritime domains. On the ground, a peak total of 13,700 federal and national guard soldiers deployed to the area, comprised of expeditionary support commands, combat support hospitals, and U.S. Army Corps of Engineers. Within the air domain, 92 rotary-wing aircraft were committed to include UH-60 Blackhawk, CH-47 Chinook, MV-22 Osprey helicopters. 19 fixed-wing aircraft like the C-130 Hercules, C-17 Globemaster III, and the C-5 Galaxy, complimented with aerial refueling assets were additionally committed. Finally, in the maritime domain, naval forces included three amphibious and docking ships the *USS Kearsage*, *USS Wasp*, and *USS Iowa Jima*, afloat with their elements of the 26th Marine Expeditionary Unit. The *USNS Comfort*, an 892-foot combat hospital ship and only one of two in the U.S. Navy inventory for use during large scale combat operations, was also dispatched to support (Department of Defense 2017a). Substantial military assets were brought to bear to conduct the disaster relief mission.

A litany of different missions spawned from the relief efforts in Puerto Rico. Overall relief efforts provided and distributed life sustaining supplies like food and water to local citizens, restored critical infrastructure, and generated power for hospitals and water systems (Dickstein 2017). The first unit deployed to assist Puerto Rico was the 26th Marine Expeditionary Unit who conducted essential commodity distribution and route clearance to facilitate an increased flow of follow-on supplies. The Defense Logistics Agency also provided high quality maps of the devastated areas to assist in the coordination of efforts as well as serving 2.5 million meals a day. Strategic lift assets facilitated transport and delivery of powerful generators that provided power to essential services to crippled infrastructure. The armada of the Combined Task Force 189 offered offshore helicopter landing platforms and distributed much needed supplies to the interior of the island. The *USNS Comfort* treated up to 200 patients per day while anchored off the coast of Puerto Rico (Department of Defense 2017a). But this was not the end of commitments in precious military combat power for these relief operations.

Additional maritime assets were also sent to the region to assist in the disaster response. USNORTHCOM dispatched three U.S. Navy vessels, the aircraft carrier *USS Abraham Lincoln*, the destroyer *USS Farragut*, a transport dock vessel, and the *USS New York* to support ongoing efforts (Werner 2017). The majority of ground forces comprised support, medical, and engineer assets and produced water, treated the wounded, and conducted route clearance of the cluttered and destroyed road infrastructure that reestablished ground lines of communication. Over the course of time between September 20th and November 3rd, 160 million meals were served, all but one hospital was operational, 82 percent of the country had potable water, 84 percent of gas stations were reopened, and 40 of the 51 wastewater plants were online (Department of Defense 2017a). The DoD relief efforts of Hurricane Maria, Irma, and Harvey committed vast military resources but were successful in alleviating suffering in Puerto Rico, Florida, and Texas. Assuredly, tropical cyclones will continue to strike the U.S. Homeland in the future and create widespread devastation to which large amounts of combat power will be dedicated.

Atlantic Basin tropical cyclones present a direct threat to the U.S. Homeland through deaths of American citizens and destruction of property. However, the associated disaster response commits large quantities of military manpower and assets from USNORTHCOM. Figure 1, highlights the paths of all storms between 1851 to 2010 that caused at least 25 deaths or more. On average, five hurricanes strike the United States Homeland every three years (National Oceanic and Atmospheric Administration 1999, 4). These storms are predicted to become more powerful in a warmer world as sea surface temperature continue to increase, adding more energy into the hurricane (Wuebbles et al. 2017, 22). Due to the increasing potential for more destructive tropical cyclones, a more definitive understanding of them is warranted. This is particularly true if these systems will more readily overwhelm local and state authorities, charged as the first responders to the resultant disaster. If senior decisionmakers do not recognize the increasing threat of tropical cyclones in the next 50 years, it will restrict USNORTHCOM from fulfilling requests for assistance and the nation can expect more devastation along its coastlines.

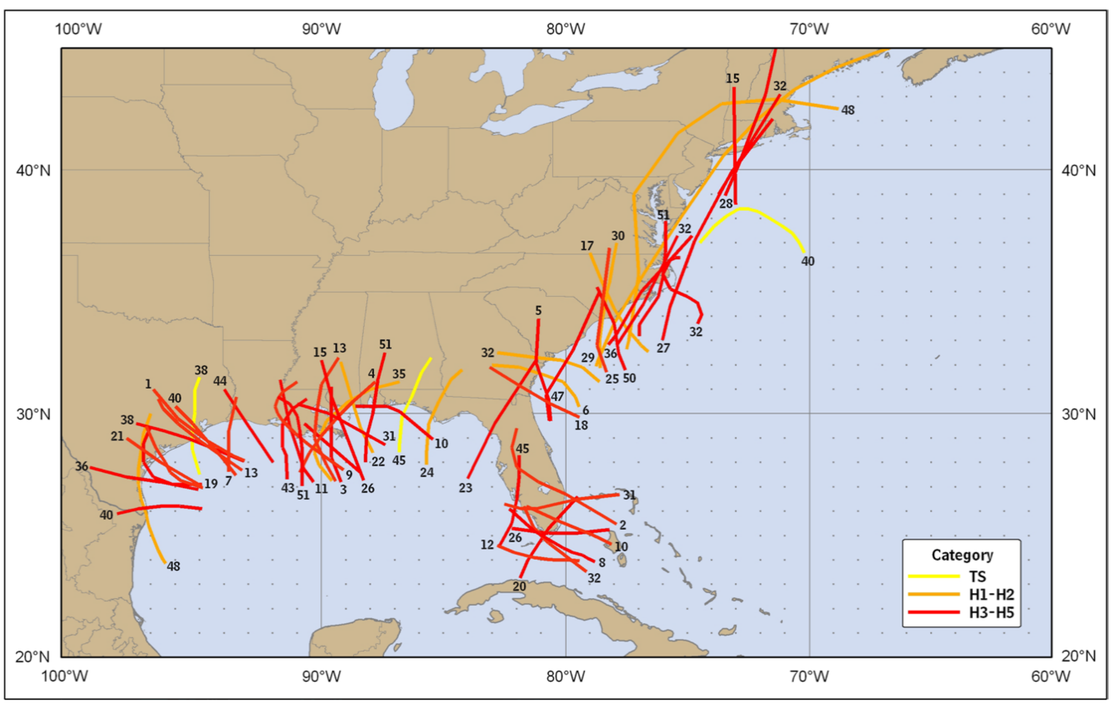

Figure 1. Hurricane Strikes Causing at least 25 Deaths from 1851 to 2010

Source: (National Hurricane Center 2017).

Primary Research Question: How does USNORTHCOM adapt to the impacts of more destructive tropical cyclone strikes against the homeland due to global climate change in the next 50 years?

Subordinate Research Question 1: Will global climate change increase the frequency, duration, or magnitude of destruction caused by Atlantic Basin tropical cyclones in the next 50 years?

Subordinate Research Question 2: How can senior leaders better understand the threat posed by Atlantic Based tropical cyclones using existing military models to better prepare and execute when called upon to assist in disaster relief?

Subordinate Research Question 3: Does the National Guard, FEMA, or USNORTHCOM need to revise its posture, organization, or and capabilities to more effectively respond to disaster relief efforts?

Assumptions

Global climate change will continue to occur to some degree despite the amount of anthropogenic contribution of greenhouse gases. The Area of Responsibility for USNORTHCOM will not change in the next 50 years as per the Unified Command Plan. Significant changes in solar irradiance will not occur, thereby changing the amount of radiative forcing in the earth's climate system.

Key Terms

Atlantic Basin: Ocean area comprising North Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico (McAdie et al. 2009).

Catastrophic Incident: Any natural or manmade incident, including terrorism that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, or government functions (Department of Homeland Security 2013, i).

Combat Power: The total means of destructive, constructive, and information capabilities a military unit or formation can apply at a given time (Department of the Army 2016, 5-1).

Defense Support of Civil Authorities (DSCA): Support provided by U.S. Federal military forces, DoD civilians, DoD contract personnel, DoD Component assets, and National Guard forces . . . in response to requests for assistance from civil authorities for domestic emergencies, law enforcement support, and other domestic activities, or from qualifying entities for special events (Department of the Army 2010, 1-1).

Foreign Humanitarian Assistance: Assistance that can be used immediately to alleviate the suffering of foreign disaster victims (Joint Chiefs of Staff 2014, GL-17).

Global Climate Change: Change in the Earth's overall climate, with climate change defined as a change in the typical or average atmospheric conditions over a long time span, normally thirty years or more (i.e. temperature, precipitation, etc.) (May 2017).

Hurricane: An intense tropical weather system of strong thunderstorms with a well-defined surface circulation and maximum sustained winds of 74 mph (64 kt) or higher (National Oceanic and Atmospheric Administration 1999, 4).

Major Hurricane: Category 3 (maximum sustained winds of 110mph or greater) or higher hurricane (University Corporation for Atmospheric Research 2013).

Tropical Depression: An organized system of clouds and thunderstorms with a defined surface circulation and maximum sustained winds of 38 mph (33 kt) or less (National Oceanic and Atmospheric Administration 1999, 4).

Tropical Storm: An organized system of strong thunderstorms with a defined surface circulation and maximum sustained winds of 39-73 mph (34-63 kt) (National Oceanic and Atmospheric Administration 1999, 4).

Storm Surge: The excess above the level expected from the tidal variation alone at a specified time and place Intergovernmental Panel on Climate Change (IPCC) Summary. During a hurricane, it is a large dome of water, 50 to 100 miles wide that sweeps across the coastline near where a hurricane makes landfall. It can be more than 15 feet deep at its peak (National Oceanic and Atmospheric Administration 1999, 13).

Title 10, Federal Forces: Full time duty in the active military service of the United States (United Stated Code Title 10, Section 101 Paragraph D, Subparagraph 1).

Scope

This study will not focus on global climate change impacts on all aspects of national security relating to USNORTHCOM. Instead, the emphasis concentrates on how USNORTHCOM and senior decision-makers better understand and ultimately respond to potentially more intense Atlantic Basin tropical cyclones within the next 50 years. This timeframe is selected for two reasons. First, predictions of global climate change from the Intergovernmental Panel on Climate Change and National Climate Assessment are based on similar timelines and allow for a sufficient timespan in their models to determine the severity of these impacts. Second, though these significant impacts may not be fully realized until the aforementioned horizon, 50 years affords USNORTHCOM and its higher authorities time to adapt. Only with a greater appreciation of the growing threat can USNORTHCOM begin to address the issue. This is possible by providing additional resources, allocations, and authorities to prepare itself while balancing many other threats now and in the future.

Limitations

All data included in this thesis is limited to the unclassified level. Additionally, Atlantic based tropical cyclone monitoring was severely limited prior to the advent of the weather satellite in the mid-1960s. The first aircraft reconnaissance of tropical cyclones began in 1944 but likely still missed those storms forming east of longitude 55 West (Landsea 2007, 200) based on shorter range capabilities at the time. Therefore, as it pertains to the frequency of tropical cyclones, data collection before the aforementioned times is biased without the ability to effectively monitor for such weather events.

Significance of the Study

Tropical cyclones (particularly hurricanes) are a destructive force that cause prolific damage to property and loss of life within the United States and its Atlantic territories every year. This coupled with the potential increase in their intensity, frequency, or duration due to global climate change, makes this study ever more critical to help senior military leaders understand the impending threat they face. Senior leaders must understand these natural forces much as they would an adversarial force to better defend against and respond to them. Additionally, this study serves to help solve the Army Warfighting Challenge #6, Homeland Operations, as it facilitates understanding of an emerging threat that the homeland will face in the future.

CHAPTER 2

LITERATURE REVIEW

The impacts of global climate change have several implications for national security. These include warming trends and effects on Arctic ice sheets, thereby causing sea levels to rise as well as a now navigable Northwest Passage as of 2007 (Kahn 2016). The Department of Defense Climate Adaptation Roadmap 2014 highlights a plethora of consequences of global climate change that consider it to serve as a "threat multiplier" in combat areas. Secretary of Defense James Mattis corroborated this point during his testimony to the Senate Arms Senate Committee when he stated, "Climate change is impacting stability in areas of the world where our troops are operating today." He later affirmed, "Climate change can be a driver of instability and the Department of Defense must pay attention to potential adverse impacts generated by this phenomenon" (Revkin 2017). Additionally, the roadmap calls attention to possible increases in operational tempo of the U.S. Military for defense support to civil authorities and foreign humanitarian assistance due to more frequent and severe natural disasters (Department of Defense 2014, 5). The three main sources of information relating to global climate change implications for USNORTHCOM exist in academic and scientific reports, national strategy, and U.S. Military policy and publications.

Before this study dives into these three critical areas relevant to climate change a review of the primary and secondary research questions must be completed:

Primary Research Question: How does USNORTHCOM adapt to the impacts of more destructive tropical cyclone strikes against the homeland due to global climate change in the next 50 years?

Subordinate Research Question 1: Will global climate change increase the frequency, duration, or magnitude of destruction caused by Atlantic Basin tropical cyclones in the next 50 years?

Subordinate Research Question 2: How can senior leaders better understand the threat posed by Atlantic Based tropical cyclones using existing military models to better prepare and execute when called upon to assist in disaster relief?

Subordinate Research Question 3: Does the National Guard, FEMA, or USNORTHCOM need to revise its posture, organization, or and capabilities to more effectively respond to disaster relief efforts?

With this in mind, this study now turns to an overview of the three main categories of literature that assists in providing a foundation to help answer the above questions.

Academic and Scientific Reports

The IPCC having released its Fifth Assessment Report (FAR) in 2014 highlights observed global climate changes, as well as predicted trends for future climate change. To clearly delineate the amount of certainty in their findings to the reader, the panel uses a method that indicates both the severity of the change and the probability that it will occur. The two main categories utilized in the presentation of their data are the likelihood, or probability, the event or occurrence has already happened or will happen and the confidence level associated with that assessment. The five main types of likelihood with corresponding probabilities are:

Table 1. IPCC AR5 Likelihood and Probabilities

Likelihood	*Probability*	Likelihood	*Probability*
Virtually Certain	99-100 percent	About as Likely as Not	33-66 percent
Extremely Likely	95-100 percent	Unlikely	0-33 percent
Very Likely	90-100 percent	Very Unlikely	0-10 percent
Likely	66-100 percent	Extremely Unlikely	0-5 percent
More Likely than Not	>50-100 percent	Exceptionally Unlikely	0-1 percent

Source: Created by Author, data from (Intergovernmental Panel on Climate Change, 2014).

Matching these probabilities with associated levels of confidence reinforces the quality of the data, the multiple lines of evidence, synthesis of data and the amount of agreement that exists. The five levels of confidence are then: very low, low, medium, high, and very high. These follow the likelihood assessments to illustrate to the reader the chance of something having already occurred or that will occur coupled with a level of confidence (Pachauri and Meyer 2014, 37).

The IPCC FAR presents a significant amount of data regarding both the observed changes in climate over several decades and offer predictions of future changes. The overarching theme of this report is that warming has been occurring to include the atmosphere, oceans, and melting of polar ice caps with an associated rise in sea levels. For an average land and ocean temperature increase, data suggests that an increase of 0.85 degrees Celsius has occurred between 1880 and 2012. This increase in warming, however, is primarily absorbed by the earth's expansive oceans, with the most considerable amount of warming occurring nearer the ocean surface (Pachauri and Meyer 2014, 40). This warming has caused an increase in ocean heat content and a rise in sea surface temperatures. Between 1900 and 2016, a 0.7 degree Celsius increase has occurred in these surface layers of the oceans (Wuebbles et al. 2017, 25). More recently, between 1971 and 2010, an increase of 0.11 degrees Celsius per decade to a depth of 75m has been observed (Pachauri and Meyer 2014, 4). According to NOAA's Hurricane Basics, this layer in the oceans (down to 150 feet or 45.7 meters) is the primary precursor for tropical cyclone development (National Oceanic and Atmospheric Administration 1999, 6). Unfortunately, warming of oceans impacts other areas of the earth's climate system.

One such affected area from warming oceans is the cryosphere that makes up the regions of the earth that are in solid water form, or ice. Since 1979 and the advent of accurate satellite monitoring of ice sheets, the annual extent of ice loss in the Arctic has increased. The rate at which this increase in loss has occurred lies between 3.5 to 4.1 percent per decade (very likely) in the decades between 1979 and 2012. During the summer peak loss of ice in the Arctic, it is assessed that 0.73 to 1.07 million square kilometers per decade was lost. However, it has been observed that on the opposite pole, in the Antarctic, a slight increase in sea ice has occurred. Increases of 1.2 to 1.8 percent (very likely) during this same above timeframe, corresponding to 130,000 to 200,000 square kilometers of ice per decade (Pachauri and Meyer 2014, 42). Nonetheless, a net loss of sea ice has occurred due to warming and has cascading effects on other components of the earth's climate.

