NATIONAL WINDSTORM IMPACT REDUCTION PROGRAM

BIENNIAL PROGRESS REPORT TO CONGRESS FOR FISCAL YEARS 2023 AND 2024

FEMA

U.S. National Science Foundation

NOAA

NIST

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This progress report for the National Windstorm Impact Reduction Program (NWIRP) is submitted to Congress by the Interagency Coordinating Committee of NWIRP.

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1. Executive Summary

The National Windstorm Impact Reduction Program (NWIRP or Program) is a science- and engineering-based coordinating Program whose stated mission is to achieve major measurable reductions in losses of life and property from windstorms, through a coordinated federal effort in cooperation with other levels of government, academia, and the private sector. The four designated Program agencies are the National Institute of Standards and Technology (NIST), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the Federal Emergency Management Agency (FEMA). This report documents the progress of the Program for Fiscal Years (FYs) 2023 and 2024 in forwarding its mission.

From 1980-2024, severe thunderstorms, wildfires and tropical cyclones (TCs) caused over $2.2 trillion in economic losses and over 9,800 fatalities in the United States (U.S.), with over 7,700 fatalities since 2010. In 2024, there were 27 individual weather disasters with at least $1 billion in damages, trailing only the record-setting 28 events that occurred in 2023. The 2024 disasters caused at least 568 direct or indirect fatalities, which is the eighth highest for these billion-dollar disasters over the last 45 years (1980-2024). The cost was approximately $182.7 billion.[1] Yet, the NWIRP agencies have made significant progress. In 2018, the Program agencies released the NWIRP Strategic Plan, which sets forth a research-to-applications paradigm that integrates foundational research in understanding windstorm behavior, applied research to understand and gather insight into windstorm impacts, and applications and technology transfer to improve the windstorm resilience of the Nation. The various agency-specific contributions and accomplishments in advancing the NWIRP research-to-applications paradigm during FYs 2023-2024 are documented in Section 5 and organized around the NWIRP strategic goals.

Highlights of agency contributions include significant improvements to the understanding of hurricane intensification processes which led to improved and timely hurricane forecasts, progress in the understanding of tornadic vs. non-tornadic storms, advancements in Warn-on-Forecast and other storm scale modeling, advancements in the science of wind mapping to inform engineering-based design standards, improved coordination practices and increased resources for scientific research in support of post-windstorm investigations, and implementation of post-windstorm research-based recommendations into standards and codes development processes such as provisions for windstorm-resistant construction, a new storm shelter standard, and inclusion of tornado wind loading factors into a new standard for high occupancy and essential use buildings.

During the 2023-2024 reporting period several extreme windstorm events plagued the United States. Hurricane Ian, which made landfall in late FY 2022, severely impacted Southwest Florida and was a focus for several NWIRP agencies to examine the event and resulting damage. Other Hurricanes include Hurricane Idalia of August 26-31, 2023, in Florida's Big Bend area, and Hurricane Beryl in the Matagorda and Houston, Texas areas in June 28-July 9, 2024. This early season Cape Verde type system twice rapidly intensified. Major Hurricane Helene impacted the Big Bend area of Florida mainly on September 26, 2024, parts of Georgia and western North Carolina (September 27-28, 2024) severely with winds and rains well inland. Historic flooding, mudslides, and large swaths of trees downed due to winds being forced up and through mountainsides were all impacts from Helene well inland mostly in the NC mountains.

[1] Visit https://www.ncei.noaa.gov/access/billions/time-series

Tornadoes occurred in many outbreaks from late March and early April through August 2023, with a notable event on December 9th with devastating tornadoes in Nashville and (EF3) Clarksville, Tennessee. In May 16-17, 2024, a rare derecho impacted the south from Texas to southeastern Louisiana with a small portion continuing to northwest Florida causing widespread damage particularly to the city of Houston. Several wind observations measured gusts over 70 mph with damage-based estimates of wind over 100 mph in Houston. Baton Rouge, Louisiana, had several trees and power lines downed when it passed through, and New Orleans had gusts over 80 mph.

In early August 2023, a major wind-driven wildfire ran through Lahaina, Maui and killed 102 people. The winds gusted to 67 mph.

As windstorm impacts grow due to a variety of factors, it is critical that the NWIRP agencies continue to implement the NWIRP Strategic Plan. Furthermore, it is critical that NWIRP identifies new opportunities for improved synergy across scientific disciplines, interagency engagement, and education and outreach to amplify awareness of NWIRP and support the development of the next generation of windstorm scientists and engineers. The path forward represents visions in which NWIRP would become active should they be supported:

- expanding awareness of the NWIRP research-to-applications paradigm across the federal enterprise including housing and transportation agencies and beyond;
- strengthening NWIRP post-windstorm assessments by supporting federal coordination with university-based researchers;
- exploring the application of model projections to inform the development of forward-looking national structural design standards, building codes, and other resilience applications;
- contribute to building a Weather Ready Nation by integrating scientific advances in real-time impact-based extreme weather event forecasting and delivery, informed by social science and engineering disciplines, to elicit the appropriate responses by individuals and organizations;
- supporting and promoting the implementation of recommendations from interagency post-windstorm research; and,
- integrating scientific advances in real-time extreme weather event forecasting and social sciences to enhance emergency communication and life safety warning information to the public.

The NWIRP agencies are committed to advancing these priorities to reduce windstorm impacts across the Nation.

2. Background

Windstorms, along with associated flooding, hail, and wildfires, produce more losses in the U.S. than any other hazard.

Windstorms and associated flooding, hail, and wildfires comprise the majority of individual loss-producing natural hazard events that exceed $1 billion in the U.S.,[2] with hurricanes and tornadoes comprising the majority of the total. From 1980-2024, severe thunderstorms[3], wildfires and TCs caused over $2.2 trillion in economic losses.[4] The trends in losses from wind and related hazards continues to rise. In recognition of the need to significantly decrease economic costs and loss of life, Congress established NWIRP.[5] In 2024 alone, there were 27 individual weather disasters with at least $1 billion in damages, trailing only the record-setting 28 events that occurred in 2023. The 2024 disasters caused at least 568 direct or indirect fatalities, which is the eighth highest for these billion-dollar disasters over the last 45 years (1980-2024). The cost was approximately $182.7 billion. Hurricane Helene alone had damage estimated at $79.6 billion and 219 lives lost.

NWIRP is a federal interagency science- and engineering-based Program focused on achieving major measurable reductions in losses of life and property from windstorms. The four designated Program agencies are NIST, NOAA, NSF, and FEMA. NWIRP collaborates with other agencies and levels of government, academia, and the private sector.

Since NWIRP's inception in 2004, the participating agencies have made notable progress. Some of the improvements include:

- An improved understanding of the hurricane intensification which has led to improved hurricane warnings and the understanding of hurricane intensification processes which led to improved hurricane forecasts;[6]
- progress in the understanding of tornadic vs. non-tornadic storms;
- advancements in Warn-on-Forecast and other storm scale warn-on-forecast modeling;
- advancements in the science of wind mapping to inform engineering-based design standards;
- improved coordination practices and increased resources for scientific research in support of post-windstorm investigations;
- implementation of post-windstorm research-based recommendations into codes and standards development processes such as provisions for windstorm-resistant construction, a new storm shelter standard, and tornado load requirements for high occupancy and essential use buildings; and
- studies on wind-driven wildfires. These wildfires when located next to the built environment (Wildland Urban Interface WUI) represent the wildfires responsible for greatest damage and lives lost. Findings include how to safely clear fuels from areas next to WUIs, how to build without

[2] Visit https://www.ncei.noaa.gov/access/billions/time-series/US

[3] As defined by the National Weather Service, "thunderstorm producing winds equal or greater than 58 miles an hour or producing hail one inch or larger in diameter."

[4] National Oceanic and Atmospheric Administration, National Centers for Environmental Information. Billion-dollar weather and climate disasters: Table of events. Retrieved from https://www.ncei.noaa.gov/access/billions/time-series

[5] 42 U.S.C. § 15703(a).

[6] https://www.nhc.noaa.gov/verification/verify8.shtml

plants or wooden fences next to homes, and fire-resistant building materials for the protection of homes.

However, challenges in windstorm impact mitigation efforts remain. The Nation continues to experience increasing property losses due to extreme weather events, as evidenced by the devastating severe weather and tornado outbreaks in 2011, 2013, 2020, 2021, 2023, and 2024 and the recent set of damaging hurricane seasons from 2017 to 2024. The loss of life and property from Hurricane Ian's storm surge of 2022 highlighted the vulnerability of coastal residents even when storm surge warnings were issued a day in advance. Hurricane Helene highlighted the vulnerability of communities that, despite being located well inland, could still be subject to high winds that could be accelerated through mountainous regions. The increased losses originate from two major causes. First, only 31% and 33% of U.S. jurisdictions have adopted hazard resistant building codes for FY 2023 and FY 2024, respectively, leaving many areas where new and existing buildings remain vulnerable to severe storms (Figure 1).[7] These are percentages of tracked jurisdictions that adopted the 2018 or later International Building Code (IBC) and International Residential Code (IRC) in FY 2023 and FY 2024 without removing or weakening the hazard resistant provisions of the codes for any of five hazards (flood, seismic, damaging wind, hurricane wind, and tornado) which present a high risk to the given community. Second, more people are moving to the coastal regions and areas prone to hurricanes and tornadoes. Thus, more homes are subject to damage, even in areas which have adopted building codes.[8] It should be noted that the design wind speed is not the same in all areas of the country. For example, Figure 2B shows the Big Bend region of Florida has a basic wind speed for Risk Category III buildings that is lower than surrounding areas, yet, during 2023-2024, Hurricanes Idalia, Debby and Helene all made landfall there. More than twice as many housing units could be exposed to TCs in 2100 compared to today in the largest urban areas along the Atlantic and Gulf coasts even if the frequency and severity of storms remains the same. Additionally, increasing population in areas exposed to wildland urban interface wildfires is likely to follow the same pattern of increasing damage costs.

[7] https://www.fema.gov/emergency-managers/risk-management/building-science/bcat

[8] Freeman and Ashley, Changes in the US hurricane disaster landscape: the relationship between risk and exposure, 2017, Natural Hazards DOI 10.1007/s11069-017-2885-4

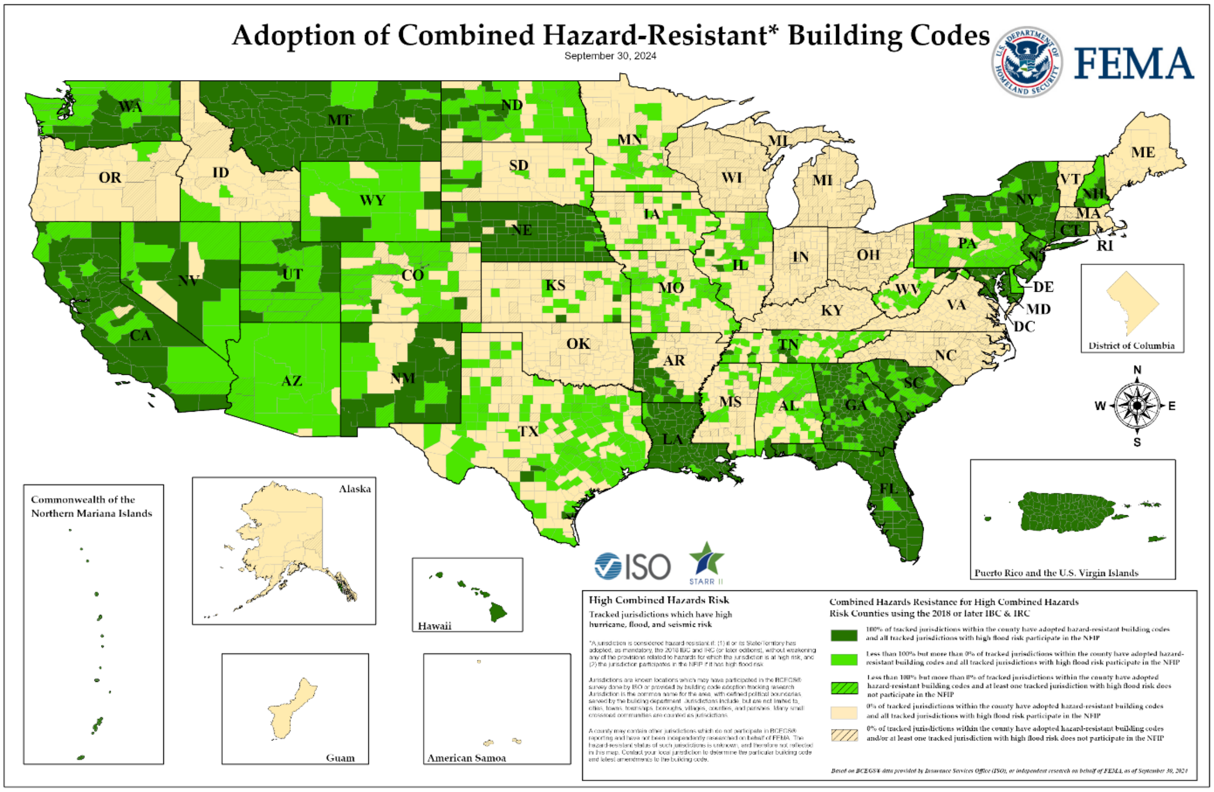
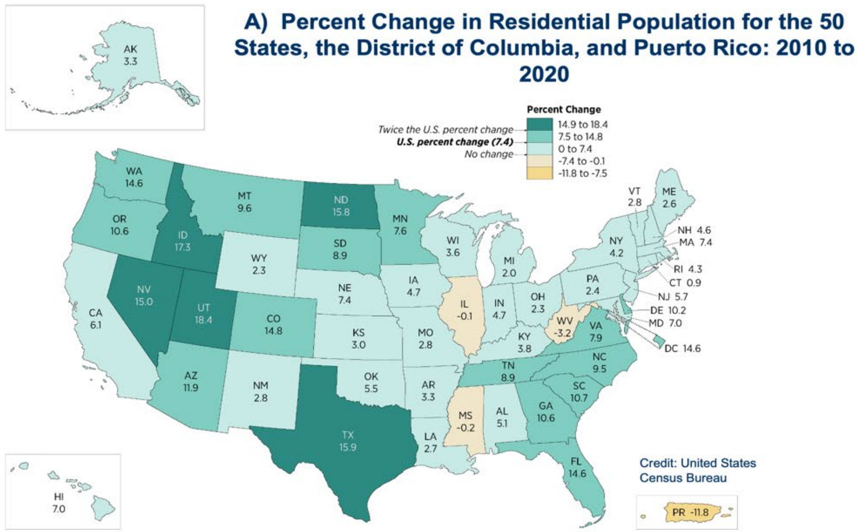


Figure 1. *Building code adoption levels as of 2021 identified in the FEMA nationwide building code adoption tracker courtesy of a survey by the Building Code Effectiveness Grading Schedule.*[9]*. Each county is colored green where greater than 0% of jurisdictions reported adopting hazard-resistant building codes. Source: FEMA.*

[9] https://www.isomitigation.com/bcegs/



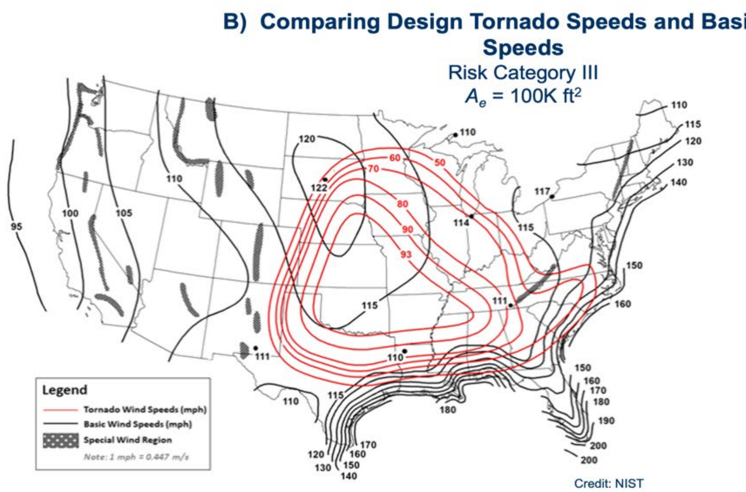


Figure 2A. *Change in state population from 2010 to 2020 identified by the US Census Bureau. Source:* *https://www.census.gov/library/visualizations/2021/dec/2020-percent-change-map.html*

Figure 2B. *Design Tornado Wind Speeds (red contours) and Basic Wind Speeds (black contours) for Risk Category III buildings occupying a 100 Kft2 developed by NIST for the ASCE 7-22 Building Loads Standard. Higher wind speeds reflect higher risk levels of winds from tornadoes and other phenomena (e.g., tropical cyclones).*

Furthermore, other challenges remain to be addressed.

