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Severe Thunderstorms and Tornadoes in the United States

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Summary

Severe thunderstorms and tornadoes affect communities across the United States every year, causing fatalities, destroying property and crops, and disrupting businesses. Tornadoes are the most destructive products of severe thunderstorms, and second only to flash flooding as the cause for most thunderstorm-related fatalities. Damages from violent tornadoes seem to be increasing, similar to the trend for other natural hazards, and some analysts indicate that losses of $1 billion or more from single tornado events are becoming more frequent. Insurance industry analysts state that tornadoes, severe thunderstorms, and related weather events have caused nearly 57%, on average, of all insured losses in the United States in any given year since 1953.

Policies that could reduce U.S. vulnerability to severe thunderstorms and tornadoes include improvements in the capability to accurately detect storms and to effectively warn those in harm's way. The National Weather Service (NWS) has the legal authority to forecast weather and issue warnings. Some researchers suggest that there are limits to the effectiveness of improvements in forecasting ability and warning systems for reducing losses and saving lives from severe weather. The research suggests that, for example, social, behavioral, and demographic factors now play an increasingly important role in tornado-related fatalities.

At issue for Congress is its role in mitigating damages, injuries, and fatalities from severe thunderstorms and tornadoes. The National Science and Technology Council has recommended that communities implement hazard mitigation strategies and technologies, some of which—such as conducting weather-related research and development and disseminating results—Congress has supported through annual appropriations for federal agencies such as the National Oceanic and Atmospheric Administration, the National Science Foundation, the Federal Emergency Management Agency, NASA, and others. Other recommended strategies include land use and zoning changes, which are typically not in the purview of Congress.

Congress attempted to clarify the federal role in mitigating damages from windstorms (including tornadoes and thunderstorms) by passing the National Windstorm Impact Reduction Act of 2004 (P.L. 108-360). It is not evident whether the program made progress toward its objective: achievement of major measurable reductions in the losses of life and property from windstorms. Authorization for the program expired at the end of FY2008. It is also unclear whether changes to climate over the past half-century have increased the frequency or intensity of thunderstorms and tornadoes. At issue for Congress is whether future climate change will lead to more frequent and more intense thunderstorms and tornadoes, and whether efforts by Congress to mitigate long-term global warming will also reduce future losses from thunderstorms and tornadoes.

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Overview

Severe thunderstorms and tornadoes affect communities across the United States every year, causing fatalities, destroying property and crops, and disrupting businesses. State and local governments are typically the first to respond to the consequences of extreme weather events, but the federal government has responsibilities for forecasting and issuing warnings to citizens and communities lying in harm's way. When severe weather catastrophes overwhelm the resources of state and local governments, the Stafford Act authorizes the President to issue major disaster or emergency declarations, resulting in the distribution of a wide range of federal aid to those affected.[1] Also, U.S. Department of Agriculture programs, such as federal crop insurance and emergency disaster loans, can help farmers recover financially from severe weather disasters even without a presidential disaster declaration.[2]

Many observers note that although the number of lives lost each year to natural hazards in the United States has decreased, the costs of major disasters continues to rise.[3] According to the National Science and Technology Council: "Due to changes in population demographics and more complex weather-sensitive infrastructure, Americans today are more vulnerable than ever to severe weather events caused by tornadoes, hurricanes, severe storms, heat waves, and winter weather."[4]

This report first discusses issues that may be of interest to Congress in three general categories: (1) forecasting and issuing warnings for severe thunderstorms and tornadoes; (2) the role of mitigation; and (3) the effect of climate change. The second part of the report describes in more detail the risk these hazards pose to communities and individuals; where, when, how, and why they occur in the United States; and what damage they may cause. It also describes the role of the National Weather Service in forecasting severe weather and communicating the risk to communities and individuals at risk.

Issues for Congress

This report focuses on the risk from severe thunderstorms and tornadoes to U.S. citizens and infrastructure, the federally sponsored forecast and warning systems, federally backed efforts to improve the scientific understanding of severe weather phenomena, and efforts to mitigate the risk of catastrophe. Congress has oversight and funding responsibilities for the federal agencies charged with these tasks. At issue is whether those programs are effective at reducing damage, injuries, and loss of life from severe thunderstorms and tornadoes.

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[1] For more information about the Robert T. Stafford Disaster Relief and Emergency Assistance Act (the Stafford Act), see CRS Report RL33053, *Federal Stafford Act Disaster Assistance: Presidential Declarations, Eligible Activities, and Funding*, by Keith Bea.

[2] For more information on federal agricultural assistance, see CRS Report RS21212, *Agricultural Disaster Assistance*, by Ralph M. Chite.

[3] National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Disaster Reduction, "Grand Challenges for Disaster Reduction" (Washington, DC, June 2005), p. 1. Hereafter referred to as Grand Challenges for Disaster Reduction (2005).

[4] Ibid., p. 4.

Also at issue is the concept of disaster resilience; namely, those precautions and strategies—such as improved building materials and structural systems—that decrease the vulnerability of communities and individuals to severe thunderstorms and tornadoes. The federal role in supporting programs of hazard mitigation, such as those included in the National Windstorm Impact Reduction Act of 2004 (P.L. 108-360), is a concern for Congress. Authorization for the Windstorm Impact Reduction Program expired at the end of FY2008, and it is not clear whether the program achieved any of the goals specified in the legislation.

Projections of a changing climate for the United States and the possibility of a more intense hydrologic cycle (e.g., more intense storms, rainfall, heat waves, and other phenomena) have raised questions about whether the costs of severe weather disasters will continue to rise in the future. Observers note that extreme events, more than shifts in average climate conditions, drive changes in natural and human systems.[5] According to the U.S. Climate Change Research Program:

> In the future, with continued global warming, heat waves and heavy downpours are very likely to further increase in frequency and intensity. Substantial areas of North America are likely to have more frequent droughts of greater severity. Hurricane wind speeds, rainfall intensity, and storm surge levels are likely to increase. The strongest cold season storms are likely to become more frequent, with stronger winds and more extreme wave heights.[6]

Distinguishing between increased frequency and intensity of extreme weather events due to global warming and other factors that contribute to higher costs from disasters—such as changing demographics in hazard-prone regions—also may be an important issue for Congress.

Focus on Short-Term Detection and Warning

Policies that reduce U.S. vulnerability to severe thunderstorms and tornadoes will likely include improvements in the capability to accurately detect storms and to effectively warn those in harm's way. The National Weather Service (NWS) is authorized by law to forecast weather and issue warnings. How Congress chooses to fund NWS and conduct oversight of its activities bears directly on the agency's effectiveness.

In its strategic plan for 2005-2010, the NWS cited several preferred outcomes for the nation, including (1) reduced loss of life, injury, and damage to the economy; and (2) better, quicker, and more valuable weather and water information to support improved decisions.[7] To achieve these outcomes, NWS would employ a strategy to "improve the reliability, lead-time, and understanding of weather and water information and services that predict changes in environmental conditions."[8] Improving the lead-time and reliability of severe thunderstorm and tornado forecasts could provide communities and individuals with information to help them better prepare and thus reduce their vulnerability.