The melting of Arctic ice contributes to rising sea levels. The IPCC FAR suggests with high confidence that seas have risen 0.19m between 1901 and 2010 and that this rate is higher than the previous two millennia (Pachauri and Meyer 2014, 42). Increases in sea levels may further compound storm surges created by tropical cyclones in the Atlantic Basin. This rise in sea level may cause a larger extent of property and infrastructure destruction in addition to higher deaths tolls. This is because the most expansive amount of damage to property and loss of life normally comes from a tropical cyclone's storm surge (National Oceanic and Atmospheric Administration 1999, 14). The IPCC report also establishes that 75 percent of the observed sea level rise has occurred due to a synergistic effect of the melting of glaciers and the thermal expansion of the oceans (Pachauri and Meyer 2014, 42). Therefore, the synergistic effects of both higher sea surface temperatures and higher mean sea levels may have resulted in changes in extreme weather events.

Blending many of the above factors together, a cause for concern over the development of more intense tropical cyclone activity is warranted. The IPCC FAR presents data to show that since 1950, changes in extreme weather events have occurred. This increase in extreme weather is due mostly to the increase in warmer temperatures, higher mean sea levels, and more frequent heavy precipitation events. Included in this is a likely assessment of both more intense and more frequent heavy precipitation events in North America. Additionally, the extent to which tropical cyclone intensity has increased since 1970 is virtually certain. It should be addressed, however, that definitive long-term changes in tropical cyclone activity have low confidence of occurring. Nonetheless, due to increased mean sea levels, it is likely that extreme sea levels associated with tropical cyclone storm surges have increased since 1970. When adding these natural forces to increased exposure of property, people, and economic assets along coastlines, it is observed with high confidence that weather-related disasters have caused increased cost in recent decades across the globe (Pachauri and Meyer 2014, 53). Between higher global surface temperatures, rising sea surface temperatures and mean sea levels, and increases in tropical cyclone activity, it is observed that the climate has been changing. Yet the presented data has only noted what has already been measured and does not yet address the implications of future predicted change.

Having looked at the certain past changes of the climate, the IPCC FAR also addresses the projected changes in the future climate system. Before this study turns to this, however, a brief description of the mechanisms of global warming must be performed to enable further discussion of these forecasts. The greenhouse effect provides the earth with a sustainable amount of heat to facilitate life. Originally identified in 1896 by Svante Arrhenius, a Nobel laureate and Swedish Chemist, he understood the correlation between atmospheric carbon dioxide and its ability to trap heat. As the sun provides solar radiation or heat to the earth's surface it is absorbed and reemitted upward as infrared radiation. This radiation, however, does not just bounce off the surface of the planet back into space. Gasses in the atmosphere like carbon dioxide, along with other greenhouse gases including water vapor, methane, and nitrous oxide, absorb this heat and reemit it in all directions. Half of this, therefore, is directed downward back to the earth's surface and lower atmosphere contributing to further heating. This process is an example of a positive feedback loop and is crucial to trapping the necessary heat to facilitate a climate hospitable to life on the surface of the Earth (Emanuel 2016, 3). However, the issue with this process is a rapid rise in carbon dioxide levels, likely due to anthropogenic influence, into the atmosphere. This has the potential to cause heating beyond what the earth's natural cycles indicate.

Within the report exist four scenarios in which they predict future warming based on greenhouse gas (GHG) emissions and their concentration in the atmosphere, air pollutant emissions, and land use. Four Representative Concentration Pathways (RCPs) scenarios are used to make these projections that vary in total GHG emissions and range from low (RCP 2.6) to intermediate (RCP 4.5 and 6.0) to high (RCP 8.5). RCP 2.6 represents a significant mitigation effort to lower GHG to keep global warming likely below 2 degrees Celsius below pre-industrial levels (Pachauri and Meyer 2014, 8). Overall, global surface temperatures are predicted to continue to rise along with ocean temperatures, increases in mean sea level, and more frequent and intense extreme precipitation events (Pachauri and Meyer 2014, 58). Projections for increases in global mean surface temperature based on these multiple scenarios range between 0.4 to 2.6 degrees Celsius between 2046 and 2065 and by centuries end from 0.3 to 4.8 degrees Celsius (Pachauri and Meyer 2014, 60).

Additionally, predictions are virtually certain of an ice-free Septembers in the Arctic Ocean by 2150 as well as a medium confidence of 15 to 55 percent decreases in global glacier volume (Pachauri and Meyer 2014, 12). This will contribute to further sea level rise, with very likely estimates that the rate of sea level rise will surpass the current 2.0 millimeters per year to as high as 8 to 16 millimeters per year in the last two decades of the 21st century (Pachauri and Meyer 2014, 62). Severe consequences of increased flooding in coastal areas are forecasted with very high confidence to increase during the 21st century as mean sea levels rise. This is particularly true as people continue to migrate to coastal and littoral areas, thus increasing their exposure to the aforementioned risks (Pachauri and Meyer 2014, 67). The IPCC FAR though very robust in their methodology and findings is not the only report to highlight important implications in considering global climate change.

Zeroing in the focus of global climate change that will impact the United States and the areas within the scope of this study, the United States Global Change Research Program (USGCRP) offers great insight. The USGCRP produced a Climate Science Special Report that synthesizes several sources, including peer-reviewed studies, journals, technical reports, the third National Climate Assessment, the Fifth Assessment Report by the Intergovernmental Panel on Climate Change, National Academy of Sciences and the National Research Council. Using the same probability intervals and confidence qualifiers as the IPCC FAR, this report focuses more closely on the impacts of global climate change as it related to the United States. The country is further broken down into 10 sub-regions, to include the Southeast, Southern Great Plains, and the Caribbean (Puerto Rico and the US Virgin Islands) typically the most impacted by Atlantic Basin tropical cyclone strikes (Wuebbles et al. 2017, 4). The report, much like the IPCC FAR provides both observed data and projected trends.

The USGCP report covers observed data in damage costs of storms, temperature increases both globally and in the ocean, and patterns of extreme weather. The latter of these has caused noteworthy costs in damages both direct and indirect. The United States paid an estimated $1.1 trillion in damages due to extreme weather events since 1980 (Wuebbles et al. 2017, 12). As significant an economic burden that this severe weather is to bear, an increased understanding on the linkages between global climate change and tropical cyclones as it relates to the United States, should be welcomed. It is noteworthy that 16 of the warmest years occurred in the last 17 years (1998 as the exception). Additionally, an increase of 1.0 degrees Celsius (1.8 degrees Fahrenheit) has been measured in the United States with very high confidence between 1901 to 2016 (Wuebbles et al. 2017, 13). However, this data highlights only what has occurred since weather records have been maintained. Looking into the projections of future global climate change, this rise is predicted to continue. Between the years 2021 and 2050, compared to the temperature average from the year 1976 to 2005, increases on the order of 1.4 degrees Celsius (2.5 degrees Fahrenheit) are expected to occur on all RCPs (Wuebbles et al. 2017, 17). Increases in global temperatures will have other critical impacts, like changes in the Arctic and rising of sea levels.

The report also presents evidence regarding the loss of Arctic sea ice as the globe continues to warm. Thickness in Arctic ice sheets since the early 1980s are thinner by 4.3 to 7.5 feet and continue to melt for an additional 15 days each year. Rates of arctic ice sheet decline are reported to be 3.5 to 4.1 percent per decade since the 1980s. This timeline corresponds to the beginning of satellite monitoring of the cryosphere (Wuebbles et al. 2017, 29). This additional melting of the ice sheets causes increases in global mean sea level. According to the USGCRP report, from 1900 the global mean sea level has already risen by 18 to 20 centimeters with nearly 7 to 8 centimeters of that rise occurring since 1993. As this trend is not likely to cease, it is expected that the rise in sea levels will continue in the future. Compared to sea levels of 2000, very likely increases of an additional 9 to 18 centimeters by 2030 and 15 to 38 centimeters total by 2050 are projected (Wuebbles et al. 2017, 25). However, global sea levels will not occur uniformly around the planet.

Of particular note is the disproportionality in where this sea level rise will occur as it will not occur uniformly. It is assessed likely that a more dramatic increase will occur along the U.S. Atlantic and Gulf Coasts (Wuebbles et al. 2017, 52). Unfortunately, states along these shores, namely North Carolina, Florida, and Texas are most frequently struck by major hurricanes (Category 3 or higher) and most repeatedly than other states (Blake, Landsea, and Gibney 2011, 26). Coupling higher sea levels with increased in sea surface temperatures may contribute to more intense storms and associated storm surge. Between the years 1900 and 2016, for instance, surface waters have increased temperature by 0.7 degrees Celsius (+/- 0.08C) and even more concerning is under more intense warming scenarios a very high confidence projection of up to 2.7 degrees Celsius by 2100 (+/- 0.7C) (Wuebbles et al. 2017, 25). Compounding these factors together concocts a perfect recipe for more intense tropical cyclones and extreme weather events.

Several factors will contribute to the potential of more intense tropical cyclones. Looking at the modeling simulations and physics that take these critical factors into account, the USGCRP presents evidence of increases in tropical cyclone activity. These models indicate that in a warmer environment, an associated increase in the number of very intense tropical cyclones is anticipated. Particular to the Atlantic Ocean, hurricanes are projected with high confidence to increase their precipitation rates. However, though the intensity of storms is expected to increase with high confidence, the frequency of tropical cyclones is only expected to increase with low confidence (Wuebbles et al. 2017, 22). Nonetheless, even if the most severe tropical cyclones do not increase in frequency, the additive effect of sea level rise and increased tropical cyclone precipitation will still prove destructive. Assessments from the USGRCP suggest with very high confidence that sea level rise will exacerbate extreme flooding associated with hurricanes. As a corollary, projections of more intense North Atlantic hurricanes could also impact the U.S. Atlantic and Gulf Coast states with a higher chance of extreme flooding (Wuebbles et al. 2017, 27). However, there are also other climate influences that act on shorter timescales that can impact the activity of hurricanes in the Atlantic Basin.

The El Nino and La Nina Southern Oscillation cycle is another important factor to consider when discussing hurricane development. Normally, global trade winds flowing from east to west are strong enough to push the warm water near the equator away from the westers coasts of Central and South American and into the western Pacific Ocean. This area exists between the International Date and Line and 120 degrees west in longitude. This allows for upwelling of water from the lower, cooler masses of the ocean to take its place. However, when these trade winds are weak, this upwelling process isn't completed causing the warmer temperatures surface water in the east-central Equatorial Pacific region to remain stagnant. The warmer water causes the higher altitude west to east running jet stream to flow lower in latitude (Becker 2014). A more southerly jet stream brings higher winds in the upper parts of the atmosphere creating the potential for higher wind shear. Differences in the wind speed and direction at different levels of the atmosphere can cripple the development of a tropical cyclone. Normally, El Nino events are associated with higher wind shear and thus stymie hurricane activity in the Atlantic Basin. But an opposite sequence of this oscillation exists.

The opposite of this cycle is known as La Nina and includes cooler sea surface temperatures and drier air off of Central and South America. In the case of La Nina, the equatorial trade winds moving east to west are strong enough to pile up the warmer water in the western Pacific, thereby empowering the replenishment of cooler water to the surface. This cooler water mass drives the jet stream higher in latitude, generally north and away of the Atlantic Basin. This shift lowers the potential for high wind shear, helping enable tropical cyclone development there. Both El Nino and La Nina variances usually last between two to seven years (Becker 2014). These oscillations have impacts globally and can affect the severity of hurricane seasons. In addition to large research groups and panels and significant climate influences, academia also has much to say on the topic of tropical cyclone intensification due to a changing climate.

Dr. Kerry A. Emanuel of the Massachusetts Institute of Technology in Boston, Massachusetts is one such researcher of TC intensification due to climate change. With a specific focus on hurricane physics and the thermodynamic exchanges that occur within TCs, he is an expert in his field. Three main points stand out in his research that may offer evidence of more destructive effects caused by TCs, strengthened by climate change and a warming atmosphere.

First, the increase in global sea surface temperatures will add more energy into the thermodynamic system thereby creating more intense storms. As warm sea surface temperatures, those 26.7 degrees Celsius or 80 degrees Fahrenheit to a depth of 150 feet, are a prerequisite for tropical cyclone development (National Oceanic and Atmospheric Administration 1999, 6). Increases in temperature therefore can intensify their strength. Dr. Emanuel has calculated that a 1 degree Celsius or 1.8 degrees Fahrenheit increase in tropical waters correspond to an increase in a five percent intensification in tropical cyclone windspeed. As of 2005 and an observed increase in these waters was 0.5 degree Celsius since 1900 an associated increase of two to three percent in wind speeds can be computed. Since 1949, an overall increase in hurricane wind speeds have amplified by 49 percent in the North Atlantic (Emanuel 2005, 687). Warmer seas also lead to other compounding factors in hurricanes destructiveness, however.

Second, increasing global mean sea levels will elevate the risk of flooding during tropical cyclones strikes on the homeland. This rise in sea level is composed of two main components with the first being thermal expansion of the column of water and second runoff from melting ice sheets. Adding these two products together, sea levels are projected to rise as much as one meter (three feet) by 2100. This increase in sea level will add to the amount of flooding associated with tropical cyclones as they make landfall, as witnessed in 2012 with Hurricane Sandy (Emanuel 2016, 12). This presents a substantial change and enhances tropical cyclone storm surges.

And finally, third, as global air temperatures increase it will physically increase its capacity to hold more moisture and thereby produce precipitation. Dr. Emanuel argues that between 1981 and 2000 a one percent annual chance existed of an extreme precipitation event, much like Texas experienced during Hurricane Harvey in 2017. However, based on the most severe warming scenarios as per the Intergovernmental Panel on Climate Change's Fifth Assessment Report, the probability of a 500mm Tropical Cyclone Precipitation (TCP) event is likely to increase in Texas to eighteen percent by 2081 to 2100. Since 2000 then and looking at this prediction linearly, in the seventeen years since 2000 a six percent increase can be extrapolated (Emanuel 2017, 1).

This represents a substantial increase in the probability of an extreme rainfall event. Seeing that both observed data and future models show further increase in many factors that may contribute to more destructive storms, a strategy and adaptation plan is needed.

Strategy

The *National Security Strategy* of 2015 addressed many threats to the U.S. Homeland. Most of these threats relate to both nation states and non-nation state actors that possess military capabilities that could be employed against the United States or its interests. Within the executive summary signed by then President Barack Obama, he addressed both the threat posed by increased aggression from Russia, continued threats from violent extremist organizations like Islamic State in Iraq and al-Sham, and the accelerated impacts of climate change (National Security Council 2015, 3). Within the body of the strategy there are three paragraphs that speak to how the U.S. will confront climate change stating "climate change is an urgent and growing threat to our national security, contributing to increased natural disasters". It identifies increased sea levels and associated storm surge along coastlines as predominant contributors to the threat. However, the strategy deals with long term mitigation strategies and how global greenhouse gases, namely carbon dioxide, will be reduced by 26 to 28 percent of 2005 levels by the year 2025, implemented through the Climate Action Plan (National Security Council 2015, 12). This strategy does not, however, address any adaptation that must occur now before the long-term impacts of this mitigation plan may come to fruition.

In the newest version of the *National Security Strategy*, current as of December 4, 2017, vast changes have been made to the 2015 version. Most importantly, the topic of climate change no longer exists as a threat in the latest document. For example, the previous strategy had a total of three paragraphs and thirteen mentions relating to climate change, all of which are removed from the current strategy (The President 2017). Impact of this drastic shift in strategy is also seen within the updated *National Defense Strategy* where once again, there is no direct mention of the term or topic (Department of Defense 2018). Despite this change, the highest levels of our military have previously published documents that still address climate change as a threat to be dealt with.

The *Quadrennial Defense Review* (now called the *Defense Strategy Review*) also speaks to the concerns the Department of Defense has over climate change. First and foremost, this report addresses the fact that defense support to civil authorities may be required more often. This is because the changing environment will increase the mission of the military in frequency, complexity, and scale (Secretary of Defense 2014, vi). The review also discusses the challenges posed by climate change relating to rising sea levels, increasing global temperatures, and more rapidly changing severe weather patterns. The impact of these climate changes is labeled a threat multiplier that will further worsen existing stressors in the operational environment which may enable violence or terrorist activity (Secretary of Defense 2014, 8).