- In terms of the metrics for performance, operational tornado warning accuracy values have consistently plateaued since the historic outbreak season of 2011,[10] after years of gradual increasing of annual accuracy values following the National Weather Service (NWS) modernization in the 1990's and early 2000's. After the 2011 season, there was a community-wide emphasis on the

[10] Correia and Brooks, 2018: Long-Term Performance Metrics for National Weather Service Tornado Warnings. https://doi.org/10.1175/WAF-D-18-0120.1

messaging of known tornado threats and reductions in false alarms which over time was reflected in a slight decrease in mean tornado warning lead times to around 10 minutes, annually[11].

- Wildfires are burning more acreage now than before, from an average of 3,000,000 acres per year in the late 1980s to 8,000,000 acres burned per year in the 2020s. Of note, the largest fires since 2020 were recorded in the states of California, Colorado, and New Mexico. Many of these fires featured explosive wind-driven growth rates such as with the Lahaina, Maui in Hawaii fire of August 2023, which was the most-deadly fire in U.S. history. Carr, CA fire of 2018 where a firefighter was killed and a neighborhood was damaged well outside the burn zone.[12] A later fire near Loyalton, CA resulted in the first ever tornado warning issued by the NWS for a fire-generated tornado.[13] Fire tornado research is young relative to research on traditional tornadoes and the NWS has little guidance to support fire-related tornado or other fire-generated windstorm warnings. Yet, the combined hazards of wind-driven wildfire, and fire-generated tornadoes represent an increasing concern as population and wealth accumulate in areas of increasing fire risk along the Wildland Urban Interface (WUI).[14]
- Wind-generated storm surges coupled with the increasing amount of coastal wealth and population are resulting in rising losses. The rising surge-related property damage highlights a vulnerability of our population along coastlines and the need to improve our understanding of all of the mechanisms of storm surge that affect buildings and infrastructure including inundation depth, water current velocity, wave action and debris impacts. Subsequently, building surge resistance standards need to be updated to address new research findings.
- Efforts to mitigate wind-induced losses will continue to be challenging, partly due to a limited understanding of the likely spatial and temporal changes in the wind and related hazards. Confidence is high that future weather will result in increasing wildfire risk,[15] but is medium for TC intensity,[16] and is low for severe local storms, including tornadoes.[17] Research is needed to improve the confidence of past and future trends of severe winds and related hazards. Parallel research needs to evaluate how building performance standards would need to change in the future.

Continuing to improve windstorm impact reduction measures requires a research-to-applications paradigm featuring a sustained and robust interdisciplinary approach based on:

- meteorological research to better understand the short- and long-term changes in the behavior and impact of windstorms on society;
- research on improving understanding of how wind interacts with and causes damage to buildings in a variety of windstorms;

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[11] NOAA website https://performance.commerce.gov/KPI-NOAA/NOAA-Severe-weather-warnings-for-tornadoes-Storm-b/ysdv-8h2r

[12] Lareau, N. J., and co-authors, Fire-Generated Tornadic Vortices, 2022: Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-21-0199.1

[13] https://www.washingtonpost.com/weather/2020/08/16/california-fire-tornado-warning/

[14] https://www.nist.gov/news-events/news/2021/02/new-timeline-deadliest-california-wildfire-could-guide-lifesaving-research

[15] https://www.pnas.org/doi/full/10.1073/pnas.1607171113

[16] Walsh and Co-authors, 2015: Hurricanes and Climate: The U.S. CLIVAR Working Group on Hurricanes, Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-13-00242.1

[17] Taszerak and Co-authors, 2021: Differing Trends in United States and European Severe Thunderstorm Environments in a Warming Climate, Bulletin of the American Meteorological Society, https://doi.org/10.1175/BAMS-D-20-0004.1

- engineering research on improving new structures and retrofitting existing ones to better withstand windstorms; and
- social sciences research to understand economic and social factors influencing windstorm risk reduction measures.
- Improved future research needs to be focused on the understanding of building wind damages in hurricanes due to the duration and sharp wind directional shifts in a short period of time.

The primary functions of NWIRP are carried out by two interagency coordinating bodies. The Windstorm Working Group (WWG), composed of scientists and program/portfolio leaders from the designated NWIRP agencies and other entities, meets approximately once every two months to implement the Program. The Interagency Coordinating Committee, comprised of the heads of the four designated Program agencies (FEMA, NIST, NOAA, and NSF), the Office of Management and Budget (OMB), and the Office of Science and Technology Policy (OSTP), meets annually to discuss the direction of the Program and make decisions regarding interagency implementation of the NWIRP Strategic Plan. A detailed history of NWIRP statutory and technical Program activities from FYs 2005-2022 has been documented in a series of previous biennial reports to Congress.[18]

The structure of this report is as follows:

- Section 3 presents a brief overview of windstorm impacts during FYs 2023-2024.
- Section 4 discusses NWIRP interagency post-windstorm coordination activities during the reporting period.
- Section 5 details agency specific activities in support of the NWIRP strategic priorities and the three NWIRP strategic goals.
- Section 6 briefly articulates a shared vision for the path forward.
- Appendices include a listing of NWIRP strategic objectives and priorities, detailed descriptions of select agency technical activities, and recent interagency coordinated budget information.

3. Windstorms and Their Impacts in 2023 and 2024

The number of individual severe storm, TC and wildfire events with losses exceeding $1 billion rose significantly in FYs 2023-2024 from their prior peak in 2020 (Figure 3). This aligns with the overall trend of increased events occurring since 1980. Thirty-one events related to wind occurred over these two years – 22 of them from severe thunderstorms, seven from TCs and two from wildfires – each with losses exceeding $1 billion (Consumer Price Index (CPI) adjusted for inflation).[19]

[18] NWIRP Biennial Reports to Congress, https://www.nist.gov/el/mssd/nwirp/biennial-reports-congress.

[19] Department of Labor Bureau of Labor Statistics. Historical Consumer Price Index for All Urban Consumers (CPI-U). https://www.bls.gov/cpi/tables/supplemental-files/historical-cpi-u-202109.pdf.

Impacts go beyond the monetary losses as in 2023 tornadoes and hurricanes claimed 89 lives through direct effects.[20] In 2024 there were 54 lives lost to tornadic activity and at least 335 lives lost to hurricanes – mostly from Helene. This makes the 2024 Atlantic hurricane season the deadliest since 2005.

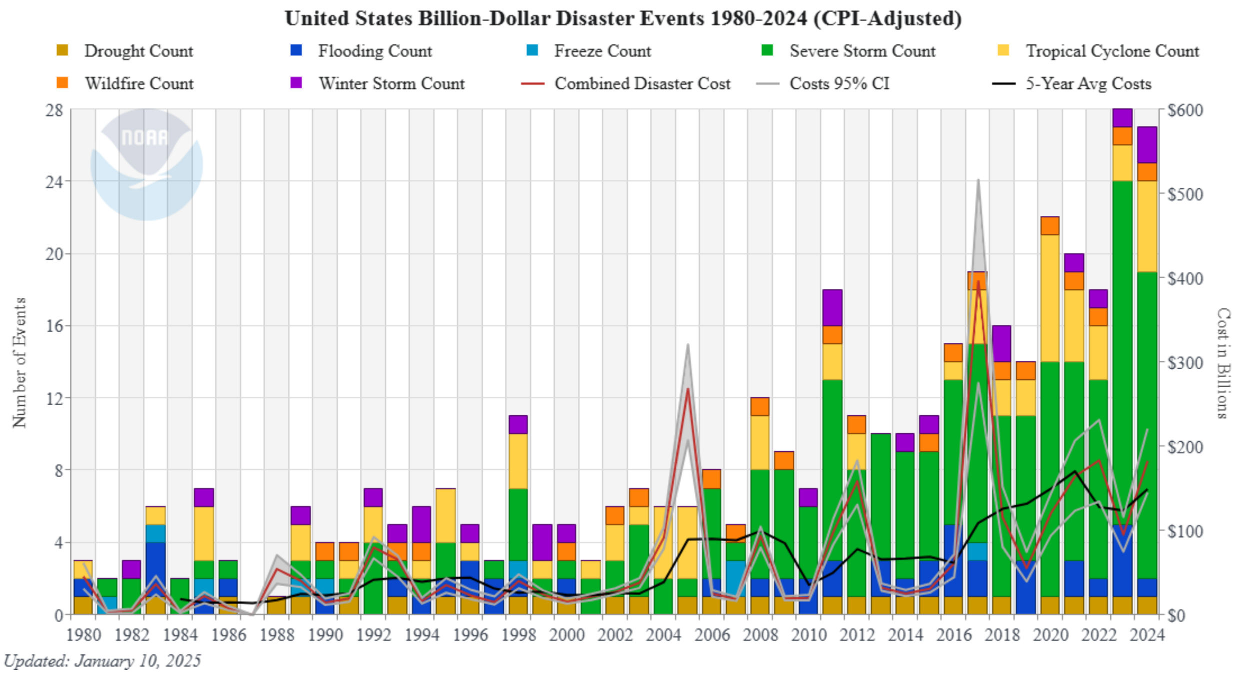

Figure 3. *Number of individual tropical cyclone (yellow), severe storm (green) and wildfire (orange) events from 1980-2024 exceeding one billion USD (inflation adjusted) comprise the majority of all $1 billion hazards. The annual cost is in gray and its five-year running mean in black.*[21] *Source: https://www.ncei.noaa.gov/access/billions.*[22]

3.1 2023

As in the previous six years, 2023 was a more active Atlantic hurricane season than usual with 20 named storms and seven hurricanes, three of them reaching major hurricane status (Figure 4). (An average hurricane season consists of 14 tropical names storms of which seven become hurricanes with three becoming major hurricanes.[23]) August had seven tropical systems while September had six, and there were five hurricanes and three major hurricanes during these two months. Both major Hurricanes Idalia (August) and Lee (September) rapidly intensified. The US suffered over $4B in damages from Idalia and Ophelia during 2023. Hurricane Idalia made landfall in the Big Bend region of Florida's Gulf Coast, while Tropical Storm Ophelia made landfall on the south-central coast of North Carolina. Since Idalia had a compact inner core and made landfall in one of the more remote parts of Florida, there were no observations of sustained hurricane-force winds. The highest observed wind was in Horseshoe Beach, Florida, where a WeatherSTEM observation site recorded a peak sustained wind of 63 kt and a wind gust of 70 kt at 1026

[20] Source: https://www.weather.gov/media/hazstat

[21] Property values have outpaced inflation, and development in disaster-prone areas has continued. As a result, the increasing cost with time is also due to property value and density.

[22] In alignment with evolving priorities, statutory mandates, and staffing changes, NOAA has indicated that this product is being discontinued.

[23] https://www.cpc.ncep.noaa.gov/products/outlooks/hurricane2025/May/hurricane.shtml

UTC 30 August, about an hour before Idalia made landfall. The highest reported wind gust was 74 kt in Perry, Florida, near the landfall location.[24] Damaging winds spread across southern Georgia during the afternoon and evening hours on 30 August. The highest wind gusts reported were along the coast in St. Simons and Tybee Sound, where gusts to 57 kt and 60 kt occurred, respectively. Tropical-storm-force winds were also reported along the coast in North and South Carolina. There were 8 EF-0 and four EF-1 tornadoes spawned by Idalia as it tracked across the southeastern United States. Hurricane Idalia brought 8 to 12 feet of storm surge to the Florida Big Bend region.

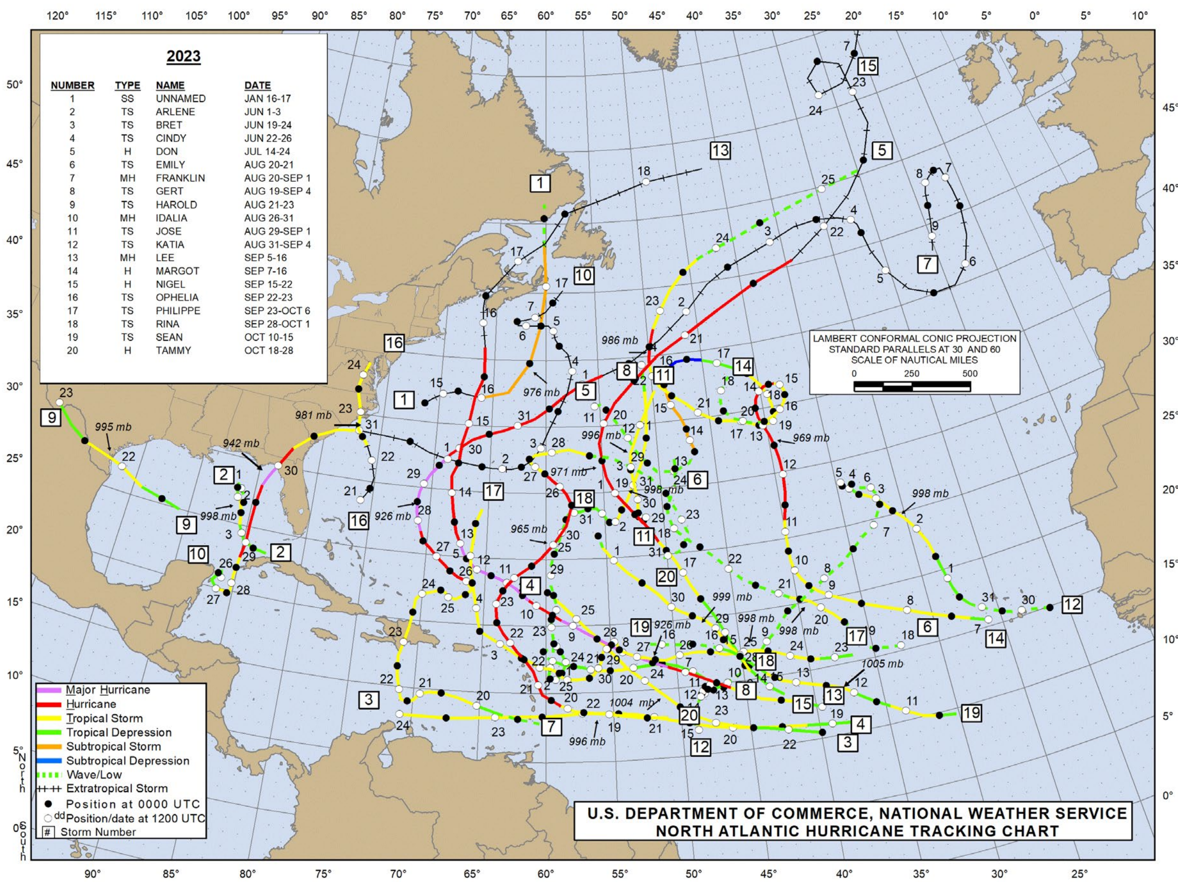

Figure 4: *From the NOAA/NWS National Hurricane Center, a summary of the Atlantic tropical systems during 2023.*

In the eastern Pacific basin, a rare tropical system made landfall in southern California. Hurricane Hilary initially made landfall in the Baja California peninsula of Mexico and moved north into southern California as a post tropical cyclonic low but prompted the first ever tropical storm warnings issued for California by the National Hurricane Center, extending from the Mexico-US border to just north of Los Angeles. Hilary was estimated to have caused $948 million in damage – mainly from rainfall and flooding along with one fatality in the US. As the system moved north into California it was accompanied by a 5.1 magnitude

[24] https://www.nhc.noaa.gov/data/tcr/AL102023_Idalia.pdf

earthquake in the region. Rainfall totals were as high as 11+ inches in a few spots in California with Death Valley having a one-day total rainfall record 2.20 inches (average yearly rainfall 2.15 inches)[25].