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[5] C. S. Parmesan et al., "Impacts of extreme weather and climate on terrestrial biota," *Bulletin of the American Meteorological Society*, vol. 83 (2000), pp. 443-450.

[6] U.S. Climate Change Science Program, Synthesis and Assessment Product 3.3, "Weather and Climate Extremes in a Changing Climate" (Washington, DC, June 2008), p. VII. Hereafter referred to as CCSP, Weather and Climate Extremes in a Changing Climate (2008).

[7] NOAA, National Weather Service Strategic Plan for 2005-2010 (Jan. 3, 2005), p. 13; at http://www.nws.noaa.gov/sp/.

[8] Ibid.

NWS receives the most funding of any agency or program within NOAA's budget, and the local warnings and forecasts (LW&F) program receives approximately 70% of the NWS funding each year. **Table 1** shows appropriations for the LW&F program, NWS, and overall NOAA appropriations since FY2004.

Table 1. NWS and NOAA Funding from FY2004 to FY2008

(millions of dollars)

	FY04	FY05	FY06	FY07[a]	FY08	Change FY04-08	FY09 Request
LW&F	$576.1	$560.5	$591.4	$616.5	$659.3	14.4%	$663.2
NWS	$824.9	$782.3	$848.2	$884.4	$911.4	10.5%	$930.7
NOAA[b]	$3,731.7	$3,918.7	$3,911.5	$3,684.1	$3,907.3	4.7%	$4,109.8

Source: NOAA, Blue Book (Budget Summary) for fiscal years 2004 through 2009.

Notes: LW&F is the local warnings and forecasts program within NWS. Funding values used as reported in the Control Tables chapter of the budget summaries (not adjusted for inflation).

a. Values reflect the FY2007 budget request.

b. Values reflect the total appropriated amounts, as reported in the Control Tables chapter of the budget summaries.

As **Table 1** shows, the NWS budget has increased at a higher percentage than the total NOAA budget over the five-year period, and the LW&F program within NWS has increased at a higher percentage than NWS itself. The LW&F program averages nearly three-quarters of the NWS budget each year, indicating that short-term weather prediction and warning is a high priority for NWS and for NOAA, in accord with its statutory authority. Reports from RAND and other research organizations suggest, however, that reorienting research and development funding toward longer-term loss reduction efforts—particularly for weather-related hazards—might provide the nation with more long-lasting solutions to reducing natural disaster losses.[9] These recommendations favor increased focus on mitigation techniques and R&D to reduce loss of life and property from severe weather hazards.

Mitigation

The National Science and Technology Council (NSTC) noted that the nation's primary focus on disaster response and recovery is "an impractical and inefficient strategy for dealing with these ongoing threats. Instead, communities must break the cycle of destruction and recovery by enhancing their *disaster resilience*" (italics added).[10] Among the six "Grand Challenges" identified in its report, the NSTC recommended that communities implement hazard mitigation strategies and technologies, such as development of advanced construction materials and structural systems that allow facilities to "remain robust in the face of all potential hazards."[11] The

[9] Charles Meade and Megan Abbott, "Assessing federal research and development for hazard loss reduction," prepared for the Office of Science and Technology Policy (RAND, Arlington, VA.), 2003, 65 p. See also "Advice to the New Administration and Congress: Actions to Make our Nation Resilient to Severe Weather and Climate Change," a document produced by the University Corporation for Atmospheric Research and seven other stakeholder organizations; at http://www.ucar.edu/td/.

[10] Grand Challenges for Disaster Reduction (2005), p. 1.

[11] Ibid., p. 8.

report also recommended nonstructural mitigation measures, such as land use and zoning regulations that recognize the risk of natural hazards. Land use measures, such as zoning laws and building codes, are typically prerogatives of state and local governments, and thus the federal role in that aspect of hazard mitigation is limited.[12]

The National Windstorm Impact Reduction Program

The federal role in developing disaster-resilient materials and structures, and evaluating their relative effectiveness in mitigating damages from severe thunderstorms and tornadoes, has been unclear. Congress attempted to clarify the federal role in mitigating damages from windstorms (including tornadoes and thunderstorms) by passing the National Windstorm Impact Reduction Act of 2004 (P.L. 108-360). The legislation identified three primary mitigation components: (1) improved understanding of windstorms; (2) windstorm impact assessment; and (3) windstorm impact reduction.

Authorization for the National Windstorm Impact Reduction Program expired on September 30, 2008, and it is not clear whether the program made progress toward its objective: achievement of major measurable reductions in the losses of life and property from windstorms. That lofty goal may have been difficult to achieve within the three-year authorization, even if appropriations for the program matched authorization levels, and the program was well implemented. On these points, the House Science and Technology Committee found that spending on the program by the four agencies responsible for program implementation—the National Science Foundation, the National Institutes of Standards and Technology (NIST), NOAA, and FEMA—was far below authorized levels, and that the program had not been well implemented.[13]

The Administration cites many research activities and other programs underway within each of the four agencies that contribute to goals of the windstorm program and to the need to incorporate wind hazards reduction measures into an "all-hazards view."[14] A biennial progress report discussed the importance of aspects of the program—specifically the goal of increasing the effectiveness of existing program efforts through better coordination among agencies.[15] The report indicated that interagency coordination is improving through the work of the Interagency Working Group, established under §204 of P.L. 108-360.[16] However, it is difficult to assess the effect of improved interagency coordination on the broader goals of the program—to achieve measurable reductions in loss of life and property—or whether the law has compelled the

[12] See also testimony given by Sharon Hays, Associate Director and Deputy Director for Science, Office of Science and Technology Policy, to the Subcommittee on Technology and Innovation, House Science and Technology Committee, Hearing: *The National Windstorm Impact Reduction Program: Strengthening Windstorm Hazard Mitigation* (July 24, 2008).

[13] Subcommittee on Technology and Innovation, House Science and Technology Committee, Hearing: *The National Windstorm Impact Reduction Program: Strengthening Windstorm Hazard Mitigation* (July 24, 2008), Hearing Charter. The subcommittee estimated that NOAA, NIST, and FEMA spent approximately $7.45 million between FY2004 and FY2008, approximately 17% of authorized amounts for the three agencies. Spending for NSF under the program is more difficult to estimate, although NSF reportedly will spend approximately $6.7 million on research related to the windstorm reduction program in FY2008.

[14] Sharon Hays, Associate Director and Deputy Director for Science, Office of Science and Technology Policy, to the Subcommittee on Technology and Innovation, House Science and Technology Committee, hearing: *The National Windstorm Impact Reduction Program: Strengthening Windstorm Hazard Mitigation* (July 24, 2008).