In Chapter Two: The Defense Strategy, pictured next to the paragraph labeled "Protect the Homeland" is a photo of the 1140th Engineer Battalion, a Missouri National Guard unit building a flood wall to prevent floodwaters from spilling over onto a major highway (Secretary of Defense 2014, 13). Yet again, in subsequent pages a photo shows an Army UH-60 Blackhawk and its crew delivering supplies to a village stranded by a severe weather event. At the close of the chapter is a discussion of creatively adapting to the potential impacts of climate change. This includes maintaining operational resiliency as the roles and missions of the U.S. Armed Forces may be affected (Secretary of Defense 2014, 25). Though the topic of this threat multiplier is limited in the context of the many other threats in the *Quadrennial Defense Review*, another document from the DoD addresses the issue in more depth.

The Department of Defense released its Climate Change Adaptation Plan in 2014, influenced heavily by the *Quadrennial Defense Review* in 2010 and 2014, and addresses both adaptation and mitigation. Relating to mitigation, it nests with the National Security Strategy in that it seeks to reduce its GHG emissions but differs in that it has established goals for adaptation to the impacts that are to occur in the near term by climate change. Nonetheless, this roadmap takes verbiage directly from the 2014 *Quadrennial Defense Review* stating "the impacts of climate change may increase the frequency, scale, and complexity of future missions, including Defense Support to Civil Authorities (DSCA)." Adding to this, the roadmap also uses data from the third National Climate Assessment used in the U.S. Global Change Research Program regarding heavy precipitation, melting ice sheets, rising sea levels, and floods and that in the next 100 years this trend is only expected in increase in frequency and duration (Department of Defense 2014, 2). To combat these potential impacts, the roadmap outlines three major goals:

Goal 1: Identify and assess the effects of climate change on the Department.

Goal 2: Integrate climate change considerations across the Department and manage associated risks.

Goal 3: Collaborate with internal and external stakeholders on climate change challenges (Department of Defense 2014, 1).

To corroborate the creation of these goals, a quote from then Secretary of Defense Chuck Hagel in November 2013 confirms that climate change is indeed taking place and a need exists to be resilient to its effects (Department of Defense 2014, 4). The DoD identifies four main areas that climate change will impact, including plans and operations, training and testing, built and natural infrastructure, in addition to acquisition and supply chain management.

Within the first goal, the DoD has acknowledged the impacts from climate change from increasing frequency and severity of extreme weather events, to rising sea levels, and increased storm surge are likely to affect it (Department of Defense 2014, 4). As it relates to DoD's plans and operations, they have identified the potential for increased demand for DSCA. Due to climate change that is literally and physically changing the operational environment, DoD recognizes that its capabilities and capacity to assist in disaster response may be committed more readily. This would place not only increased demands on the department, including the Reserve Component during DSCA but also require potential adjustments in those capabilities and capacity (Department of Defense 2014, 5). Realizing the potential for more severe storms, the DoD is already beginning to adapt to the changing climate. In response to more extreme storms, installations are building structures to be more wind-resistant, removing vulnerable trees, and burying utility lines underground (Department of Defense 2014, 11). The evidence exists of a changing environment and the need to adapt to meet those challenges.

These increased impacts due to these storms will likely increase the chance of local, state, and federal agencies of requesting federal support, resulting in USNORTHCOM commitment of vast combat power, to provide disaster relief in the wake of these destructive tropical cyclone events in the future. Potential increase in disaster response operations by USNORTHCOM as a result of global climate change contributions to stronger storms, is crucial for senior leaders to better understand. Much like a Geographic Combatant Commander conducts a strategic assessment of their Area of Responsibility and uses military models to determine adversary capability and capacity, senior leaders must understand tropical cyclones to better prepare their response. Fortunately, there are several policy documents and publications that describe the threat posed by tropical cyclones, or hurricanes, as it relates to military operations.

Policy

Recognizing that global climate change has the potential to contribute to more extreme weather, including more intense tropical cyclones, a discussion of how the U.S. military prepares and responds to these events is conducted. The Department of Defense's response to such events exists in two main categories. The first relates to the planning and execution of DSCA, whereas the second addresses the legalities of conducting such operations. This information is provided in both doctrine and in contingency plans that the military, namely U.S. Northern Command, use to plan and execute DSCA. These documents cover the planning and execution of DSCA and outline the phasing and critical tasks associated with disaster response. To do this, however, also requires the discussion of the U.S. Codes, statutory acts, and policies of requesting federal support to support civil authorities during a catastrophic incident.

In order for the U.S. Military to effectively respond to disasters through action, doctrine must be established that lays the groundwork for these types of operations. Joint

Publication (JP) 3-28 *Defense Support of Civil Authorities*, focusing on the joint level and operational DSCA planning, defines DSCA as:

> Support provided by federal military forces, DOD civilians, DOD contract personnel, DOD component assets, and NG forces (when the Secretary of Defense [SecDef], in coordination with the governors of the affected states, elects and requests to use those forces in Title 32, USC, status or when federalized) in response to a request for assistance (RFA) from civil authorities for domestic emergencies, law enforcement support, and other domestic activities, or from qualifying entities for special events. DSCA includes support to prepare, prevent, protect, respond, and recover from domestic incidents including terrorist attacks, major disasters, both natural and man-made, and planned domestic special events (Joint Chiefs of Staff 2013, I-2).

These operations are conducted in support of another U.S. Government department or agency, normally the Department of Homeland Security or the Federal Emergency Management Agency. Additionally, DSCA operations are executed within the framework of both the National Response Framework and the National Incident Management System. The National Response Framework serves as a comprehensive approach to all-hazards response and establishes several Emergency Support Functions, or ESFs, that task organize critical functions to particular organizations. The National Incident Management System, is a template that provides common terminology, concepts, and principles and enables local jurisdictional authorities to serve as a nexus of communication for external resources. The objective of these two systems strive to promote efficiency and improve capability during disaster response by providing a common lexicon and reporting system routed through a single entity, most typically at the lowest jurisdiction possible (Joint Chiefs of Staff 2013, I-6).

This document also contains several key definitions relating the DSCA operations. Firstly, it defines what constitutes a catastrophic incident by stating “any natural or man-made incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, and or government functions" (Joint Chiefs of Staff 2013, II-1). As expected, a tropical cyclone making landfall on the Atlantic seaboard, or its territories in the Caribbean, can become such catastrophic incidents. For example, in 2012, when Hurricane Sandy devastated the coasts of New York and New Jersey with its inundating storm surge, it caused significant economic impacts. This storm forced a two-day closure of the New York Stock Exchange for the first time since 1888 (Burke and McNeil 2015, 29). It is then essential to determine the appropriate response to such forces.

Due to the incredible impact of these storms and their associated effects, developing an effective posture and subsequent response is of vital importance. The genesis of disaster response begins at the local, state, and then federal levels, operating as a tiered or layered response. As much as possible, these operations are managed at the lowest possible level, and support from higher levels is requested when the disaster exceeds the capability or capacity of subordinate entities to respond (Joint Chiefs of Staff 2013, II-2). Since tropical cyclones typically effect an entire state or multiple adjacent state coastlines due their winds and rains extending over hundreds of miles (Defense Support of Civil Authorities 2010, 8-7), response normally begins at the state level.

The state governor has many resources at his or her disposal to assist in disaster response efforts. In addition to organizations like the state police, emergency management crews, homeland security agencies, specialized incident teams and others, the state governor has control of the state's military force, the National Guard (Department of the Army 2013, I-12). With advice from the Adjutant General of the

National Guard, may employ the national guard in state active duty or Title 32 status to assist in response efforts. Providing logistics, medical care, search and rescue, communications, and civil engineering are all tasks the State National Guard may execute (Department of the Army 2012, I-13). However, an additional authority that exists while serving on state active duty is the ability to employ these forces in a law enforcement role as they are excluded from the Posse Comitatus Act. This act limits the ability of active duty military forces or federalized National Guard from conducting law enforcement roles (Elsea and Mason 2008, 1). These resources at the state governor's level may not always be enough though.

If still overwhelmed, the state will seek the assistance of adjacent states through the Emergency Management Assistance Compacts or EMACs, which are mutual agreements of automatic support and sharing of assets in response to disasters (Joint Chiefs of Staff 2013, I-4). These multi-state agreements provide critical additional resources when faced with a disaster that exceeds state level. Since these arrangements are congressionally ratified and are administered through the National Emergency Management Association, it provides a guarantee of external support to effected states. When even this level of cooperative support between states is insufficient to respond appropriately or timely to the disaster created, state governors can then turn to the federal government for help (Department of the Army 2012, I-12).

The DoD is a prime candidate to fulfill the role of disaster response at the federal level for several reasons. First, due to DoD's dispersed footprint across the nation and its substantial capacity of combat power and state of readiness make it advantageously postured for assistance to states following a disaster (Joint Chiefs of Staff 2013, I-4).

Second, the dispersion of federal military capabilities across the nation, particularly in the south east, enables the quick response of DoD assets to arrive and posture within the affected area, particularly following hurricane landfalls. They can then begin to save lives, prevent human suffering, and mitigate great damage loss. Third, the missions and training that the military services normally conduct apply well during a disaster response operation making them an effective and task-oriented unit. However, a critical point highlighted in this document is that while DoD conducts DSCA operations it does so in support of another federal agency or entity that coordinates the disaster response effort. This supported agency is typically the Federal Emergency Management Agency or FEMA.

The Federal Emergency Management Agency is the coordinating agency tasked with providing effective disaster response and mitigation of a myriad of hazards and falls under the Department of Homeland Security. Its mission is to "reduce the loss of life and property and protect communities nationwide from all hazards, including natural disasters, acts of terrorism, and other man-made disasters" (Department of Homeland Security 2008, 1). In order to do this, it breaks down the nation into ten regions as shown in figure 2. Inside of each of these regions, USNORTHCOM assigns one Defense Coordinating Officer, or DCO, who acts as a liaison between the Combatant Commander and the Joint Field Office within that FEMA Region. Acting as the sole point of contact between the DoD and that region, Defense Coordinating Officers have the responsibility of validating Requests for Assistance, or RFAs, from the state to the federal level and send to DoD for approval (Joint Chiefs of Staff 2013, II-12).

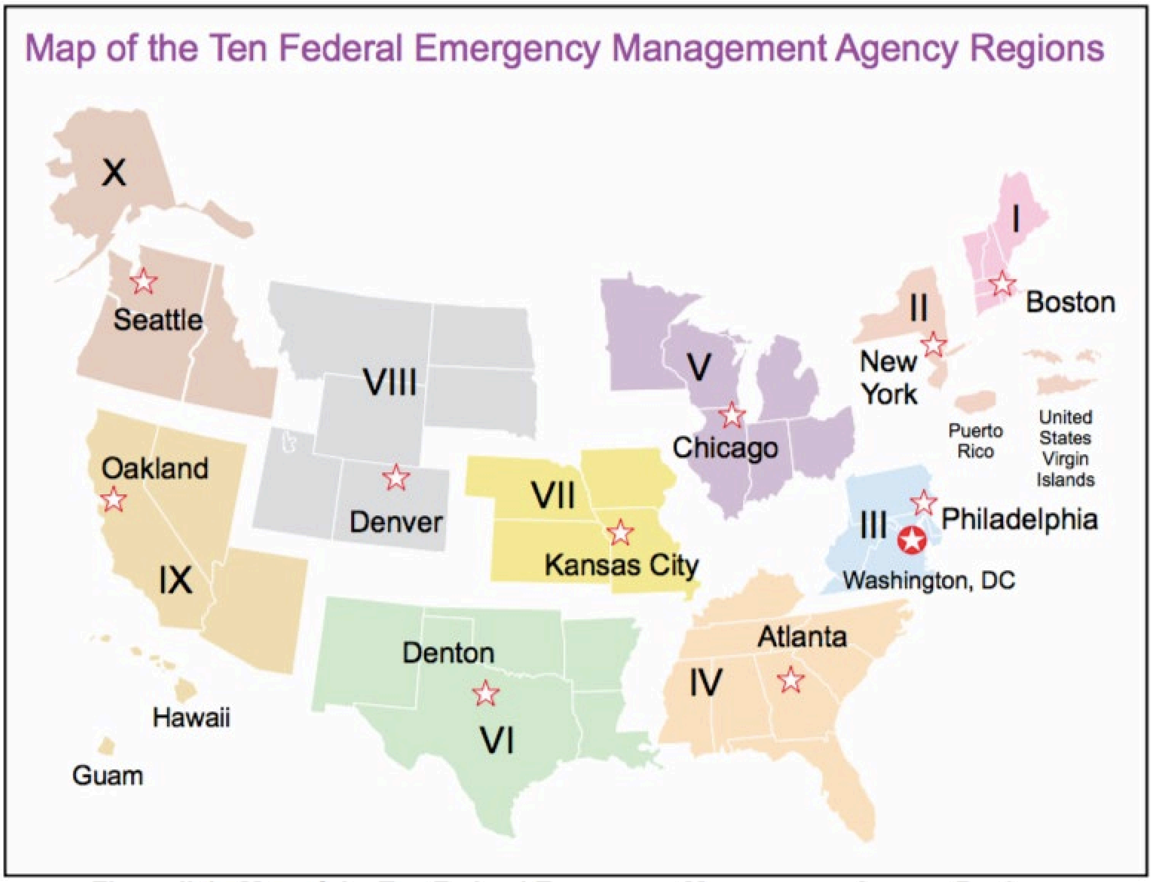

Figure 2. The Ten FEMA Regions

Source: (Joint Chiefs of Staff 2013, II-13).

In the event a disaster exceeds the resources and capabilities at the state level, federal military forces may conduct DSCA via three predominant methods. Federal military forces are those that fall under Title 10 of United States Code, who operate under full time active duty. First, the state governor may submit a request for assistance for federal assistance as their resources are either depleted or are not sufficient even with Emergency Management Assistance Compact support. Second, the President or the Secretary of Defense may authorize the use of federal troops to conduct disaster response. If a disaster occurs, and conditions exists such that no ability to get approval from these two authorities in a timely manner is possible, military commanders may also use an Immediate Response Authority to temporarily commit federal forces to save lives, prevent human suffering, and mitigate great damage within the United States until such time an approving authority becomes available (Department of Defense 2012, 4). Commonly, though not an absolute requirement, once a request for assistance is approved, and immediate response authority committed, or a Presidential or Secretary of Defense directed employment authorized, a JTF will be created.

This JTF will serve as the senior federal military force organization in the execution of its DSCA duties. Typically co-located within the Joint Field Office within the FEMA region affected, the JTF will also include the Defense Coordinating Officer but does not replace his or her duties. Due to the nature of the operations executed during DSCA in response to a catastrophic event, these JTFs will likely require even greater amounts of support units and associated support capabilities than those necessary during a deployment to combat. The JTF will also operate within the National Response Framework and the National Incident Management System to fully nest with the primary or federal coordinating agency to facilitate greater unity of effort (Joint Chiefs of Staff 2013, II-11-12). Once established, the JTF may begin to plan its response to the disaster as part of DSCA operations.

Much like a combat operation, a significant amount of planning is required to execute a successful response to a disaster in support of civil authorities. This is particularly true as DSCA operations are inherently joint and require significant interagency coordination, as federal military forces operate in support of another federal entity or primary coordinating agency. To achieve such an effect, a familiar phased construct is utilized that covers planning before, during, and after a catastrophic incident. DSCA operations consist of six major phases:

1. Phase 0 (Shape): Monitoring of events and situational awareness to increase preparedness, conducting training exercises and use of compacts and coordination efforts. This phase acts to set conditions to increase unity of effort between multiple agencies, organizations, and entities for an effective response. This phase is always ongoing as multiple disasters can occur simultaneously or in close sequence.
2. Phase I (Anticipate): Begins once an event that may require DSCA operations is identified or when the President or Secretary of Defense direct federal force's use. This phase includes deployment of response forces assigned or deciding that the event does not require the execution of DSCA.
3. Phase II (Respond): If DSCA is directed, this phase begins with the deployment of assigned response forces and ends once required capabilities are postured to provide timely and effective DSCA in conjunction with the primary agency. This phase includes deployment of the Defense Coordinating Officer to the affected area.
4. Phase III (Operate): The commencement of recovery operations signals the beginning of this phase and includes posturing enough assets in the affected area to support civil authorities. This phase is complete as Title 10 forces begin completing mission assignments and the determination is made that additional requirements for Title 10 forces are not likely beyond what is committed.

5. Phase IV (Stabilize): At the decision that Title 10 forces are able to scale down, their retrograde can then get underway. Once all mission assignments are finally complete for Title 10 forces, this marks the end of this phase.
6. Phase V (Transition): This phase begins with the redeployment of Title 10 forces and ends once response forces have been relieved and normal operating procedures are back in effect, to include command relationships to their commands (Joint Chiefs of Staff 2013, II-16).