Further west into the Pacific Ocean Typhoon Mawar hit northernmost tip of Guam on May 23rd as a Category 4 120 knots storm. The system had earlier reached sustained winds of 190 mph before weakening prior to landfall on Guam. Typhoon Mawar was the strongest typhoon to impact Guam since 2002 and was the strongest tropical cyclone on the globe during 2023. The Weather Forecast Office of the NWS in Apia, Guam recorded gusts to 115 mph. More than $338 Million were awarded ~~given~~ through Federal funding to help the island recover.

Other remarkable windstorm events occurred in 2023. While no single tornado was a major damage creator, there were at least 17 separate tornadic outbreaks from March to August. The single worst tornado seems to have occurred on December 9th as an EF3 tornado in Clarksville, Tennessee (Figure 5). The Clarksville tornado stayed on the ground for more than an hour, eventually crossing into Kentucky. This tornado resulted in 62 injuries and four fatalities, and damaged or destroyed many homes. Additionally, an EF2 tornado occurred in Nashville on the same day and stayed on the ground through Madison, Hendersonville and Gallatin. This tornado resulted in another 22 injuries and three fatalities, as well as widespread structural damage.

[25] https://www.nhc.noaa.gov/data/tcr/EP092023_Hilary.pdf

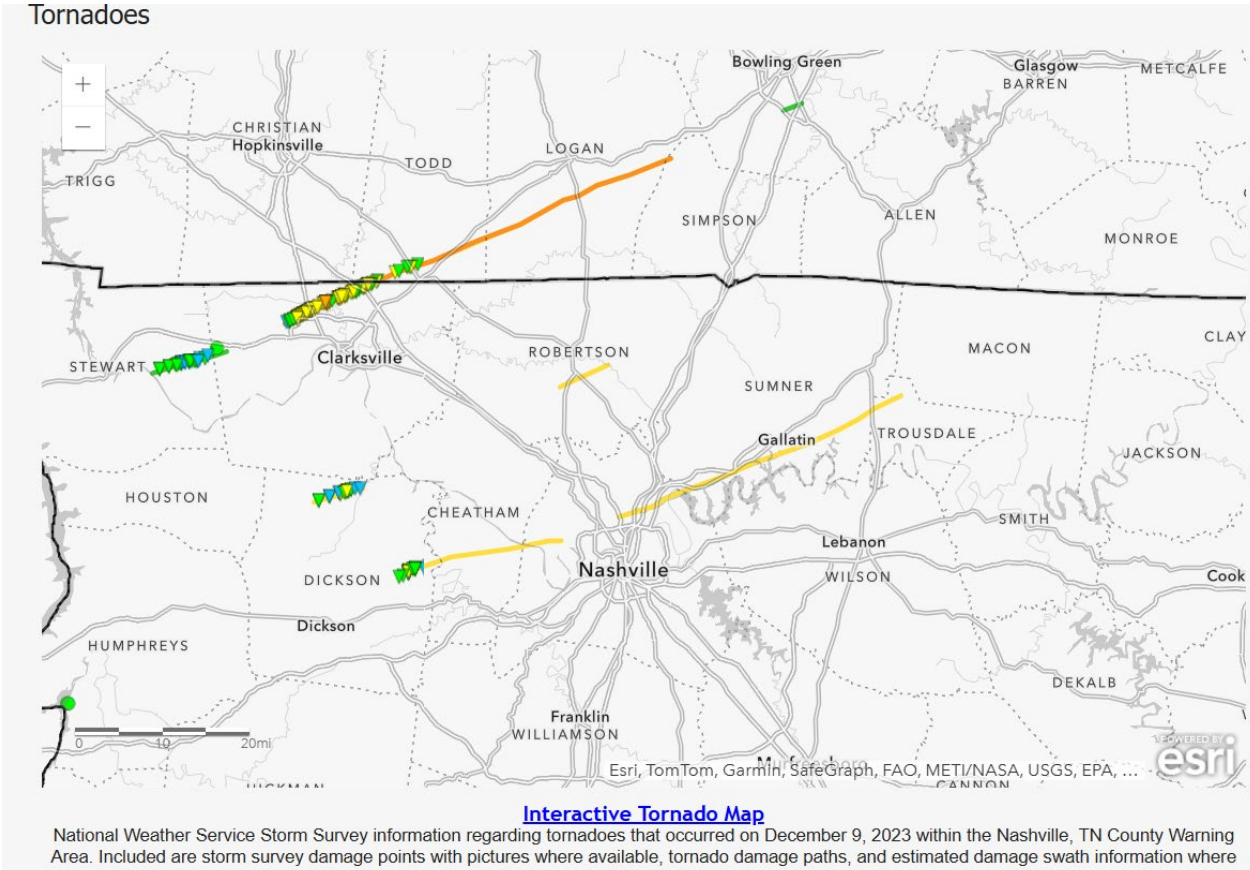

Figure 5. *Courtesy of the NOAA/National Weather Service Forecast Office Nashville, TN. Tracks of the Nashville and Clarksville, TN tornadoes from December 9th, 2023.*

There were approximately 12,000 less wildfires in 2023 than in 2022, and some 4.5 million fewer acres of land have been burned in 2023 compared to 2022. However, in Hawaii on Aug. 8, gale force winds were created between Hurricane Dora to the south and a low pressure system to the north collided with extremely dry terrain on Maui. Toppled power lines ignited what would become the deadliest wildfire in modern U.S. history, killing over 100 people and destroying most of the historic town of Lahaina[26].

3.2 2024

In 2024, there were 18 named storms that formed in the Atlantic basin (Figure 6), of which 11 became hurricanes and five strengthened into major hurricanes (category 3 or higher on the Saffir-Simpson Hurricane Wind Scale), three of which made landfall in the US. Major Hurricane Helene was the most devasting and caused widespread catastrophic damage and numerous fatalities across the Southeastern United States in late September. It was the strongest hurricane to strike the Big Bend region Florida and the deadliest to strike the continental U.S. since 2005[27] and at a cost of $200B it is the costliest hurricane ever to hit the U.S.. Helene maintained hurricane status well inland into Georgia and tropical storm status to the

[26] https://journals.ametsoc.org/view/journals/wefo/39/8/WAF-D-23-0210.1.xml

[27] NOAA/NWS National Hurricane Center https://www.nhc.noaa.gov/data/tcr/AL092024_Helene.pdf

Kentucky-Tennessee border. The damage associated with rainfall was magnified by a decaying frontal boundary that brought heavy rains to western North Carolina for three days prior to Helene moving into the region, and strong upslope winds forced moisture up the Appalachian and Smoky Mountains, causing more than 600 mudslides in the area. Widespread tree damage led to long term power, water and internet outages in the region. The TC-induced losses in 2024 were associated with five events that produced a total of $325 Billion in damage.[28]

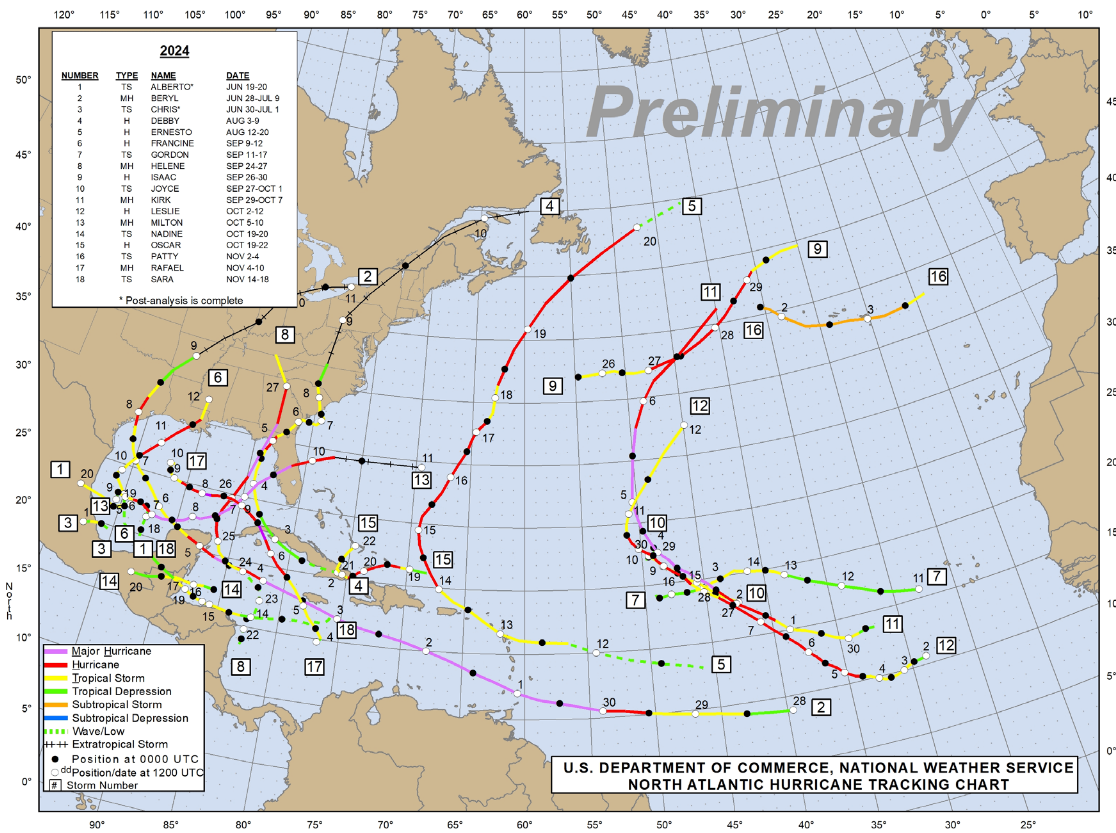

Figure 6*. From the NOAA/NWS National Hurricane Center a summary map of the Atlantic 2024 hurricane season.*

There were 1796 tornadoes that occurred in 2024, the second most on record only, behind only the 2004 season (Figure 7)[29]. This is above the 1991-2010 U.S. annual average of 1,225 tornadoes. The most prolific months during 2024 for tornadoes were April, May, June, July and December, as each of these months reported 100 or more tornadoes.

[28] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2025). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73. In alignment with evolving priorities, statutory mandates, and staffing changes, NOAA has indicated that this product is being discontinued.

[29] (Source National Weather Service https://www.weather.gov/news/250703_tornado_activity)

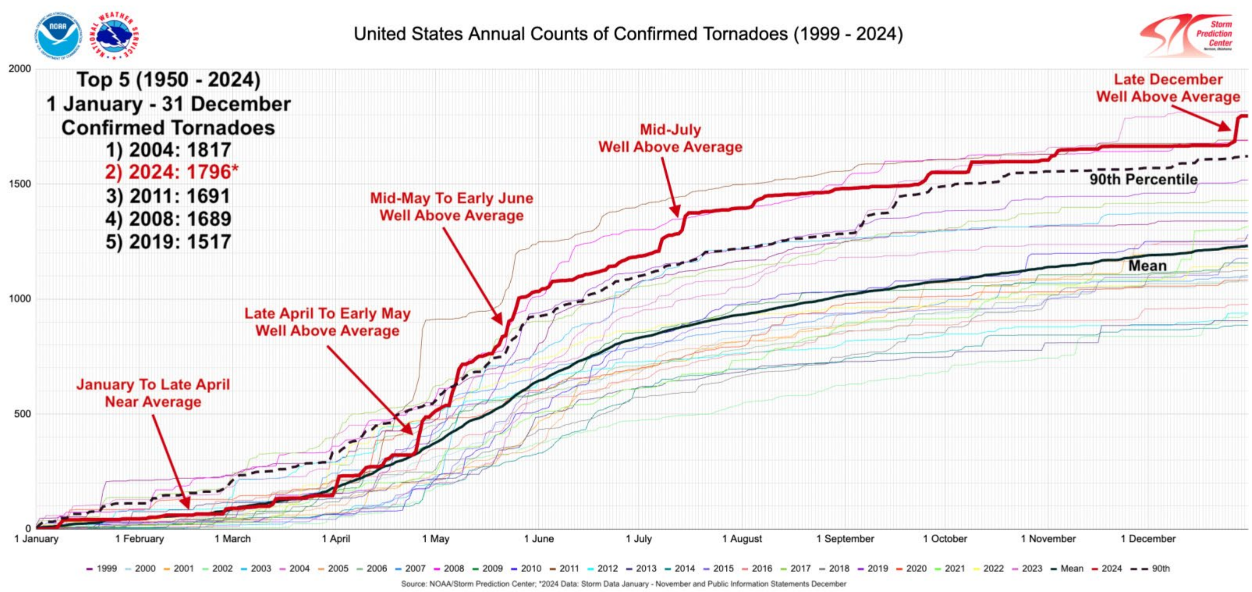

***Figure** 7. A graph showing the 2024 tornado season was historically significant.*

April 25-28 and May 19-26 were the most significant multi-day outbreaks of tornadoes.[30] During April 25-28, 183 tornadoes occurred across parts of the Midwest and Great Plains. The states most affected were Nebraska, Iowa, Kansas, Oklahoma and Missouri. This outbreak included at least 40 EF-0, 59 EF-1, 16 EF-2, eight EF-3, one EF-4 tornado and dozens of EF-U tornadoes, causing widespread damage to many homes, businesses, vehicles, agriculture and other infrastructure. Eastern Nebraska was particularly impacted, with multiple EF3s striking the state for the first time since 2014, wreaking havoc along their paths. Lincoln narrowly avoided a direct hit, with a large tornado packing 158 mph winds touching down on the edge of the city. The same storm also spawned a mile-wide tornado that heavily damaged the towns of Elkhorn, Bennington, and Blair on the outskirts of Omaha. This was the first EF4 tornado recorded in Nebraska since June 16, 2014. Near downtown Omaha, another EF3 touched down at Eppley Airfield, which destroyed several hangars and airplanes. Several tornadoes also touched down close to Topeka, Kansas while an EF-3 tornado caused extensive damage to the town of Westmoreland. The National Weather Service in Omaha issued 48 tornado warnings on April 26, which was the most the office has ever issued in a single day. On April 27, an EF4 tornado struck Marietta, Oklahoma damaging a large commercial distribution center.