[15] Windstorm Impact Reduction Program Biennial Progress Report for Fiscal Years 2005-2006.

[16] Ibid.

agencies to do more than what they had already been trying to achieve without passage of the National Windstorm Impact Reduction Act. The Administration further concludes that the benefits of an improved understanding of severe wind hazards will not be fully realized until that understanding is incorporated more completely into actions at the state and local level.[17]

Senator Bill Nelson introduced S. 3638 on September 26, 2008, to reauthorize the National Windstorm Impact Reduction Program through FY2013 and to expand the agencies involved under an interagency working group to also include the U.S. Department of Transportation (DOT), the U.S. Army Corps of Engineers (Corps), NASA, and the Office of Management and Budget (OMB). The bill would have designated NIST as lead agency for the interagency working group, similar to its role as lead agency for the National Earthquake Hazards Reduction Program.[18] The bill was referred to the Senate Commerce, Science, and Transportation Committee. The committee did not act on the legislation.

Climate Change and Severe Weather

According to several reports that synthesize recent findings in the scientific literature, there will likely be changes in the intensity, duration, frequency, and geographic extent of weather and climate extremes as the Earth continues to warm.[19] These changes may continue upward trends that have already been observed, such as the frequency of unusually warm nights, frequency and intensity of extreme precipitation events, and the length of the frost-free season.[20] However, the evidence is unclear as to whether the frequency and intensity of severe thunderstorms and tornadoes has increased or will increase in the future due to climate change.

Part of the difficulty in sorting out trends in frequency and intensity of severe thunderstorms and tornadoes lies in the way they have been observed and reported. For example, the number of annual reported tornado occurrences has doubled between 1954 and 2003.[21] Some studies indicate that the doubling reflects changes in observing and reporting. When the artificial trend produced by these changes is removed, the adjusted data show little or no trend in the number of reported tornadoes since the 1950s.[22]

Reports of severe thunderstorms without associated tornadoes increased by a factor of 20 between 1955 and 2004.[23] However, researchers indicate that the increase is mainly in reports of marginally severe thunderstorms, and suggest that the evidence for a change in the long-term trend of severe thunderstorms is lacking.[24] In studies that reanalyze environmental conditions that could have produced severe thunderstorms, changes in the frequency of those environmental

[17] Sharon Hays testimony (July 24, 2008).

[18] Also known as NEHRP, a multiagency program reauthorized under P.L. 108-360 to reduce the national risk from earthquake disasters. For more information, see CRS Report RL33861, *Earthquakes: Risk, Monitoring, Notification, and Research*, by Peter Folger.

[19] CCSP, Weather and Climate Extremes in a Changing Climate (2008); IPCC, *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva, Switzerland), 2007, 104 p.

[20] CCSP, Weather and Climate Extremes in a Changing Climate (2008), p. 35.

[21] Ibid., p. 76.

[22] Ibid., Figure 2.25.

[23] Ibid., p. 77.

[24] Ibid.

conditions are observed. However, the record of observations may not be long enough to determine the range of natural variability.[25] Given the uncertainty, it is not yet possible to determine if these changes are due to natural variability or changing climatic conditions from greenhouse warming.

Excessive rainfall from severe thunderstorms may trigger flash floods, which are typically responsible for most flood-related deaths in the United States each year. According to researchers, one of the clearest trends over the last 30 years has been an increase in the frequency and intensity of heavy precipitation events.[26] Despite this clear trend, the relationship between these heavy precipitation events and the frequency and intensity of severe thunderstorms is not clear, nor do scientists agree on the relationship between increased precipitation and streamflow extremes, such as flooding.[27] As a further complication, studies of trends in streamflow using similar data have produced different results.[28] Also, human influences on streamflow, such as building dams and creating large reservoirs, may mask climatic changes.[29]

Climate model predictions suggest that with continued global warming due to increasing concentrations of atmospheric greenhouse gases, precipitation intensity is projected to increase.[30] However, it is unclear whether this intensification of precipitation is or will be linked in the future to more severe thunderstorms, and to more severe or more frequent flash floods.

The section below discusses why severe thunderstorms and tornadoes are threats to some areas of the country and not others, and why they occur during some parts of the year and not others. The following section also describes the role of the National Weather Service in forecasting and issuing warnings, and its relationship to private forecasters and the news media in providing clear and consistent messages to the public at risk.

Risk, Forecasting, and Warning

Thunderstorms and tornadoes affect U.S. citizens and communities every year, albeit only rarely with the same level of widespread destruction as a major hurricane or flood. Although floods are one consequence of severe thunderstorms, floods that cause widespread and prolonged destruction are typically not annual events in the United States. Major floods, such as those that affected parts of the Mississippi River region in the Midwest in 2008 and in 1993, are the result of many factors and are not solely caused by heavy rains from severe thunderstorms.[31]

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[25] CCSP, Weather and Climate Extremes in a Changing Climate (2008), p. 77.

[26] Ibid., pp. 46-47.

[27] Personal communication, Kenneth Kunkel, Executive Director of the Division of Atmospheric Science, Desert Research Institute, Reno, NV, Sept, 22, 2009.

[28] See, for example, H. F. Lins and J. R. Slack, "Streamflow trends in the United States," *Geophysical Research Letters*, vol. 26 (1999), pp. 227-230; and P. Ya. Groisman et al., "Heavy precipitation and high streamflow in the contiguous United States: trends in the 20th century," *Bulletin of the American Meteorological Society*, vol. 82 (2001), pp. 219-246.

[29] CCSP, Weather and Climate Extremes in a Changing Climate (2008), p. 53.

[30] Ibid., p. 102.

[31] For a list of CRS experts on the Midwest flooding of 2008, see http://www.crs.gov/experts/WE04010.shtml.

Severe Thunderstorms

Compared to tropical storms such as hurricanes, thunderstorms are small and short-lived, but can still be dangerous. An average thunderstorm is 15 miles in diameter and lasts an average of 30 minutes. Thunderstorms also occur much more frequently than large tropical storms. There are an estimated 100,000 thunderstorms in the world each year, of which 10% are severe.[32] A severe thunderstorm is defined by the NWS as one that produces hail at least three-quarters of an inch in diameter, has winds of 58 miles per hour or higher, or produces a tornado.[33]

Severe thunderstorms may produce lightning, high winds, hail, flash floods, and tornadoes, any of which may be a hazard to people and property. Lightning can cause fires as well as deaths when people are directly struck. Heavy rainfall from thunderstorms can cause flash floods, which can change small creeks into raging torrents in minutes. Hail can cause crop damage, and large hail can damage cars, roofs, and windows. Strong, straight-line winds can knock down trees and power lines, and can sometimes cause damage equal to that caused by many tornadoes.[34] Downbursts—outward bursts of damaging winds on or near the ground—can cause wind shear and lead to aircraft accidents. Tornadoes, the most destructive phenomenon associated with thunderstorms, can destroy structures and cause fatalities.[35] (Tornadoes are discussed separately below.)

