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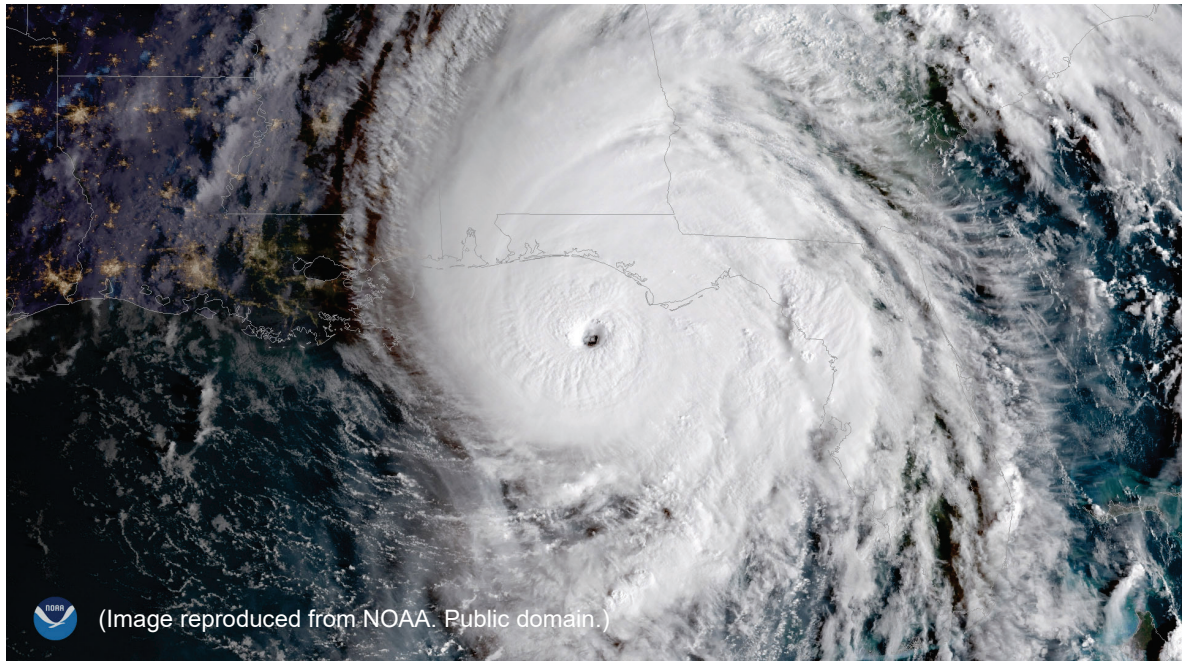
Navigation Systems Research Program

A Resilient Path Forward for the Marine Transportation System

Recommendations for Response and Recovery Operations from the 2017–
2019 Hurricane Seasons

Katherine Chambers, Jessamin Straub, Joshua Murphy,
Emily Russ, and the US Committee on the Marine
Transportation System Resilience Integrated Action Team

September 2023



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A Resilient Path Forward for the Marine Transportation System

**Recommendations for Response and Recovery Operations from the 2017–
2019 Hurricane Seasons**

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Final report

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Abstract

The Marine Transportation System (MTS), Resilience Integrated Action Team (RIAT), is tasked by the coordinating board of the US Committee on the MTS to serve as a coordinating body to identify the impacts, best practices, and lessons learned by federal agencies involved in the response and recovery of the MTS after hurricane seasons. In response to this request, the RIAT has focused its analysis on the ability of MTS federal agencies to prepare, respond, recover, and adapt to as well as from disruptions. This was accomplished through workshops focused on gathering the collective experiences of emergency response professionals. In 2017, recommendations were gathered based on experiences responding to Hurricanes Harvey, Irma, and Maria. In this report, a similar approach was adopted to gather findings from Hurricanes Florence and Michael in 2018 and Hurricane Dorian in 2019. Utilizing the successes, challenges, and best practices from all six of these storms, the RIAT identified key coordinating bodies and the participants for each and key takeaways relative to the coordination of agencies with respect to the four steps of resilience: prepare, absorb, recover, and adapt.

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Preface

This study was conducted for the Navigation Systems Research Program, Coastal and Hydraulics Laboratory (CHL), US Army Engineer Research and Development Center (ERDC), under Funding Acct Code U4368911; AMSCO Code 031391. The technical monitor was Ms. Katherine Chambers.

The work was performed in part by the Coastal Processes Branch of the Flood and Storm Protection Division, ERDC-CHL. At the time of publication of this special report, Mr. Victor Gonzalez-Nieves was chief of the Coastal Processes Branch; Mr. David May was chief of the River and Estuarine Engineering Branch; Ms. Lauren Dunkin was acting chief of the Flood and Storm Protection Division; Ms. Morgan Johnston was program manager of the Navigation Systems Research Program; Mr. Charles E. Wiggins was the ERDC technical director for Navigation; and Ms. Tiffany Boroughs was chief of the USACE Navigation Division.

The deputy director of ERDC CHL was Mr. Keith Flowers. The director of ERDC-CHL was Dr. Ty V. Wamsley.

This special report was prepared by an interagency team entitled the Resilience Integrated Action Team under the US Committee on the Marine Transportation System (CMTS). The interagency team also consisted of members from 12 different marine transportation system agencies. These members contributed content and review for the report, and the report was passed on to the CMTS Coordinating Board for subsequent review and approval. It was initially released online in December 2020. Report development was funded in part by the Navigation Systems Research Program, Project No. 462579; “Navigation Systems Resilience.”

Portions of this report have been modified and reprinted from US Committee on Marine Transportation System, *A Resilient Path Forward for the Marine Transportation System: Recommendations for Response and Recovery Operations from the 2017–2019 Hurricane Seasons* (Washington, DC: US Committee on Marine Transportation System, 2020), https://www.cmts.gov/assets/uploads/documents/CMTS_RIAT_Hurricanes_Report_FINAL.pdf. Public domain.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

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1 Introduction

1.1 Background

The United States relies heavily on the Marine Transportation System (MTS) for commerce and security, to facilitate the movement of international and domestic goods, and to support continued growth, jobs, and productivity. The MTS is the primary mode of transport for international imports and exports—in 2022, vessels moved goods and services valued at \$6.9 trillion (USA Trade Online 2023). The value of the MTS extends beyond the movement of goods to the benefit of regional economies by supporting \$4.6 trillion of economic activity every year and generating jobs for more than 23 million workers in the United States (USCG 2018).

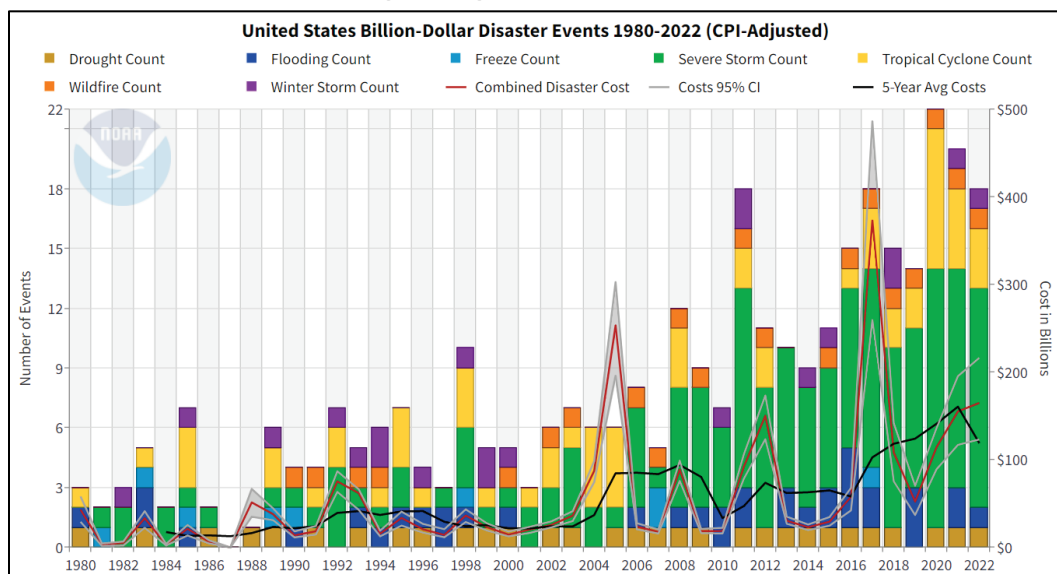
The MTS is exposed and vulnerable to disturbances from a variety of natural and man-made hazards such as hurricanes, extreme precipitation and flooding, sea level rise, temperature extremes, cyberattacks, pandemics, and terrorist attacks. The MTS is particularly susceptible to the impacts of coastal storms as encountered during the 2017, 2018, and 2019 hurricane seasons. The 2017 hurricane season was a record year for the United States and its territories with four of six major hurricanes making landfall in the United States, impacting both coastal communities and the infrastructure systems they rely upon. The 2018 hurricane season recorded 15 named tropical storms (sustained winds above 39 mph*) with two major hurricanes, Florence and Michael, making landfall. Hurricane Dorian took place in the following 2019 hurricane season, which exhibited considerable uncertainty in its forecasted track before devastating the Caribbean. Each of these hurricanes exhibited distinct characteristics that created unique challenges and required MTS stakeholders to adjust response and recovery operations to better serve communities in need.

Since 1980, the frequency, number, and severity of weather- and climate-related disasters that could impact the MTS has been increasing (Figure 1),

* For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–347, respectively. <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

and as climate continues to change, this pattern will likely continue. Additionally, impacts in future events are likely to be worsened by compounding factors like sea level rise and increased populations and infrastructure in vulnerable areas. Since the frequency and severity of disruptions are expected to increase with time, a comprehensive approach is required to identify current and future risks and vulnerabilities to the MTS and to develop strategies to become more resilient.

Figure 1. Billion dollar weather and climate disasters, 1980–2022. Weather and climate-related disasters have been increasing in recent years. This upward trend is expected to continue due to climate change. (Image reproduced from NOAA 2023. Public domain.)