Between May 19-26, 259 tornadoes were reported across many midwestern states over this continuous tornado-producing period. These tornadoes were rated as: 65 EF-0, 105 EF-1, 20 EF-2, 12 EF-3, one EF-4 and more than one dozen EF-U (unknown or unconfirmed) tornadoes. The states most affected included Nebraska, Iowa, Kansas, Illinois, Wisconsin, Missouri, Arkansas, Oklahoma, Texas and Kentucky. On May 21, an EF4 tornado cut a 44-mile path across southeast Iowa, resulting in five fatalities.

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[30] NOAA National Centers for Environmental Information, Monthly Tornadoes Report for Annual 2024, published online January 20241, retrieved on February 27, 2025 from https://www.ncei.noaa.gov/access/monitoring/monthly-report/tornadoes/202413. **DOI:** https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00769

A rare southern U.S. derecho occurred from Texas to Florida on May 16-17. On May 14, the Storm Prediction Center (SPC) forecasted for severe weather across portions of central and northern Texas. This risk area was zonally extended westward to the Texas–New Mexico border and eastward into southern Mississippi the following day. [31]By the morning of May 16, an enhanced risk was delineated across central Texas, extending southward and eastward toward the Texas and Louisiana Gulf coasts during the afternoon hours. Damage costs were estimated to be $1.2B with winds gusting to 100 mph in downtown Houston and 78 mph in Highlands, Texas[32]. There were four tornados over the course of the 2-day derecho which tracked from southeast Texas through Louisiana, southern Mississippi, Southern Alabama and Florida, with eight fatalities reported.

In 2024 there were nearly 65,000 wildfires that burned over 8,924,000 acres, which is the highest amount of acreage burned since 2020[33]. There were 11 deaths and 4552 structures destroyed form these wildfires. The largest of these was the Smokehouse Creek Fire in Texas from the end of February until mid-March burning over 1,054,000 acres and attributed to causing two fatalities[34]. Another wildfire in Phoenix, Arizona, in June consumed nearly 2,000 acres and caused the evacuation of more than 1,000 residents. In addition, an 80,000-acre wildfire spread across California and Nevada in early August[35].

4. Post-Windstorm Coordination During the Reporting Period

In NWIRP's 2015 authorizing legislation (Public Law 114-52), the U.S. Congress directs NIST to "coordinate all Federal post-windstorm investigations, to the extent practicable." Through the NWIRP WWG, several post-windstorm coordination activities were conducted during the reporting period. These included interagency NWIRP meetings and email exchanges that were held to provide an open forum for interagency information exchange in the aftermath of several weather disasters throughout FYs 2023-2024. Some examples follow.

Hurricane Ian

While Hurricane Ian made landfall in late FY 2022, the NWIRP agencies engaged in several coordinating activities in FY 2023. Interagency meetings in October 2022 and January 2023 included a discussion of Hurricane Ian activities, including storm surge reconnaissance efforts undertaken by academic colleagues. NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) scientists also produced wind maps to support ongoing work for the Florida Public Hurricane Loss Model (FPHLM). This model is used by the insurance community to determine damage rates. In FY 2023, FEMA deployed a Mitigation Assessment Team (MAT) to Florida following Hurricane Ian, which resulted in three Recovery Advisories,

[31] https://www.spc.noaa.gov/products/outlook/archive/2024/day2otlk_20240516_0600.html

[32] *National Centers for Environmental Information* (April 2024). *"U.S. Billion-Dollar Weather and Climate Disasters"* (*Press release*). Events. *Asheville, North Carolina*, United States: *National Oceanic and Atmospheric Administration*. *Archived* from the original on April 15, 2024.

[33] Source is National Interagency Fire Center https://www.nifc.gov/fire-information/statistics/wildfires

[34] "Smokehouse Creek Fire Information". InciWeb. InciWeb. March 16, 2024. Archived from the original on March 8, 2024.

[35] https://www.newsweek.com/york-fire-map-california-blaze-grows-80000-acres-crosses-nevada-1816757

a flood insurance claims case study, and a MAT report published in December 2023[36]. In FY 2024, FEMA executed a variety of training and outreach related to the Hurricane Ian MAT Report including numerous presentations virtually via webinars as well as in person at conferences. In addition, NIST, through an interagency agreement with NSF, funded Oregon State University to conduct a workshop on Hurricane Ian in June 2023 to bring together stakeholders and discuss data collection efforts and gaps. NIST has continued a long-term Hurricane Ian NWIRP research study focused on storm surge effects, emergency communications methods and effectiveness, and wind and wind-driven rain impacts, and this study, and efforts to implement recommendations from it, is expected to continue through at least FY28.

Maui Wildfires

Several NWIRP activities were undertaken in response to the August 2023 wildfires in Hawaii on the island of Maui, particularly in Lahaina. With coordination assistance from the U.S. Fire Administration (USFA) and FEMA, NIST deployed a preliminary reconnaissance team to connect with local officials and other stakeholders to understand the sources and availability of datasets in the event of a future in-depth research study or investigation. In addition, throughout FY 2023-2024, FEMA and USFA conducted wildfire MATs for the Maui wildfires with reports and recovery advisories being published beginning in FY25 and NIST contributing to the review of these output products.

Hurricane Idalia

The NWIRP agencies undertook a variety of activities in association with Hurricane Idalia in FY2023. NOAA's AOML collected atmospheric and oceanic data throughout the lifecycle of Idalia. Scientists flew eight flights gathering data to support NWS's National Hurricane Center operational efforts. Many instruments were launched to gather the data including Saildrones, ocean floats and gliders. Researchers also produced wind maps for the Florida Public Hurricane Loss Projection Model. This model is available to the insurance community to determine damage estimates. NWS's offices also issued forecasts, watches and warnings guided by data collected from operational radar, surface, upper air, and polar and geostationary satellites. NIST produced rapid estimates of the surface level peak gust winds under mission assignment (MA) from FEMA to support their Hazus (Hazards U.S.) Hurricane Model loss estimates (Figure 8). NIST widely distributed these results to federal and academic hurricane researchers as well as private sector stakeholders through FEMA's public disaster geodatabase website[37], the NSF-supported DesignSafe-CI Recon Portal,[38] and stakeholder emails and briefings.

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[36] https://www.fema.gov/case-study/harnessing-knowledge-impact-hurricane-ian-mat-report

[37] https://disasters.geoplatform.gov/publicdata/NationalDisasters/

[38] https://www.designsafe-ci.org/data/browser/tapis/designsafe.storage.community/Recon%20Portal%2F2023%20Hurricane%20Idalia%20Big%20Bend%20area%20Florida%20USA%2FNIST-ARA%20Windfield%20Data%20Release%201

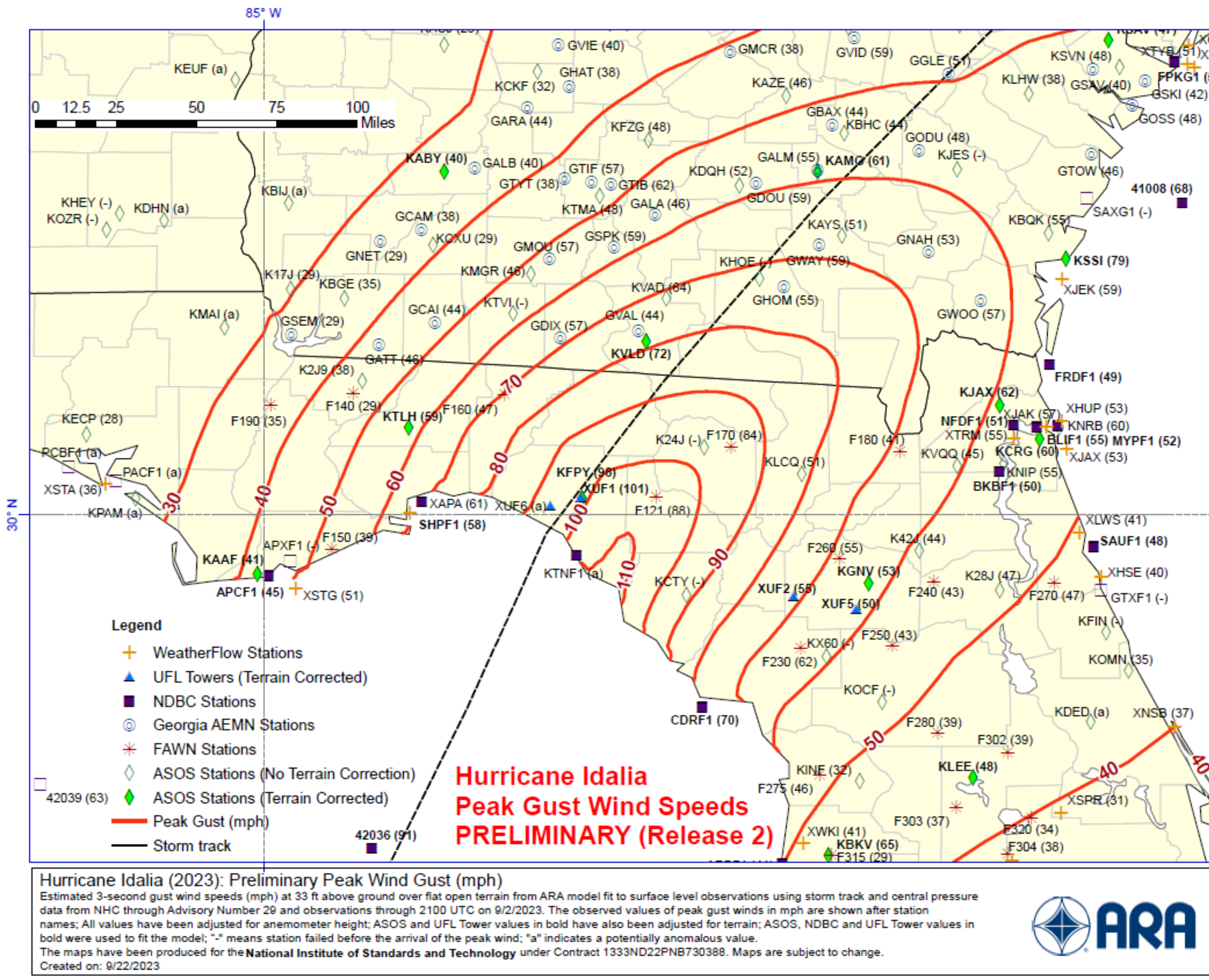

Figure 8. *Estimated peak wind gusts for Hurricane Idalia, corrected to standard height, averaging time, and exposure (3-sec peak gust at 10 m height in flat, open terrain. This product was developed by NIST and its contractor, Applied Research Associates (ARA, Inc).*

Spring 2024 Severe Weather Season

NIST coordinated with the NWS to support the study of warehouse performance in tornadoes. NIST preliminary reconnaissance field teams deployed to Marietta, Oklahoma, Lincoln, Nebraska, and Portage, Michigan, immediately following strong tornadoes in April and May of 2024. Figure 9 shows one of these facilities after being struck by an EF4 tornado. NWS staff at the National Weather Center provided NIST with initial data from local field offices and the Civil Air Patrol to aid in planning the field deployments, and the local NWS office in Omaha, Nebraska provided contact information for staff at a warehouse that was damaged near Lincoln.

Figure 9. *Tornado-damaged warehouse in Marietta Oklahoma following the April 27, 2024 storm. Source: Civil Air Patrol.*

Hurricane Helene

A number of activities were undertaken by NWIRP agencies in association with Hurricane Helene. NOAA's AOML collected atmospheric and oceanic data throughout the lifecycle of Helene. Scientists flew eight flights gathering data to support NWS's National Hurricane Center operational efforts. Many instruments were launched to gather the data including Saildrones, ocean floats and gliders. A coordinated effort across several NOAA offices was undertaken to gather these datasets. NWS's offices also issued timely forecasts, watches and warnings guided by data collected from operational radar, surface, upper air, and polar and geostationary satellites. The NSF-supported NEER team conducted pre-Helene lidar and drone scans in the anticipated areas of landfall. They also deployed wave gages, pore pressure transducers, and an acoustic Doppler current profiler in coastal areas in advance of landfall to collect data. NIST produced rapid estimates of the surface level peak gust winds for under mission assignment from FEMA to support their Hazus Hurricane Model loss estimates (Figure 10). NIST widely distributed these results to federal and academic hurricane researchers as well as private sector stakeholders through FEMA's public disaster geodatabase website[39], the NSF-supported DesignSafe-CI Recon Portal,[40] and stakeholder emails and briefings. Agencies outside those mandated by Congress to participate in NWIRP continue to support the program. For example, the United States Forest Service used uncrewed aerial systems (UAS) and remote sensing to gather imagery of damage to Federal lands caused by Hurricane Helene and Hurricane Milton. An interagency meeting in November 2024 included a session to discuss any further NWIRP agency plans related to this event.