Risks from Severe Thunderstorms

Severe thunderstorms can produce lightning, high winds, hail, and heavy rainfall which may lead to flash flooding. All of these phenomena may pose a risk to people and property depending on their location and the storm's intensity.

Lightning

Lightning is commonly considered the most dangerous and most frequently encountered weather hazard. Between 1977 and 2006, an average of 62 people were killed each year by lightning in the United States. Lightning-caused fatalities are often highest each year in Florida.[36] Lightning is also the primary cause of wildfires, which threaten natural resources, homes, businesses, and lives, particularly in the West. The National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory estimates that lighting causes approximately $4-$5 billion in

[32] National Severe Storms Laboratory, "Severe Weather Primer: Thunderstorms," at http://www.nssl.noaa.gov/primer/tstorm/tst_basics.html.

[33] NWS, "A Comprehensive Glossary of Weather Terms for Storm Spotters," at http://www.srh.noaa.gov/oun/severewx/glossary4.php.

[34] Straight-line winds are strong winds produced by a thunderstorm that are not associated with rotation, as distinguished from tornadoes, which are narrow, violently rotating columns of air extending from the base of a thunderstorm to the ground.

[35] National Severe Storms Laboratory, "Severe Weather Primer: Thunderstorms," at http://www.nssl.noaa.gov/primer/tstorm/tst_damage.html.

[36] Florida has more lightning strikes than any other state and has the fourth highest population in the United States. On average, 10 people die each year in Florida from lightning. National Weather Service, "Natural Hazard Statistics," at http://www.weather.gov/os/hazstats.shtml#.

damage each year, affecting buildings, communications systems, power lines, and electrical systems.[37]

High Winds

Damage caused by severe straight-line winds during thunderstorms occurs more commonly than damage caused from tornadoes.[38] Straight-line wind speeds that can occur during severe thunderstorms may reach up to 100 miles per hour (although damaging winds are classified as those exceeding 50-60 mph).[39] Estimates for the annual amount of damage caused by high winds are not provided in this report because wind damage from tropical storms, thunderstorms, and tornadoes are often reported together.

Damaging winds can develop with little or no advanced warning. Microbursts—one category of damaging winds—are dangerous to aviation and can occur in an isolated rain shower or thunderstorm.[40] Downbursts or microbursts may produce wind shear—a variation in wind speed and/or direction over a short distance—which can slow airspeed and cause an aircraft to lose altitude when a plane is taking off or landing and is near the ground.

Hail

Although Florida typically experiences the most thunderstorms in the United States each year, Nebraska, Colorado, and Wyoming normally experience the most hail storms.[41] Crops are particularly vulnerable to hail damage; even relatively small hail can severely damage plants in minutes. Hail greater than three-quarters of an inch in diameter is considered severe and potentially damaging to aircraft. Hail also damages vehicles, roofs of buildings and homes, and landscaping. Damage from hail approaches $1 billion in the United States each year.[42] Hail has been known to cause injury to humans, and occasionally has been fatal.

Flash Floods

Floods are a common and widespread natural hazard in the United States.[43] Flash floods as discussed in this report can also cause significant damage and fatalities, but they result from

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[37] National Severe Storms Laboratory, "Severe Weather Primer: Lightning," at http://www.nssl.noaa.gov/primer/lightning/ltg_damage.html. The National Lightning Safety Institute indicates that losses from lightning may be $5-$6 billion per year. See http://www.lightningsafety.com/nlsi_lls/nlsi_annual_usa_losses.htm.

[38] National Severe Storms Laboratory, "Severe Weather Primer: Damaging Winds," at http://www.nssl.noaa.gov/primer/wind/wind_basics.html.

[39] Ibid.

[40] Microbursts are small, concentrated *downbursts* from a thunderstorm, usually less than 4 kilometers across, that produce an outward burst of damaging winds at the ground surface. Downbursts are similar to microbursts but larger, usually greater than 4 kilometers across. See http://www.nssl.noaa.gov/primer/wind/wind_basics.html.

[41] In the high plains of these three states the freezing levels are much closer to the ground than at sea level. At sea level the hail has more time to melt before reaching the ground. See National Severe Storms Laboratory, "Severe Weather Primer: Hail," at http://www.nssl.noaa.gov/primer/hail/hail_damage.html.

[42] Ibid.

[43] Slowly developing and widespread floods, such as the 2008 and 1993 floods along the Mississippi River, can cause billions of dollars in flood-related damages, although the number of deaths from floods is small in the United States relative to some other countries. For example, in 1998 floods resulting from Hurricane Mitch resulted in over 9,000 (continued...)

short-lived thunderstorms, and not from a prolonged weather pattern that produces higher than normal amounts of precipitation over several days or weeks.[44]

Flash floods are short in duration.[45] They are most commonly associated with thunderstorms, severe weather, and melting snow or ice. Flash floods can occur within minutes or a few hours of excessive rainfall, such as that from a severe thunderstorm or a series of thunderstorms occurring over the same location. Because flash floods can occur suddenly and with little warning, they are the most dangerous types of floods; typically most flood-related deaths each year in the United States are caused by flash floods.[46] It is difficult to assess the costs of actual damage from flash floods each year; cost estimates may vary widely, and the actual costs may not consistently correlate to preliminary estimates.[47]

Where and When Severe Thunderstorms Form

Thunderstorms occur most frequently over the Florida peninsula and in other parts of the Southeast, although the most severe weather threat from thunderstorms extends from Texas to southern Minnesota along the Great Plains and midwestern United States.[48] Thunderstorms are most likely to occur in the spring and summer and during the afternoon and evening. In the Great Plains, most thunderstorms occur in the afternoon and at night; and along the Gulf Coast, southeastern United States, and western states they occur most frequently in the afternoon.[49]

The greatest potential for severe weather develops in geographical regions that are subject to warm, humid air at low levels while dry, conditionally unstable air prevails aloft. Thunderstorms form during the summer in the southern Great Plains when a southerly flow of warm, very moist air from the Gulf of Mexico meets with a dry, westerly current aloft. The thunderstorms that form in Colorado, Arizona, and New Mexico are due to orographic lifting—ascending airflow caused by the Rocky Mountains. Few thunderstorms occur along the west coast of the United States because this region is frequently influenced by cooler, maritime air masses that suppress convectional uplift over land.[50]

(...continued)

deaths in Central America, although some sources estimate as many as 18,000 deaths from Hurricane Mitch. See Roger A. Pielke, Jr. and Mary W. Downton, "Precipitation and damaging floods: Trends in the United States, 1932-97," *Journal of Climate*, vol. 13 (Oct. 15, 2000), pp. 3625-3637.

[44] Significant flooding along the main stems of large river basins, such as the Mississippi River, results from excessive precipitation over weeks or months. See CCSP, Weather and Climate Extremes in a Changing Climate (2008), p. 50.