Between 2018 and 2025, worldwide demand for waterborne commerce is predicted to more than double (USCG 2018). As the infrastructure, technology, and management systems that underpin the MTS evolve to support this demand, the best practices for the preservation of these functions through disruptions must be kept current and collaborative. The MTS is a critical node within a larger national transportation network that facilitates the flow of goods to every consumer in the United States. As such, disruptions affecting a single part or several parts of the MTS system, including ports, waterways, vessels, and supporting roadways, railways, and bridges, could potentially have national impacts. Furthermore, ports and the MTS play a key role in the recovery of the surrounding region after disruption, facilitating the mobilization of response and recovery assets and the delivery of life-sustaining commodities for impacted communities. A resilient MTS is critical to the national economy and to the communities in the region.

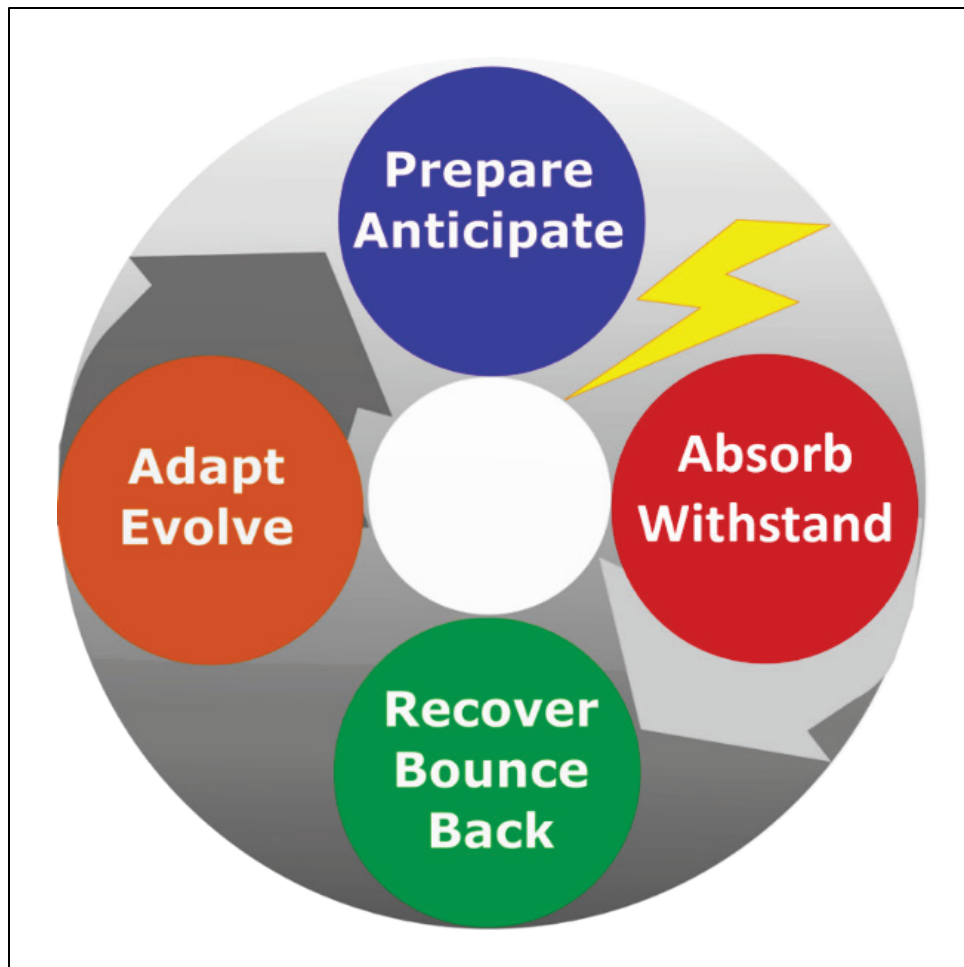
1.2 Objective

The objective of this study is to describe the impacts, challenges, and successes from the 2018 and 2019 hurricane seasons and compare them with findings from the 2017 hurricane season. The report reviews changes in response practices between storm seasons and makes overall recommendations to enhance the future resilience of the MTS. The audience for these recommendations is federal agencies with a major role in MTS recovery planning and efforts. However, note the critical role that nonfederal stakeholders play in ensuring the continued operation of the MTS in response and recovery. Much of the disaster recovery is the responsibility of state and local governments, nonprofits, and private industry. It is anticipated that the report will assist the coordination between federal and nonfederal partners' efforts to support the US MTS return to normal operations after a disruption.

1.3 Approach

Resilience is defined as the ability to prepare, absorb (resist), recover, and adapt to and from disruptions (The White House 2013). This work employs a four-phase resilience cycle to conceptualize resilience, gather information, and analyze impacts and changes through time (Figure 2) (Rosati et al. 2015). By utilizing these four phases, it is possible to identify improvements in response and recovery efforts and make recommendations to advance the resiliency of the MTS to future events.

Figure 2. The cycle of the fundamental actions found in nearly all resilience definitions: prepare, absorb, recover, and adapt. (Image adapted from Rosati et al. 2015.)



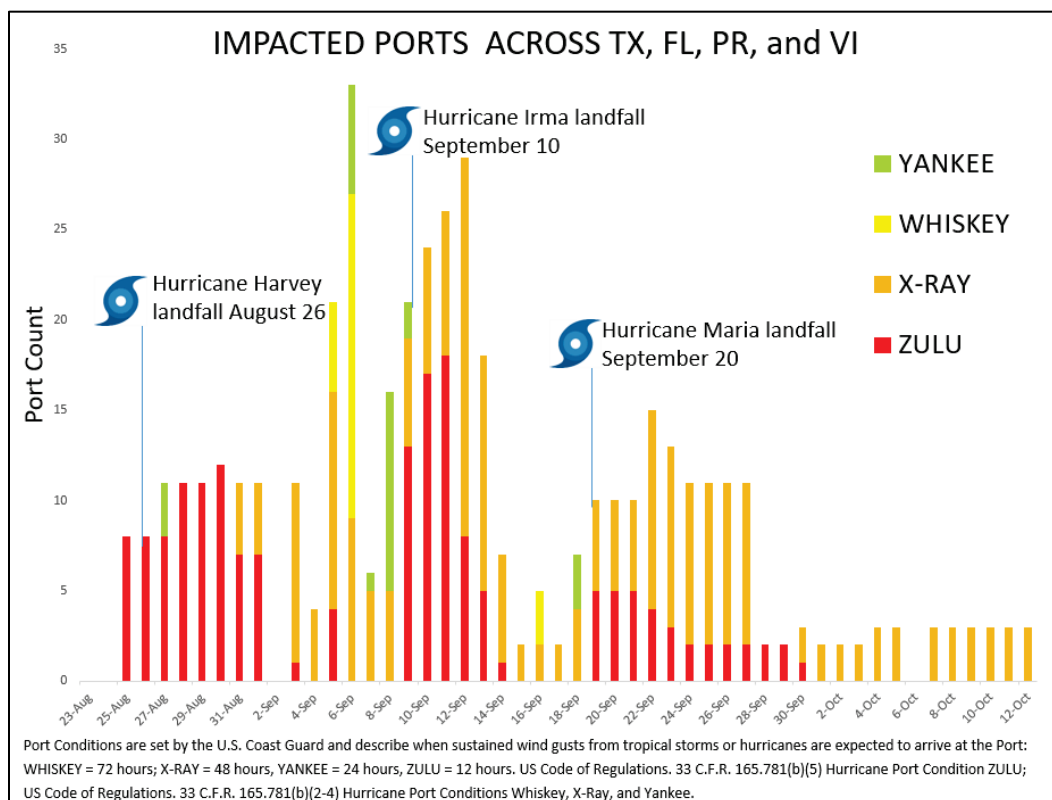
The ability to adapt between events to be better prepared so that future events will have lower impacts and faster recovery is critical to resilience. One key part of adaptation is learning from the past, and the Committee on the Marine Transportation System (CMTS), Resilience Integrated Action Team (RIAT), has emerged as a platform to convene federal agencies to share and discuss their experiences and potential improvements with their partners. The RIAT is a consortium of federal agencies that manage, operate, or are stakeholders in the MTS and have interests in increasing the resilience of the MTS to prepare, respond, recover, and adapt to disruption. The CMTS RIAT has served as a platform to gather federal agencies to foster collaborations, improve understanding of emerging challenges, and to determine impacts, best practices, and lessons learned after disruptive events. In 2017, the Coordinating Board of the CMTS tasked the RIAT with identifying the best practices and lessons learned from the 2017 hurricane season. The ensuing report, *The 2017*

Hurricane Season: Recommendations for a Resilient Path Forward for the Marine Transportation System, outlines challenges, successes, and recommendations for increasing resilience based upon reported experiences of responding and recovering to hurricanes Harvey, Irma, and Maria (CMTS 2018). Following recommendations that post storm interagency collaboration should continue, the RIAT committed to develop a companion report that would examine the federal agency response during the 2018 and 2019 hurricane seasons including Hurricanes Florence, Michael, and Dorian. The RIAT held several virtual workshops and outreach events in 2019 to capture federal agency input on the impacts, challenges, and best practices of the 2018 and 2019 hurricane seasons and any adaptations to these practices that have occurred between seasons. Input to these findings was from federal agency personnel located in field offices and directly responsible for response and recovery actions. The names of these agencies and offices are found in the appendix.

2 2017 Hurricane Season in Review

The extremely active 2017 hurricane season produced 17 named storms, 10 that became hurricanes of which 6 became major hurricanes. During the 2017 season, three devastating major hurricanes* made landfall including Hurricane Harvey in Texas, Hurricane Irma in the Caribbean and southeastern United States, and Hurricane Maria in the Caribbean and Puerto Rico. Over the course of the 2017 hurricane season, Hurricanes Harvey, Irma, and Maria affected the operating status of at least 45 ports throughout the lower continental United States and US Caribbean territories (Figure 3).

Figure 3. The 2017 hurricane season affected the operating status of at least 45 ports throughout the lower continental United States and US Caribbean territories. (Image reproduced with permission from CMTS 2020.)