These six phases are conducted to cover the tasks included in preparing and anticipating for, responding to, and recovering from catastrophic events much like a major hurricane strike within the United States. USNORTHCOM has adapted the doctrinal planning construct into seven phases and subphases to fit a tropical cyclone strikes situation as shown below.

Phase 1: Pre-Incident

a. Normal Operations: Planning and exercises, monitoring of Atlantic Basin.

b. Elevated Threat: Develop situational awareness, select personnel deployed. Ends when TC identified with potential landfall along Atlantic coastline within 120 hours.

c. Credible Threat: Anticipate state's needs by pre-positioning resources, ends once tropical storm force winds make landfall on Atlantic coastline.

Phase 2: Response

a. Initial Response: Begins at tropical storm force wind landfall to 24 hours after they cease. Includes search and rescue, and medical, logistics, and communications support.

b. Deployment: Conducted 24 hours to 72 hours following cessation of tropical storm force winds. Includes mass care services and life-sustaining commodities provided to those in need and critical infrastructure identified.

c. Sustained Response: Begins 72 hours after tropical storm force winds cease and ends once decision to reduce T10 support is made. Continued life-saving, provision of life-sustaining commodity logistics and critical infrastructure restored.

Phase 3: Recovery: Begins once T10 support is no longer needed, transition to civil authorities is completed, and T10 forces are postured for normal operations (USNORTHCOM 2018b, 23).

The above USNORTHCOM phasing adapts the construct of ADRP 3-28 *Defense Support to Civil Authorities*, to best suit the scenario of a tropical cyclone making landfall on the Atlantic coastline. However, just because a plan exists for federal forces to conduct DSCA operations does not mean that they have automatic authority to execute them.

The execution of DSCA operations requires navigation though a combination of United States Codes, policy, and acts. First and foremost, the President is authorized to utilize federal aid, to include the use of the nation's armed forces, in response to a state governor that has become overwhelmed by either a natural or a man-made disaster under the Robert T. Stafford Disaster Relief and Emergency Assistance Act. Within this authorization, operations such as providing medical care, distributing essential goods like food and water, conducting search and rescue, removing debris and clearing of roads are normally executed by federal forces. In the event of communication impediments with state governors or an inability of FEMA to coordinate, this act also allows the President to authorize emergency work of federal forces for up to ten days. During this time, activities such as debris clearance and assisting in restoring essential services are authorized (Elsea and Mason 2008, 4). Outside of the above conditions, however, require a more formal process of a state's request for assistance from the federal government.

Upon the occurrence of a disaster, the state governor has certain inherent responsibilities. This includes utilizing the resources at their disposal as previously stated, (which include incident teams, state police, and of course the State National Guard) as part of the state's emergency response plan. However, if the governor deems that these assets are not sufficient in capability or capacity and that an effective response to the disaster is not possible without federal aid it will make a request for assistance. This type of request, known as an emergency declaration, must include the type and amount of assistance being requested from the federal government. Much like an emergency declaration, a major disaster declaration requires the state governor to make a request for federal assistance, however no specific type or amount is identified. In both scenarios, however, the Posse Comitatus Act, which prohibits federal forces from conducting law enforcement operations within the U.S., does not apply to State National Guard who remain on state active duty or Title 32 status (Elsea and Mason 2008, 5). Though these legalities and authorities will likely consume the time of those who plan or coordinate these operations, those at the tactical level must operate within them. In addition to being armed with this knowledge, another asset that exists at the tactical level is a field handbook published by USNORTHCOM.

The third and perhaps most succinct document relating to responding to hurricane disasters is USNORTHCOM's DSCA Handbook. This comprehensive handbook offers tactical level commanders and staffs a reference handbook for a multitude of different DSCA operations, to include disaster response to major hurricane strikes on the United States. Chapter 8 describes hurricanes and tornadoes and provides an in-depth look at the pre-requisite conditions for their formation. In particular, it identifies three conditions which must be met that include pre-existing disturbance or low-pressure systems including thunderstorms, 80 degrees Fahrenheit or warmer sea surface temperatures (down to 150 feet), and low wind-shear, or stable winds in the upper atmosphere. Also included in this useful handbook is a detailed description of the laws and acts that are critical to performing legal DSCA operations, as a quick reference to those executing them.

Conclusion

Global climate change is likely to incur substantial security considerations to USNORTHCOM in the next 50 years. The IPCC, USGCP, and leading researchers in academia all provide significant and sound data and analysis to show that extreme weather events will become more of a concern. These include rising sea levels due to melting arctic ice due to warming seas, that then contribute to more intense hurricanes with more damaging storm surge, and a warmer environment that will produce a significant increase in extreme precipitation. To combat this, there are many documents relating to both strategy and plans to adapt to these contemporary changes and those that will continue in the future. The *National Security Strategy* of 2015, the DoD Climate Change Adaptation Roadmap, and Climate and Security Advisory Group all speak to the threat multiplier of climate change. This will lead to decreased operational readiness of federal military forces as they become more likely the "go-to" response force to deal with more intense hurricanes and the resulting catastrophic incident. Additionally, strategic risk and risk to mission is incurred following tropical cyclone strikes on the Atlantic coastline of the United States. These intense storms have the potential to affect the power projection of the military by crippling critical sea and air ports of debarkation. This would stymie the ability to meet global military objectives (USNORTHCOM 2018b, 18). It is important then for senior leaders and decisionmakers to comprehend the capabilities a tropical cyclone possesses, particularly a major hurricane, to negatively impact the nation.

The number of American lives lost, the extent of damage to property and infrastructure, and the frequency of federal forces deployments to support the disaster response are key figures to keep in mind when framing the problem. In the next chapter, this study conducts a center of gravity analysis of the critical capabilities, critical requirements, and critical vulnerabilities of both the "adversary" force, the tropical cyclone, and the "friendly" forces response to the associated disaster. This analysis will assist senior leaders and planners in thinking of these storms as military threats and not purely as a weather phenomenon.

CHAPTER 3

RESEARCH METHODOLOGY

Tropical cyclones, intensified through global climate change, are likely to have a significant impact on USNORTHCOM's mission. As the earth, including air, land, and sea, warms, arctic ice sheets will melt, contributing to rising sea levels. Warmer sea surface temperatures increase the available energy inputted into the thermodynamic properties of these tropical cyclones, making them more intense. Stronger winds, lower pressures, and warmer and therefore more expanded water columns coupled with higher sea levels will contribute to greater storm surge along the eastern seaboard and Gulf of Mexico. These ever more intense storms are more likely to overwhelm state authorities and their resources requiring federal assistance in a higher quantity of DSCA missions. To better understand this threat that federal military forces will continue to face and respond to in the future, this study asks one primary and three secondary research questions and uses two main forms of research methodology.

1. How does USNORTHCOM adapt to the impacts of more destructive tropical cyclone strikes against the homeland due to global climate change in the next 50 years?

The study also asked three subordinate research questions as part of this:

1. Will global climate change increase the frequency, duration, or magnitude of destruction caused by Atlantic Basin tropical cyclones in the next 50 years?
2. How can senior leaders better understand the threat posed by Atlantic Based tropical cyclones using existing military models to better prepare and execute when called upon to assist in disaster relief?

3. Does the National Guard, FEMA, or USNORTHCOM need to revise its posture, organization, or and capabilities to more effectively respond to disaster relief efforts?

This study also conducts quantitative research, particularly the cost of property damage, lives, and U.S. military combat power that results from tropical cyclone relief in the southeast U.S. and U.S. territories during DSCA. This study conducts a review of significant historical examples of Atlantic basin tropical cyclone strikes of the U.S. Homeland, their cumulative destruction and the U.S. military response to them. The five deadliest and costliest storms, Galveston, Camille, Andrew, Katrina, and Maria are used as mini case studies. Each storm listed includes the year it made landfall and at what category. The cost of damage, U.S. lives lost, and the number of federal troops committed to the response effort for each storm is also calculated. The below chart illustrates how even one intense storm can cause remarkable and widespread effects within the U.S. Homeland and serve as a catalyst for a considerable federal military response.

Table 2. Format of Summation of Impacts of Major Hurricane Landfalls

Hurricane	Year	Category	Cost $ Damage	Lives Lost	Federal Troops Committed
Hurricane X					
Hurricane Y					
Hurricane Z					

Source: Created by author.

This study also utilizes interactions with military leaders, mainly from a research trip to USNORTHCOM in Colorado Springs, Colorado. This provided the researcher to better understand the role of all branches of the U.S. Military in the wake of such catastrophic events. These discussions were not used as Human Subjects Research but rather to gain and confirm facts about current postures and operations conducted during DSCA. One of the purposes of this trip was to collect documentation on troop commitment totals from different USNORTHCOM staff. The command historian, personnel, lessons learned, public affairs, current operations, and plans cells were visited to acquire quantitative records of federal troop commitment in response to these disasters. In this way, this study compiles totals for major DSCA operations. The use of the data mentioned above is to validate the threat posed by tropical cyclone landfalls. This hazard exists towards American citizens, their property, and critical infrastructure in addition to the military who dedicate significant military combat power in its aftermath.

The second form of research comes through qualitative narrative research of thematic analysis specific to threats due to climate change. This thesis serves to apply common military frameworks in describing how tropical cyclones form, their structure, their devastating capabilities, to inform senior leaders more completely. The intent of this work is to describe tropical cyclones as an adversarial force and apply a center of gravity, or COG, analysis to them. In this way, this study converts technical weather and climate data into a more familiar lexicon that is readily comprehended by senior military leaders and decision makers.

Utilizing both the model from Colonel Joe Strange, developed at the U.S. Marine War College and Joint Publication 5-0, *Joint Planning*, this study informs senior leaders by applying the concept of center of gravity analysis to a tropical cyclone. It achieves this through identifying what the center of gravity is, or the "primary sources of moral or physical strength, power, or resistance" (Strange 1996, 2). Joint Publication 5-0, *Joint Planning*, closely follows the above by defining a center of gravity as, "a source of power that provides moral or physical strength, freedom of action or will to act" (Joint Chiefs of Staff 2017, IV-23). Specific to this, the question of what capabilities the adversary possesses that prevent the friendly force from conducting its mission effectively is paramount. This study seeks to first identify the adversary capabilities and then second to illustrate how they are expected to increase in strength in the next 50 years.

A further breakdown of this concept addresses the critical requirements and critical vulnerabilities within the COG. Certain conditions, or critical requirements must first exist for critical capabilities to be employed. Additionally, as with any system, there are intrinsic vulnerabilities. Use of this military model determines the weaknesses in the adversary COG. However, since this immense force of nature is not able to be attacked in a traditional military sense, thereby exploiting its critical vulnerabilities, a COG analysis of the "friendly" force is also conducted. In this way, this study helps identify critical capabilities that are necessary for effective DSCA operations following hurricane strikes on the southeastern coastline of the United States. As with the adversary, the friendly COG analysis identifies critical requirements that serve as the foundation for the critical capabilities to endure. Finally, this model distinguishes the friendly force critical vulnerabilities to understand the disaster response force and its inherent weaknesses.

Table 3. Format of Center of Gravity Analysis of Adversary and Friendly Force

Center of Gravity	Critical Capabilities	Critical Requirements	Critical Vulnerabilities
Adversary	1.		
	2.		
	3.		
Friendly	1.		
	2.		
	3.		

Source: Created by author.

If a senior leader were made aware of a threat within their Area of Responsibility and did not conduct due diligence to fully understand the adversary's capabilities, that leader would be seen as negligent. Why then should one of the most destructive forces mother nature can create be any different? Tropical cyclones have already proven their capacity for expansive and patterned devastation many times in the past and are predicted to become further intensified in the next 50 years. Vast amounts of combat power will be consumed in disaster response operations creating strategic risk in an operating environment containing several military threats around the globe. The intent of this study is to create a more informed and knowledgeable audience regarding disaster response operations following tropical cyclone strikes in the U.S and how to adapt to this increasing threat sooner than later.

The contribution this study makes is to translate data-intensive descriptions of weather and climate phenomena into relatable terms that senior military leaders can digest and use to develop solutions. This enables leaders to be more situationally aware, thereby empowering them to make more informed decisions and respond more soundly this growing threat to our country.

Threats to Validity and Biases

To improve the credibility of the researcher, this study discusses the author's biases and threats to validity. The argument of assessing if climate change is increasing the frequency, duration, or magnitude of death and wreckage caused by tropical cyclones utilized data from scientific reports, not subjective opinions formed previously. These reports and technical assessments are inherently objective, thereby reducing the subjective nature of arguments made. This is in large part due the physical measurements of observed changes and computer simulations to forecast future changes as part of the analysis of the findings. The author subscribed to the application of information from reputable sources to include the Intergovernmental Panel on Climate Change, the United States Global Change Research Program, and notable scientists like Dr. Kerry A. Emanuel of the Massachusetts Institute of Technology among others.

The author of study earned a Bachelor's of Science in Meteorology at the Pennsylvania State University in State College, Pennsylvania in 2006. To limit favoritism from the author's alma mater, research selected for inclusion in this study is not solely based on any professor or scientist linkage to the Pennsylvania State University. The author first investigated the research questions by finding quality research of methodical and peer-reviewed publications. The fact that the author possesses a degree in meteorology may cause the reader to believe the author has biases towards definitive climate change, including causes from anthropogenic, or man-made means. However, the instruction and education received from this world-class institution made the author more open minded to scientific weather and climate data. The researcher's education also enabled the application of critical thinking when assessing technical scientific data. As an example, the author conducted an independent research study in December 2006 on refuting predictions of more intense tropical cyclones due to global climate change. That research paper took an alternative stance to this study based on the evidence and facts gathered at the time. The author's foundation of meteorology and climatology received from the Pennsylvania State University enables him to have credibility to analyze and present research from reliable sources from both points of view.

Additionally, the author has been involved in the planning and execution of Defense Support to Civil Authorities during Superstorm Sandy in 2012. In no way does this study attempt to advocate for greater reliance on active duty forces to conduct disaster relief for added job security of the author. The focus of this study is to shed light on a tropical cyclone's increasing capabilities, due to climate change, to cause disaster and the resulting federal military response to them.

CHAPTER 4

ANALYSIS

History has proven that Mother Nature destroys vast amounts of property and infrastructure and kills numerous American citizens as it unleashes massive energy in the form of hurricanes. In its wake as part of the disaster response, USNORTHCOM commits a large number of federal troops and military resources to save lives, reduce human suffering, and mitigate great damage loss. Measurements of raised mean sea levels, increased sea surface temperatures, and heightened air temperatures have already been observed. The outlook for the future, unfortunately, predicts a further escalation in these areas that contribute to more intense tropical cyclone development and their impacts on the country.

Hurricanes will continue to strike the United States and cause carnage, especially as population trends shifts to vulnerable and exposed coastal regions. With even grander damage and death, local and state authorities will more likely become overwhelmed requiring more assistance from federal military forces. Since disaster response to hurricane strikes on the United States has committed precious resources, a fuller understanding of the forces at play is necessary. Military leaders can more fully understand and ultimately respond to these storms by thinking of them as an adversarial force rather than a weather phenomenon.

Landfall of hurricanes on the Atlantic and Gulf of Mexico coast is a problem set that USNORTHCOM currently deals with and will continue to deal with. Called Defense Support of Civil Authorities, or DSCA, this command plans and executes operations to augment local and state authorities that cannot provide the necessary response with organic assets. These types of requests have occurred several times following many types of disasters, natural or man-made, and include hurricane strikes on the United States. With more intense hurricanes predicted due to global climate change, the frequency of these operations will increase. In light of this, looking at the quantitative data of five major hurricanes described in Chapter 1 will provide insight into the impacts of these damaging and deadly forces of nature.

Table 4. Summation of Impacts of Five Major Hurricane Landfalls

Hurricane	Year	Category	Most Significant Factor	Cost $ Damage (w/inflation)	Lives Lost	Federal Troops Committed
Camille	1969	5	Storm Surge Torrential Rain Winds	9.8 billion	256	16,500
Andrew	1992	5	Winds	47.8 billion	26	24,371
Katrina	2005	3	Flooding	160 billion	1,833	22,000
Harvey	2017	4	Torrential Rains	125 billion	68	3,018
Maria	2017	4	Wind Torrential Rain	90 billion	64	12,800
Totals	---	---	---	**432.6 billion**	**2,244**	**78,689**

Source: Created by the author using information from (National Hurricane Center 2017; Wombell 2009; Hearn 2004; USNORTHCOM 2012; USNORTHCOM 2017b; and Blake, Landsea, and Gibney 2011).