[45] A National Weather Service definition of flash flood is a flood caused by heavy or excessive rainfall in a short period of time, generally less than six hours.

[46] Deaths due to flooding created by Hurricane Katrina in 2005 far exceeded the annual average number of flash flood-related deaths; however, many complicating factors make comparison between hurricane-induced flooding and flash floods difficult, such as the role of levees, storm surge, tides, and other factors.

[47] Mary W. Downton and Roger A. Pielke, Jr., "How accurate are disaster loss data? The case of U.S. flood damage," *Natural Hazards*, vol. 35 (2005), pp. 211-228.

[48] NOAA National Severe Storms Laboratory, at http://www.nssl.noaa.gov/primer/tstorm/tst_climatology.html.

[49] Ibid.

[50] PhysicalGeography.net, "Thunderstorms and Tornadoes," at http://www.physicalgeography.net/fundamentals/7t.html.

How and Why Thunderstorms Form

A thunderstorm forms when moist, unstable air is vertically lifted in the area by unequal warming of the Earth's surface, orographic lifting due to a topographic obstruction (such as a mountain or mountain range), or the presence of a weather front. Three types of thunderstorms can produce severe weather: a squall line, a multicell storm, and a supercell storm.[51]

Squall Line

A squall line is a line of storms with a continuous, well developed *gust front*—a boundary that separates a cold downdraft of a thunderstorm from warm, humid surface air—at the leading edge of the line. Severe weather frequently occurs near the updraft/downdraft interface at the storm's leading edge. Downburst winds are the main threat. Hail as large as golf balls along with *gustnadoes*—weak and short lived tornadoes—can occur. Flash flooding can occur when the squall line slows down or even becomes stationary, with thunderstorms forming parallel to the line and repeatedly moving across the same area.

Multicell Storm

A multicell storm consists of a group of cells moving as a single unit, with each cell in a different stage of the thunderstorm life cycle.[52] As the multicell storm evolves, individual cells take turns at being the most dominant. New cells tend to form along the upwind (typically western or southwestern) edge of the cluster, with mature cells located at the center and dissipating cells found along the downwind (eastern or northeastern) portion of the cluster. Multicell storms come in a variety of shapes, sizes, and intensities.[53] They are stronger than single cell thunderstorms, but less severe than supercell storms. Each cell in a multicell storm lasts about 20 minutes; however, the multicell cluster may persist for several hours. Most flash floods occur during multicell storm events.[54]

Supercell Storm

A supercell storm is defined as a storm with a persistent rotating updraft in which the entire storm behaves as a single entity, rather than as a group of cells.[55] These supercell storms are the most dangerous and rarest of the thunderstorms; they produce strong downbursts of 80 mph or more and damaging hail, and they can last for hours. Some are very prolific precipitation producers, whereas others produce very little precipitation that reaches the ground. The leading edge of the precipitation from a supercell is usually light rain. Heavier rain falls closer to the updraft with

[51] John M. Wallace and Peter V. Hobbs, *Atmospheric Science: An Introductory Survey* (San Diego, CA: Academic Press, 1977), p. 240.

[52] A *cell* in meteorology refers to an updraft or downdraft or combination of both. Updrafts and downdrafts, or their combination represent types of convection in an unstable atmosphere. The terms convection and thunderstorm are often used interchangeably, although thunderstorms are only one form of convection. For more information on meteorological terminology, see http://www.srh.noaa.gov/oun/severewx/glossary.php.

[53] Wallace and Hobbs, pp. 244 - 245.

[54] The Weather World 2010 Project, University of Illinois, Multicell Cluster Storms, at http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/svr/type/clstr/home.rxml.

[55] Wallace and Hobbs, pp. 245-248.

torrential rain and/or large hail immediately north and east of the main updraft. Severe weather prefers to form near the main updraft, typically towards the rear of the storm.[56] Most large and violent tornadoes come from supercell storms.

Tornadoes

Tornadoes—the most violent storms on Earth—can sometimes produce winds that exceed 300 mph. They are the destructive products of severe thunderstorms, and second only to flash flooding as the cause for convective storm related fatalities.

Risks from Tornadoes

Damages from violent tornadoes seem to be increasing, similar to the trend for other natural hazards. According to some insurance industry analysts, losses of $1 billion or more from single tornado events are becoming more frequent.[57] For example, the so-called Super Tuesday Tornado Outbreak during February 5-6, 2008, in several southern states (including Arkansas, Mississippi, and Tennessee) caused approximately $850 million in insured losses.[58] Insurance industry analysts indicate that tornadoes, severe thunderstorms, and related weather events (such as hailstorms, but not hurricanes or earthquakes) have caused nearly 57%, on average, of all insured losses in the United States in any given year since 1953.[59]

Fatalities caused by tornadoes have declined significantly since the 1930s, generally because of improved forecasting, warning systems, and increased public awareness of the tornado risk. However, some researchers suggest that the decline is unlikely to continue and may have already stopped.[60] These findings attribute the stalled decline to increasing vulnerability due to demographic factors, rather than shortcomings in tornado forecasts and warnings.[61] The results would suggest that there are limits to the number of potential lives saved by improvements in forecasting ability and warning systems, and that social, behavioral, and demographic factors may play an increasingly important role in tornado-related fatalities.[62] Other stakeholders, however, emphasize the need for increased investment in observations, computing power, research and weather modeling to improve the nation's resilience to severe weather.[63]

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[56] NOAA National Severe Storms Laboratory, at http://www.nssl.noaa.gov/primer/tstorm/tst_basics.html.

[57] A. M. Best Company, Inc., *Tornado Losses Approach Those of Hurricanes* (Oldwick, NJ: A. M. Best Company, 2008), p. 1.

[58] A. M. Best Company, Inc., p. 1 and Exhibit 4. According to the report, the costliest thunderstorm/wind/tornado event occurred between May 2 and May 11, 2003, affecting 18 states and resulting in over $3.2 billion in insured damages.

[59] Ibid., p. 7.

[60] Walker S. Ashley, "Spatial and Temporal Analysis of Tornado Fatalities in the United States: 1880 - 2005," *Weather and Forecasting*, vol. 22 (December 2007), p. 1216.

[61] Ibid.

[62] See, for example, Dennis S. Mileti, *Disasters by Design: A Reassessment of Natural Hazards in the United States* (Washington, DC: Joseph Henry Press, 1999), p. 226.

[63] See, for example, "Advice to the New Administration and Congress: Actions to Make our Nation Resilient to Severe Weather and Climate Change," a document produced by the University Corporation for Atmospheric Research and seven other stakeholder organizations; at http://www.ucar.edu/td/.