These ports provide critical services to regional economies in the Gulf, southeastern United States, and the Caribbean and were confronted with a succession of major storms that impacted a vast geographical region,

* A major hurricane is a storm with maximum sustained winds of 111 mph or higher, corresponding to a Category 3, 4, or 5 based on the Saffir-Simpson Hurricane Wind Scale. NOAA National Hurricane Center, <https://www.nhc.noaa.gov/climo/?text>.

posing unique challenges. The scale and impact of these storms strained the US emergency response community and the ability of MTS agencies to reposition and prioritize recovery efforts. Despite these challenges, the MTS community successfully adjusted to communicate and engage across sectors and quickly and efficiently reopen these ports.

A review of federal agency activities to restore MTS operations in response to all three storms revealed several shared beneficial actions (CMTS 2018). For prestorm preparedness, these common actions included hosting early planning meetings, communicating among agencies, centralizing information distribution, and maintaining or updating existing response plans. Issues related to telecommunication and the prioritization of assistance to ports or other critical infrastructure were experienced by most MTS agencies. Last, the successes shared among agencies included engaging with the private sector to fill gaps in federal response operations, implementing local coordination efforts, and adapting and improving throughout the hurricane season as each storm presented new obstacles to overcome.

3 2018 and 2019 Hurricane Seasons

Following the historic hurricane season of 2017, the 2018 hurricane season offered little respite for the Nation's battered coastlines and MTS, as 15 named storms formed in the Atlantic basin and two major hurricanes, Florence and Michael, made landfall on the US coastline. A similarly active 2019 followed, which included Category 5 Hurricane Dorian in September 2019. These hurricanes exhibited distinct characteristics that posed unique challenges for the MTS, particularly with port response and recovery.

As each hurricane season passes, it is advantageous for the MTS community to reflect on the impacts of the storms and how response and recovery personnel met those challenges. Hurricanes Florence, Michael, and Dorian challenged the MTS with entirely different characteristics—Florence was destructive because of its slow movement, rainfall, and flooding. Michael was devastating because of its fast speed, winds, and storm surge. Dorian had a massive area of impact and was highly variable in terms of speed and intensity. It spent almost 3 days in the vicinity of the Bahamas and southern Florida before rapidly weakening as it moved north towards Georgia and the Carolinas. In contrast, both Florence and Michael made direct hits on localized areas and impacted fewer ports than those impacted during the 2017 season and during Dorian in 2019. For the ports that were impacted, a highly coordinated effort was necessary to get commerce moving again.

3.1 Hurricane Florence: 12–15 September 2018

Hurricane Florence made landfall on 14 September 2018 near Wrightsville Beach, North Carolina, as a Category 1 storm. While not as strong as previous hurricanes upon landfall, Florence's slow-moving track caused major flood damage. According to the National Oceanic and Atmospheric Administration (NOAA), it was the wettest tropical cyclone on record in the Carolinas (Stewart and Berg 2018), causing approximately \$24 billion in wind and water damage (\$22 billion in North Carolina; \$2 billion in South Carolina; NOAA NCEI 2019) and resulting in 22 direct and 24 indirect fatalities (NWS 2018). A maximum storm surge of 8–10 ft above ground level occurred along the shores of the Neuse River. Hurricane Florence produced rainfall totals of over 30 in. in southeastern North Carolina between Wilmington and Elizabethtown, with maximum measured rainfall occurring in Elizabethtown, North Carolina (35.93 in.). The combined surge

and rainfall made large stretches of main highways (Interstates 40 and 95, US-70) impassable, effectively closing all access routes to Wilmington and limiting access to the city for several days after Florence dissipated.

3.1.1 Impacts

On 10 September 2018, as Florence approached the coastline, the US Coast Guard (USCG) issued port condition warnings for several ports from Georgia to Maryland. The increased availability of Automatic Identification System (AIS) data and new analytical techniques has made it possible to visualize and quantify the impacts of storms on port performance and across the region. A timeline of the most significant closures as well as accompanying vessel densities derived from AIS data is found in Figure 4. On 12 September, the Port of Charleston entered condition YANKEE* and the Ports of Wilmington (42 ft controlling depth at entrance channel) (NOAA OCS, n.d., North Carolina Cape Fear River) and Morehead City (45 ft controlling depth at entrance channel) (NOAA OCS, n.d., North Carolina Beaufort Inlet), both in North Carolina, entered Port Condition ZULU, suspending all maritime traffic into and out of these ports. That same day, the Port of Virginia entered a modified Port Condition ZULU, closing navigation routes at the mouth of the Chesapeake Bay and in southern coastal Virginia. The Port of Georgetown (27 ft depth) (NOAA OCS, n.d., South Carolina Winyah Bay), in South Carolina, entered Port Condition ZULU on 14 September.

The Port of Charleston and the Port of Virginia returned to Port Condition NORMAL on 15 September 2018. The Port of Georgetown reopened without restrictions on 16 September. The Ports of Wilmington and Morehead City were closest to Florence's landfall and reopened with restrictions on 18 September. The Port of Wilmington issued the following restrictions: 37 ft draft restriction, daylight only transit (due to power outages), and no traffic permitted north of the Cape Fear Memorial Bridge. The Port of Morehead City restricted all self-propelled, oceangoing vessels over 500 gross tons, ocean-going barges and their supporting tugs, and tank barges over 200 gross tons to daylight transit only. Restrictions were lifted at the Port of Morehead City on 19 September. The draft restriction at the Port of

* 33 CFR 165.781(b) (2-4) *Hurricane Port Conditions Whiskey, X-Ray, and Yankee*. When sustained gale force winds (39–54 mph [34–47 kn]) from a tropical storm or hurricane are predicted to make landfall at the port within 72 hr, Port Condition Whiskey is set; when landfall at the port is within 48 hr Port Condition X-Ray is set; and when sustained gale force winds are predicted within 24 hr of landfall, Port Condition Yankee is entered. Condition ZULU is set when gale force winds are expected in under 12 hr.

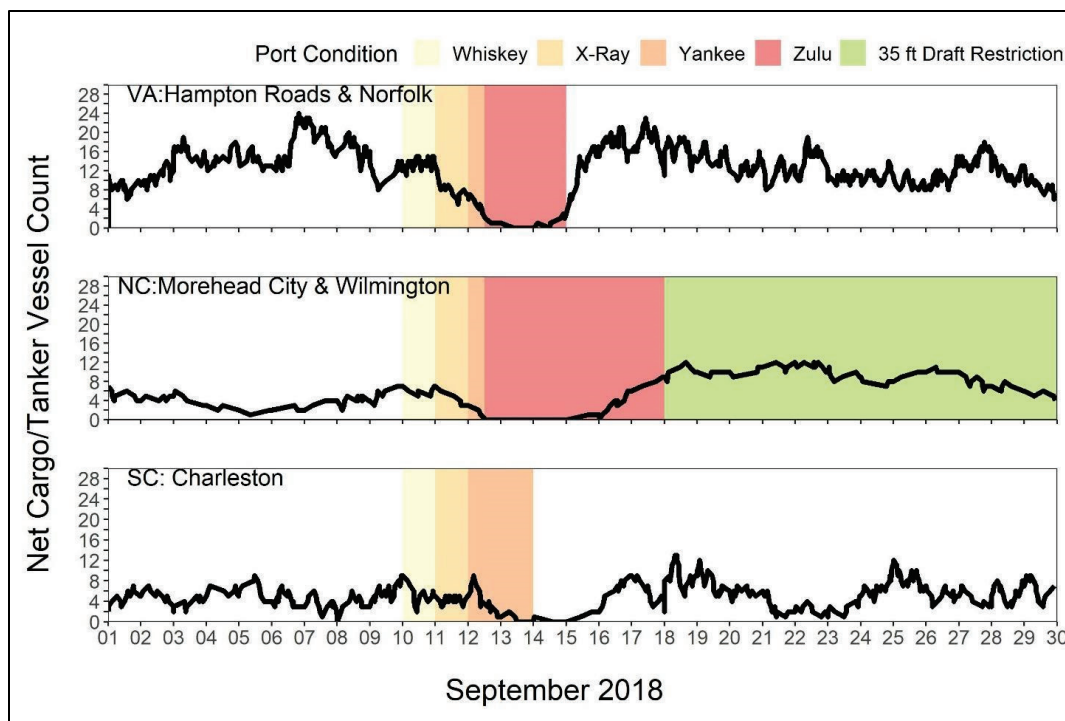
Wilmington was updated to 35 ft on 20 September after identifying features or objects of interest on multibeam surveys that might impact navigation. All restrictions were lifted at the Port of Wilmington on 30 September.

Figure 4. Hurricane Florence cargo and tanker vessel signal density plots: Select times from 1–24 September 2018. The Cargo and Tanker Vessel Density maps were derived from Automatic Identification System Analysis Package (CIRP 2023). (Image reproduced with permission from CMTS 2020.)



These port conditions and subsequent restrictions have impacts on port performance that can be quantified with indicators derived from AIS data. Net vessel counts are a useful proxy for port performance because they measure ship traffic into and out of a major port area and can provide insights to the magnitude of the impacts of the storm (Touzinsky et al. 2018). Figure 5 provides a net vessel count for several of the largest ports in the Carolinas and Virginia—Charleston, Morehead City, and Wilmington, and the Port of Virginia. Net vessel counts are derived from the Automatic Identification System Analysis Package (AISAP) developed by the US Army Engineer Research and Development Center with data furnished by the USCG (ERDC 2021). The largest finding from these vessel counts is that while Florence was devastating to the Ports of Wilmington and Morehead City, the effects across the region were short lived. Vessels were quickly able to regain access to their necessary ports of call.

Figure 5. Net cargo and tanker vessel counts at the Ports of Virginia, Morehead City and Wilmington, and Charleston before, during, and after Hurricane Florence: 1–30 September 2018. The cargo and tanker vessel density maps were derived from AISAP (CIRP 2023). (Image reproduced with permission from CMTS 2020.)



3.1.2 Challenges

The challenges during Hurricane Florence response and recovery efforts centered on the evolving track of the storm making it difficult to make

prestorm plans, to communicate due to reduced cell service, and to understand local needs.