The above five major hurricanes that struck the United States mainland or its territories created hundreds of billions of dollars in damages, caused thousands of deaths, and committed tens of thousands of federal troops. The above examples also highlight the most important factors to consider when investigating a hurricane's capability to inflict destruction. Storm surge, torrential rains or TCP, and high winds are the most critical components of a storm to further analyze from these historical cases.

Hurricane Camille was the second of only three Category 5 hurricanes to strike the United States, making landfall on the gulf shores of Mississippi and Louisiana. It was also the first major hurricane to make landfall after the launching of ESSA-1, the first polar orbiting satellite providing daily photographs of developing tropical cyclones (McAdie et al. 2009, 12). It devastated this region with an incredibly high storm surge, averaging 24 feet and was responsible for a majority of the deaths (Zebrowski and Howard 2005, 128). In concert with this wall of water were wind speeds estimated over 200 miles per hour. This resulted in $9.8 billion in damage when adjusted for inflation, and caused 256 deaths in Mississippi, Louisiana, and as far away as Virginia due to heavy rains and subsequent mudslides. With an emergency declaration by then President Nixon, 16,500 federal forces were brought in to assist local and state authorities with missions including distributing life-saving commodities, search and rescue, and providing medical aid (Hearn 2004, 143). It would be 22 years until another Category 5 storm came crashing ashore, this time in Florida.

The most recent landfall of a Category 5 hurricane in the United States remains Hurricane Andrew in 1992 when it struck Miami-Dade County, Florida. The most deadly and life-threatening capability within this powerful storm was its high winds that destroyed 80,000 homes that forced the displacement of 250,000 Florida residents (Wombell 2009, 14) Joint Task Force Andrew was established and included elements of both the 82nd Airborne Division and 10th Mountain Division among United States Navy and Marine Corps units. This organization totaled 24,731 federal forces and deployed to assist in response efforts (Government Accountability Office 1993, 15). Only 26 United States citizens were killed in this storm, due to improved forecasting and effective evacuation procedures, but still yielded over $47.8 billion in damages in 2017 dollars. Though this storm produced a storm surge over 17 feet, the tightly concentrated and high intensity winds were responsible for the majority of the damage and deaths incurred. Other hurricanes, however, would prove that storm surge and flooding are just as formidable as hurricane force winds.

Hurricane Katrina quickly became the largest disaster response in the United States history when it made landfall in Louisiana in August 2005. This storm, at its height a Category 5 hurricane as it intensified over the warm waters of the Gulf of Mexico, weakened to a Category 3 at landfall. Notwithstanding, the combination of a powerful storm surge of 27 feet striking an area of increased exposure, the areas of New Orleans that were at sea level or in fact under mean sea level, caused widespread devastation (Townsend 2006, 6). The pervasive flooding forced roughly 770,000 Louisiana residents to displace. This equated to a larger exodus of inhabitants than the Dust Bowl migration of the Great Plains in the 1930s (Townsend 2006, 8). These effects overwhelmed local and state agencies, in addition to supporting forces from neighboring states through an Emergency Management Assistance Compact. With 1,833 deaths and damages at $160 billion in 2017 dollars (National Hurricane Center 2018, 3), 22,000 federal forces supplemented the near 50,000 National Guard forces that participated in the disaster response (USNORTHCOM 2012, 7). Although this was the most expensive natural disaster the United States has ever experienced, it would be nearly matched in 2017.

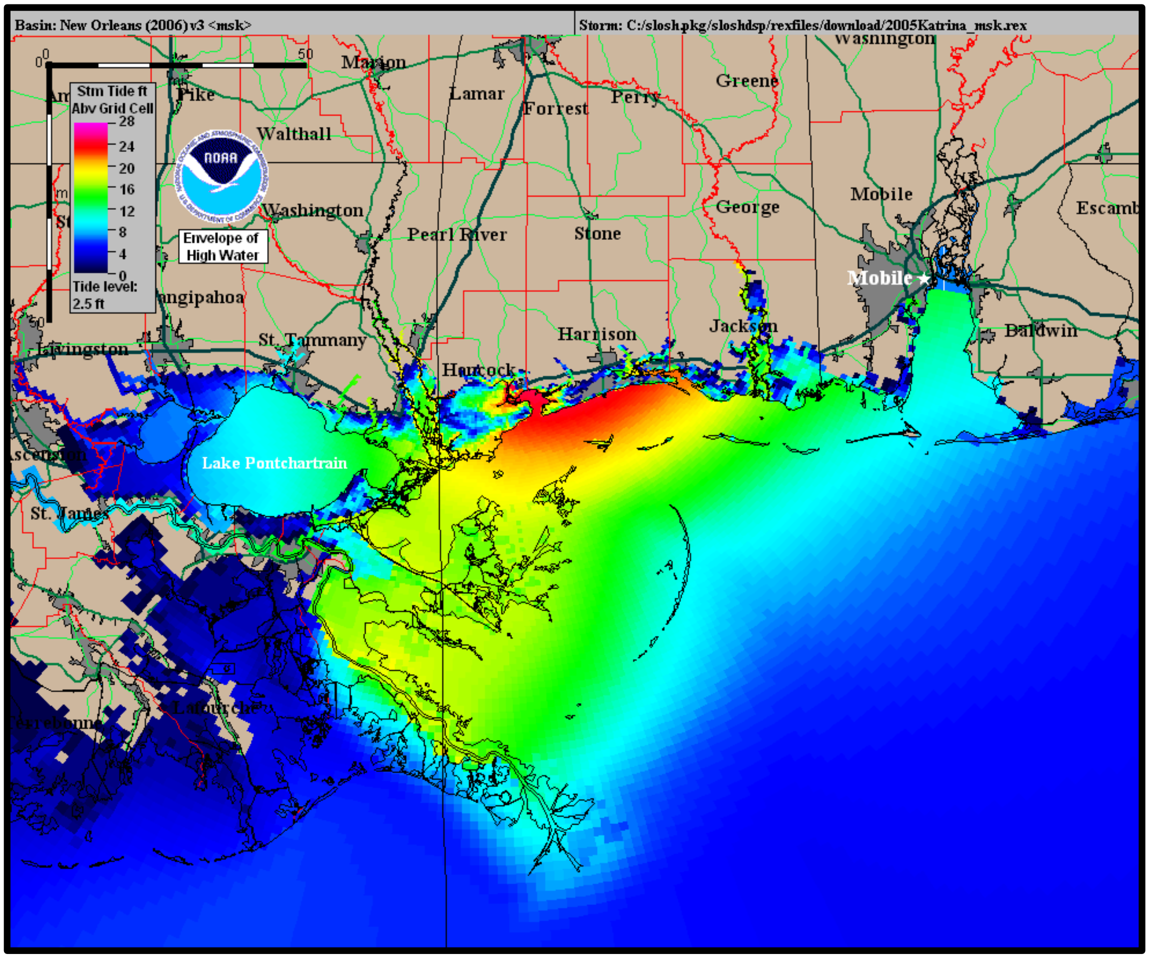

Figure 3. Storm Surge Field During Hurricane Katrina in August 2005

Source: (National Hurricane Center 2017).

Hurricane Harvey struck Texas and Louisiana in August 2017 as a Category 4 hurricane. Now the second-costliest storm in United States history, behind only Hurricane Katrina mentioned above, set records for tropical cyclone precipitation. In peak rainfall totals, amounts of up to 60.56 inches around Nederland, Texas were recorded, easily surpassing previous records of 48.00 inches in Medina, Texas, nearly 40 years before. In addition to these peak totals, another 18 stations reported totals over 48 inches, or four feet (National Hurricane Center 2017, 6). Of the 68 direct deaths caused by this storm, none of them were a result of storm surge, but all but three of the deaths were caused from freshwater, or rainfall, flooding (National Hurricane Center 2017, 8).

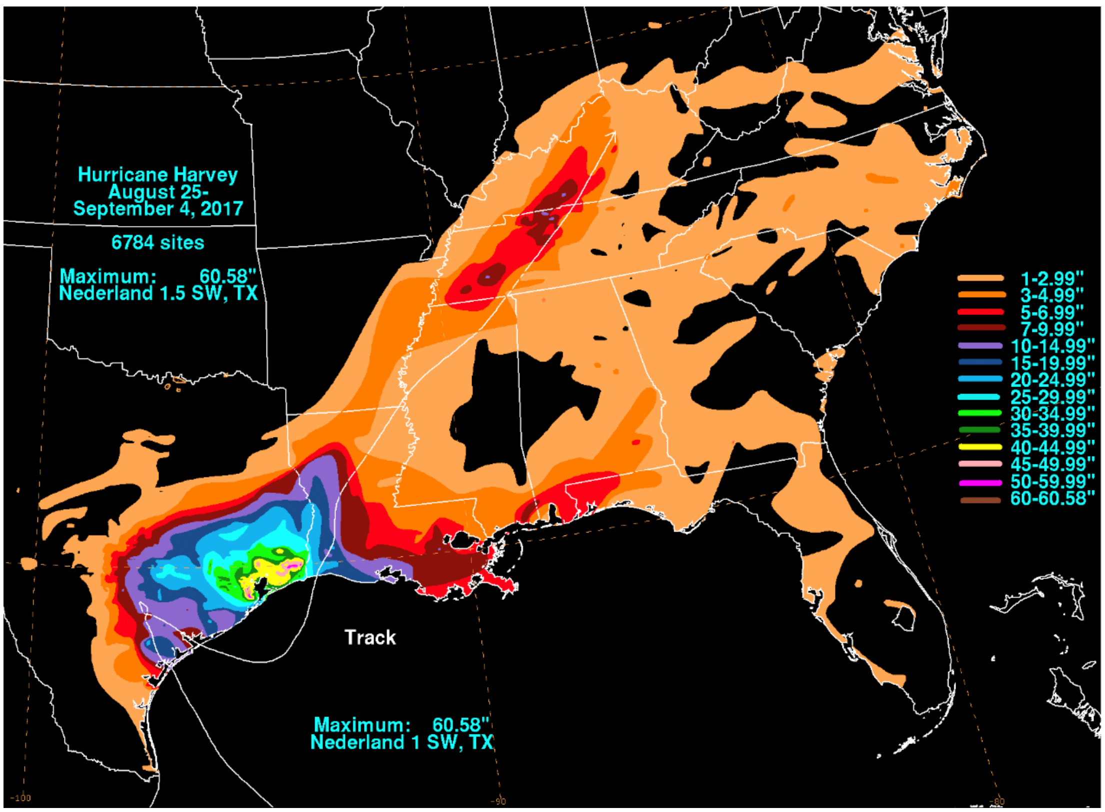

Figure 4. Hurricane Harvey Tropical Precipitation Rainfall Totals

Source: (National Hurricane Center 2017).

As a result of the extensive freshwater flooding caused by the record-breaking rainfalls, 300,000 structures and 500,000 vehicles flooded with 30,000 water rescues conducted of those stranded in its midst (National Hurricane Center 2017, 9). This amount of TCP is not only record breaking, but historically significant. According to Laiyin Zhu, Steven QM. Quiring, and Kerry A. Emanuel in a 2013 Geophysical Research Letter, an event totaling more than 1400mm, in Harvey's case up to 1538mm, is a one in a 1000-year TCP event. In this same 2013 study, a prescient forecast of the areas hardest hit by TCP in future hurricane seasons were Corpus Christi and the Houston area (Zhu, Quiring, and Emanuel 2013, 6226). Damages caused by this hurricane and its unprecedented rainfall caused $125 billion in damages. USNORTHCOM committed a peak total of 3,018 federal troops to support the disaster relief efforts alongside nearly 20,000 Texas National Guard soldiers (USNORTHCOM 2018a, Appendix C). But Harvey was just the first of three massive storms to wreak havoc that season.

Closely following Hurricane Harvey was yet another Category 4 hurricane to strike the United States or its territories. Hurricane Maria, following an intermediate Category 4 Hurricane Irma that struck Florida, unleashed her massive amount of energy on Puerto Rico and the U.S. Virgin Islands in September 2017. Maria's winds and TCP of up to 37 inches destroyed much of the energy infrastructure on the island, severely affecting the transportation and communication networks there. Of note, Maria experienced the quickest intensification of any hurricane on record. Within 54 hours she went from the lowest strength of tropical cyclone, a tropical depression, to the strongest, a Category 5 hurricane. Damages were estimated at $90 billion with 64 people killed and over 12,800 federal troops committed to the area. However, the total number of troops was not the only impressive figure of this disaster response.

United States Northern Command, the geographic combatant command charged with North America, Canada, and a great portion of the Atlantic Ocean committed an immense amount of resources during the relief efforts of the 2017 hurricane season. With three Category 4 hurricane landfalls sequenced within three weeks of each other, USNORTHCOM contributed significantly to save lives, alleviate suffering, and restore critical infrastructure. In regards to military manpower and combat assets, the command deployed roughly 14,638 federal troops, dispatched eight maritime vessels, for a total of 287 mission days. Additionally, the joint task force fulfilled 119 mission assignments with these forces over an immense array of critical tasks. These included 1,476 strategic air sorties, 2,679 rotary-wing hours flown to bring in life-saving supplies with 3,400 miles of routes cleared to distribute them. This permitted the delivery of up to 3.7 million gallons of fuel, 126 million meals, and 47.4 million liters of water thereby providing basic human needs to the stricken citizens of the island. Finally, the installation of 1,176 generators enabled power generation to critical infrastructure including hospitals. These hospitals treated those affected by the storm's fury and its aftermath and ultimately provided essential medical care to 11,635 patients. Additionally, USNORTHCOM conducted 7,127 rescues throughout the entire 2017 hurricane season (USNORTHCOM 2017b).

With these impressive numbers in mind and the potential for these events to become more intense due to global climate change, identifying a center of gravity is appropriate. Using the framework of Dr. Joe Strange from the Marine Corps University, a Center of Gravity (CoG), Critical Capability, Critical Requirements, and Critical Vulnerabilities framework is applied. Center of gravities are "the primary sources of moral or physical strength, power and resistance." Further breaking this down, the critical capabilities feed into the above as they are the "primary abilities which merit a center of gravity to be identified as such in the context of a given scenario, situation or mission." For these capabilities to exist there must be critical requirements defined as "essential conditions, resources, and means for a critical capability to be fully operative." As with any system, there are always areas that can be exploited or are points of weakness, in this case, critical vulnerabilities. Dr. Joe Strange defines these as "critical requirements or components thereof which are deficient, or vulnerable to neutralization, interdiction or attack (moral/physical harm) in a manner achieving decisive results" (Strange 1996, 4).

In the scenario of hurricane landfalls within the United States, though not a traditional adversary, a center of gravity analysis works well in this construct. With the immense amount of physical force or energy unleashed and its associated destruction that a hurricane is capable of producing, the hurricane is the center of gravity of the adversarial context. Conversely, the joint task force created to provide defense support to civil authorities in the wake of these landfalls on the Atlantic seaboard and the Gulf of Mexico, is seen as the resistance against the ensuing death and wreckage. Therefore, the friendly center of gravity is the Joint Task Force. This analysis, as shown below, is conducted for both the adversary, or the hurricane, and friendly forces, or the Joint Task Force.

Table 5. Center of Gravity Analysis of Adversary and Friendly Force

Center of Gravity	Critical Capabilities	Critical Requirements	Critical Vulnerabilities
Adversary (Hurricane)	1. Storm Surge	Low-pressure disturbance or T-Storm	Surface Friction
	2. Tropical Cyclone Precipitation (TCP)	Sea Surface Temperatures at 80F to 150’ depth	Cooler Sea Surface Temperatures
	3. Winds	Low Wind Shear	High Wind Shear
Friendly (JTF)	1. Save Lives	Sufficient Advanced Warning	Response Time
	2. Alleviate Human Suffering	Proper request / authority for execution	Population trends to littoral areas
	3. Restore Critical Infrastructure	Posturing of critical assets and manpower and establishing LOCs	Weather (follow-on hurricanes)

Source: Created by the author using information from Department of the Army 2013; Joint Chiefs of Staff 2013; National Oceanic and Atmospheric Administration 1999; U.S. Department of Commerce 2010; USNORTHCOM 2008; USNORTHCOM 2012; USNORTHCOM 2017).