Most tornado fatalities occur within housing structures, unlike fatalities from floods which occur in vehicles. This indicates that people are more likely to seek shelter during tornadic events; however, the risk of injury or death seems to depend on what type of housing stock in which they choose to seek shelter. For example, one study indicated that manufactured houses, such as mobile homes, are particularly vulnerable to tornadoes. Mobile home deaths accounted for an average of 44% of all deaths caused by tornadoes between 1985 and 2005, and showed an increasing trend over the 20-year period.[64] During the same time period, tornado-related deaths within permanent homes fluctuated between 20% and 30%, and deaths in vehicles decreased to 9.9% of all tornado-related deaths, on average.[65] The study concluded that the high percentage of mobile homes in the Southeast may be the key factor explaining why most tornado-related deaths occur in lower Arkansas, Tennessee, and lower Mississippi River valleys.

Members of Congress have recognized the increased vulnerability of citizens living in manufactured housing to tornadoes. In the 110th Congress, the House passed H.R. 2787, CJ's Home Protection Act of 2007, on October 30, 2007. The bill would amend §604 of the National Manufactured Housing Construction and Safety Standards Act of 2004 (42 U.S.C. 5403) to require that all manufactured homes be equipped with a NOAA Weather Radio.[66] NOAA Weather Radios would presumably give the residents of manufactured homes a better chance of receiving tornado warnings and allow them to take precautionary measures. A companion bill, S. 2724, was introduced in the Senate on March 6, 2008. The Senate did not act on the bill.

In 2003, the 108th Congress passed the Tornado Shelters Act (P.L. 108-146), which amended the Housing and Community Development Act of 1974 (42 U.S.C. 5305(a)) to authorize communities to use Community Development Block Grant (CDBG) funds for construction of tornado-safe shelters in manufactured home parks. The law was aimed at communities of at least 20 manufactured homes and which consist of predominately low and moderate income residents. To be eligible, the community has to be located in a state that was struck by a tornado during the fiscal year when funds were made available or during the previous three fiscal years.[67]

Since 1950, violent tornadoes were responsible for 67.5% of all tornado deaths in the United States, yet comprise only 2.1% of all tornadoes.[68] The number of fatalities caused by less violent tornadoes is also significant, and some studies suggest that the percentage of fatalities caused by less violent tornadoes has increased since the 1970s.[69] (See the **Appendix** for an explanation of how violent tornadoes and less destructive tornadoes are classified: the F-Scale and enhanced F-scale.)

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[64] Ashley (2007), p. 1224.

[65] Ibid.

[66] NOAA Weather Radio broadcasts official NWS warnings, watches, forecasts, and other hazard information 24 hours a day, 7 days a week to all 50 states, adjacent coastal waters, Puerto Rico, the U.S. Virgin Islands, and the U.S. Pacific Territories. See http://www.nws.noaa.gov/nwr/.

[67] For more information on the CDBG program, see CRS Report RL33330, *Community Development Block Grant Funds in Disaster Relief and Recovery*, by Eugene Boyd and Oscar R. Gonzales.

[68] Ashley (2007), p. 1217.

[69] Ibid., p. 1218.

Where and When Tornadoes Form

Tornadoes have been reported on all continents except Antarctica; however, they occur most commonly in North America and particularly in the United States.[70] They can occur in all 50 states but they form most commonly in three regions: (1) a swath of the Midwest extending from the Texas Gulf Coastal Plain northward through eastern South Dakota (known as "Tornado Alley"); (2) an area that extends across the Gulf Coastal Plain from south Texas eastward to Florida (known as "Dixie Alley"); and (3) an area located in eastern Iowa, south-central Indiana, western Pennsylvania, and central Arkansas (a smaller "tornado alley"). See **Figure 1**.

Tornadoes occur mostly during spring and summer, and usually occur during the late afternoon and early evening. However, tornadoes can occur on any day of the year and at any hour.[71] The United States averages approximately 1,000 tornadoes per year—the highest average annual number in the world. (The actual number of recorded tornadoes per year varies, depending on the source of information.) The first part of 2008 was relatively active, with 1,390 confirmed tornadoes through July.[72] Tornadoes also caused 123 deaths between January and September of 2008, the ninth highest total for the nine-month period since reliable record keeping began in 1953.[73]

How and Why Tornadoes Form

A tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground. Tornadoes develop from severe thunderstorms in warm, moist, unstable air along and ahead of cold fronts. There are two types of tornadoes, those that come from a supercell thunderstorm and those that do not.[74]

Tornadoes that form from supercell thunderstorms are the most common, usually the largest, and the most dangerous. In supercell thunderstorms, a rotating updraft is essential to development of a tornado. Rotation of the updraft can be caused by wind shear, which occurs when winds at two different levels above the ground blow at different speeds or in different directions. An invisible tube of air begins to rotate horizontally, and rising air within the thunderstorm tilts the rotating air from horizontal to vertical, resulting in rotation that extends through much of the storm. Once the updraft is rotating and being fed by warm, moist air flowing in from the ground level, a tornado can form. The mechanisms that cause tornadoes to form from supercell storms are not known precisely, and it is not currently possible to predict which supercell thunderstorms will produce tornadoes and which will not. Based on observations, approximately 20% of supercell thunderstorms produce tornadoes.[75]

[70] National Severe Storms Laboratory, at http://www.nssl.noaa.gov/primer/tornado/tor_faq.shtml.

[71] National Severe Storms Laboratory, at http://www.nssl.noaa.gov/primer/tornado/tor_climatology.html#.

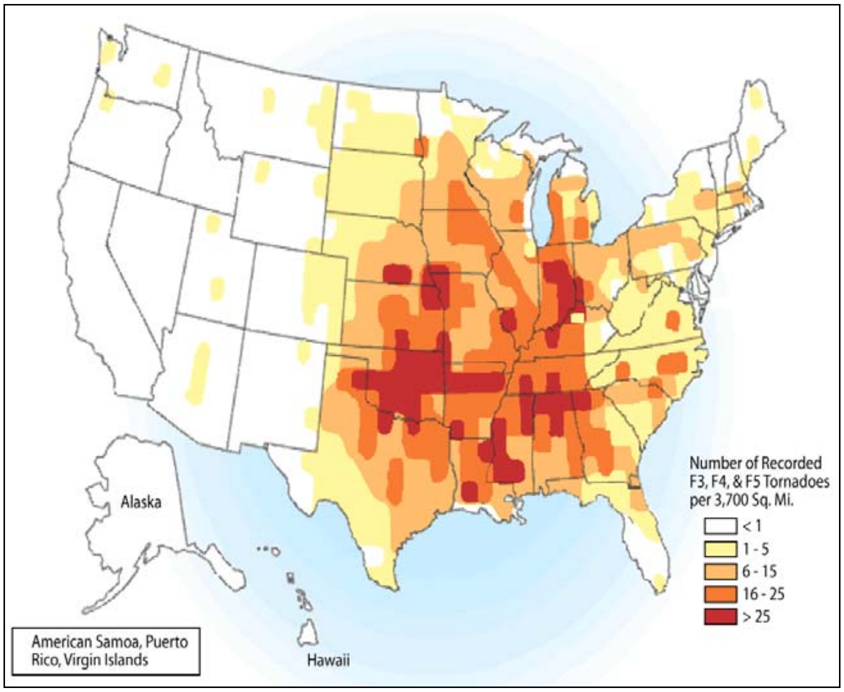
[72] NOAA, National Climatic Data Center (Asheville, NC), "Climate of 2008 U.S. Tornado Overview," at http://www.ncdc.noaa.gov/oa/climate/research/2008/tornadoes08.html. Data as of Oct. 10, 2008.