- At one time, the forecast had the hurricane moving more towards Hampton Roads, and the Navy was evacuating Norfolk Naval Station since the storm was a Category 3 SE of Cape Lookout. With changes in track, it was challenging to communicate forecast confidence among stakeholders, and the strength of the storm contributed to this.
- It was challenging to preposition assets and people due to a rapidly changing storm track. Once landfall occurred, there was a narrow window of time for teams to deploy from the locations where they rode out the storms to get teams into the impacted areas before flood waters from the prolonged post-landfall rain event cut off access to Wilmington, North Carolina, and Morehead City, North Carolina. Had the team responding to Wilmington been delayed (for any reason) by approximately 2 hr, it likely would have been 2 days before flood waters receded enough for them to gain access to Wilmington to begin survey operations on the Cape Fear River.
- Restoring the Port of Wilmington to full navigational depth of operation after Florence was a significant effort. Several bridges were damaged, prohibiting the passage of vessel traffic. There was also significant inland flooding, causing peak river flows and strong currents. Dive teams had to wait approximately 4 days after these peak flows until the river channels were safe to survey and remove obstructions.
- In Wilmington, the Navigation Response Team (NRT) was cut off from the supply chain, and utilities were unreliable for several days. The NRT ran a portable gasoline generator at night to augment the power availability at the hotel to process the survey data acquired each day. Personnel resources had to divide time between executing the mission and finding food and fuel once the provisions they brought with them were depleted.
- There was a need for more radios for communications with the Port Recovery Teams, especially with the cellular network potentially going down.
- The need to colocate a USCG MTS professional assigned to Emergency Support Function 1 in the Federal Emergency Management Agency (FEMA) regional response coordination center was highlighted. This professional would provide perspective on maritime issues and align MTS operations with other transportation response and recovery efforts and priorities.

- The USCG Common Assessment and Reporting Tool (CART) is a helpful resource to provide information on disruption events such as port closures. However, CART is only as good as the information that is feeding it and information must have an improved validation process.

3.1.3 Successes

Many of the successes identified came from putting into practice lessons learned from past hurricane seasons. These successes included the efficient coordination between federal agencies and transportation modes as well an organized approach to distribute assets.

- There was excellent coordination between different transportation modes (road, rail, marine) to identify the best routes and mechanisms to get resources into the area, especially with the intense flooding.
- Established coordination between federal agencies was leveraged and improved before and during Florence providing frequent updates on navigation conditions. The USCG relied on NOAA to help with deep-draft surveys. NOAA identified multiple obstructions within the channel, resulting in salvage operations. The US Army Corps of Engineers (USACE) utilized lessons learned from the Jacksonville District and brought in the Navy to start salvage operations more efficiently.
- To hasten the recovery of Aids to Navigation (ATON) and completion of channel surveys, the USACE South Atlantic Division and Wilmington District coordinated to have vessels on standby and ready to perform poststorm channel surveys to restore waterway and port navigation operations.
- There was a more centralized approach to distributing recovery assets using an on-going database to identify and flag for potential obstructions prestorm and share that information with other agencies. The USACE Charleston District was able to effectively assist the Port of Wilmington with the distribution of recovery assets and personnel.
- Based on lessons learned from Hurricanes Irma and Maria in 2017, the USACE South Atlantic Division was well prepared to respond to and restore navigation with numerous dredges under contract and available for support.

3.2 Hurricane Michael: 7–11 October 2018

Hurricane Michael was a fast-moving and powerful storm that caused approximately \$25 billion in wind and water damage (\$18.4 billion in

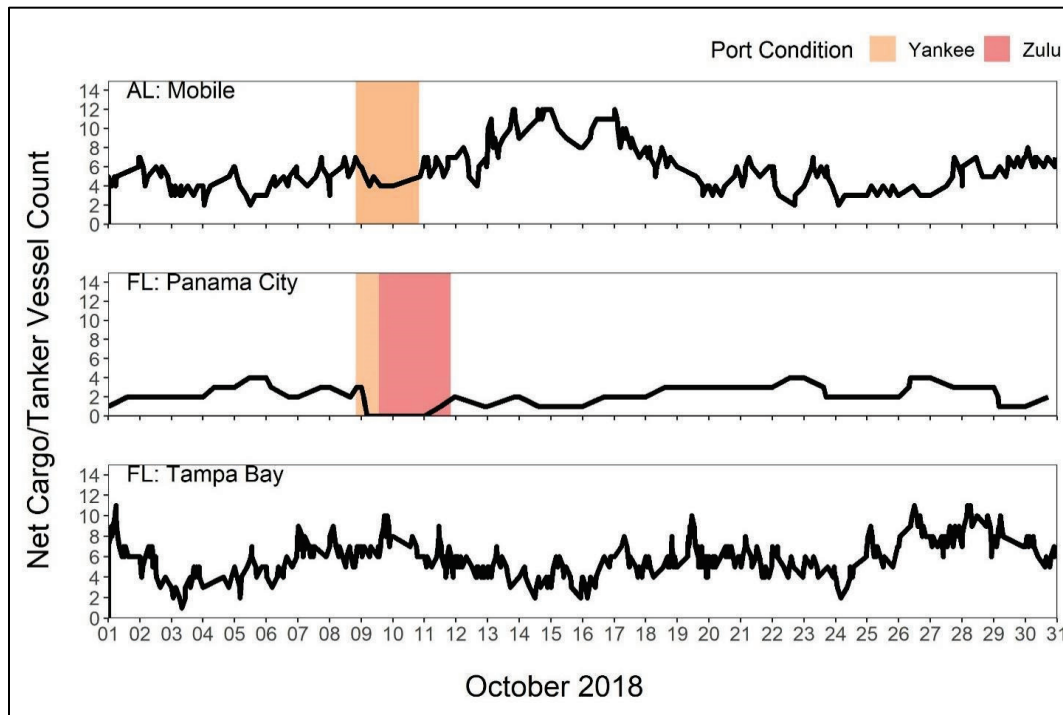
Florida, \$4.7 billion in Georgia, \$1.1 billion in Alabama, and approximately \$1 billion in South Carolina, North Carolina, and Virginia; NOAA 2019a). Hurricane Michael made landfall on 10 October 2018 as a Category 5 storm near Mexico Beach, Florida, with estimated wind speeds of 161 mph (Beven et al. 2018). Hurricane Michael was initially described as a strong Category 4 storm at landfall; however, the storm was upgraded to Category 5 after detailed poststorm analysis of aircraft wind, surface wind, surface pressure, satellite intensity, and Doppler-radar velocity data. This upgrade ties the storm as the fourth strongest hurricane making landfall in the United States and the strongest hurricane landfall along the Florida Panhandle. Maximum measured wind speeds of 139 mph were measured at Tyndall Air Force Base, and storm surge estimates ranged from 9 to 14 ft above ground level between Tyndall Air Force Base and Port St. Joe. Strong winds and large storm surges were exacerbated by wave activity and resulted in catastrophic damage in Bay County, Florida. The worst damage occurred in Mexico Beach, where approximately 95% of buildings were reported damaged, and at Tyndall Air Force Base, where all buildings were reported damaged. Less severe but extensive damage was also reported along the eastern portion of the Panama City metropolitan area.

3.2.1 Impacts

USCG port sectors along the Gulf Coast, from Gulfport, Mississippi, to Panama City, Florida, began issuing Port Condition Warnings as Hurricane Michael approached the Florida Panhandle. On 9 October, the Port of Mobile went into Condition YANKEE, and the Ports of Panama City (36 ft draft) and Pensacola (33 ft draft), both in Florida, entered Port Condition ZULU. The Gulf Intracoastal Waterway (12 ft draft) was closed east of mile marker 166 between 9 October and 11 October, and east of mile marker 221 between 12 October and 18 October. The Ports of Wilmington and Morehead City North Carolina entered Port Condition Zulu on 11 October. After landfall on the 10 October, the Port of Pensacola returned to prestorm operations on 11 October. The North Carolina Ports at Wilmington and Morehead City returned to prestorm operations on 12 October. The Port of Panama City reopened with daylight transit only restrictions on 12 October. Figure 6 measures the impacts of the storm for several nearby ports (Mobile, Panama City, and Tampa Bay) with a net vessel count analysis derived from AIS data. It is clear from these net vessel counts that Michael was devastating to areas where it made a direct hit, but all nearby ports were able to quickly recover and begin to move cargo. Notably, Tampa Bay

had almost no noticeable change in traffic during or after the storm. The ports throughout the Florida Panhandle are generally low tonnage, minimizing the number of affected vessels.

Figure 6. Net vessel counts before, during, and after Hurricane Michael for the Ports of Mobile, Panama City, and Tampa Bay: 1–31 October 2018. Tampa Bay is included because as a neighboring port, it was unaffected by the storm and assisted in the recovery of Panama City (CIRP 2023). (Image reproduced with permission from CMTS 2020.)



3.2.2 Challenges

Hurricane Michael posed challenges due to the rapid intensification of the storm and issues with loss of cell phone service, stressing the importance of clear and consistent communication.

- Rapid intensification of hurricanes, such as Hurricane Michael, is not atypical and can provide both forecast and risk communication challenges. It is important to be mindful of compressed preparation timelines.
- As it moved inland after landfall, Michael quickly became a hybrid storm that impacted a large region many hundreds of miles from landfall. The NOAA National Weather Service (NWS) office in Wakefield, Virginia, was providing information on storm projections for the USCG and the Navy in Chesapeake Bay and Hampton Roads.

- These projections were challenging because of uncertainties and the distance overland.
- Challenges arose with federal cell phones and lack of service because the Verizon fiber cables in the Panama City area were destroyed in the storm. These issues were overcome with the use of personal cell phones on different carriers.
 - There were many challenges with getting survey assets from USACE and NOAA in the far-eastern areas of the Gulf Intracoastal Waterway (GIWW) to support waterway and ATON constellation restoration. The GIWW is a crucial waterway that most notably connects petrochemical centers in East Texas and West Louisiana to commercial operations and consumers in population centers in Florida and Alabama. Terrestrial damages impeded access to the waterway and programmatic prioritization challenges delayed resource allocation to the area.