Center of Gravity-Adversary: The Hurricane

Joint Publication 5-0, *Joint Planning* defines a center of gravity as a “source of power that provides moral or physical strength, freedom of action, or will to act” (Joint Chiefs of Staff 2017, IV-23). Dr. Strange of the Marine Corps University also defines the concept as “primary sources of moral or physical strength, power or resistance” (Strange 1996, 43). Dissecting this term further he identifies three types of centers of gravity, namely political, moral, or physical with the latter best fitting this construct of a hurricane. Within a physical center of gravity, he defines three sub-categories with one categorized as armed forces—strength—power. Since a tropical cyclone, or hurricane, contains an immense amount of power, with an average of three-trillion watts (Emanuel 1999, 107), a center of gravity analysis applies.

Though the idea of establishing a hurricane as an adversarial center of gravity may seem odd as it is a weather phenomenon, it will assist in understanding the components of this natural force more readily. JP 5-0, like Dr. Strange states that a center of gravity may be a set of critical capabilities, which this powerful weather system possesses. They consist of storm surge, tropical cyclone precipitation (TCP), and winds. Dr. Strange also submits that centers of gravity are dynamic agents of action or influence (Strange 1996, 47). The descriptions of the five hurricane disaster examples listed above significantly illustrate the influence on the population and infrastructure left in the path of these storms.

Hurricanes also fit as the adversary center of gravity, as they prevent friendly forces from accomplishing their disaster response mission. Corroborating this is the fact that one characteristic of an adversary center of gravity is the ability to compromise the friendly center of gravity (Joint Chiefs of Staff 2017, IV-24). For example, maritime assets had to move out of the way of incoming Hurricane Jose prior to resuming operations in the Virgin Islands and Puerto Rico and cease RW operations due to its associated high winds (USNORTHCOM 2017b, 30). The threat of this follow-on hurricane making landfall within the disaster response area halted efforts as maritime assets had to reposition and air assets were unable to continue off-loading supplies onto the islands. With the identification of the tropical cyclone or hurricane as the adversarial center of gravity, a delineation of its critical capabilities must be accomplished.

Critical Capabilities

Within the construct of the center of gravity, Dr. Strange proposes the definition of a critical capability as "primary abilities which merits a center of gravity to be identified as such in the context of a given scenario, situation, or mission." He also submits the question "what particular capabilities are we especially concerned about?" to help identify these (Strange 1996, ix-x). The adversary capabilities that USNORTHCOM is most concerned with are those that will kill citizens, destroy infrastructure, and ultimately lead to a catastrophic event resulting in the commitment of a Joint Task Force. For a tropical cyclone to destroy and take lives of United States citizens, there are certain capabilities it possesses that USNORTHCOM must be especially concerned about. These critical capabilities are storm surge, tropical cyclone precipitation, and winds.

Storm surge is a dome of water that is created by both the low pressure of the storm and the winds that push the water onto shore. Due to the counter-clockwise rotation of tropical cyclones, the winds usually are strongest on the right flank of the storm, making this area at landfall the most at risk for increased storm surge. The difference between mean sea level and the height of the dome of water constitute storm surge. A storm tide, however, is the additive effects of a storm surge added to the high tide. This is important to consider as storm surge accounts for the preponderance of property damage and death of all the capabilities a hurricane possess (National Oceanic and Atmospheric Administration 1999, 13). Investigating the most deadly and costliest hurricanes between 1851 and 2010 shows that storm surge of over 10 feet is the biggest contributor to death during a major hurricane landfall (Blake, Landsea, and Gibney 2011, 6). Since mean sea level is the baseline for storm surge, increases between 1901 and 2012 of an additional eight inches, and predictions of a further 15 to 38 centimeters by 2050 are specifically concerning. This is particularly true as the rise is expected to be disproportional with greater rise along the Atlantic seaboard and Gulf of Mexico (Wuebbles et al. 2017, 52). Storm surge is, however, but one capability to create flooding within a tropical cyclone.

Another critical capability a tropical cyclone possesses is flooding due to intense rainfall otherwise known as Tropical Cyclone Precipitation. On average, a typical hurricane produces between six to twelve inches of rain, contributing to additional flooding. Much like storm surge, rainfall amounts and intensity are most significant along the right side of the hurricane track and can span as far as 100 miles inland or more (National Oceanic and Atmospheric Administration 1999, 13). These heavy rains occurring further inland can act as a catalyst for other natural hazards like mudslides or flash floods. Hurricane Camille in 1969 for example, made landfall in the Mississippi and Louisiana coastlines but progressed northeast into Virginia where TCP caused flash flooding and mudslides resulting in 162 deaths in Nelson County (Hearn 2004, 138). This capability of tropical cyclones is only expected to increase in severity in the future. According to Dr. Kerry A. Emanuel of the Massachusetts Institute of Technology, the probability of an event like Hurricane Harvey in Texas was only one percent between 1981 and 2000. Under the most severe warming scenario of the Intergovernmental Panel on Climate Change's Fifth Assessment Report, the annual probability of 500mm TCP events in Texas are likely to increase to 18 percent between 2081 to 2100. Looking at this change linearly between these two date ranges, represents an increased probability of six percent in 2017, a significant increase in the predicted frequency of devastating flooding events. This type of TCP in conjunction with higher storm surges will create more damage and endanger more lives. The result of this is state and local authorities becoming overwhelmed requesting federal assistance more often. But tropical cyclones possess yet another capability to inflict its wrath upon the United States coastlines.

Winds are another dominant force that a tropical cyclone possesses to create widespread damage. The maximum sustained wind during a hurricane is the one-minute average wind speed at the height of 10 meters in altitude (Emanuel 2005, 687). Beginning at the lower end of the wind spectrum, tropical storms produce winds of 39 to 73 miles per hour and top out at Category 5 strength with wind speeds of over 156 miles per hour. These winds can cause structural damage to buildings, including roofs and curtainwalls (National Oceanic and Atmospheric Administration 1999, 18). When these structures collapse, not only do they trap occupants inside but also create vast amounts of flying debris which act as projectiles towards other unprotected persons. Hurricane Andrew demonstrated this enormous force a hurricane possesses with maximum sustained winds of 172 miles an hour (Rappaport 2005). These forceful winds leveled 80,000 homes causing nearly 250,000 Florida citizens to become displaced (Wombell 2009, 14).

Unfortunately, average wind speeds of hurricanes in both the North Atlantic and eastern and western Northern Pacific have increased since 1949 by a margin of nearly 50 percent (Emanuel 2005, 687). Sea surface temperatures are a primary driver of a hurricane's power, especially waters of 26.7 degrees Celsius, or 80 degrees Fahrenheit, to a depth of 150 feet (National Oceanic and Atmospheric Administration 1999, 6). With each 1 degree Celsius increase, or 1.8 degrees Fahrenheit, in these tropical waters induces an associated increase in wind speed by five percent. As of 2005 an observed increase of 0.5 degrees Celsius has already occurred, resulting in a net increase of two to three percent in wind speed increase (Emanuel 2005, 687). Stronger winds, along with storm surge and TCP, will contribute to the damage caused by these storms. The trio of these three capabilities and their predicted increases will create future disasters by 2050 that force state and local authorities to request federal assistance more often. Assuming the status quo in local and state capabilities, this will result in more Title 10 forces committed to the disaster response.

Hurricanes possess an incredible capability to cause prolific destruction and death due to the ability to cause widespread flooding due to storm surge and tropical cyclone precipitation as well as incredibly powerful winds. However, these critical capabilities of a hurricane don’t exist in a vacuum. This requires a discussion of the established conditions that enable its capabilities to exist.

Critical Requirements

Certain conditions must exist for a tropical cyclone to develop, particularly into the formation of a hurricane and further into a major hurricane, or Category 3 or greater. The three primary requirements for tropical cyclogenesis. First, a pre-existing low-pressure system or disturbance must develop, as seen in a typical thunderstorm. Second, sea surface temperatures must be 80 degrees Fahrenheit, or 26.7 degrees Celsius, or warmer to a depth of 150 feet. Third, low wind shear must be prominent throughout the atmosphere. This means winds higher in the atmosphere are low in velocity and flow in a similar direction to those in the lower atmosphere. A low-pressure system forms into a thunderstorm, enabling air to rise over the ocean waters. If these oceans contain enough heat and energy, the contact with this air mass will contribute to its convection and upward movement through increased evaporation and moisture into the developing storm. This upward convection will eventually cool the air mass as it rises facilitating condensation. Through this condensation process, additional energy enters the storm system through the release of latent heat. Since energy is neither created nor destroyed, the preliminary energy required to cause evaporation of the water molecules from the warm ocean's surface to the atmosphere is maintained. When these water molecules condense, this energy is not destroyed of course, but rather transferred into the surrounding air mass. Therefore, more moist air carries with it more available energy to the tropical cyclone. As this convective action rises into higher levels of the atmosphere it interacts with winds there (National Oceanic and Atmospheric Administration 1999, 6). To continue its development, there must be favorable winds aloft that do not counteract the tropical cyclone's motion or development through wind shear. This wind shear is winds at varying directions and velocities at different levels of the atmosphere.

Critical Vulnerabilities

Though tropical cyclones and hurricanes seem like unstoppable natural forces, they do suffer from vulnerabilities that act to diminish their energy. The three primary ways dissipation of this cyclonic energy is caused by the system passing over cooler sea surface temperatures, increasing friction due to contact with a landmass, and significant wind shear.

As mentioned before, the heat engine for tropical cyclones are warm tropical ocean waters, namely those at above 80 degrees Fahrenheit, or 26.7 degrees Celsius down to 150 feet in depth (National Oceanic and Atmospheric Administration 1999, 6). In contrast to warmer waters, cooler temperature oceans do not evaporate as much moisture into the atmosphere, thereby limited the available amount of energy into the system, forestalling further development. These cooler waters lack the required energy for continued tropical cyclogenesis. This serves as a primary reason why hurricane dissipate as they head north into cooler Atlantic water. This requirement for warm tropical waters is indicative of the traditional tracks of tropical cyclones forming near the warm waters near the equator.

Additionally, as a tropical cyclone makes landfall, this also bleeds precious energy. The increased amount of friction due to coming in contact with a rougher surface comparatively to the ocean physically slows the storm down. Surfaces like trees, uneven ground, buildings, and terrain all add resistance to the overall system of the storm. This causes a hurricane's energy to eventually dissipate, particularly when coupled with a lack of warm tropical waters underneath them.

Another way hurricanes are vulnerable is through wind shear. As the storm builds and warm waters provide warmer, more buoyant moist air and the heights of the storm increase becoming exposed to higher levels of atmospheric wind currents. If these currents are of higher velocities and oppose the direction of a developing or already defined tropical cyclone it can significantly sap the storm's energy (National Oceanic and Atmospheric Administration 1999, 7). One such example of the effect of wind shear was illustrated in August 1992. Hurricane Andrew, one of only three Category 5 hurricanes to ever make landfall in the United States, was nearly torn apart due to wind shear 96 hours before it made its arrival over Florida (National Hurricane Center 2018b).

Analyzing a hurricane then as an adversary in the context of a center of gravity analysis will provide a more in depth look at the capabilities, requirements, and vulnerabilities of these incredible weather systems. Within these critical capabilities, this analysis also identifies the significant changes already experienced in history and the expected changes predicted for the future. The combination of storm surge and tropical cyclone precipitation create extensive flooding, normally the biggest contributor to death and destruction during a hurricane. Intense winds are another major capability within a tropical cyclone that can also create death and destroy homes and infrastructure and cause massive power outages, causing further indirect deaths.

For these capabilities to exist however, the hurricane must have warm oceans with a pre-existing low-pressure system with favorable winds aloft. As these systems move over cooler waters, over land, or meet opposing higher level trade winds, they begin to decay. However, these vulnerabilities cannot be directly targeted in the traditional sense of a center of gravity analysis. Long term mitigation of warming trends through decreased emissions of greenhouse gases can stymie the increase in atmospheric and oceanic warming. By stabilizing if not decreasing sea surface temperatures, further tropical cyclone intensity may be reduced. However, the timeline for these changes to come to fruition is beyond the scope of this study.

Instead, the nation must begin to adapt to the changes that are likely inevitable at this point. For example, due to carbon dioxide's long residence time in the atmosphere, even if carbon dioxide emissions are significantly reduced, its impacts are still inevitable for decades to come (Pachauri and Meyer 2014, 78). This lag time between emissions control and climate change impacts will not be instantaneous as sea surface temperatures are likely to continue to warm despite reductions in GHG emissions. USNORTHCOM, charged with protecting North America and its citizens and interests, must begin this adaptation to address the impacts of more intense tropical cyclones on the mainland and the associated disaster response. With this in mind, this study now turns to a center of gravity analysis of the friendly force and its disaster response to these destructive hurricane landfall events.

Center of Gravity-Friendly: The Joint Task Force

Large populations of citizens may require assistance in the wake of a major hurricane strikes the United States due to widespread damage caused by flooding and winds. If local and state level authorities have employed their capabilities but are still overwhelmed by the need of those affected, officials will request or be supported by other states. This is normally conducted through an Emergency Management Assistance Compact, a congressionally ratified mutual support agreement between adjacent states to help during a disaster. If the capacity of resources and capabilities still do not match the need, a request for assistance to the federal government will be made by the governor of the state. This begins the process of a potential deployment of Title 10 forces that will augment civil authorities with either capability, capacity, or both. At this point, USNORTHCOM will likely establish a Joint Task Force which serves as a "dynamic agent of change," as Dr. Strange defines a physical center of gravity, in the disaster response efforts. This center of gravity possesses many critical capabilities.

Critical Capabilities

There are three critical capabilities the JTF must normally possess during defense support to civil authorities. Corresponding with themes that exist in JP 3-28 "Defense Support to Civil Authorities" and DODD 3025.18 "Defense Support to Civil

Authorities", these capabilities are to save lives, prevent human suffering, and mitigate catastrophic damage (Joint Chiefs of Staff 2013 I-7).

Saving lives may seem like an obvious capability required in a disaster response scenario. For citizens that remain in the path of such destructive forces as a major hurricane, these individuals may have their property destroyed and become trapped underneath the wreckage while lacking their basic needs. During Hurricane Camille that struck Mississippi and Louisiana coastlines, 41 of the 172 people that perished in this Category 5 hurricane were listed as missing and never found (Hearn 2004, 123). Conducting search and rescue from the air using helicopters, on water using shallow draft boats, or on foot visiting house to house by troops are all methods of finding survivors and removing them from harm's way. Search and rescue efforts of the 82nd Airborne Division's Task Force Panther following Hurricane Katrina illustrates this capability, as they conducted 853 rescues and safely evacuated 4,906 New Orleans residents that would have otherwise been stranded (Wombell 2009, 169).

Outside of directly saving lives from those stricken on rooftops or amongst the rubble, the Joint Task Force also prevents human suffering. One of the primary ways this is accomplished is through the distribution of life-sustaining commodities, namely food, water, medical supplies, and basic shelter items. During the 2017 hurricane season that struck Texas, Florida, the U.S. Virgin Islands and Puerto Rico, the Joint Task Force provided more than 160 million meals, delivered 47.4 million liters of water, and distributed 3.7 million gallons of fuel, and nearly 121,000 tarps to provide temporary roof repairs. Additionally, the responding forces treated more than 11,635 patients helping to prevent human suffering and provide basic human needs (USNORTHCOM 2017b).

Beyond directly saving lives and providing life-saving commodities to prevent greater suffering or eventual death, the Joint Task Force also mitigates catastrophic damage. Dewatering of flooded areas as seen in New York City at the World Trade Center Memorial and subway transit system following Superstorm Sandy in November 2012 provided a niche capability that did not exist at local and state level (Burke and McNeil 2015, 70). During Hurricane Maria's sweep over Puerto Rico, the island's power grid was virtually knocked out. Of the thousands of generators brought to the island, one of the largest was delivered by a United States Air Force C-5 Galaxy. This powered the Combined Radar Approach Control facility to enable future flights to land safely and deliver additional life-saving supplies (USNORTHCOM 2018a, 34). The Department of Defense possesses these critical capabilities that other organizations either do not have or cannot match in capacity.

Critical Requirements

Specific critical requirements must be met for these capabilities to be provided promptly to those in need. Just having the capabilities listed above will not be useful in disaster response. Only by delivering the right capability in the right capacity to the right place and time can they prove beneficial to those that need them. The three most essential requirements for the JTF to bring the above capabilities to the need is an advanced warning and accurate forecasting, proper approval or authority to act, and the posturing of assets and resources to reduce response time.

Perhaps most important is the requirement to be forewarned of an imminent disaster with adequate time to plan a response. This is done primarily through weather forecasting of tropical cyclones, particularly during the period of heightened awareness that USNORTHCOM establishes at the height of the annual hurricane season. Embedded within the staff is a Meteorological Operations Center within the current operations cell that provides the commander updates of developing TCs that could impact the United States. The use of different sensors to detect the development and track of tropical cyclones include satellite monitoring, aircraft reconnaissance, ship buoy sensors, and ground-based radar systems. Since the advent of aircraft reconnaissance in the mid-1940s and weather satellites in the mid-1960s, the amount of advanced warning of hurricanes has increased immensely. But only knowing that a catastrophic event may occur in the future is not enough.