[73] Ibid. Also, for a list of declared disasters because of tornadoes or related weather events, see FEMA, 2008 Federal Disaster Declarations, at http://www.fema.gov/news/disasters.fema.

[74] NOAA National Severe Storms Laboratory, "A Severe Weather Primer: Questions and Answers about Tornadoes," at http://www.nssl.noaa.gov/primer/tornado/tor_basics.html.

[75] Ibid.

Figure 1. Map Showing the Number of Recorded Tornadoes Greater than F3 in the United States Between 1950 and 1998



Source: Federal Emergency Management Agency (FEMA), at http://www.fema.gov/plan/prevent/saferoom/tsfs02_torn_activity.sht. According to FEMA, the map is based on NOAA, Storm Prediction Center statistics.

A non-supercell tornado forms from a vertically spinning parcel of air near the ground, about 1-10 kilometers in diameter, that is caused by wind shear from a warm, cold, or sea breeze front, or from a *dryline*—the interface between warm, moist air and hot, dry air. When an updraft moves over the spinning parcel of air and stretches it, a tornado can form. This type of tornado formation commonly occurs in eastern Colorado, where cool air descending from the Rocky Mountains toward the west collides with hot dry air from the Great Plains.[76] Land-falling tropical storms and hurricanes can also generate non-supercell tornadoes.

Forecasting and Warning: The Role of the National Weather Service

The NWS, at the discretion of the Secretary of Commerce, has statutory authority for weather forecasting and for issuing storm warnings (15 U.S.C. §313). The NWS provides weather, water, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. The NWS employs 4,700 employees in 122 weather forecast offices, 13 river forecast centers, national centers, and other supporting agencies around the country.[77]

[76] Ibid.

[77] The nine centers of the NWS include the Aviation Weather Center, Climate Prediction Center, Environmental Modeling Center, Hydrometeorological Prediction Center, National Center for Environmental Protection, Ocean Prediction Center, Space Weather Prediction Center, Storm Prediction Center, and Tropical Prediction Center. See http://www.nws.noaa.gov/organization.php.

Each of the 122 weather forecast offices is equipped with technologies for observing, forecasting, and warning of severe thunderstorms and tornadoes.[78] These technologies include Weather Surveillance Radar (WSR-88D, also known as NEXRAD, a network of 161 radars), Automated Surface Observing Systems (ASOS)[79] at over 1,200 sites, access to data from two Geostationary Operational Environmental Satellites (GOES 8 and 10), and the Automated Weather Interactive Processing System (AWIPS).[80]

Severe thunderstorm and tornado forecasts are made by the Storm Prediction Center (SPC) and local weather forecast offices. Forecasters at the SPC use numerical weather prediction models to determine if atmospheric conditions, temperature, and wind flow patterns may lead to formation of severe weather. The SPC uses its suite of products to relay forecasts of organized severe weather as much as three days ahead of time, and continually refines the forecast up until the event has concluded.[81] The severe weather forecast process typically follows the following pattern: (1) convective outlook; (2) mesoscale discussion; (3) watch; and (4) warning.

Convective Outlook

The severe weather forecast process typically begins with a forecast issued one to two days in advance of where both severe and non-severe thunderstorms are expected to occur around the country.[82] This is known as a convective outlook. Areas of possible severe thunderstorms are labeled slight risk, moderate risk, or high risk, depending upon the coverage and intensity of expected severe thunderstorms in a region. The outlooks are the first severe weather threat notifications that the local NWS offices and local emergency officials receive.

Mesoscale Discussion

As a convective outlook area becomes more defined, a next step in the forecast process is often needed to describe an evolving severe weather threat. This is known as a mesoscale discussion.[83] Mesoscale discussions contain information that helps forecasters at local NWS offices understand the causes and prepare for the types of severe weather expected.

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[78] Joseph H. Golden and Christopher R. Adams, "The Tornado Problem: Forecast, Warning, and Response," *Natural Hazards Review* (May 2000), p. 107.

[79] ASOS is a climatological observing network that generates weather reports at hourly intervals, except when weather conditions are changing rapidly.

[80] AWIPS is an interactive computer system that integrates meteorological and hydrological data from an array of meteorological sensors—radar, satellites, surface instruments—and enables the forecaster to prepare and issue more accurate and timely forecasts and warnings.

[81] The SPC suite of products includes satellite imagery, radars, surface weather stations, weather balloon soundings, wind profilers, lightning detection network, and information from local NWS offices. See http://www.spc.noaa.gov/misc/aboutus.html.

[82] NOAA Storm Prediction Center, the Severe Storms Forecast Process: Outlook to Mesoscale Discussion to Watch to Warning, at http://www.spc.noaa.gov/misc/aboutus.html.

[83] Ibid.

Watch

If development of severe thunderstorms or tornadoes is imminent, or likely to occur in the next several hours, the next step is a severe storm watch. Such watches alert the public, aviators, and local NWS offices that environmental conditions have become favorable for the development of severe storms or tornadoes. Following the issuance of a severe storm watch, local networks of storm spotters[84] are activated, and forecasters in the threat area closely monitor radar imagery and spotter reports to issue the appropriate severe thunderstorm and tornado warnings.[85]

Warning

As the severe weather threat continues to develop, the local NWS offices and the storm spotters try to detect severe thunderstorms and tornadoes using radar or other detection technology and visual evidence. When severe hail, damaging winds, or a tornado appears imminent from radar or visual evidence, local NWS offices will issue a severe thunderstorm or tornado warning as appropriate. The warning contains specific language about areas at risk, time frames, specific hazards, recommended protective behavior for those at risk, and the office issuing the warning.[86]

Communicating the Severe Weather Risk

Several methods exist to communicate alerts and warnings to the public. The NWS maintains and operates NOAA Weather Radio (NWR). NWR is a nationwide network of radio stations broadcasting continuous weather information directly from the nearest NWS office. The NWR works with the Emergency Alert System (EAS). The EAS is an automated simultaneous retransmission system that allows NWS warnings to be disseminated over most radio and television networks, and over cable and satellite TV systems.[87] NOAA Weather Radio broadcasts official NWS warnings, watches, forecasts, and other hazard information 24 hours a day, 7 days a week, to all 50 states, adjacent coastal waters, Puerto Rico, the U.S. Virgin Islands, and the U.S. Pacific Territories.[88]

Issuing severe weather warnings to the public has evolved into what some observers term a weather warning partnership: a roughly triangular exchange of information between the NWS, private forecasters and the news media, and local emergency managers. The objective of the weather warning partnership is to provide a consistent warning message to the public at risk.[89]

The NWS depends on weather warning partnerships with the electronic news media and local and state emergency management officials to ensure that communities are prepared for severe weather

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[84] Storm spotters report critical weather information in real time to the NWS from a specific location.