3.2.3 Successes

Successes with Hurricane Michael relied on having relationships and coordination channels within and between agencies already established before the hurricane.

- Information from the NWS Mobile was provided with enough lead time to give the Port of Mobile the opportunity to focus their efforts farther east.
- The isolated impacts of Michael allowed neighbors to quickly convene on the area and complete recovery efforts. Michael made landfall between NRT homeports in Fernandina Beach, Florida, and Stennis Space Center, Mississippi. This allowed NOAA to quickly respond with two NRTs. Additionally, because nearby airports in Jacksonville, Florida, and Mobile, Alabama, were unaffected, additional personnel resources were easily flown to rendezvous with the teams in route to Panama City and augment the personnel on the two NRTs. Because it was a single port impacted, multiple teams could respond to the same location and complete the survey efforts more quickly than is possible for storms that require each team to survey one or more waterways individually.
- Coordination among neighboring USACE districts included expediting funds transfer to allow for faster assistance.
- Michael quickly became a hybrid storm that impacted a large area causing NWS Wakefield to inform the USCG and Navy in Chesapeake Bay and Hampton Roads, which was challenging due to the distance

- from landfall. However, having the coordination channels and relationships already in place positively impacted coordination.
- The USCG had increasingly outstanding support from the NWS, including expanding efforts to colocate response and recovery personnel including an effort to get USACE staff in their incident command centers.
 - The cell phone outages were somewhat mitigated by Iridium satellite phones.

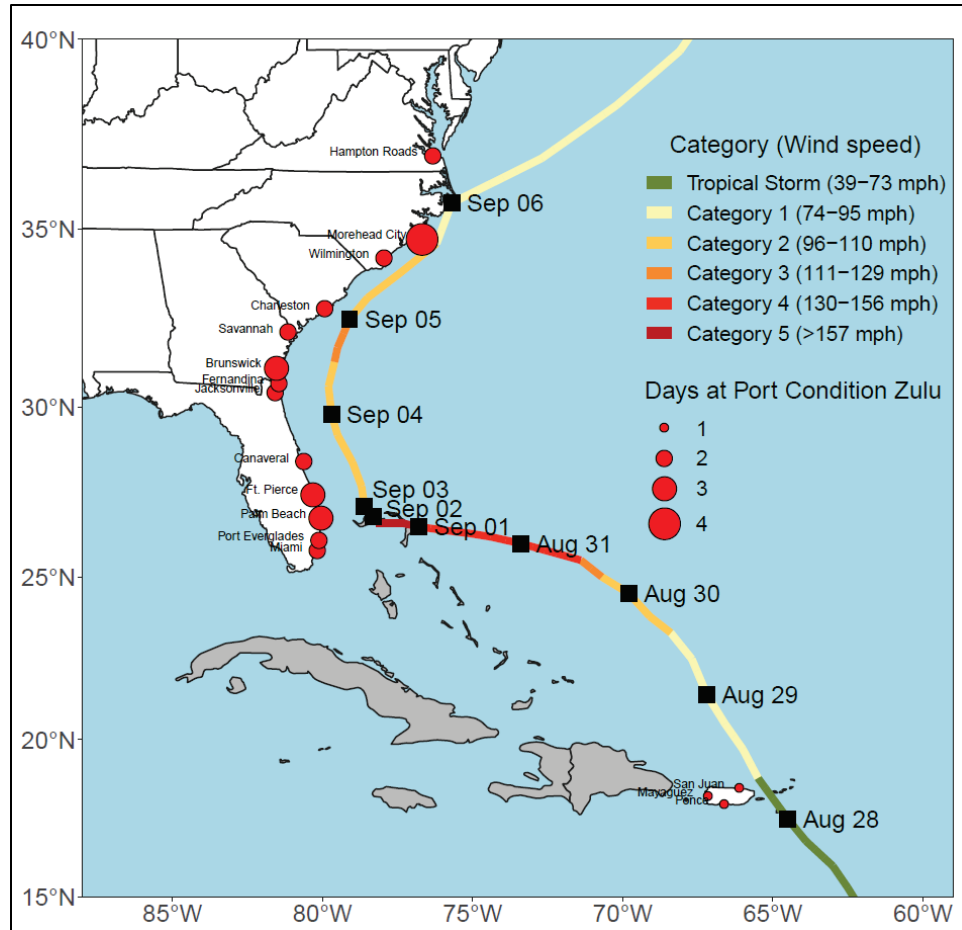
3.3 Hurricane Dorian: 24 August 24–29 September 2019

Hurricane Dorian was the fourth-named Atlantic storm of the 2019 season and the second storm that made landfall in the United States (after Hurricane Barry, which made landfall in Louisiana as a Category 1 hurricane on 13 July). Dorian's speed and intensity varied over the course of its life cycle, shown in Figure 7. This figure displays how slow and intensely the storm moved over the Bahamas and the variation and speed of the storm as it moved up the East Coast before making landfall in North Carolina and moving offshore. As the National Hurricane Center reports (Avila et al. 2019), it formed on 24 August and initially made landfall in the northern Bahamas as a Category 5 storm on 1 September. After stalling for several days over the Bahamas, Dorian weakened to a Category 2 storm as it traveled north off the coast of Florida. Approximately 70 miles southeast of Charleston, South Carolina, it intensified to a Category 3 storm and subsequently weakened to a Category 1 storm before making landfall near Cape Hatteras, North Carolina, on 6 September. From North Carolina, the system transitioned into an extratropical storm as it rapidly tracked northeast to Canada, making landfall in Nova Scotia on 7 September 2019.

Total loss caused by Dorian in the Bahamas was estimated at \$3.4 billion, which is over a quarter of the country's gross domestic product (IADB 2019). Most of the heavy rainfall for the US portion of the storm track occurred offshore; however, notable rainfall totals were recorded in Wilmington, North Carolina (8.32 in.), Charleston, South Carolina (6.59 in.), and on Ocracoke Island, North Carolina (13.74 in.). Dorian caused significant storm-surge flooding in North Carolina to the landward side of the barrier islands, with the most severe storm surge of 4–7 ft occurring on Ocracoke Island. Two 500 ft sections of North

Carolina Highway 12 on Ocracoke sustained severe damage, which was repaired by the North Carolina Department of Transportation.

Figure 7. Hurricane Dorian storm track and the duration of closure (Port Condition ZULU) for 15 ports on the east coast and Caribbean (CMTS 2020).



3.3.1 Impacts

As Dorian tracked northward, 15 ports from Puerto Rico to Virginia were closed; 7 of which are in the top 25 in the United States for tonnage movements (Figure 7). The 15 ports were closed for a minimum of 1 day (Port of San Juan) to a maximum of 4 days (Morehead City). At the Port of Wilmington, reopening required daylight-only transits and a 30 ft draft restriction. One of the largest impacts to the MTS is the wide region of hurricane preparation that had to occur in advance of Dorian, stretching from Puerto Rico to Virginia. Shippers had to carefully track hurricane projections to avoid the storm's effects.

The quantitative impact of these closures can be measured again with net vessel count. Figure 8 attempts to align each of the net vessel count impacts with a comparison of USCG warnings, closures, and reopenings as the storm moved north up the coast. While the storm did not close any of the ports in question for long durations (as with Florence and Michael in 2018), Dorian offered its own challenges. Uncertainty around its projected path and intensity put the entire southeast coastline on high alert for the storm’s potential arrival as it devastated the Bahamas. As Dorian moved north up the Atlantic Coast, the cumulative preparation across all 15 ports and harbors that were closed in anticipation of its arrival resulted in large disruptions to normal traffic flow and density (Figure 9).

Figure 8. Net vessel counts of cargo and tanker vessels for each of the top 25 ports (by tonnage) impacted by Hurricane Dorian (CIRP 2023). (Image reproduced with permission from CMTS 2020.)