Armed with the information that a hurricane may threaten lives and property, it must be coupled with a decision to act. Relevant to USNORTHCOM, this comes in the forms of approval or authority for federal forces to be committed to the disaster response. This can occur either before landfall as directed by the National Command Authority or after landfall once local and state authorities commit their organic assets and determine federal assistance is required. Paramount to this approval and authority is the fact that military resources will augment and support civil authorities who take the lead in coordinating the disaster response, usually the Federal Emergency Management Agency. The mission assignment assists in this process to identify capabilities that require augmentation from Department of Defense assets. However, this process takes time to validate the requirement and identify the proper military asset to fulfill the request. The difficulty lies in either waiting to determine the need following the disaster occurs and risking a longer response or acting preemptively and committing federal resources not knowing exactly what needs they will serve.

After a decision to commit federal forces to the disaster response is made, the physical movement of assets into the affected area is vital. The selection of potential Base Support Installations may be selected to provide an aerial port of debarkation for the flow of manpower, assets, and equipment required in the response effort. However, even if an emergency or major disaster declaration has not been made from the state governor or directed from the president, the DoD may position assets in the vicinity of the potential disaster area at their own expense (USNORTHCOM 2018b, 27). This move ahead of landfall can be essential to reducing the lag time from request to the need and may result in more lives saved and more infrastructure protected. In any large organization or system of processes, there are innate vulnerabilities that exist.

Critical Vulnerabilities

One of the most significant vulnerabilities within a Department of Defense disaster relief effort is the ability to respond quickly. First and foremost, the Department of Defense must be requested or directed before it can legally act. Though federal forces are often viewed as first responders to catastrophic disaster due to their inherent capability and capacity, they are not set up to serve as such. This is due in large part to certain United States codes that provide the legalese for the authorization of federal forces conducting DSCA. The Posse Comitatus Act prohibits the employment of Army or Air Force for law enforcement tasks within the borders of the country. In the aftermath of hurricane landfalls, a need to maintain law and order normally exists. The state National Guard, not subject to the Posse Comitatus Act will most often accomplish this task, as federal forces are prohibited from conducting this. The Insurrection Act does, however, allow the President of the United States to employ federal armed forces in a law enforcement role as one exception to the Posse Comitatus Act as was seen during Hurricane Hugo in 1989 in the U.S. Virgin Islands due to the extensive looting there (Elsea and Mason 2008, 2).

Additional authorizations allow federal forces to be employed during disaster relief efforts. Expressly, the Stafford Act authorizes the president to employ the armed forces in a disaster relief role, but not as a law enforcement entity. The President of the United States can authorize up to 10 days of emergency work by the Department of Defense. This can be approved before a state governor requests an emergency or major disaster declaration. These two types of declarations originate from the state governor and contain requests for federal assistance once determined that the capabilities at state level are not sufficient to fully meet the need. According to the Congressional Research Service, between 1953 and 2014 the result of hurricane landfalls accounted for 27.8 percent of all emergency declarations (Lindsay and McCarthy 2015, 9).

The last type of authority to employ federal forces is the Immediate Response Authority that allows military commanders to assist civil authorities with their resources even if a declaration has not been given. The goal of this authorization is to "prevent human suffering, save lives, and mitigate great property damage" (Joint Chiefs of Staff 2013, II-5). Due to the tiered response model as per the National Response Framework, disaster response is primarily conducted at the lowest level and federal assistance and resources are committed only if required (Department of Homeland Security 2013, 6). This results in the Department of Defense normally being the last asset to be committed to disaster response. Once requested, additional time is involved to analyze the requirement to determine which capability and unit matches appropriately to the need.

Time is then required to plan and get the capability to the disaster area. The tiered response has benefits as it prevents the involvement of federal forces during each disaster but limits the response time following one. Within Field Manual 3-28, this lag time is specifically identified and even cautions commanders during initial response phases to "expect criticism from media representatives who demand why more is not being done" (Department of the Army 2010, 3-3). This criticism can be expected more with higher severity particularly when the JTF operates in more populous and exposed areas.

Population trends are another source of vulnerability within the context of the Joint Task Force during a hurricane response. With more citizens susceptible to storm surge, TCP, and high winds created by tropical cyclones, there is greater likelihood that state and local agencies will become overwhelmed with more citizens and infrastructure to protect. In the last 25 years, for example, an estimated 50 million citizens have moved into coastline communities (Blake, Landsea, and Gibney 201l, 6). Between 1960 and 2008 a population increase of 150 percent in the Gulf of Mexico coastline states and a 56 percent increase along the Atlantic has occurred (U.S. Department of Commerce 2010, 3). This increase is illustrated by comparing past populations to current populations and their vulnerability to hurricanes. For example, the 10 most intense hurricanes that struck the United States between 1960 and 2008 impacted 51 million citizens living in coastal counties. If those same hurricanes were to make landfall only in 2008, they would impact nearly 70 million citizens, or an increase in 19 million residents (U.S. Census 2015). This population increase creates more citizens to protect and save and more infrastructural damage to mitigate. This will likely require states and local authorities to request federal assistance, namely DoD, more frequently.

Another large vulnerability of the Joint Task Force is follow-on weather, particularly subsequent hurricanes. These systems cause significant disruption to air, ground, and maritime movement that is normally critical to the JTF to save lives, prevent human suffering, and mitigate infrastructure damage. High winds limit the ability of rotary wing aircraft to conduct search and rescue and prevent fixed-wing aircraft from delivering additional supplies. Rough seas close ports and force maritime assets to reposition away from the response site. This significantly degrades ship to shore distribution operations. Further wind damage, storm surge, and tropical cyclone precipitation impact ground lines of communications, ports, and roads hampering ongoing debris clearing and distribution efforts. Effectively, the entire disaster response operation comes to a halt due to an impending follow-on severe weather event. There have been two instances in which these effects were demonstrated.

In August in 2005, during the largest disaster response in United States history following Hurricane Katrina, the effects of follow on weather significantly impacted the Joint Task Force. Near the height of their efforts, oncoming Hurricane Rita forced many naval assets to reposition and major ports to close. Due to the incoming threat, five ports in Texas and Louisiana closed and five naval vessels were forced to move out of the path of the storm. These assets included the *USS Iwo Jima*, Shreveport, and Tortuga, in addition to the *USNS Patuxent* and the combat hospital ship *USNS Comfort* (USNORTHCOM 2005, 1). The power of this subsequent tropical cyclone caused a heavy delay in the Joint Task Force's ability to continue to provide critical capabilities to those in need. During the 2017 hurricane season, this impact was felt once again.

Following Hurricane Irma's devastation in the U.S. Virgin Islands and Puerto Rico another subsequent hurricane, Maria, began brewing to the southeast of the ongoing recovery efforts there. On September 18, 2017, this forced the *USS Kearsarge*, *Oak Hill*, and *Wasp* to reposition out of the then Category 3 storm's path significantly hampering disaster response efforts. As mentioned before, Dr. Strange submits that "an enemy center of gravity has the moral or physical ability to prevent friendly mission accomplishment." The fact that these two tropical cyclone examples physically prevented the Joint Task Force from conducting disaster response lends credence to the fact that on the adversary side, the hurricane is the center of gravity.

Conclusion

Hurricanes possess a significant, continued, and potentially increasing threat to the United States. The devastating impacts over time result in tens of thousands of deaths, hundreds of billions of dollars in damage, and commit several tens of thousands of federal troops to assist civil authorities in response to such disasters. The five examples above demonstrated the most critical capabilities that tropical cyclones possess to inflict death and destruction along the coastlines of our country. Powerful storm surge flooded coastal areas exacerbated by intense tropical cyclone precipitation that caused drownings, power outages, and severe structural damages to personal property and critical infrastructure. Winds as high as 200 miles an hour as seen during Hurricane Camille ripped through coastal areas more akin to massive tornadoes destroying buildings and sending debris flying like missiles that endangered many people. These historically validated capabilities are only forecasted to increase. Storm surge becomes more devastating as mean sea level rises, warmer atmospheres carry more moisture that forms as precipitation, and increasing ocean temperatures correspond to more intense winds. It is crucial that senior leaders at USNORTHCOM and senior decision makers understand the threats they face and how they are expected to be impacted by global climate change in the future.

Viewing a tropical cyclone as the adversarial center of gravity provides focus to senior leaders. The below Figure 5 is a visual representation of how senior military leaders and decision makers can interpret the threat posed by tropical cyclones, or hurricanes, is more common military lexicon. It aids in identifying these storm system's most casualty producing and destructive capabilities while understanding their underlying requirements and vulnerabilities. Due to an inability to target these storms directly, a center of gravity analysis of the responding Joint Task Force allows senior leaders to accurately identify critical capabilities they must employ to support civil authorities. With impending further increase in the capability of tropical cyclones, a center of gravity analysis will also inform future resourcing, authorities, and force management initiatives to disaster response forces. This perspective of both the adversary's capabilities to inflict disaster and friendly force's ability to respond to the aftermath is imperative to save lives, prevent human suffering, and mitigate catastrophic damage. This is particularly so with the predictions of more intense hurricanes in decades to come that will result in increased frequency of deployment by USNORTHCOM and DoD resources.

Figure 5. Hurricanes Represented as an Adversary

Source: Created by author.

The fifth and final chapter of this study will make recommendations based on this analysis presented here. Both recommendations for decision makers and recommendations for further study will be made to complement the research and analysis conducted. Additionally, a final and conclusive answering of the primary and subordinate research questions is performed in the next chapter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Chapter Introduction

This study incorporated a quantitative and qualitative method to determine if the application of military models assists senior military leaders and senior decision makers in increased understanding the threat posed by tropical cyclones landfalls in the United States. Beginning with historical hurricane case studies, the analysis highlighted the incredible devastation caused by mother nature when these storm systems made landfall. These disasters also induced significant commitment of Title 10, or federal forces in response. Following this, a summation of the quantitative data that included deaths, damage caused, and federal troops committed to the disaster response was conducted. Extracted out of this examination were tropical cyclones' most critical capabilities that led to death and damage (in 2017 dollars). Additionally, a review and application of scientific and academic research regarding climate change impacts on tropical cyclone intensity were completed. This primarily was achieved through the use of data provided by the Intergovernmental Panel on Climate Change Fifth Assessment Report, the United States Global Change Research Program Report, and other climate scientist studies on the topic. Using a blend of models from Dr. Joe Strange of the Marine Corps University and Joint Publication 5-0 Operations Process, this study then identified capabilities as part of a center of gravity analysis with the hurricane as the adversary.

This analysis led to a more holistic comprehension of the threat hurricanes pose to the United States and identified them as a center of gravity or source of physical power. This examination showed that tropical cyclones possessed certain critical capabilities, critical requirements (or conditions to enable those capabilities), in addition to critical vulnerabilities. The analysis of each capability confirmed the observed increases that have already occurred up to this point. Between 1901 and 2010, sea level rise of 19 centimeters has contributed to more intense storm surges (Pachauri and Meyer 2017, 4). Winds were also shown to increase as much as 5 percent with every 1.8 degree Fahrenheit or 1 degree Celsius increase in sea surface temperature. An observed increase of 0.5 degrees Celsius as of 2005 stimulates an accompanying increase of 2 to 3 percent increased strength in winds (Emanuel 2005, 687). Though this may not seem significant, under this equation a Category 5 storm that produces 156 mile-per-hour winds would be intensified with an additional 3.1 to 4.7 miles per hour causing added destruction and death. Finally, the probability of a 500mm or greater TCP event in the Texas area has already increased as much as 6 percent due to warming of the atmosphere and a greater ability to retain moisture that condenses and falls as rain during a tropical cyclone (Emanuel 2017, 1). But as mentioned before, these data points above provide only observation of intensification until the present day and does not address predictions for future change.

Further analysis showed that these capabilities are expected to increase in magnitude in the future. Comparatively to 2000, storm surges damages will continue to increase with predictions of an additional 15 to 38 centimeters of sea level rise by 2050 (Wuebbles et al. 2017, 52). Sea surface temperatures are also forecasted to increase as much as 2.7 degrees Celsius by 2100 (Wuebbles et al. 2017, 25). This additional energy will strengthen tropical cyclones based on thermodynamic exchanges between the oceans and overlying atmosphere. As stated before, with each 1 degree Celsius increase a 5 percent associated increase in wind speeds can be predicted (Emanuel 2005, 687). Due to these anticipated increases, hurricanes will continue to amplify in intensity in the next 50 years. This threatens the country with more frequent disasters of increased destructiveness causing USNORTHCOM to commit forces in their aftermath. The scope of this study does not allow for either a direct or indirect approach to target tropical cyclones. However, long term mitigation could be accomplished through decreased GHG emissions resulting in eventual stabilization or even potential reduction of sea surface temperatures. Therefore, a center of gravity analysis is also conducted on the response to hurricane landfalls.

In this way, this study illustrated the critical capabilities of the Joint Task Force are to save lives, prevent human suffering, and mitigate catastrophic damage. It also highlighted the requirements that must exist for this formation to be of assistance to civil authorities. These requirements include an advanced warning, the decision and authority to act, and the posturing of forces and assets to respond swiftly and effectively, to those in need. However, vulnerabilities exist and include response time to the area in need, population trends that are adding residents to vulnerable coastal areas, and follow-on extreme weather, namely subsequent hurricanes, that hamper the disaster response efforts.

Overview of the Study

The purpose of this study was to change the perception of tropical cyclone landfalls as strictly a weather phenomenon and instead as an adversary. It also lends continued awareness of the associated disaster relief that follows to better empower and assist USNORTHCOM to accomplish its mission of civil support and safeguard the people and interests of the United States. To do this the primary research question asked was:

> How does USNORTHCOM adapt to the impacts of more destructive tropical cyclone strikes against the homeland due to global climate change in the next 50 years?

The study also asked three secondary research questions as part of this:

1. Will global climate change increase the frequency, duration, or magnitude of destruction caused by Atlantic Basin tropical cyclones in the next 50 years?
2. How can senior leaders better understand the threat posed by Atlantic Based tropical cyclones using existing military models to better prepare and execute when called upon to assist in disaster relief?
3. Does the National Guard, FEMA, or USNORTHCOM need to revise its posture, organization, or and capabilities to more effectively respond to disaster relief efforts?

Table 6. Research Question Answers

Subordinate Research Question	Answer
Will global climate change increase the frequency, duration, or magnitude of destruction caused by Atlantic Basin tropical cyclones in the next 50 years?	Yes. Sea level rise will add to storm surge and coastal flooding, increased sea surface temperatures will increase wind speeds and cause further structural damage, and increased air temperatures will cause greater TCP resulting in more coastal and inland flooding more frequently.
How can senior leaders better understand the threat posed by Atlantic Based tropical cyclones using existing military models to better prepare and execute when called upon to assist in disaster relief?	Applying JP 5-0 and Dr. Strange's Center of Gravity analysis allows senior leaders to identify a TC's critical capabilities, namely storm surge, TCP, and winds. A CoG analysis of the friendly force disaster response highlights its critical capabilities to save lives, prevent human suffering, and mitigate great property damage in the wake of TC landfalls in the United States. This analysis also sheds light on vulnerabilities the JTF possesses, specifically response time, population trends toward vulnerable coastal regions, and follow-on hurricanes.
Does the National Guard, FEMA, or USNORTHCOM need to revise its posture, organization, or and capabilities to more effectively respond to disaster relief efforts?	Yes, with an increased likelihood of more intense storms, local agencies, National Guard, and FEMA will likely be overwhelmed more often. This will result in more frequent requests for federal assistance and associated mission assignments. Additional federal forces need to be allocated to USNORTHCOM for the hurricane season to respond to this more proactively to disaster.

Source: Created by the author with data (Intergovernmental Panel on Climate Change 2014; Wuebbles et al. 2017; Joint Chiefs of Staff 2017; Strange 1996, and Joint Chiefs of Staff 2013).

In answering these subordinate research questions, this study now turns to answer the primary research question through the recommendations this study offers in the below section.

Recommendations

This study presents two recommendation types as a result of the blend of quantitative and qualitative analysis conducted. First, this study offers five recommendations for senior military leaders within USNORTHCOM and senior decision makers and policy writers in how they adapt to the threat posed by tropical cyclones thereby answering the primary research question "How does USNORTHCOM adapt to the impacts of more destructive tropical cyclone strikes against the homeland due to global climate change in the next 50 years?" The second set of three recommendations are offered for areas of further research, with greater focus on mitigation of the threat outside of the 50-year scope of this study.