[39] https://gis-fema.hub.arcgis.com/pages/incident-page-hurricane-helene-2024 https://gis-fema.hub.arcgis.com/pages/incident-coordination#model
[40] https://www.designsafe-ci.org/data/browser/tapis/designsafe.storage.community/%2FRecon%20Portal%2F2024%20Hurricane%20Helene%20Perry%20Florida%20USA%2FHurricane_Helene_Windfield_Release_2

The NSF-supported Structural Extreme Events Reconnaissance (StEER) Network conducted several data collection efforts to document the impacts from Helene. Virtual data gathering began a few days after landfall. Field teams collected street-level panorama data in Keaton Beach, Steinhatchee, Horseshoe Beach, and Cedar Key in Florida. A follow-up team conducted building performance assessments in the same areas. The data were made available online for quick perusal by researchers, and practitioners.[41]

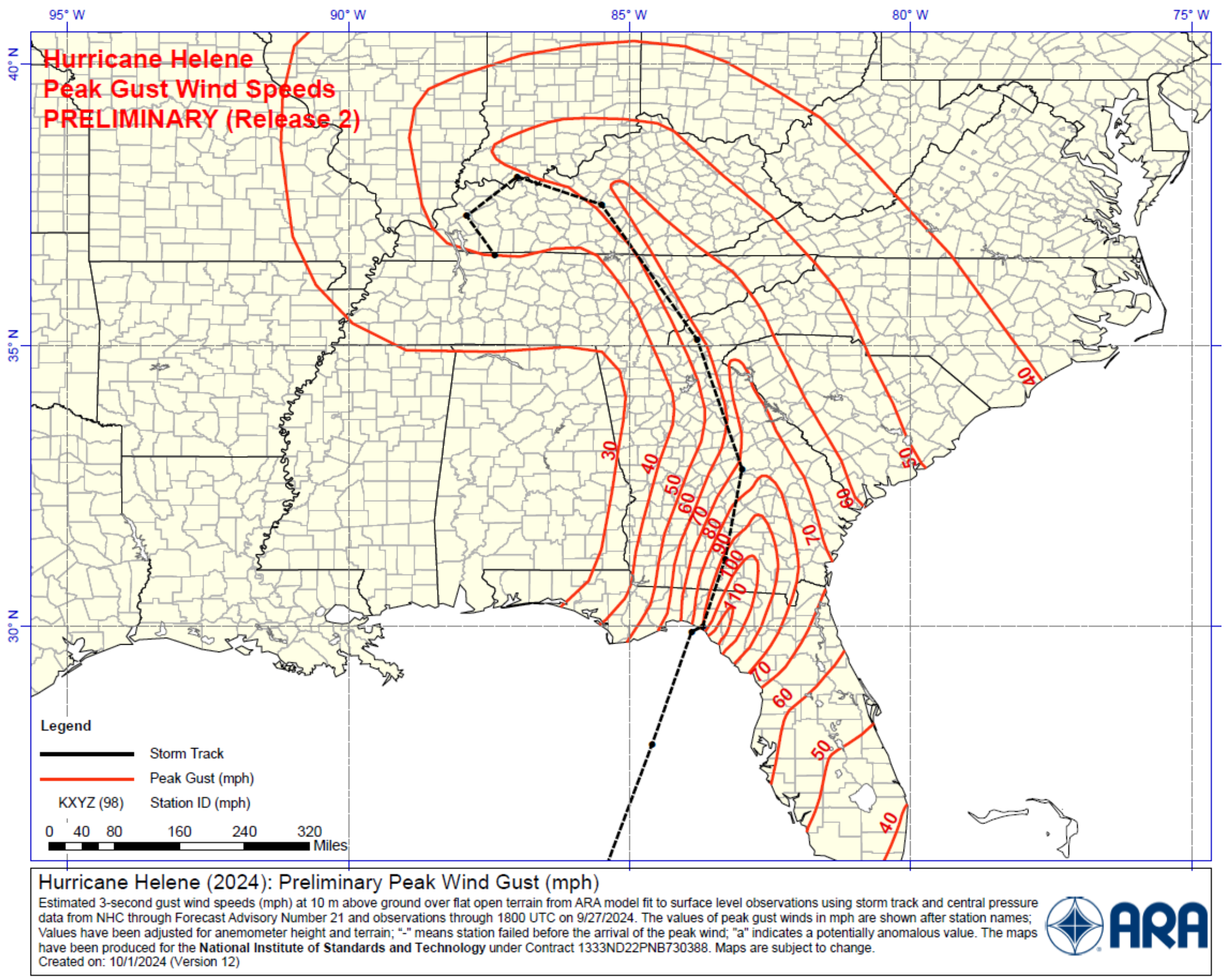

Figure 10. *Estimated peak wind gusts for Hurricane Idalia, corrected to standard height, averaging time, and exposure (3-sec peak gust at 10 m height in flat, open terrain. This product was developed by NIST and its contractor, Applied Research Associates (ARA, Inc).*

5. Progress in Fiscal Years 2023 and 2024

The NWIRP agencies continued to implement the NWIRP Strategic Plan[42] (released in late FY 2018) by focusing on advancing agency-relevant objectives across the Plan's three strategic goals and eight strategic priorities. The goals form a two-way research-to-applications paradigm that focuses on improving fundamental understanding of windstorm morphology, advancing understanding of impacts to the built

[41] https://www.steer.network/response/hurricane-helene

[42] See Appendix B for a complete list of NWIRP strategic goals, objectives and priorities.

community and related social and economic recovery mechanisms, and deployment of this basic and applied research to improve the resilience of communities nationwide. These goals are well-suited to address the challenges presented in Section 2 of this report. In this section of the report, the NWIRP agencies provide brief descriptions of key activities that support the three goals of the NWIRP Strategic Plan. Each entry also includes its relevance to 14 objectives and eight strategic priorities listed in Appendix B, which underpin the goals of the NWIRP Strategic Plan.

5.1 Strategic Priorities

FEMA: Hazus Hurricane Loss Estimation Model. FEMA develops and maintains the Hazus model, a nationally applicable standardized methodology that contains models for estimating potential losses from multiple hazards, including hurricane winds. Hazus uses geographic information system (GIS) technology to estimate physical, economic, infrastructure, and social impacts of disasters and graphically illustrates communities of high-risk due to a region's hazards. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the mitigation, preparedness, response, and recovery phases of the emergency management decision making process. The current Hazus model runs as a standalone program. However, FEMA is also researching cloud computing technologies to decrease processing times required for future hurricane response Hazus loss estimation efforts. This effort is known as OpenHazus. (*Strategic Priority 1, Objective 9*)

NIST: Storm Surge Flood Sensor. NIST developed specifications and awarded a contract in FY24 for the design and testing of a novel sensor for measurement of overland storm surge flooding. The low-cost, rapidly-deployable sensor will use digital cameras and image processing software including large-scale particle image velocimetry to measure flood depth, surface current, and wave height and period to assess the impact and forces of storm surge on buildings and other structures. (*Strategic Priority 2, Objective 1*)

NOAA: Advances in Severe Storm Data Collection. The NWS has been improving its high-resolution post-storm data collection of severe wind data since 2011 with the advent of new GIS tools and improved access to aerial and satellite imagery. The NWS maintains the Damage Assessment Toolkit (DAT), a GIS-based application made operational in FY 2023. The DAT is designed for efficient collection, analysis and delivery of storm damage data for documenting wind damage surveys, including tornadoes. NOAA has expanded its use of Saildrones, marine-based mobile observation platforms, which help analyze the strength of hurricanes before they move onshore. Saildrone data are now readily available to NWS forecasters via the same software used to issue marine wind watches, warnings and advisories. Uncrewed aerial systems are also being tested and deployed. NWS forecasters have access to the data as well. (*Strategic Priorities 2, 3*)

NIST: Tornado Strikes Database. NIST made progress on development of a database of tornado strikes on critical facilities, including buildings such as schools, fire stations and hospitals.[43] Once completed, this database and associated web-based GIS platform will provide a tool for communities to make risk-informed decisions about adoption of the latest model building codes, including provisions for tornado shelters and design of critical facilities to resist tornado loads. (*Strategic Priority 3, Objectives 8 and 12)*

[43] https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=934425

NIST: Performance-Based Design for Windstorm Hazards. The American Society of Civil Engineers (ASCE) conducted a stakeholder workshop for NIST to review the current state-of-the-art in Performance-Based Wind Design and identify research needs and priorities. The workshop was held in FY 2023, followed by publication of the workshop report.[44] *(Strategic Priority 4)*

NSF: Faculty Early Career Development (CAREER) Program. NSF's prestigious CAREER program supports early-career faculty who have the potential to serve as role models in research and education and to lead advances in the mission of their department or organization. CAREER awards are five-year investments in extended research and education projects that free promising early-career faculty to concentrate on their work rather than writing proposals for funding. In this reporting period NSF made 17 CAREER awards to scholars working on NWIRP-relevant research and education topics. *(Strategic Priority 8)*

NSF: National Academies' Roundtable on Risk and Resilience of Extreme Events (also known as the 'Resilient America Roundtable'). NSF funded the Roundtable to convene experts from academic, public, and private sectors to catalyze innovation at local, regional, national, and international levels. Its members, comprised of experts across disciplines and sectors, engage with policymakers, federal agencies, local communities, and practitioners in discussions on resilience and provide advice on program priorities, design, and evaluation. Roundtable meetings, held twice per year, aim to assess the state of resilience planning and implementation across diverse communities; and advance policies, knowledge, and practice that will build resilience and enhance safety and prosperity of communities across the nation and globally. *(Strategic Priority 6)*

NSF: Convening Groups. In FY24, NSF/GEO funded National Academy of Sciences, Engineering, and Medicine for a U.S. community study of "Attribution of Extreme Weather Events and their Impacts". In addition, NSF/GEO funded the U.S. research community to collaborate with the international community in the 3rd International Workshop on Waves, Storm Surges, and Coastal Hazards in 2023. NSF continued to support inter-departmental (DoW, NOAA, NASA, and NSF) annual discussion/review at the Tropical Cyclone Operation and Research Forum. *(Strategic Priorities 2, 6)*

NSF supports conferences and workshops in special areas of science and engineering that bring experts together to discuss recent research or education findings or to expose other researchers or students to new research and education techniques. In this reporting period the NSF made six conference and workshop awards on tropical cyclones, urban land uses and planning, and ocean mixing. *(Strategic Priorities 1, 2)*

FEMA: Education, Outreach, and Information Dissemination. Each year, many thousands of publications dealing with wind hazards are ordered and distributed by FEMA. For example, FEMA's safe room guidance publications are among the most widely downloaded and distributed documents by FEMA's library and publications warehouse. In FY 2023 - 2024, FEMA updated their safe room guidance publications and multiple fact sheets to be released in early FY 25. The two main publications included FEMA's most popular publication, FEMA P-320,[45] Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home, and FEMA P-361,[46] Safe Rooms for Tornadoes and Hurricanes: Guidance

[44] https://nvlpubs.nist.gov/nistpubs/gcr/2023/NIST.GCR.23-045.pdf

[45] https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf
[46] https://www.fema.gov/sites/default/files/documents/fema_safe-rooms-for-tornadoes-and-hurricanes_p-361.pdf

for Community and Residential Safe Rooms. This update will align FEMA's guidance and funding requirements with the 2023 edition of the storm shelter standard (ICC 500). *(Strategic Priorities 5, 6, 7)*

NOAA: Education, Outreach, and Information Dissemination. NOAA continues to be actively engaged in outreach to promote the protection of lives and property from windstorms. #HurricaneStrong is a joint initiative between the Federal Alliance for Safe Homes (FLASH®) and NOAA that provides hurricane safety and mitigation information through business summits, digital channels, home improvement store workshops, media outreach, school lesson plans, and a social media campaign featuring a #HurricaneStrong "pose".[47] In addition to #HurricaneStrong and the aforementioned Weather-Ready ambassador program, the NWS has been very active in preparedness activities with the public and its core partners. A small example of these events is provided here to reinforce the breadth of activities that occur.

- The NWS conducted training for emergency managers at the 2023 and 2024 National Hurricane Conferences and Florida Governor's Hurricane Conference.
- The NWS, in conjunction with other NOAA line offices, executed the Hurricane Awareness Tour. The tour coincided with National Hurricane Preparedness Week and had stops at cities along the U.S. Gulf Coast in 2023 and the East Coast in 2024. These events promote hurricane safety to the public and are organized by local NWS Weather Forecast Offices (WFOs).
- NWS WFOs conducted numerous tabletop severe storm and hurricane exercises with their emergency management and media partners such as the City of Los Angeles County Emergency Management Department's Extreme Weather Functional Exercise which centered on a hurricane scenario in 2024.
- The NWS staffed booths at public events and hosted forums with partners to provide precautionary and preparedness information that will help mitigate their risk from wind hazards.
- The NWS, in conjunction with other NOAA line offices, used opportunities like the various press conferences for the hurricane seasonal forecasts for the Atlantic/East Pacific, Hawaii, South Pacific, and West Pacific to promote hurricane safety.

These kinds of activities occur across all NWS offices in advance of severe storm, fire, and hurricane seasons. (*Strategic Priorities 6, 7*)

NIST/FEMA: Storm Shelter Standard. NIST and FEMA staff serve on the committee (chaired by a NIST staff member) responsible for development of the International Code Council (ICC)/National Storm Shelter Association (NSSA) *Standard for the Design and Construction of Storm Shelters*. The fourth edition of the standard (ICC 500-2023) was completed and published during this reporting period. Numerous change proposals submitted by NIST and FEMA were incorporated. Development of the separate commentary to the fourth edition began and is still ongoing. *(Strategic Priority 7, Objective 11)*

NSF: Rapid Response Research (RAPID). NSF has the capability to issue awards quickly, based on internal review only, when there is severe urgency with regard to availability of or access to data. Most often, these grants for RAPID are issued when disasters strike and researchers need to get into the field quickly in order to gather data before it disappears or degrades in such a way that a scientific opportunity would be lost. During this reporting period, NSF issued approximately 40 RAPID awards pertinent to NWIRP, including projects addressing the behavior and impacts of Hurricanes Fiona, Ian, Dora, Beryl,

[47] https://hurricanestrong.org

Hillary, Idalia, Debby, Ida, the tornado outbreak of December 10–11, 2021, and the December 15, 2021 Midwest derecho and tornado outbreak. RAPID research topics, which were proposed by university-based researchers, ranged from meteorological observations to measurement of impacts on natural and built environments, to evacuation behaviors, to effects on buildings and businesses. NSF/GEO funded a number of RAPID studies in response to national natural disasters and captured rare research opportunities. These included awards for wind and meteorological factors that contributed to 2023 Hawaii Maui Wildfires, during which 100+ lives were lost. *(Strategic Priorities 1, 2, 3, 7, 8)*

NSF: Research Experiences for Undergraduates (REU) Sites Program. NSF funds many research opportunities through its REU Sites program. An REU Site consists of a group of 10 or so undergraduates who work actively with faculty and other researchers on a shared research project. REU Sites aim to provide the kinds of exciting, engaging experiences that attract students to a career in science. They provide financial and housing support to the recipients and actively recruit students from schools where Science, Technology, Engineering, and Mathematics (STEM) research opportunities are limited.