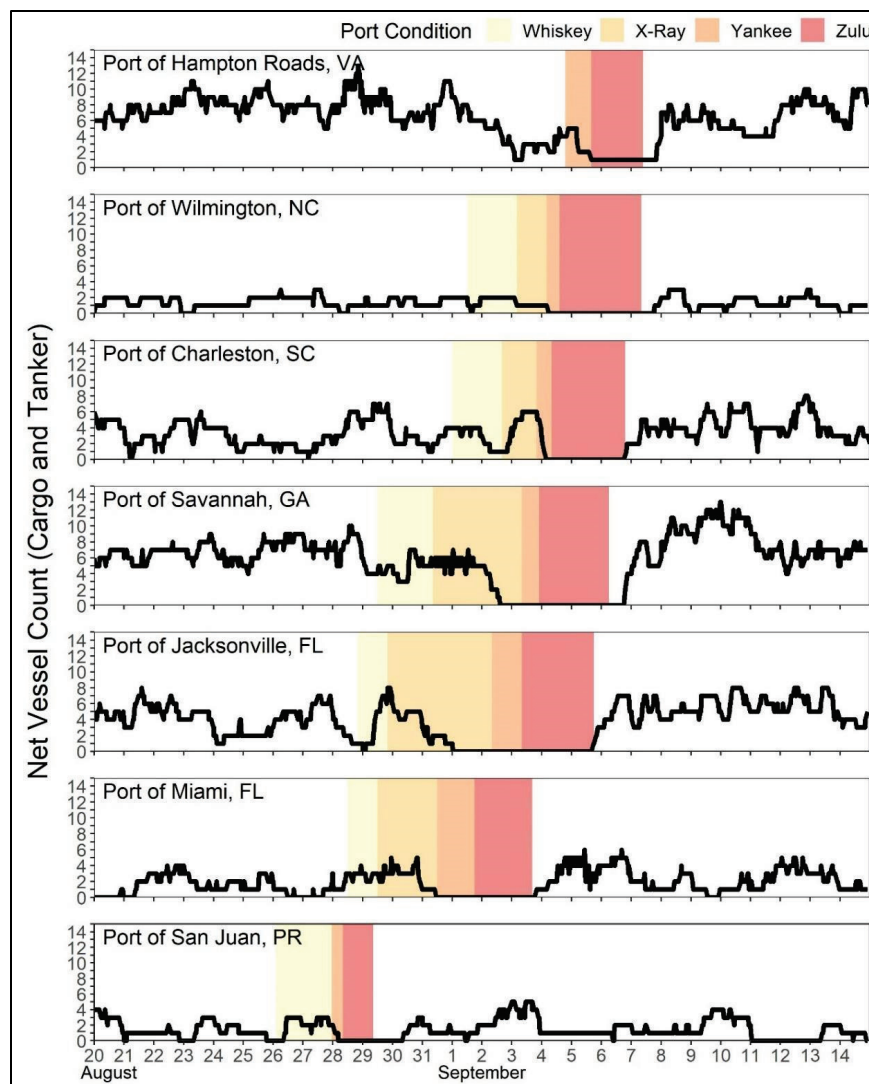
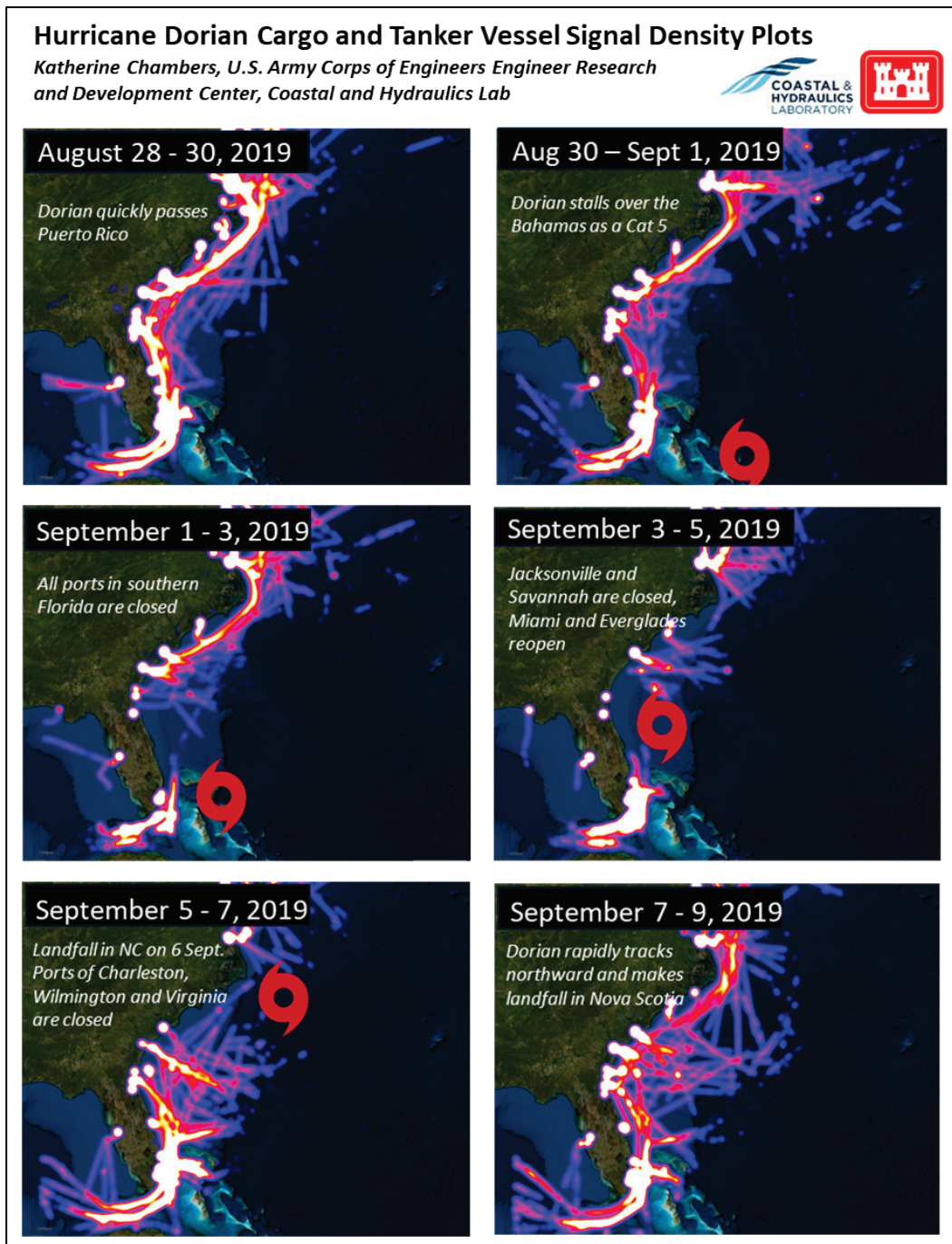


Figure 9. Cargo and tanker vessel density plots on the east coast of the United States during Hurricane Dorian; eye of the storm is in *red* (CIRP 2023). (Image reproduced with permission from CMTS 2020.)



3.3.2 Challenges

Hurricane Dorian was the strongest hurricane on record to impact the Bahamas, with sustained winds of 185 mph. Dorian resulted in the potential need for international aid to the Bahamas poststorm recovery

efforts. At the same time, the United States was preparing for widespread response along ports in the southeastern United States, inhibiting a larger response to the Bahamas.

- This storm posed a need for potential international aid which was challenging to plan for.
 - NOAA had the Mobile Integrated Survey Team (portable survey equipment and personnel) standing by to board a USCG cutter to respond as necessary to ports in the Bahamas. The mission was ultimately scrubbed and the USCG cutter was tasked to a domestic mission.
- Hurricane Dorian required planning for widespread potential response at any of the ports from Miami, Florida, to Morehead City, North Carolina.
- Charleston, South Carolina, has been historically fortunate with only a few direct hits and fast poststorm response and recovery operations. As a result, some navigation managers at the USACE worry that stakeholder expectations of channel survey speeds have become unrealistic and that they will be disappointed and surprised with the delay when a larger storm does greater damage.
- Dorian impacted DOD strategic ports and the military operations that had been scheduled through them. Maritime Administration (MARAD) tracks the readiness of Commercial Strategic Ports daily to ensure their ability to meet DOD national defense purposes, including downgrades even when no military action is scheduled.

3.3.3 Successes

The track of Hurricane Dorian was very similar to the track of Hurricane Matthew in 2016, making Dorian an event for which teams had practiced and were prepared. Dorian benefited from 3 yr of previous hurricane responses, leading to more successful planning and response. Many of the successes identified and discussed came from putting into practice lessons learned from the 2017 and 2018 hurricane seasons.

- FEMA was able to enact mission assignments very quickly, a significant improvement from Hurricane Michael. Dorian efforts began 5 days prior to forecasted landfall in Puerto Rico rather than after landfall, which has been the past precedent.

- The track of Dorian was originally a worst-case scenario, with NOAA NRTs planned for a response from Miami, Florida, to Hampton Roads, Virginia. The storm did not bring worst-case scenario impacts, instead providing a real-world training opportunity to test coordination and communication efforts.
- NOAA was able to exercise a memorandum of understanding (MOU) with USCG to preposition its vessels in a hardened USCG facility outside of Miami, which allowed the team to follow behind the storm as it moved northward along the coast. Other teams were positioned to leapfrog from port to port as waterways were surveyed by the various federal agencies involved.
 - NOAA was able to prestage survey equipment on MARAD vessels in Charleston.
- In Wilmington, North Carolina, USACE, USCG, and NOAA were all colocated at USCG at Sector North Carolina.
 - NOAA provided contract support to procure ocean bar surveys to supplement USACE. This tremendously benefitted overall recovery efforts as USACE was preoccupied with survey efforts for the ferry channels to Ocracoke Island.
 - The USACE was also able to colocate physical assets with USCG as well as personnel.
- Coordination with multiple federal agencies allowed the Commercial Sea Lift program to provide support to the Bahamas.
- NRT/MTS Response Units (MTSRU) and USACE coordination in Miami, Florida, was successful due to collocation. Face-to-face coordination meetings were important and took minutes to hours, a significant improvement over prolonged email communication. For example, NOAA and USACE coordination on poststorm surveys took only a few hours.
- USACE had prestorm coordination with the Navy to have assets in place at Navy facilities prepared to assist as needed.
- In Charleston, South Carolina, USACE was able to utilize the private-sector dredging resources to help survey and clear the channel.
- The MTS also relies on the ability of employees within ports, related service organizations, and federal agencies to protect their families and access their workplaces. Following the 2018 hurricanes, restricted

access to port facilities, as well as personal property and housing losses for port employees who live in the local community was a challenge. In Wilmington, North Carolina, port facilities sustained minimal damage; however, power outages and restricted access to the Wilmington area for returning employees prolonged port reopening. In 2019, the Port of Wilmington altered its hurricane plan to give more time for employees and tenants to prepare their own personal affairs as well getting the port facilities ready. The new hurricane plan results in the port being ready 12 hr ahead of the planned USCG port conditions (Port of Wilmington. 2019. Personal communication.).

3.4 Summary of Findings from 2018 and 2019 Hurricane Seasons

3.4.1 Federal Best Practices to Restore and Recover Marine Transportation System (MTS) Operations

The actions summarized below show common best practices that were employed during and among all three storms (Florence, Michael, and Dorian) and can be utilized to better respond to future storms. RIAT member agencies emphasized proactive preparation and establishing relationships and plans before events as vital in successful poststorm response and recovery efforts.