Recommendations for Decision Makers

The first recommendation is to increase education on the potential impacts of climate change, particularly as it relates to the United States. This comes in two main forms. First, to stay up to date on the impacts of climate change on the frequency of DSCA, USNORTHCOM must continue to conduct mission analysis and intelligence preparation of the battlefield for the future. In 2012 General Jacoby, then USNORTHCOM Commander, initiated a mission analysis of climate change and its potential to impact DSCA and USNORTHCOM operations (USNORTHCOM 2013, 1). These predictions predominately were based on the fourth assessment report from the Intergovernmental Panel on Climate Change and second national climate assessment of the United States Global Change Research Program. This type of analysis needs to be continued to both help determine changes in the operating environment and additionally to integrate more current reports and assessments. As climate change increases the frequency of USNORTHCOM employing federal forces for DSCA, those that execute these operations must be better informed. The Command and General Staff Operations Course, for example, currently provides zero contact hours of DSCA to the student body during common core or advanced operations course. Only during electives is a student offered courses on the subject. The second part of this recommendation is to provide a minimum of four contact hours regarding DSCA during common core, with a particular focus on authorities and legalities. This will better enable those that are likely to plan these operations with the references and knowledge to perform more effectively. This will contribute positively to the Joint Task Force's critical capabilities of helping save lives, preventing human suffering, and mitigating catastrophic damage with more informed leaders and planners.

The second recommendation this study makes is for USNORTHCOM to establish a climate change monitoring cell in the USNORTHCOM J5. The tasks of this cell include monitoring academic and scientific reports and areas of interest that highlight the potential for increases in the critical capabilities of tropical cyclones as summarized in Figure 5 of Chapter 4. This includes sea level rise, increases in sea surface temperatures, and tropical cyclone intensity trends. The indicators above would provide warning of further increase in tropical cyclone critical capabilities, namely storm surge, TCP, and winds. By highlighting these capabilities more readily USNORTHCOM can advocate for additional resourcing in disaster relief operations following hurricane landfalls. This cell would also cooperate closely with the USNORTHCOM Historian and J1 to maintain historical data on the associated troop and military resources committed during DSCA operations. By also establishing a more substantive baseline of Title 10 forces and assets committed to these operations, future resourcing will be greatly facilitated. Though beyond the scope of this study, this cell would also be the appropriate location within the USNORTHCOM staff to examine the other impacts to homeland security posed by the many other effects of climate change on the United States, including a warming Arctic.

The third recommendation is the continued funding and resourcing of USNORTHCOM exercise planning and execution, particularly Exercise Ardent Sentry. This DSCA focused exercise stresses not only USNORTHCOM but also interagency entities like FEMA in providing more effective and timely response. For example, the scenario of Ardent Sentry 2018 involved a Category 3 hurricane landfall in FEMA Region III, which encompasses the national capital region. This type of catastrophic situation is crucial to understanding how tropical cyclones prove incredibly deadly and destructive. A scenario of this nature would create significant costs in damages and death, but also develop immense vulnerabilities for USNORTHCOM as they conduct simultaneous homeland security and homeland defense responsibilities. In fact, the command has identified the strategic risk involved with the above as well as the vulnerability created if critical defense infrastructure is damaged during such disasters (USNORTHCOM 2018b, 18). Decision makers are greatly informed by the outcomes of these types of exercises. This assists USNORTHCOM in maintaining its ability to effectively respond after landfall of tropical cyclones, particularly those which are more intense that strike more vulnerable areas.

The fourth recommendation made is to include climate change as a national security threat as part of the National Security Strategy of the United States. Not only does increasing sea level rise put coastal military installations at risk, but also exacerbates many forms of extreme weather, including severe storm surge events (White House 2015, 7). These occurrences will more frequently overwhelm local and state authorities who request federal assistance. This commits a plethora of military manpower and assets. If resourcing and force structure initiatives are to be pursued, an endstate must first be determined. Protecting United States citizens and their property through effective disaster response following these intensified weather events must be designated as this endstate. This will allow the country to both begin to mitigate the threats of climate change in the long term, but more importantly, adapt in the short term. Flowing down from the National Security Strategy, the National Defense Strategy would be informed to better enable USNORTHCOM to assume responsibility for the task and begin to build appropriate force structure to meet the requirement.

The fifth and final recommendation this study makes is to establish a Joint Task Force Hurricane. Similar to the Joint Task Force Civil Support that exists to provide critical capabilities in response to a Chemical, Biological, Radiological, Nuclear, or High Yield Explosive event, a similar structure must be created for disaster relief following tropical cyclone strikes. Just as the possibility of Chemical, Biological, Radiological, Nuclear, or High Yield Explosive attacks have increased with the potential for greater terrorist actions involving such weapons, the possibility of more destructive tropical cyclones due to global climate change also exists. However, hurricanes already pose a threat to the United States. For example, of the twenty-three notable responses conducted in the first ten years of its existence, USNORTHCOM conducted nearly half of them exclusively due to hurricane landfalls (USNORTHCOM 2012, 25). Joint Task Force Hurricane would be activated during the hurricane season, ranging from June 1st to

November 30th and possess the critical capabilities and requirements of the friendly force as identified in chapter 4 Analysis. The critical capabilities of saving lives, preventing human suffering, and mitigating catastrophic damage would be organic to this formation. Within this, its ability to provide logistics and distribution, search and rescue, medical support, route clearance, and communications support when requested is paramount. The time is now to face the threat of more intense tropical cyclone landfalls by building force structure aptly to account for a mission set of increasing importance. This initiative, as any new one has, possesses both advantages and disadvantages.

Several benefits emerge from the construct of Joint Task Force Hurricane, namely lower strategic risk, greater unity of command, and flexibility. First, allocating forces dedicated to disaster response at the federal level decreases draw from other units with commitments to other parts of the world. Most notably, forces already allocated or apportioned against other security interests can maintain their focus and training on those external threats without the distraction of a possible DSCA commitment. Conversely, Joint Task Force Hurricane can preserve focus on DSCA without competing demands for training or resourcing. Second, as opposed to an ad hoc creation following a disaster, this pre-existing formation enjoys the added benefit of greater unity of command. There is, therefore, less likelihood of a disjointed response with multiple unfamiliar components working together for the first time. Third, the amount of flexibility to commit this force is also a noteworthy advantage. This JTF can move between states and regions with greater freedom of action without being tied to a state's jurisdiction, as is the case with the National Guard. By having pre-designated units on standby that are most likely to be employed in DSCA, the mission assignment process will take less time from request to need. Additionally, the JTF can posture to respond to any area that requires its capabilities with more agility without itself becoming compromised in the affected disaster area. But the benefits do not end here.

The amount of oversight to provide resourcing and budgeting for a federal level disaster response force would likely be much more efficient. With fewer layers of bureaucracy to navigate, changes can be made more quickly to adapt to an ever-evolving environment. In the public eye, a formation of a unit specifically designed to assist civil authorities in disaster response may contribute to an increased positive perception of the United States Armed Forces. This observation was witnessed in the aftermath of Hurricanes Andrew, Katrina, and Maria among many others. Additionally, this unit would also demonstrate the willingness of the government to assist state and local authorities. Creation of this unit also provides an incentive for federal decision makers to think long-term about the impacts of climate change and how to mitigate it, beyond just resourcing to adapt to it. Ultimately, when state and local authorities become overwhelmed, the federal government is asked to respond. With American lives and property hanging in the balance amidst increasingly intense disasters, a more proactive force structure must be created. However, disadvantages still remain with the formation of a federal level disaster response unit.

Despite the advantages of such a force structure, disadvantages persist. These include less available contingency forces and lowered state incentive in disaster response planning. First, by dedicating a unit with the sole task of responding to disasters, the number of available units for other contingencies around the globe would initially be reduced. To mitigate this, a majority of the units providing critical capabilities to JTF

Hurricane would come from the reserve component. In the long term, this risk could be mitigated through increased force structure, budgeting, and resourcing to offset the formation of JTF Hurricane. Second, the creation of such a unit could cause local and state authorities to perceive an over militarization of disaster response instead of relying more heavily on their organic National Guard assets. With the existence of such a federal level entity, states may also be less inclined to promote effective disaster responses or build their capability or capacity. This is particularly so as states may see the increase in resourcing at federal levels as a higher priority than the initial tier response at state and local level. However, this can be mitigated by ensuring, as the Stafford Act calls for, that the states have employed or plan to engage all available resources before requesting federal assistance. An increased sensitivity that the Department of Defense is taking the lead in disaster response is also a potential disadvantage, as this proves the opposite of the intent of Defense Support of Civil Authorities. Promoting a narrative that the purpose of the JTF is to reduce the time to need and not to supersede civil authorities can alleviate this issue.

Ultimately, the creation of Joint Task Force Hurricane provides more benefits than risks. With the increased threat of more destructive and intense tropical cyclones that make landfall in the United States, an adaptation must begin now. By building this JTF with pre-designated units that have the required capabilities most often requested during DSCA operations, this will significantly reduce the time for mission assignment processing and enable a more rapid response. This will protect American lives by getting forces and life-sustaining supplies to those in need faster and help limit damage to critical infrastructure. The current USNORTHCOM Commander, GEN Lori Robinson stated after the 2017 hurricane season “We have the authorities, do we have the force structure, to execute DSCA EXORD? I don’t know.” This study seeks to help create this required change.

Recommendation for Further Research

The first recommendation that this study offers for further research is a more detailed analysis; to create Joint Task Force Hurricane. One such topic is the conduct of a Capabilities Based Assessment to determine specific mission sets, gaps, and solutions based on the future operating environment that global climate change will impact. Once these solutions are identified, a force design update can be conducted along with associated force management considerations in delivering the required capabilities to meet the need.

Second, due to the limited scope of this study, areas of further research are also recommended in the mitigation of climate change. As discussed in chapter 4, this study identified the likely impacts the United States will face in the near term, within 50 years, from intensified tropical cyclones due to climate change. The above recommendations are therefore designed to help USNORTHCOM adapt to these impending threats. However, as this 50 year timeline aligns closer to scientific prediction ranges of the IPCC and USGCRP, this study does not address the methods of mitigating further future change. It is recommended then, that additional research is conducted to determine appropriate mitigation strategies, to include curbing emissions of greenhouse gases like carbon dioxide among others. Due to the long residence time of carbon dioxide in the atmosphere, even if emissions were significantly reduced or even cut altogether, the effects of climate change would still be endured on the order of decades (Pachauri and

Meyer 2014, 16). The focus of further research should zero in on how to mitigate this issue in the long term.

The third recommendation for further study is how global climate change will increase the frequency of Foreign Humanitarian Assistance. As this study has recognized, climate change will increase the frequency by which USNORTHCOM conducts DSCA within the United States. However, the impacts of global climate change will, of course, be, global. Geographic Combatant Commanders, with responsibilities outlined in the Unified Command Plan, will, like USNORTHCOM, face situations following natural disasters in which they are directed to assist those in need. More severe drought, increased water scarcity, and increased intensity of extreme weather events globally will likely be seen (CNA Military Advisory Board 2014, 7). To balance nation-state and non-nation state adversarial threats along with increased Foreign Humanitarian Assistance abroad, this presents a problem set to be further analyzed.

Final Thoughts

United States Northern Command is charged with protecting the country and its interests. This comes in both the form of foreign adversaries that wish to do us harm and from forces of nature. These include wildfires, earthquakes, and of course tropical cyclone landfalls on the homeland. All of these natural forces create immense damage, cause the death of American citizens, and employs large quantities of state, local, and federal military assets to respond to them. Coupled with the command's mission of homeland defense, it also conducts DSCA to save lives, prevent human suffering, and mitigate catastrophic damage. This study makes recommendations to assist and enable USNORTHCOM to more effectively and rapidly perform a frequently executed mission.

However, the climate is changing for the worst and making tropical cyclones more intense. These enhanced storms will strike the United States and exceed the capabilities and capacity of local and state entities more often. As Mother Nature's wrath continues to increase in intensity, the time is now to improve USNORTHCOM's response to subsequent disasters through appropriate resourcing of assets and manpower. This allocation of forces for DSCA through the creation of JTF Hurricane will enable other combat power assets to maintain focus on other national security interests.

Waiting to make a decision on climate change impacts until perfect data is presented has inherent risk, as vast amounts of property and numerous American lives hang in the balance. As retired General Gordon Sullivan stated, "Speaking as a soldier, we never have 100 percent certainty. If you wait until you have 100 percent certainty, something bad is going to happen on the battlefield" (CNA Military Advisory Board 2014, 1). Hurricanes and global climate change, whether we like it or not, have made our very own coastlines that battlefield.

GLOSSARY

Atlantic Basin: Ocean area comprising North Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico (McAdie et al. 2009).

Center of Gravity: a source of power that provides moral or physical strength, freedom of action, or will to act (Joint Chiefs of Staff 2017, xxii).

Climate: A description of the long-term pattern of weather in a particular area, normally averaged for a period of 30 years. Climate typically focuses on averages of precipitation, temperature, humidity, sunshine, wind velocity, and other phenomenon (Gutro 2017).

Combat Power: The total means of destructive, constructive, and information capabilities a military unit or formation can apply at a given time (Department of the Army 2016, 5-1). Catastrophic Incident: Any natural or manmade incident, including terrorism, that results in extraordinary levels of mass casualties, damage, or disruption severely affecting the population, infrastructure, environment, economy, national morale, or government functions (Department of Homeland Security 2013, i).

Defense Support of Civil Authorities: Support provided by U.S. Federal military forces, DoD civilians, DoD contract personnel, DoD Component assets, and National Guard forces . . . in response to requests for assistance from civil authorities for domestic emergencies, law enforcement support, and other domestic activities, or from qualifying entities for special events (Department of the Army 2010, 1-1).

El Nino and La Nina Southern Oscillation (ENSO): A vacillation between the temperatures of the ocean and the atmosphere in the east-central Equatorial Pacific, or the area between the intergovernmental Date and Line and 120 degrees west in longitude. El Nino events are associated with warmer waters and moister air above in the described area, whereas La Nina is associated with cooler waters and drier air above. These variances normally last between two to nine years between El Nino and La Nina (Becker 2014). These oscillations have impacts globally and can affect the severity of hurricane seasons. In the Atlantic Basin, El Nino suppresses hurricane activity and conversely La Nina facilitates it.

Federal Emergency Management Agency: FEMA is part of the Department of Homeland Security. Its mission is to support citizens and first responders, and ensure the nation builds, sustains, and improves its capability to prepare for, protect against, respond to, recover from, and mitigate all hazards (Department of the Army 2013, I-15).

Foreign Humanitarian Assistance: Assistance that can be used immediately to alleviate the suffering of foreign disaster victims (Joint Chiefs of Staff 2013, I-2).

Global Climate Change: Change in the Earth's overall climate, with climate change defined as a change in the typical or average climate conditions (i.e. temperature, precipitation, etc.) (May 2017).

Hurricane: An intense tropical weather system of strong thunderstorms with a well-defined surface circulation and maximum sustained winds of 74 mph (64 kt) or higher (National Oceanic and Atmospheric Administration 1999, 4).

Major Hurricane: Category 3 (maximum sustained winds of 110 miles per hour or greater) or higher hurricane (University Corporation for Atmospheric Research 2013).

Storm Surge: The excess above the level expected from the tidal variation alone at a specified time and place (IPCC Summary). During a hurricane, it is a large dome of water, 50 to 100 miles wide, that sweeps across the coastline near where a hurricane makes landfall. It can be more than 15 feet deep at its peak (National Oceanic and Atmospheric Administration 1999, 13).

Title 10, Federal Forces: Full time duty in the active military service of the United States (United Stated Code Title 10, Section 101 Paragraph D, Subparagraph 1).

Tropical Cyclone Precipitation: Intense rainfalls.

Tropical Depression: An organized system of clouds and thunderstorms with a defined surface circulation and maximum sustained winds of 38 mph (33 kt) or less (National Oceanic and Atmospheric Administration 1999, 4).

Tropical Storm: An organized system of strong thunderstorms with a defined surface circulation and maximum sustained winds of 39-73 mph (34-63 kt) (National Oceanic and Atmospheric Administration 1999, 4).

United States Northern Command: A unified command with an area of responsibility including the United States, Canada, and a significant portion of the Atlantic Ocean that conducts homeland defense and provides defense support to civil authorities (USNORTHCOM Posture Statement 2017, 3-4).

Weather: Conditions of the atmosphere over a short period of time ranging from minutes to months (Gutro 2017).

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