The NHERI REU Summer Program provides research opportunities at ten NHERI multi-hazard engineering research infrastructure sites during a 10-week summer research program. The Program enables undergraduate college students to experience multi-hazard engineering as well as reconnaissance, cyberinfrastructure, data management, simulation, and social science research. In 2023 and 2024, the Program hosted 29 and 31 undergraduate students, respectively, from institutions across the United States. *(Strategic Priority 8)*

5.2 Goal A: Improve the Understanding of Windstorm Processes and Hazards

NIST: Topographic Effects on Wind Speeds. As part of its Hurricane Maria Program, NIST continued to make progress investigating the influence of topography on surface-level wind speeds in Puerto Rico. During FYs 2023-2024, NIST completed the analysis of wind tunnel testing data of topographic models representing Mayaguez and Yabucoa regions of Puerto Rico where the surrounding topography produces significant increases in wind speeds. NIST collected pre- and post-Hurricane Maria LiDAR (Light Detection and Ranging) vegetation data in Puerto Rico and applied these data to computational fluid dynamics (CFD) simulations, to better understand the impact of damaged forests on topographic wind speed. NIST has also successfully recorded field wind velocity and direction data from anemometers on three cell towers in the Yabucoa region since March 2021. These measurements have been analyzed to evaluate topographic effects and validate both the wind tunnel and computational models. *(Objectives 1, 2, 4, 6)*

NOAA: New Observing Technologies. Observing technologies such as the UAS that gather data in the lower atmosphere and the Saildrone technology that sails in the open ocean gathering data were utilized in Early Stage Experiments as a part of NOAA's Advancing the Prediction of Hurricanes Experiment (APHEX). These technologies were tested during the hurricane season and have proven to be of great value for learning about the air-sea environment during hurricanes. Records were broken using uncrewed aerial system for endurance in extreme environments. These records were recognized by the Guiness Book of World Records for two accomplishments: highest wind speed recorded by an uncrewed aircraft and longest endurance flight inside a tropical cyclone. Hurricane Field Program reports for 2023 are listed.[48] (*Objective 2*)

NOAA: New Observations. The National Severe Storms Laboratory (NSSL), and partner, Texas Tech University, embarked on a new VORTEX-USA funded project called NOAA: LIFT (Low-Level Internal Flows in Tornadoes, to observe the low-level wind and damage fields of tornadoes by deploying mobile surface stations, radars, and a high-resolution LIDAR. They collected data on several tornadoes in 2024, including a large tornado on May 23, 2024 near Eldorado, Oklahoma. The results from their work will benefit other NWIRP organizations involved in analyzing tornado loads on buildings *(Objectives 5, 6)*, improving wind speed estimation *(Objective 8)* as well as improving windstorm-resilience standards and codes *(Objective 11)*.

NOAA/NIST/FEMA/NASA/NRC/ASCE/AMS: Wind Speed Estimation (WSE) Standards Committee. The ASCE/Structural Engineering Institute (SEI)/American Meteorological Society (AMS) WSE is continuing the work on developing a new standard on wind speed estimation in tornadoes and other severe windstorms. Members of the ASCE/AMS WSE committee come from multiple affiliations, including NIST, NOAA, NASA, FEMA, NRC, non-profit agencies, private companies, and academic institutions. Several methods are under development, including a significantly expanded EF-Scale, three tree-fall pattern analysis techniques, engineering forensics, Doppler radar measurements, passive remote sensing support, and in-situ measurements involving anemometry. As of end of FY2024, the radar chapter passed internal balloting. The chapters on tree-fall pattern analysis and remote sensing were nearly finished, with work continuing to complete the EF-Scale, in-situ, and forensics chapter. Once all chapters finish internal balloting, they will go out for public comment, anticipated soon. (*Objective 2)*

NSF: Research Projects Examining Fundamental Principles in Windstorms. While finalizing a number of major multi-year field programs, i.e., PERiLS (Propagation, Evolution and Rotations in Linear Storms), TORUS (Targeted Observation by Radars and UAS of Supercells), SWEX (Sundowner Winds Experiment) which studies downslope winds and wildfires in California, and PRECIP (Prediction of Rainfall Extremes in the Pacific) which examines Typhoons, and monsoon induced and orographic-enhanced heavy precipitation study in the Pacific, initially reported in the 2021-2022 NWIRP biennial report, several extended studies and new field programs were initiated. These included BEST (Boundary-layer Evolution and Structure of Tornadoes;); TORUS-LItE (Targeted Observations by Radars and UAS of Supercells) which is an investigation of supercell left flank boundaries and coherent structures; ESCAPE (Experiment of Sea Breeze Convection, Aerosols, Precipitation and Environment); MITTEN CI (Maritime to Inland Transitions Towards ENvironments for Convection Initiation); ICECHIP (In-situ Collaborative Experiment for the Collection of Hail In the Plains). NSF/GEO funded a project to study environmental control over tropical cyclone formation; Tropical cyclone intensity change; Cloud-Radiation Feedback at Convective Scales in Tropical Cyclones; lightning and precipitation related to sea-breeze convection *(Objectives 1, 3; Strategic Priorities 2, 8)*

NSF is continuing to expand the Community Instruments and Facilities program which makes university-based instruments available to the broader US research community. The cohort of facilities that can be

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48 https://www.aoml.noaa.gov/2023-hurricane-field-program/ and https://www.aoml.noaa.gov/2024-hurricane-field-program/

deployed under NSF funding now includes three radar groups (University of Alabama at Huntsville, Colorado State University, and the University of Oklahoma) with experience in tornado, hurricane, and other windstorm studies. *(Objectives 1, 2; Strategic Priorities 2, 8)*

NSF funded multi-year projects to improve understanding of supercell storms and formation of tornadoes through observations, modeling, and data science; new technology based on scientific theories and computer visualizations in four dimensions to improve the prediction of tornadoes and derechos; an examination of how severe thunderstorms and tornadoes may change in the future; investigations of various aspects of TC pathways, including development of a storm, rapid intensification, secondary eyewall cycle, as well as prediction of hurricane size and intensity; and studies on weather and wildfire interactions *(Objectives 1, 2, 3)*. Additional examples include the investigation of the processes involved in the formation and maintenance of derechos, rotation in squall lines, updraft properties relate to supercell evolution and the production of its hazards, and tornadoes and their supercells impacted by the extratropical transition of tropical cyclones. *(Objectives 1, 2; Strategic Priorities 2, 8)*

NSF: Services and Support for Academic and Agency Atmospheric Research. NSF's National Center for Atmospheric Research (NCAR) provides necessary support for the U.S. academic community and collaborations with other federal agencies. In particular, during the reporting period, NCAR has provided data services to NOAA for the Congressionally-mandated program, VORTEX-USA, that studies tornadogenesis in the Southeast U.S. and now, elsewhere. In collaboration with NOAA, DoW, DOE and many other agencies, NCAR also continues to lead the development of community weather prediction models that are widely used throughout the federal and private sectors and in the academic community. These models include CESM (Community Earth System Model); WRF (Weather Research and Forecast Model); MPAS (Model for Prediction Across Scales); and Cloud Model 1 (CM1). NCAR also assisted NOAA in the development of UFS (Unified Forecast System). During this reporting period, NCAR was also working on development of the Airborne Phased Array Radar (APAR), a world-class cutting-edge facility that would enable the U.S. research community to better research severe storms such as tornadoes and hurricanes *(Objectives 1, 2, 3; Strategic Priorities 2,8)*.

5.3 Goal B: Improve the Understanding of Windstorm Impacts on Communities

FEMA: Mitigation Assessment Team (MAT) Program: FEMA conducts building performance studies after unique or nationally significant disasters to better understand how natural events affect the built environment. The MAT is deployed only when requested by the state, federally recognized tribe, or territory. The findings and recommendations derived from field observations and analyses are used to provide design and construction guidance that will improve the disaster resistance of the built environment in the affected state or region and often prove to be of national significance to other disaster-prone regions. The MAT studies the adequacy of current building codes, local construction requirements, building practices, and building materials based on the damage observed after a disaster. Lessons learned from the MAT's observations are communicated through comprehensive MAT reports, Recovery Advisories, Fact Sheets, and Design Guides made available to communities to aid in their rebuilding effort and to enhance the disaster resistance of building improvements and new construction. In FY 2023, FEMA deployed a MAT to Florida following Hurricane Ian, which resulted in three Recovery Advisories, a flood insurance claims case study, and a MAT report published in December 2023 (discussed in the Hurricane Ian section above). In FY 2024, FEMA executed a variety of training and outreach related to the Hurricane Ian MAT

Report including numerous presentations virtually via webinars as well as in person at conferences. In FY 2024, FEMA monitored the impacts on the built environment from Hurricanes Helene and Milton as well as numerous tornadoes. Also in FY 2023-2024, FEMA and the U.S. Fire Administration (USFA) conducted wildfire MATs for the Marshall Fire in Colorado (December 2021) and Maui wildfires in Hawaii (August 2023). Both wildfire events had wind-related impacts, which are outlined in the observations, conclusions, and recommendations of the MAT publications such as *Mitigation Strategies to Address Multi-Hazard Events* (Marshall Fire MAT, 2023). *(Objective 5)*

NIST: Science-Based Methodologies for Aerodynamic Simulation to Determine Wind Loads on Buildings and Structures. NIST is engaged in an effort to develop practical CFD methods for the numerical determination of aerodynamic forces on structures induced by strong winds. Progress during FYs 2023-2024 included the development of a quantification procedure for numerical and input error uncertainties in CFD simulation results using a Gaussian Process model to produce more accurate, site-specific wind loads, resulting in safer and more economical structures. *(Objectives 5, 6)*

NIST: Tools for Analysis of Measured Wind Pressure Data: NIST is developing next-generation methods and tools to better characterize wind loads on buildings and the response of these structures to extreme winds to advance performance-based design standards. During FYs 2023-2024, in partnership with a private structural engineering firm, NIST developed ETABS-based software for reinforced-concrete high-rise buildings allowing the effective and practical use of the Database-Assisted Design (DAD) procedures by structural engineering practitioners. *(Objectives 5, 6)*

NIST: Center for Risk-Based Community Resilience Planning. The NIST-funded Center for Risk-Based Community Resilience Planning (http://resilience.colostate.edu), is a collaborative effort between NIST and 14 universities led by Colorado State University. During FYs 2023-2024, the center released version 5.5.0 of IN-CORE (Interdependent Networked Community Resilience Modeling Environment). IN-CORE models the impact of a user-designed natural hazard (e.g., a tornado) on a community to evaluate user-modified physical and socio-economic attributes of a community. This allows community planners to test different models of disaster resilience planning with the goal of optimizing disaster response. Additionally, a nonprofit organization, Project IN-CORE, was established to ensure that this cutting-edge capability continues beyond the 10-yr NIST-funded period for the Center; consulting services are offered to help communities apply IN-CORE (https://in-core.org/), *(Objectives 5, 7; Strategic Priority 3)*

NIST: Longitudinal Study of the Recovery of Lumberton, NC, from Hurricane Matthew: NIST conducted its sixth data collection in-person in FY 2023, focused on documenting the long-term impacts of and recovery from Hurricane Matthew and Hurricane Florence for housing, businesses, infrastructure systems, and the public sector. The team also expanded the collection of actions for preparedness, hazard mitigation, impact adaptation, and resilience to future events. NIST published the report from its fourth data collection in FY 2023 and from its fifth data collection in FY 2024. *(Objectives 5, 7, 8)*

NSF: Nearshore Extreme Events Reconnaissance (NEER) Network. NEER deployed fast-response research teams following Hurricane Helene in September of 2024. The teams gathered measurements spanning natural mangrove, dune, and tidal flat systems, as well as rubble mound and seawall features. They also collected extensive bathymetry, topography, and soil observations. Data is shared widely through NSF NHERI DesignSafe-CI. *(Objectives 5, 8; Strategic Priorities 2, 3)*

NSF: Structural Extreme Events Reconnaissance (StEER) Network.[49] This NSF-supported research network developed quick-response datasets and reconnaissance reports for four windstorm events (Hurricane Idalia, Hurricane Otis, Houston Derecho, Hurricane Helene) during the FYs 2023-2024 reporting period. The reports are free and available for download at https://www.steer.network/responses. *(Objectives 5, 8; Strategic Priority 3)*

NSF: Sustainable Material Management Extreme Events Reconnaissance (SUMMEER) Network. During this reporting period, the SUMMEER network collected ephemeral data on uncollected debris on public roadways during the course of debris collection operations in order to investigate illegal debris disposal. The data are available at https://doi.org/10.17603/ds2-m7zs-xr98 *(Objectives 5, 8; Strategic Priority 6)*

NSF/NIST: Wind Hazard and Infrastructure Performance Center (WHIP-C). This multi-university Industry-University Cooperative Research Center (IUCRC) addresses NWIRP-relevant research questions. The WHIP-C's Industry Advisory Board members are drawn from insurance, risk-modeling, and building and construction industries, and NIST joined as a member in FY 2022. In this reporting period, the WHIP-C initiated new studies of wind effects on ballasted rooftop photovoltaic systems; wind-induced loads on irregularly-shaped buildings; integration of field damage, hazard, and exposure data for potential use in risk models; empirical vulnerability model to assess impact of windborne tree debris on low-rise construction; evaluation of tornado-like loading on buildings of various shapes and geometries; ballasted PV system load sharing and effective wind area; risk vulnerability model for components of refinery plants or industrial facilities; among other topics. In addition to supporting WHIP-C research through its membership dues and NIST staff serving as mentors on several projects, NIST also provided enhancement funds to significantly expand the scope of the tornado load research. *(Objectives 5, 7, 8, 9; Strategic Priorities 3, 4, 5)*

NSF: Natural Hazards Engineering Research Infrastructure (NHERI). All of NHERI's major experimental facilities dedicated to natural hazards research (see Appendix C), including several specifically pertinent to NWIRP topics, continued operating during this reporting period, providing continuity and support for the relevant research communities. Planning for a new wind, wave, and surge testing facility (known as the National Full-Scale Testing Infrastructure for Community Hardening in Extreme Wind, Surge, and Wave Events (NICHE)) continued while a new National Testing Facility for Enhancing Wind Resiliency of Infrastructure in Tornado-Downburst-Gust Front Events (NEWRITE) began its design phase. *(Objectives 5, 6, 7, 9; Strategic Priorities 3, 4, 5, 8)*

FEMA: Hazus Hurricane Loss Estimation Model: FEMA enhanced Hazus by implementing updated buildings schemes for Hazus based on building code adoption. This will further refine loss estimates at the census tract level by reflecting a community's adoption of building codes. Additionally, the Hazus team took steps to ensure the longevity of the software with plans to release an updated version in the future. This version of Hazus will utilize the Esri ArcGIS Pro platform and this shift will continue until full feature parity is achieved. (*Objective 9*)

[49] https://www.steer.network/.