- Advanced Tabletop Exercises Combined with Local Knowledge
 - The implementation of tabletop exercises among local USCG, USACE, and NOAA officials to identify possible survey problem areas in each navigable channel and develop scenario-based plans contributes to more successful response. However, it would take a year to conduct enough tabletop surveys for waterways within USACE and NOAA surveyors' areas of responsibility, so it is critical that they rely on local subject matter experts when identifying which areas are of highest priority for surveying. When an MTSRU is stood up for an event, the plans can be reviewed and adapted to address actual storm response.
 - * USACE and NOAA have different missions with respect to surveys, so coordinating beforehand helps ensure that end users get accurate and complete information while avoiding duplication of efforts.
- Colocating during a Storm

- Colocating assets and personnel was extremely helpful during Dorian. The colocating allowed for more effective prepositioning of vessels as well as the coordination of channel surveys.
- **Prioritizing Assets**
 - It is vital to know what assets should be prioritized (ATONs, etc.) to get back up and running. This knowledge comes from tabletop exercises and preparation combined with reliance on local expertise during the response and recovery effort. This information is used to increase the efficiency of recovery.
- **Establishing Relationships Early and Coordinating Lines of Communication**
 - To prepare for and respond to storm events, relationships within and among federal agencies and local officials need to be established prior to events more effectively. This includes establishing and coordinating lines of communication, which can assist in identifying the best routes and mechanisms to get resources into areas following storms. Face-to-face coordination meetings were more effective and took less time than coordination through email.
- **Sharing Useful Tools**
 - CART is managed and operated by the USCG and is updated several times daily throughout the response and recovery phases of the storm to make information available on the status of all Essential Elements of Information and ultimately the overall port status. NOAA was able to take CART training before Dorian to become familiar with the system, and they found the improved familiarity with the system beneficial. CART is designed to allow access to non-USCG partners.

3.4.2 Future Recommendations

Gathering and communicating best practices between storms and hurricane seasons ensures that there is improvement in the recovery of the MTS following disruption. This allows response and recovery actions to be optimally targeted to return critical functions of the MTS to acceptable

operating levels as soon as possible. The resilience framework provides a concept to facilitate between-storm response changes leading to improved preparation for future storms. These response adaptations through time will lessen impacts of future events. Preparation and recovery action improvements from lessons learned will result in a more resilient MTS that is better prepared for future disruptions. Note that after the 2018 hurricane season, agencies were already making changes to be more efficient during the 2019 season.

The RIAT has adopted the Presidential Policy Directive 21 definition of resilience as the ability to prepare for, withstand, recover from, and adapt between disruptions as a part of a four-step cycle initiated by a disruptive event (The White House 2013). Each step needs to have equal attention to increase resilience (Rosati et al. 2015). Emergency response and recovery efforts naturally focus on preparation, absorption, and recovery. Addressing adaptation can be difficult without effective and consistent coordination and communication; this is in part why the RIAT is explicitly addressing improvements across hurricane seasons, not just within them. The following recommendations were compiled by RIAT agency representatives and workshop attendees to increase preparation, response, recovery, and adaptation.

- Establish a common operating picture of survey data from all agencies involved. A geographic information system platform available to all agencies is recommended for this purpose. Many of these viewers already exist for coordinating internal agency response (e.g., USCG's CG1View desktop interface or USACE's Common Operating Picture (uCOP). The uCOP is a highly customizable application that provides the USACE with detailed and up-to-date visualization of its mission areas for analysis and decision making. These platforms have broad applicability to other types of disasters (in addition to hurricanes). For example, the uCOP team created a similar platform that integrated various transmission models for COVID19. This platform was utilized to identify candidate counties for alternate care facilities and was made available to the public.

One major hurdle for creating a data-sharing platform is ensuring interoperability given the wide variety of requirements and restrictions across MTS agencies. The CMTS has developed a policy document entitled "US Navigation Information Strategic Action Plan: 2021–2026"

(CMTS 2021). This document identifies these challenges and provides guidelines to continue agency-to-agency data sharing.

- Participate in a hurricane response training that is geographically based and focused on the nuances of the local conditions (uniqueness of place).
 - Recommend referencing MTS Recovery Plans which exist in each Captain of the Port (COTP) area and specifically highlight uniqueness of port areas.
- Establish relationships before an event including knowing who to contact, and where to go for information so that communications amongst teams is smoother during the recovery phase. An appropriate place for this information would be in the required MTS Recovery Plans for each COTP zone. It is recommended to update these plans with the lessons learned captured from these incidents.
 - Have response-related contracts in place to save valuable time and resources.
- Hold preseason exercises to understand the waterways to better focus initial recovery efforts and prioritize sections of the waterway in advance.
- Prioritize quick and seamless sharing of viewable data among agencies to get ports back online.
- Identify recurring hurricane response training and ways to capture information from each season and disseminate prior to the next season.
- Facilitate greater coordination between USCG, MTS, and port partners to streamline information reporting to MTSRUs to keep information in CART up to date and relevant to recovery coordination amongst MTSRU partners. The MTSRU and CART training should be expanded to include federal partners and adding other port partners should be considered.

4 Federal Agency Connections

Effective coordination and communication among MTS federal agencies and stakeholders are frequently identified as a best practice for improving resilience. Within the federal government, relationships among agencies and offices under a business-as-usual state are dictated by a myriad of formal policies, agreements, and informal working groups. These connections change when the federal government is in a response or recovery posture, as national frameworks for emergency support are implemented. Knowing how federal agencies are connected to each other and to their nonfederal partners throughout the MTS can play a critical role in promoting better coordination and communication before, during, and after disruption. Table 1 documents several interagency coordinating bodies that are initiated or utilized under disaster conditions to facilitate increased communication among MTS stakeholders internal and external to the federal government.

Table 1. Federal stakeholder committees and efforts initiated or utilized during and after disasters.

—	CMTS	MTSRU	HSC	AMSC	ESF1 ³	ESF3 ⁴	ESF9 ⁵	ESF10 ⁶	ESF14 ⁷
NOAA	x ¹	xx ²	x	x	xx	xx	xx	xx	—
USACE	x	xx	x	x	xx	Primary	xx	xx	xx
BTS ⁸	x	—	—	—	—	—	—	—	—
USCG	x	xx	x	x	xx	xx	xx	xx	xx
MARAD	x	xx	x	x	xx	—	—	—	—
EPA ⁸	x	xx	—	—	—	xx	—	Primary	XX
FMC ⁸	x	—	—	—	—	—	—	—	—
CISA ⁸	x	—	x	x	xx	xx	—	xx	Primary
FEMA	x	xx	—	—	xx	—	Primary	xx	xx
DOT ⁸	x	xx	—	—	Primary	xx	—	xx	xx
NGA ⁸	x	—	—	—	—	—	xx	—	—
Public	—	xx	x	x	xx	xx	xx	xx	xx
Industry	—	xx	x	x	xx	xx	xx	xx	xx
SLTT ⁸ Governments	—	xx	x	x	xx	xx	xx	xx	xx

¹ x— collaborate during ordinary conditions

² xx—collaborate during disaster response conditions

³ ESF 1—Emergency Support Function 1; jurisdiction—Transportation

⁴ ESF 3—Emergency Support Function 3; jurisdiction—Public Works and Engineering

⁵ ESF 9—Emergency Support Function 9; jurisdiction—Search and Rescue Annex

⁶ ESF 10—Emergency Support Function 10; Oil and Hazardous Materials Response Annex

⁷ ESF 14—Emergency Support Function 14; Cross-Sector Business and Infrastructure Annex

⁸ State, local, tribal, and territorial

5 An Examination of MTS Resilience across Hurricane Seasons

The final step in this analysis is to compare the ability of the MTS to adapt between hurricane seasons. The RIAT report from the 2017 hurricane seasons identified best practices and recommendations to be carried forward during future hurricane seasons. Table 2 compares a sampling of those recommendations to findings from Hurricanes Florence, Michael, and Dorian during 2018 and 2019.

The table is divided to highlight two general themes that ensure MTS critical functions are returned as quickly and efficiently as possible: (1) preevent preparations, or actions in anticipation of a potential event and (2) response and recovery actions that occur during an event (and often depend on preparation). Several key themes resurface throughout the findings: (1) enhanced cross-agency coordination, (2) improvements in data and information exchange, and (3) capitalizing on lessons learned from previous storms to preestablish local knowledge and mechanisms for quick response.

Table 2. A comparison of recommendations from 2017 with findings from the 2018 and 2019 hurricane seasons.

2017 Hurricane Season Report Recommendation	2018–2019 Hurricane Season Findings
Preevent Preparations	
Participate in yearly trainings and drills to ensure that response and recovery teams and stakeholders are educated with the correct skill sets and credentials.	Having local knowledge of an area was critical for establishing partnerships and familiarity with missions and protocols. Tabletop exercises between USCG, USACE, NOAA, and others were key in identifying known problem areas in each waterway to develop scenario-based plans. (Florence, Dorian, Michael)
Maintain pre-established contracting mechanisms for emergency response operations	<ul style="list-style-type: none"> • NOAA was able to exercise an MOU with USCG to preposition their vessels in a hardened facility outside of Miami, which allowed the team to follow behind the storm as it moved northward along the coast. (Dorian) • NOAA provided contract support to procure ocean bar surveys that greatly aided the USACE and expedited the channel survey process. (Florence) • The USACE was able to quickly initiate navigation channel dredging and restoration by ensuring dredges were under contract and ready for support. (Florence)

Table 2. (cont.). A comparison of recommendations from 2017 with findings from the 2018 and 2019 hurricane seasons.

2017 Hurricane Season Report Recommendation	2018-2019 Hurricane Season Findings
Pre-event Preparations	
Preidentify staging areas and storage areas for response and recovery equipment, fuel, and supplies.	There was a more centralized approach to distributing recovery assets. The USACE Charleston District was called upon to assist the Port of Wilmington and was able to do so more effectively. (Florence)
Prioritize key infrastructure systems and deliveries for directing response and recovery actions.	There was successful coordination between representatives from different transportation modes (road, rail, marine) to identify the best routes and mechanisms to get resources into the area, especially under intense flooding. (Florence)
Response and Recovery Efforts	
Share data across Federal agencies for recovery projects through interagency teams and data sharing platforms.	USACE relied on an existing database to identify and flag potential obstructions prestorm and shared that information with other agencies. (Florence)
Embed MTS experts where necessary—USCG, FEMA field offices, local offices.	<ul style="list-style-type: none"> • NRT/MTSRU/USACE coordination in Miami, Florida, was great due to colocation. Face-to-face coordination meetings were important and took minutes to hours rather than the days to weeks common to email communication. NOAA and USACE coordinated poststorm surveys within hours. (Dorian) • In the Wilmington District, USACE, USCG, and NOAA were all collocated at USCG facilities, which leveraged expertise and accelerated collaboration. (Dorian)

Clearly, MTS stakeholders are well versed in storm response, but this review also identified specific actions that can improve the ability of the system to respond, recover, and better prepare for events beyond hurricanes. Increased resilience within the MTS will result in a system that is better prepared for oil spills, technological failures, shipwrecks, tsunamis, etc., in addition to future hurricanes. Table 3 provides a summary of actions that proved effective in the 2017–2019 hurricane seasons and can be adapted to address other disruptions to the MTS, such as the COVID-19 pandemic.

Table 3. Recommendations for the Marine Transportation System (MTS) to prepare, absorb, recover, and adapt to future disruptions.

	Recommendations
Preparation Actions	Budget for and hold regular trainings and drills to educate response and recovery teams on how to operate in different scenarios, such as colocated versus virtual/remote.
	Establish important relationships and connections early, reinforce them often, and document the chain of command for emergency situations.
	Hold yearly exercises to understand the needs of the local area as well as pre-identifying storage areas and key infrastructure.
Absorb (Resist) and Recover Actions	Share data seamlessly across federal agencies through interagency teams and existing easily accessible data-sharing platforms.
	Regularly and accurately update data as information continues to evolve during disaster events while keeping it relevant to recovery coordination.
	Utilize a flexible workforce that can continue operations during an emergency.
Adaptation Actions	Hold proactive after-action reviews focusing on what worked well, what challenges were faced, and then commit to implementing lessons learned and recommendations.
	Develop an accessible common operating picture of vital information (survey data, port system requirements, dependent businesses).
	Document and communicate within and across agencies on the successes, challenges, and lessons learned following events.

6 Conclusion

The MTS faces a future full of increased demand, more frequent coastal storms, and changing economic and community drivers. Ensuring that those who manage, prepare, and adapt the MTS to be more resilient have access to necessary information is critical. Therefore, the RIAT has attempted to foster a creative and collaborative approach to identify needs that are emerging out of hurricane response and recovery.

In reviewing the outcomes of this report, not only are federal MTS agencies successfully responding to the challenges of coastal storms, but they are adapting by utilizing lessons learned from the past to address vulnerabilities and improve their response to future storms. In the future, the RIAT team will continue to serve as a coordinating body for federal agencies. However, more work is warranted to also reach key partners within state, local, and tribal government agencies, as well as leaders in industry, to weigh in on the practices that will make the system more agile, flexible, reliable, and resilient.

References

- Avila, L. D., S. R. Stewart, R. Berg, and A. B. Hagen. 2019. "Tropical Cyclone Report, Hurricane Dorian 24 August–7 September 2019." National Oceanic and Atmospheric Administration, National Hurricane Center.
- Beven, J., and T. Burton. 2018. *National Hurricane Center Tropical Cyclone Report: Hurricane Michael*. AL 142018. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Weather Service. https://www.nhc.noaa.gov/data/tcr/AL142018_Michael.pdf.
- CIRP (Coastal Inlets Research Program). 2023. "Automatic Identification System Analysis Package." Use of this site requires valid government ID. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. <https://cirp.usace.army.mil/products/aisap.php>.
- CMTS (US Committee on the Marine Transportation System). 2018. *The 2017 Hurricane Season: Recommendations for a Resilient Path Forward for the Marine Transportation System*. Washington, DC: US Department of Transportation. https://www.cmts.gov/downloads/CMTS_RIAT_2017Hurricanes.pdf.
- CMTS (US Committee on the Marine Transportation System) 2020. *A Resilient Path Forward for the Marine Transportation System: Recommendations for Response and Recovery Operations from the 2017–2019 Hurricane Seasons*. Washington, DC: US Committee on Marine Transportation System. https://www.cmts.gov/assets/uploads/documents/CMTS_RIAT_Hurricanes_Report_FINAL.pdf.
- CMTS (US Committee on the Marine Transportation System). 2021. *US Navigation Information Strategic Action Plan: 2021-2026*. Washington, DC: US Department of Transportation. https://www.cmts.gov/downloads/CMTS_USNavigation2021_SAP_FINAL.pdf.
- ERDC (US Army Engineer Research and Development Center). 2021. "AIS Analysis Package (AISAP)." Software package. https://aisap.usacegis.us/aisap_portal/home.html.
- IADB (Inter-American Development Bank). 2019. *Damages and other impacts on Bahamas by Hurricane Dorian Estimated at \$3.4 Billion: Report.* <https://www.iadb.org/en/damages-and-other-impacts-bahamas-hurricane-dorian-estimated-34-billion-report>.
- NOAA NCEI (National Oceanic and Atmospheric Administration, National Centers for Environmental Information). 2019. "US Billion-Dollar Weather & Climate Disasters 1980–2023." <https://www.ncei.noaa.gov/access/billions/events.pdf>.
- NOAA NCEI (National Oceanic and Atmospheric Administration, National Centers for Environmental Information). 2023. "US Billion-Dollar Weather and Climate Disasters (2023)." <https://www.ncei.noaa.gov/access/billions/>, DOI: 10.25921/stkw-7w73.

- NOAA NWS (National Oceanic and Atmospheric Administration, National Weather Service). 2018. *Historical Hurricane Florence, September 12-15, 2018*. <https://www.weather.gov/mhx/Florence2018>.
- NOAA OCS (National Oceanic and Atmospheric Administration, Office of Coastal Survey). n.d. "North Carolina Cape Fear River–Cape Fear to Wilmington." Map 11537. <https://www.charts.noaa.gov/PDFs/11537.pdf>.
- NOAA OCS (National Oceanic and Atmospheric Administration, Office of Coastal Survey). n.d. "North Carolina Beaufort Inlet and Part of Core Sound." Map 11545. <https://www.charts.noaa.gov/PDFs/11545.pdf>.
- NOAA OCS (National Oceanic and Atmospheric Administration, Office of Coastal Survey). n.d. "South Carolina Winyah Bay." Map 11532. <https://www.charts.noaa.gov/PDFs/11532.pdf>.
- Rosati, J. D., K. F. Touzinsky, and W. J. Lillycrop. 2015. "Quantifying Coastal System Resilience for the US Army Corps of Engineers." *Environment Systems and Decisions* 35:196–208.
- Stewart, S., and R. Berg. 2018. *National Hurricane Center Tropical Cyclone Report: Hurricane Florence, 31 August–17 September 2018*. National Oceanic and Atmospheric Administration, National Weather Service. https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf.
- The White House. 2013. *Presidential Policy Directive 21–Critical Infrastructure Security and Resilience*. <https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil>.
- Touzinsky, K., B. S. Scully, M. K. Kress, and K. M. Mitchell. 2018. "Using Empirical Data to Quantify Port Resilience: Hurricane Matthew and the Southeastern Seaboard." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 144 (4): 05018003.
- USA Trade Online. 2023. *FT900: US International Trade in Goods and Services*. United States Census Bureau. June 25, 2021. https://www.census.gov/foreign-trade/Press-Release/ft900/final_2022.pdf.
- USCG (United States Coast Guard). 2018. *Maritime Commerce Strategic Outlook*. February 16, 2020. <https://media.defense.gov/2018/Oct/05/2002049100/-1/-1/1/USCG%20MARITIME%20COMMERCE%20STRATEGIC%20OUTLOOK-RELEASABLE.PDF>.

Appendix A: Agencies and Offices of Workshop Attendees

Department of Defense

US Army Corps of Engineers

Engineer Research and Development Center

Engineering and Construction Division

Directorate of Emergency Response and Contingency Operations

Operations and Regulatory Division

US Committee on the Marine Transportation

US Department of Homeland Security

Cybersecurity and Infrastructure Security Agency

US Coast Guard

District Eight New Orleans: Enforcement Branch

Headquarters: Port Resiliency/Recovery

Headquarters: Office of Port and Facility Compliance

USCG FEMA Liaison

US Department of Transportation

Bureau of Transportation Statistics

US Maritime Administration

Office of Ports and Waterways Planning

Emergency Sealift Ops and Emergency Response

US Department of Commerce

National Oceanic and Atmospheric Administration

Office of Coast Survey

Office for Coastal Management

National Weather Service

Abbreviations

AIS	Automatic Identification System
AISAP	Automatic Identification System Analysis Package
ATON	Aids to Navigation
BTS	Bureau of Transportation Statistics
CART	Common Assessment and Reporting Tool
CISA	Cybersecurity and Infrastructure Security Agency
CMTS	Committee on the Marine Transportation System
COTP	Captain of the Port
DOT	Department of Transportation
EPA	Environmental Protection Agency
ERDC	US Army Engineer Research and Development Center
FEMA	Federal Emergency Management Agency
FMC	Federal Maritime Commission
GIWW	Gulf Intracoastal Waterway
MARAD	Maritime Administration
MOU	Memorandum of understanding
MTS	Marine Transportation System
MTSRU	NRT/MTS Response Units
NGA	National Geospatial-Intelligence Agency

NOAA	National Oceanic and Atmospheric Administration
NRT	Navigation Response Team
NWS	National Weather Service
RIAT	Resilience Integrated Action Team
UCOP	USACE Common Operating Picture
USACE	US Army Corps of Engineers
USCG	US Coast Guard

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14. ABSTRACT The Marine Transportation System (MTS), Resilience Integrated Action Team (RIAT), is tasked by the coordinating board of the US Committee on the MTS to serve as a coordinating body to identify the impacts, best practices, and lessons learned by federal agencies involved in the response and recovery of the MTS after hurricane seasons. In response to this request, the RIAT has focused its analysis on the ability of MTS federal agencies to prepare, respond, recover, and adapt to as well as from disruptions. This was accomplished through workshops focused on gathering the collective experiences of emergency response professionals. In 2017, recommendations were gathered based on experiences responding to Hurricanes Harvey, Irma, and Maria. In this report, a similar approach was adopted to gather findings from Hurricanes Florence and Michael in 2018 and Hurricane Dorian in 2019. Utilizing the successes, challenges, and best practices from all six of these storms, the RIAT identified key coordinating bodies and the participants for each and key takeaways relative to the coordination of agencies with respect to the four steps of resilience: prepare, absorb, recover, and adapt.					
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