NIST: Hurricane Wind Field Analysis Mission Assignments: NIST conducted MAs for FEMA to develop rapid estimates of the surface-level wind fields for Hurricanes Idalia and Helene, in support of operational applications of the Hazus Hurricane Model and other disaster response needs. (*Objective 9*)

NIST: Advancements in Computational Wind Engineering (CWE). Working with ASCE, NIST supported a workshop to assess the current state of the art in CWE and identify needs to advance knowledge in this area and its application into practice. NIST published the workshop report[50] in early FY24. The top priority identified by the workshop participants was development of guidelines and minimum requirements for the practical application of CWE. To address this priority, NIST awarded a contract to ASCE for development of a pre-standard for use of computational wind engineering in building design. (*Objectives 6, 11*)

NIST: Hurricane Maria Program. In FYs 2023-2024 NIST completed all planned data collection activities as part of its multi-year National Construction Safety Team (NCST) investigation of the impacts of Hurricane Maria on Puerto Rico. For the complementary NWIRP research study of Hurricane Maria's impacts and subsequent recovery, NIST completed nearly all data collection activities in FYs 2023-2024, with the exception of a few remaining interviews that were completed in the first month of FY 2025. Data collection for the NCST investigation included wind tunnel testing of building and topographic models to better understand the effects of topography on wind loads; information provider interviews, household surveys, and household interviews about the public's response to emergency communications; hospital interviews, medical records abstraction, and interviews with next-of-kin of the deceased to understand the factors that contributed to hurricane-related deaths; and site visits, interviews with facility managers, and collection and review of documentation to evaluate building performance for selected critical facilities, including hospitals and schools used as shelters. Data collection for the NWIRP research study included interviews with shipping and transportation representatives and surveys of manufacturing and retail service businesses to understand hurricane impacts and subsequent recovery; two waves of school and hospital surveys and follow-up interviews with school and hospital administrators to understand the post-hurricane recovery of education and healthcare services; and structured interviews with power, water, and transportation infrastructure representatives, along with collection of transportation incident data, satellite remote-sensing data, and aerial imagery, to understand the interdependencies between infrastructure systems and the factors that contributed to failures and long-term outages. By the end of FY 2024, data analysis and report writing were well underway across all seven technical projects within the Hurricane Maria Program. The findings will support recommendations for changes to codes, standards, and practices for the purpose of increasing community resilience in the face of hurricanes. In FY 2023, supported by funding from the Disaster Relief Supplemental Appropriation Act of December 2022, the NIST team extended the Hurricane Maria Program to consider impacts of Hurricane Fiona, which struck Puerto Rico in September 2022. Observations from that event are expected to provide context and inform recommendations from the Hurricane Maria Program. *(Objectives 1-14)*

U.S. Forest Service: Tree Structure Impact Predictive (TreeS-DIP): The FY2023 Disaster Supplemental Appropriations Act provided to the U.S. Forest Service $2.056 billion to cover capacity needs related to wildfire emergency management and to provide for repair and reconstruction needs associated with recent wildfires, hurricanes, and other natural disasters. The U.S. Forest Service's Tree Structure

[50] https://nvlpubs.nist.gov/nistpubs/gcr/2023/NIST.GCR.23-047.pdf

Impact Predictive (TreeS-DIP) model estimates the extent of timber damage within 48 hours of a storm. *(Objective 5,8)*

5.4 Goal C: Improve the Resilience of Communities Nationwide

FEMA: Improving Wind-Resistant Provisions. Significant improvements have been made to model building codes and national standards pertaining to design and construction of windstorm-resistant buildings and other structures as the result of NWIRP activities. FEMA continually defends provisions that mitigate damage from all natural disasters, including high winds, and proposes changes based on findings from post-disaster investigations such as the MAT reports. *(Objective 5)*

Through a collaborative effort with stakeholders, FEMA makes available to the public a substantial library of guides and resources aimed at mitigating building damage[51] and promoting safe construction and usage of shelters[52] from severe windstorms and associated hazards. More FEMA publications, related to wind and coastal surge hazards, are available for free on FEMA's media library website, the Google Books website, and MADCAD website. Many of these presentations and training interventions were focused on hurricane wind mitigation in areas that are currently rebuilding. FEMA also provides in-person and online training based out of the Emergency Management Institute (EMI) in Emmitsburg, MD. FEMA includes advanced wind-related modules for in-person training courses at EMI. *(Objective 11)*

NIST: Translating R&D Advances into Model Building Codes and Standards. A decade of NIST-led research, development, and codes and standards engagement on tornado loads culminated with the International Code Council's publication of the 2024 IBC that included requirements for certain buildings to be designed to resist tornado loads, as determined by the ASCE 7-22 Standard for Minimum Design Loads on Buildings.[53] *(Objective 11)*

FEMA/NIST: Tornado Resistant Design Guidance. FEMA and NIST collaborated on the development of two publications supporting adoption and implementation of tornado-resistant design of buildings: the *Design Guide for New Tornado Load Requirements in ASCE 7-22*[54], and a fact sheet on *Improving Windstorm and Tornado Resilience: Recommendations for One- and Two-Family Residential Structures.*[55] *(Objective 12)*

NOAA: Forecast Improvement Programs.

- The Hurricane Forecast Improvement Project (HFIP) transitioned the Hurricane Analysis and Forecast System (HAFS) model as the next generation hurricane regional model during the 2023 Atlantic

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[51] https://www.fema.gov/emergency-managers/risk-management/building-science

[52] https://www.fema.gov/emergency-managers/risk-management/safe-rooms/resources

[53] https://codes.iccsafe.org/s/IBC2024P1/chapter-16-structural-design/IBC2024P1-Ch16-Sec1609.5

[54] https://www.fema.gov/sites/default/files/documents/fema_asce-7-22-tornado-loads-design-guide_012023.pdf

[55] https://www.fema.gov/sites/default/files/documents/fema_improving-windstorm-resilience-fact-sheet_022023.pdf

Hurricane season. Further improvements were implemented in the 2024 Atlantic Hurricane season increasing the resolution for enhanced prediction of track, intensity, and storm structure. HFIP continues toward further improvements in all aspects of hurricane prediction and analysis with an eye to future development including enhanced data assimilation, probabilistic ensemble forecasts, and deterministic model improvements to track, intensity, and structure across multiple storms at basin scales. *(Objective 13)*

- During FYs 2023-24, the Hurricane and Ocean Testbed tested new techniques, applications, and ensemble model enhancements to improve the analysis and prediction of tropical cyclones. One of the major focuses of the testbed is the development of next generation tropical cyclone wind speed probabilities that will take inland wind reduction into account to more accurately depict wind hazards. *(Objective 13)*

- NOAA continues to develop a next generation hazardous weather forecast/warning framework called FACETs (Forecasting a Continuum of Environmental Threats), which aims to provide users a suite of continuously updating probabilistic information about hazardous weather threats. Near term experimental probabilistic guidance for severe storm hazards (tornadoes, hail, wind and lightning), including a cloud-based ensemble model called the Warn-on-Forecast System (WoFS), are being evaluated with NWS forecasters and other core partners through the NOAA Hazardous Weather Testbed (HWT). In addition, a project called Threats In Motion (TIM), where current polygon-based warnings are allowed to move with severe local storms, has undergone testing at the NWS Operations Proving Ground (OPG) as well as the HWT. Once implemented, there is a strong likelihood that TIM will improve tornado and severe thunderstorm warning lead times. *(Objective 13)*

- **NSF/NIST: Joint Disaster Resilience Research Grants (DRRG) Program.** DRRG aims to advance fundamental understanding of disaster resilience in support of improved, science-based planning, policy, decisions, design, codes, and standards. In FY 2024, 18 DRRG awards were issued, including four NWIRP-relevant projects.[56] *(Objectives 10, 11, 12)*

  NSF: Innovations for Improved Community Resilience. The CIVIC Innovation Challenge, which is run in partnership with the Department of Homeland Security (DHS) and DOE, flips the usual community-university dynamic by asking communities to identify priorities ripe for innovation then partner with researchers to address those priorities. In this reporting period, CIVIC made three NWIRP-relevant awards in which researchers are working directly with communities to solve important disaster-related problems. *(Objectives 10, 12, 13, 14)*

  NSF: Large-Scale Investments in Coastal Resilience. NSF's Coastlines and People (CoPe) program issued two cohorts of large-scale "hub" awards that engages with communities vulnerable to storm and sea-level rise risks to jointly identify research priorities and co-produce knowledge, tools, and new interventions to reduce vulnerabilities and improve resilience to natural hazards. The Coastal Hazards, Equity, Economic prosperity, and Resilience (CHEER) Hub, headquartered in the Disaster Research Center at the University of Delaware, is advancing the understanding of the complex interactions among three intersecting goals in coastal communities and develop tools to help address these challenges. *(Objectives 10, 12, 13, 14)*

[56] https://www.nsf.gov/news/nsf-nist-collaborate-7m-disaster-resilience-investment

NSF: Researchers and Communities Collaborating to Define Needs and Opportunities. The NSF's NHERI Program completed a Decadal Visioning Project for 2026-2035, engaging the relevant research communities in deliberations about what types of research infrastructure and resources will be most valuable to advance an understanding that can improve the Nation's resilience to natural disasters going forward. Also, the NHERI Network Coordination Office engaged with the relevant research communities and updated its Five-Year Science Plan. These reports help the decentralized U.S. natural hazards research communities to share priorities, findings, and resources for maximum effectiveness. *(Objectives 12, 14)*

6. The Path Forward

As windstorm impacts increase, it is critical that NWIRP agencies continue to implement the NWIRP Strategic Plan and identify new opportunities for improved synergy across scientific disciplines, interagency engagement, and education and outreach to amplify NWIRP awareness. Provided below are NWIRP visions which the WWG has agreed are worthy elements of the strategic plan that should move forward should support and resources become available. These visions will be revisited by the WWG and updated in the NWIRP Strategic Plan when the opportunity arises.

- Expand awareness of the NWIRP research-to-applications paradigm across the federal enterprise by engaging in interagency councils, committees, and working groups with equities in windstorm impact reduction measures, including but not limited to, the Interagency Council for Advancing Meteorological Services (ICAMS), the U.S. Global Change Research Program (USGCRP), the National Science and Technology Council (NSTC)'s Subcommittee on Resilience Science and Technology (SRST), and the Science for Disaster Reduction (SDR) interagency working group.
- Strengthen NWIRP post-windstorm assessments by supporting federal coordination with university-based researchers and leverage disaster reconnaissance data streams to advance interactive technology transfer based on the NWIRP TC Coordination Plan for Science and Technology. This will enable the identification of high priority applied research questions that are unique to the interdisciplinary windstorm disaster reduction field. Additionally, NWIRP post-disaster research guidance will acknowledge and support efficient and effective formal and informal collaborations and support investments to recruit and enable a world-class next generation of U.S.-based windstorm-relevant researchers.
- Advance research into identifying needed building code and infrastructure adaptations for the next century. To do this, a connection must be made between global scale weather characteristics to the trends in natural hazards on a local scale that more directly affect building and infrastructure performance. Upon this, research can inform implementation and then subsequent adoption by local communities. The path to this adoption can take significant time and must begin with actionable information that can be used on the local scale. Thus, a memorandum of understanding between NOAA, NIST, and the ASCE has been signed to convene a series of workshops to identify best practices in utilizing forward-looking community resilience planning and designs of resilient buildings and infrastructure. Actions that the workshops identify will likely evolve into broader cross-disciplinary research and development between NOAA, NIST, and ASCE. NWIRP agencies, and their collaborators, should be involved to enhance the ability to advance research into mitigating adverse outcomes from severe windstorms and associated hazards. Furthermore, these activities should be backed by sufficient funding to maximize the probability of success.

- Contribute to building a Weather-Ready Nation (WRN) by integrating scientific advances in real-time impact-based extreme weather event forecasting and delivery, informed by social science and engineering, to elicit the appropriate responses by individuals and organizations, in alignment with the weather. The development of probabilistic forecasts and warnings should continue to be a high priority, along with methods to ensure such information is made available and is actionable by individuals and organizations. The social science role informs the content of the forecasts and warnings to elicit the appropriate response while the engineering informs the process of relating the hazard intensity to predict the impacts upon the built environment and infrastructure. NWIRP organizations should continue their efforts to improve the suite of options to provide forecast and warning information and guidance to take action, including promoting more options for shelters to accommodate the wide range of exposure and vulnerabilities among the public and organizations. NWIRP stands ready to support the development of short-term warnings and decision support information for wildfire hazards, by providing guidance for predicting wildfire spread in high winds, fire-generated windstorms, and tornadoes and subsequent impacts.[57,58,59] In addition, NWIRP can be leveraged to improve the verification of probabilistic warnings and forecasts which then feeds back to supporting warning improvements as well as community resilience.
- Support the implementation of recommendations from interagency post-windstorm research and development activities to improve hazard measurement science, advancing the Nation towards performance-based design, and strengthening the scientific foundation for the development of consensus codes and standards. For example, NWIRP has promoted life-safety protection measures for tornado impacts in products developed by national and international standards development organizations.
- NWIRP will ensure that the U.S. non-governmental science and engineering communities are made aware of NWIRP-relevant Federal science and technology reports, studies, and priority-setting documents, while the NWIRP agencies will stay abreast of university-based findings and promising new research approaches to strengthen coordination and shared awareness to enable more impactful work.

[57] https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
[58] https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf
[59] https://www.nwcg.gov/sites/default/files/committee/docs/fenc-satellite-data-task-team-final-report.pdf

Appendix A: Acronyms and Abbreviations

AMS	American Meteorological Society
AOML	Atlantic Oceanographic and Meteorological Laboratory
APHEX	Advancing the Prediction of Hurricanes Experiment
ASCE	American Society of Civil Engineers
CAREER	Faculty Early Career Development
CESM	Community Earth System Model
CFD	Computational Fluid Dynamics
CoPe	Coastlines and People
CPI	Consumer Price Index
CWE	Computational Wind Engineering
DAD	Database-Assisted Design
DHS	Department of Homeland Security
DoW	Department of War
DOE	Department of Energy
DRRG	Disaster Resilience Research Grants
DTC	NCAR's Developmental Testbed Center
EF	Enhanced Fujita [Scale]
EMI	Emergency Management Institute
FACETs	Forecasting a Continuum of Environmental Threats
FEMA	Federal Emergency Management Agency
FPHLM	Florida Public Hurricane Loss Model
FY	fiscal year
Hazus	Hazards U.S., a Geographic Information System (GIS)-based natural hazard analysis tool developed and distributed by FEMA
HAFS	Hurricane Analysis and Forecast System

HFIP	Hurricane Forecast Improvement Project
HWT	Hazardous Weather Testbed
IBC	International Building Code
ICAMS	Interagency Council for Advancing Meteorological Services
ICC	International Code Council
IN-CORE	Interdependent Networked Community Resilience Modeling Environment
IRC	International Residence Code
IUCRC	Industry-University Cooperative Research Center
MA	Mission Assignment
MAT	Mitigation Assessment Team
MPAS	Model for Prediction Across Scales
mph	miles per hour
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCST	National Construction Safety Team
NCSTA	National Construction Safety Team Act
NEER	Nearshore Extreme Events Reconnaissance
NHC	National Hurricane Center
NHERI	Natural Hazards Engineering Research Infrastructure
NICHE	National Full-Scale Testing Infrastructure for Community Hardening in Extreme Wind, Surge, and Wave Events
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
NSF	National Science Foundation
NSSA	National Storm Shelter Association

NSSL	National Severe Storms Laboratory
NSTC	National Science and Technology Council
NWIRA	National Windstorm Impact Reduction Act
NWIRP	National Windstorm Impact Reduction Program
NWS	National Weather Service
OAR	NOAA's Oceanic and Atmospheric Research
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PAR	Phased Array Radar
PERiLS	Propagation, Evolution and Rotation in Linear Storm
PSDA	Post-Storm Data Acquisition
RAPID	Rapid Response Research
REU	Research Experiences for Undergraduates
R2O	Research to Operations
SDR	Science for Disaster Reduction
SEI	Structural Engineering Institute
SPC	Storm Prediction Center
SRST	Subcommittee on Resilience Science and Technology
StEER	Structural Extreme Events Reconnaissance
STEM	Science, Technology, Engineering, and Mathematics
SUMMEER	SUstainable Material Management Extreme Events Reconnaissance
TC(s)	Tropical Cyclone(s)
TIM	Threats In Motion
TORUS	Targeted Observation by Radars and UAS of Supercells
UAS	Uncrewed Aerial System
UFS	Unified Forecast System

U.S.	United States
USGCRP	U.S. Global Change Research Program
VORTEX-USA	Verification of the Origins of Rotation in Tornadoes Experiment-United States of America
WHIP-C	Wind Hazard and Infrastructure Performance Center
WoF	Warn-on-Forecast
WoFS	Warn-on-Forecast System
WRF	Weather Research and Forecast
WRN	Weather-Ready Nation
WSE	Wind Speed Estimation
WWG	Windstorm Working Group

Appendix B: NWIRP Strategic Goals, Objectives, and Priorities

Goal A. Improve the Understanding of Windstorm Processes and Hazards

Objective 1: Advance understanding of windstorms and associated hazards

Objective 2: Develop tools to improve windstorm data collection and analysis

Objective 3: Understand long term trends in windstorm frequency, intensity, and location

Objective 4: Develop tools to improve windstorm hazard assessment

Goal B. Improve the Understanding of Windstorm Impacts on Communities

Objective 5: Advance understanding of windstorm effects on the built environment

Objective 6: Develop computational tools for use in wind and flood modeling on buildings and infrastructure

Objective 7: Improve understanding of economic and social factors influencing windstorm risk reduction measures

Objective 8: Develop tools to improve post-storm impact data collection, analysis, and archival

Objective 9: Develop advanced risk assessment and loss estimation tools

Goal C. Improve the Windstorm Resilience of Communities Nationwide

Objective 10: Develop tools to improve the performance of buildings and other structures in windstorms

Objective 11: Support the development of windstorm-resilient standards and building codes

Objective 12: Promote the implementation of windstorm-resilient measures

Objective 13: Improve windstorm forecast accuracy and warning time

Objective 14: Improve storm readiness, emergency communications and response

Strategic Priorities

SP-1: Develop Baseline Estimates of Loss of Life and Property due to Windstorms

SP-2: Obtain Measurements of Surface Winds and Storm Surge Current and Waves in Severe Storms

SP-3: Develop Publicly Available Databases of Windstorm Hazards and Impacts

SP-4: Develop Performance-Based Design for Windstorm Hazards

SP-5: Improve Windstorm Resistance of Existing Buildings and Other Structures

SP-6: Enhance Outreach and Partnerships to Improve Windstorm Preparedness and Hazard Mitigation

SP-7: Enhance and Promote Effective Storm Sheltering Strategies

SP-8: Develop the Nation’s Human Resource Base in Windstorm Hazard Mitigation Field

Appendix C: Detailed NWIRP Agency Activities

NIST

NIST Hurricane Maria Program. On September 20, 2017, Hurricane Maria had a devastating impact on much of Puerto Rico, damaging buildings that its communities relied upon for medical care, safety, communications, education, business, and more. In 2018, NIST launched a multi-year effort to study this disaster across seven technical projects with the goal of making recommendations to encourage the

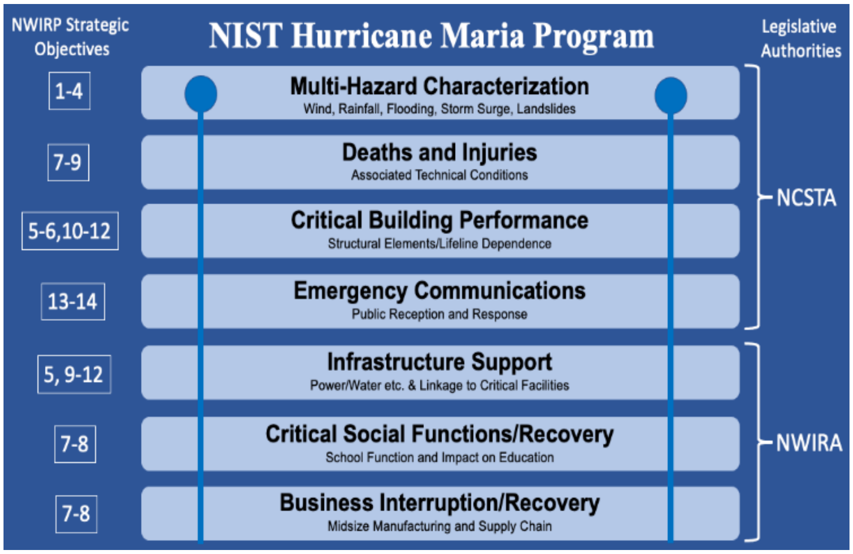

Figure 13*. An outline of projects comprising the NIST Hurricane Maria Program*

widespread adoption of improved building codes, standards, and practices that would make communities in Puerto Rico and across the U.S. more resilient to hurricanes and other hazard events. The NIST Hurricane Maria Program is conducted under two authorities, the NCST Act (NCSTA) and the NWIRA. Figure 13 shows the grouping of the various research projects with the attendant legislative authority. As complementary components of the NIST Hurricane Maria Program, the NCST technical investigation and the NWIRP research study are closely coordinated, and the foci of the seven projects span all 14 objectives contained within the NWIRP Strategic Plan, as indicated on the left side of Figure 13.

Tornado Load Requirements for Conventional Buildings. Following years of research and development on tornado hazards and tornado-structure interaction, NIST engagement with the building standards and codes processes resulted in the first-ever probabilistic tornado hazards maps and tornado load methodology for tornado-resistant design of buildings being incorporated into the ASCE 7-22 national load standard and approved for inclusion in the 2024 IBC. This accomplishment represents a paradigm shift in design for windstorms (the only prior mention of tornadoes in the IBC was for design of storm shelters). As these new tornado provisions get adopted into state and local building codes, essential facilities (e.g., hospitals, fire and police stations) and facilities that represent a substantial hazard to human life (e.g., high occupancy buildings, schools, nursing homes) in much of the U.S. can now be designed for tornado loads in addition to wind loads from hurricanes, thunderstorms, Nor'easters, and other extreme wind events. The tornado load requirements apply to buildings and other structures in the conterminous U.S. east of the Continental Divide, where most U.S. tornadoes occur.

Design tornado speeds vary from 60 to 138 mph, or approximately EF0-EF2 on the Enhanced Fujita Scale, depending on geographic location, building function, and plan size and shape of the building or facility. It is important to note that these code requirements reflect design for the most common tornadoes, not the most intense. Approximately 97% of all tornadoes in the past few decades have been rated EF2 or less. For life safety protection from more intense tornadoes, storm shelters and safe rooms should be used. The design tornado speed will be less than the design wind speed for most buildings; however, the design loads for tornadoes will often be greater than the design wind loads, due to other differences in tornado wind and wind-structure interaction characteristics. For example, uplift loads in building roofs will typically increase more than loads on other parts of the building, due in part to the strong updrafts in tornadoes that are not present in other types of windstorms. In some cases, the tornado loads may be double or more compared to wind loads required by the current version of the code. While these large load increases will translate into buildings with significantly more capacity to resist wind loads from tornadoes and other storm types, the increase in construction costs is expected to be minimal. From a study led by the NIST Office of Applied Economics,[60] considering construction cost impacts on archetype elementary and high school buildings, the maximum increases were approximately 0.14% of the total construction budget, in cities such as Kansas City, Dallas, and Memphis. Locations farther away from the central U.S. had much smaller increases or no cost increases at all.

NOAA

Hurricane Forecast Improvement Program (HFIP). Major accomplishments of the 2023 and 2024 hurricane seasons were the advancement of version 1 (2023) and version 2 (2024) of the HAFS model, a next-generation NOAA regional hurricane regional model with multi-way coupling to other UFS components. In addition to the operational implementation of HAFS, multiple real-time experiments were performed for model enhancements during both the 2023 & 2024 seasons with a focus on ensemble modeling based on the HAFS deterministic model, a multi-storm and basin scale variant of deterministic HAFS, and model physics and dynamics package enhancements. These real-time experiments have shown significant potential in model forecast performance and computational efficiencies. These experiments have been jointly carried out by developers at the NWS/National Center for Environmental Prediction (NCEP) Environmental Modeling Center (EMC), and NOAA's Oceanic and Atmospheric Research (OAR) AOML and GSL with support by the OAR Weather Program Office (WPO) EPIC program and the NCAR/Developmental Testbed Center (DTC). HFIP community members and UFS teams continue to provide strong examples of the benefits of these community-driven research-to-operations (R2O) efforts. More information on HFIP, operational and developmental HAFS and the HFIP community can be found at the new HFIP website: https://vlab.noaa.gov/web/osti-modeling/hfip/.

Warn-on-Forecast (WoF). WoF is a NOAA research project tasked to increase tornado, severe thunderstorm, and flash flood warning lead times by connecting high spatial and temporal resolution model output with confidence levels from warning forecasters. Increasing the lead time and accuracy for hazardous weather and water warnings and forecasts, in order to reduce loss of life, injury, and damage to the economy, is one of the strategic goals of NOAA. Trends in yearly-averaged tornado warning lead times suggest that the present weather warning process, largely based upon a warn-on-detection approach using NWS Doppler radars, is reaching a plateau and further increases in lead time will be difficult to obtain. A more updated

[60] Economic Analysis of ASCE 7-22 Tornado Load Requirements. NIST TN 2214. March 2022. https://doi.org/10.6028/NIST.TN.2214

approach whereby model output and the observational network are used together to effectively extend lead times on hazardous weather events. This will involve probabilistic hazard guidance provided by an ensemble of forecasts from convection-allowing numerical weather prediction models.

In addition to real-time demonstrations, WoFS guidance has been tested by forecasters and researchers within NOAA's HWT, the annual Spring Forecasting Experiment and within the Hydrometeorological Testbed. Planning is ongoing in Fiscal Year 2025 to transition a cloud-based WoFS to operations within the NWS Office of Science and Technology Integration (OSTI). The feedback provided by participants guides subsequent improvements to WoFS as NOAA NSSL collaborates with partners to reduce the billions in economic impacts from severe storms and flash floods. More information can be found at https://www.nssl.noaa.gov/projects/wof/.

NSF

NSF Overview of NHERI. The NSF-supported NHERI is a multi-hazards research community focused on mitigating the impact of earthquakes, windstorms, tsunamis, storm surge and other water-related hazards on our nation's civil infrastructure and society. NHERI enables research and educational advances that can contribute knowledge and innovation for the nation's civil infrastructure and communities to prevent natural hazard events from becoming societal disasters. Grand challenge research that can be conducted using NHERI resources is described in the NHERI Science Plan (3rd Edition) https://www.designsafe-ci.org/facilities/nco/science-plan/. The Natural Hazards Engineering Research Infrastructure (NHERI) Decadal Visioning Study 2026-2035 provides strategic guidance on facility and cyberinfrastructure needs as well as focus areas and collaboration opportunities (https://doi.org/10.17603/ds2-afza-m544)

NSF Award Search results are available at

https://www.nsf.gov/awardsearch/advancedSearchResult?PIId=&PIFirstName=&PILastName=&PIOrganization=&PIState=&PIZip=&PICountry=&ProgOrganization=&ProgEleCode=&BooleanElement=All&ProgRefCode=&BooleanRef=All&Program=&ProgOfficer=&Keyword=chinook%2C+derecho%2C+foehn%2C+hurricane%2C+katabatic+wind%2C+microburst%2C+noreaster%2C+sirocco%2C+storm+surge%2C+tornado%2C+tropical+cyclone%2C+typhoon%2C+windstorm&AwardNumberOperator=&AwardAmount=&AwardInstrument=&ActiveAwards=true&OriginalAwardDateOperator=&StartDateOperator=&ExpDateOperator=

Appendix D: NWIRP Coordinated Budget

The NWIRA Reauthorization of 2015 (Public Law 114-52) requires submission of a coordinated NWIRP budget to Congress each FY within 60 days after the date of the President's budget submission.[61]Descriptions of the activities in FY 23-24 for each of the four Program agencies (NIST, NOAA, NSF and FEMA) are provided below, and the associated budgets are listed in the table at the end of this report.

National Institute of Standards and Technology

NIST was designated as the Lead Agency for NWIRP through the enactment of Public Law 114-52 on September 30, 2015. As such, NIST's responsibilities include planning and coordination as well as technical activities.

Lead agency activities include the following:

- Plan and coordinate NWIRP, in cooperation with other federal agencies and the broader stakeholder community; and
- Coordinate all federal post-windstorm investigations, to the extent practicable.

Planned technical activities include the following:

- Continue efforts on the NIST NCST Technical Investigation of the effects of Hurricane Maria on the U.S. territory of Puerto Rico. The goals of the investigation are to characterize: (1) the wind environment and technical conditions associated with deaths and injuries; (2) the performance of representative critical buildings, and designated safe areas in those buildings, including their dependence on lifelines; and (3) the performance of emergency communications systems and the public's response to such communications;
- Continue development of performance-based design approaches for wind hazards;
- Develop computational wind engineering capability for simulating turbulent atmospheric boundary layer flow and the resulting wind pressures on buildings;
- Develop tornado resistant designs for risk category II buildings;
- Study hurricane evacuations during Hurricane Ian's impacts on the southwest Florida coast.
- Subject to the availability of funds, solicit grant proposals for research aimed to improve resilience of buildings and infrastructure against windstorm hazards, including storm surge; and
- Continue technology transfer, translating windstorm impact reduction research to practice through participation in codes and standards development processes.

National Science Foundation

NSF will support research in engineering and the atmospheric sciences to improve the understanding of the behavior of windstorms and their impact on buildings, structures, and lifelines; and research in the economic and social factors influencing windstorm risk reduction measures.

[61] 42 U.S.C. § 15703(e)(7).

National Oceanic and Atmospheric Administration

NOAA activities fall under two categories: hurricane-related and local severe weather activities.

Hurricane-related activities include the following:

- Continue the HFIP;
- Operate the National Hurricane Center (NHC)/Joint Hurricane Testbed; and
- Operate the AOML Hurricane Research Division.

Local severe weather activities include the following:

- Operate the Storm Prediction Center, including Hazardous Weather Testbed;
- WoF development;
- Operate the National Severe Storms Laboratory tornado and severe weather research; and
- Research and deliver technologies developed by the Global System Laboratory that include the High-Resolution Rapid Refresh forecasts, Advanced Weather Interactive Processing System Hazard Services, renewable energy, and aviation tools and products.

Federal Emergency Management Agency

FEMA leverages available resources as appropriate to support NWIRP goals and objectives. An estimate of the leveraged resources is provided in the budget table. A high-level summary of the wind-related activities that FEMA's Building Science Branch and Earthquake and Winds Programs Branch has or will be pursuing includes post-windstorm-related data collection and analysis; development of risk assessment tools and guidance for effective mitigation; integration of mitigation measures into consensus codes and standards; and public outreach, training, and information dissemination consistent with the agency's all-hazards approach.

National Windstorm Impact Reduction Program (NWIRP)	FY 2023 Actuals ($K)	FY 2024 Actuals ($K)
NIST [1]	5,481	5,564
NOAA [2]	16,995	17,281
NSF [3]	85,463	52,025
FEMA [4]	0	600
Total	**107,939**	**75,470**

1) NIST FY 2023 and FY 2024 actuals reflect allocation to support the Hurricane Maria Investigation.
2) NOAA totals are not reflective of hurricane supplemental funds.
3) NSF has no dedicated NWIRP solicitation, so they use the levels authorized in the National Windstorm Impact Reduction Act Reauthorization of 2015 as an estimate for NWIRP activities. This could result in a difference between the actual/enacted and the request levels.