[85] NOAA Storm Prediction Center, the Severe Storms Forecast Process: Outlook to Mesoscale Discussion to Watch to Warning, at http://www.spc.noaa.gov/misc/aboutus.html.

[86] Joseph H. Golden and Christopher R. Adams, "The Tornado Problem: Forecast, Warning, and Response," *Natural Hazards Review* (May 2000), p. 111-112.

[87] EAS is administered by FEMA, in cooperation with the Federal Communication Commission and NWS. For more information on EAS, see CRS Report RL32527, *The Emergency Alert System (EAS) and All-Hazard Warnings*, by Linda K. Moore.

[88] NOAA Weather Radio, at http://www.nws.noaa.gov/nwr/.

[89] R.A. Maddux, "The Weather Warning Partnership," *Proceedings from the Hazards Research and Applications Workshop*, Natural Hazards Research and Applications Information Center, University of Colorado, Boulder (1991).

outbreaks and to further communicate the outlooks, watches, and warnings to the public.[90] Many emergency management officials and news media monitor NWS outlooks so that they have enough lead time for activating preparedness capabilities such as storm spotters, increasing response levels, and preparing to activate the warning communication systems. The partnership is essential in guaranteeing that there is a shared understanding of the weather threats and that accurate warning information is communicated to the public at risk. Observers have noted that this shared understanding helps prevent conflicting warnings—which could lead to delays in seeking shelter—from being communicated to the public.[91]

Summary and Conclusions

Congress may consider several options for potentially reducing the costs of severe thunderstorms and tornadoes: improving detection and warning systems; fostering efforts to build more resilient buildings and infrastructure; and supporting research and development to better understand why and where severe thunderstorms and tornadoes occur, as well as other measures. Whether and how climate change is influencing or could affect the frequency and intensity of thunderstorms and tornadoes is not yet evident. Thus it is not clear whether long-term efforts to mitigate greenhouse gas-induced global warming—such as by reducing emissions of carbon dioxide and other gases—will also mitigate damage to property and reduce injuries and losses of life from severe thunderstorms and tornadoes.

Enhancing the scientific understanding of how and why severe thunderstorms and tornadoes form, and improving the accuracy and timeliness of forecasting and warning systems, will likely provide individuals and communities in the United States better information to help them avoid damage and injury from severe weather events. The role of the federal government in weather and climate research, thunderstorm and tornado forecasting, and issuing warnings is substantial. Spending on weather forecasts and warnings comprises the bulk of the NWS budget, which is itself the largest component of NOAA's annual budget. Several other federal agencies contribute to the weather and climate enterprise, including NSF, NASA, the U.S. Geological Survey, and others. The federal investment in weather-related response and recovery, including programs at the Department of Agriculture and FEMA, is also substantial.

How climate change will influence the frequency and severity of severe thunderstorms and tornadoes across the United States is not clear. Many observers and stakeholders call for increased funding for improving the understanding of physical processes that produce extreme events, such as severe thunderstorms and tornadoes, and how these processes change with climate.[92] Observers and stakeholders are broadly in agreement about the types of R&D needed, such as integrated data and observation systems, improved remote sensing capabilities, better modeling capability, and others.[93]

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[90] Golden and Adams (2000), p. 112.

[91] Ibid.

[92] CCSP, Weather and Climate Extremes in a Changing Climate (2008), p. 122. See, for example, "Advice to the New Administration and Congress: Actions to Make our Nation Resilient to Severe Weather and Climate Change," a document produced by the University Corporation for Atmospheric Research and seven other stakeholder organizations; at http://www.ucar.edu/td/. The organizations call for $9 billion in funding for weather and climate-related federal expenditures *in addition* to currently estimated spending over the next five years.

[93] Grand Challenges for Disaster Reduction (2005), p. 14.

Even if funding increased substantially, however, it may not necessarily lead to significant decreases in damages, injuries, or deaths from severe thunderstorms and tornadoes. Shifting populations, changes in wealth density, and construction of dense infrastructure in areas prone to severe weather could offset improvements in forecasting and warning systems:

> ...the potential for considerable loss of life and property due to tornadoes continues to exist, especially in highly vulnerable regions of the country. Further, the increasing population and migration patterns of this population suggest that the overall vulnerability and risk to humans and their property may amplify in the future despite improvements in forecasting, detection, and warning dissemination.[94] (References omitted.)

In fact, implementing hazard mitigation strategies may include developing and enforcing land-use planning and zoning laws, which are traditionally state and local issues and not Congressional concerns per se.[95] Disseminating results of federally sponsored R&D, from activities such as those authorized in the National Windstorm Impact Reduction Program, to states and local communities may be more squarely in the Congressional purview, and more directly addressed through oversight of the programs and annual appropriations for the participating agencies.

[94] Ashley (2007), p. 1226.

[95] See, for example, Grand Challenge #3—develop hazard mitigation strategies and technologies; one of six grand challenges developed by the National Science and Technology Council, Grand Challenges for Disaster Reduction (2005). Arguably, the National Flood Insurance Program (NFIP)—administered by FEMA—is an example of federal involvement in local community development. The NFIP makes flood insurance available to communities that agree to adopt and enforce floodplain management ordinances. For more information on the NFIP, see CRS Report RL34610, *Midwest Flooding Disaster: Rethinking Federal Flood Insurance?*, by Rawle O. King.

Appendix. Classifying Tornadoes: The F-Scale

The Fujita, or F-scale, was developed to provide a method for estimating the intensity of tornadoes, and was intended to relate the degree of damage to the intensity of wind.[96] The original F-scale was used for over three decades, but its limitations prompted the development of a new scale, called the enhanced F-scale, or EF-scale. The EF-scale is intended to be a more robust and precise method of assessing tornado damage than the original F-scale. The EF-scale calibrates tornado damage by using 28 different types of damage indicators, such as the type of construction (e.g., anchored versus unanchored houses, mobile homes, schools, garages, barns, skyscrapers, transmission towers, and others).[97] Even with the improvements over the original F-scale, the EF-scale only represents *estimates* of wind speed, based on damage, and not measurements of actual wind speeds in tornadoes.[98] Actual tornado wind speeds are still largely unknown. **Table A-1** compares the original F-scale and the EF-scale which is currently used by meteorologists and wind engineers.

Table A-1. F-Scale and Enhanced F-Scale for Tornado Damage

Original F-scale	Wind Speed (mph)	Enhanced F-scale	Wind Speed (mph)
F-0	45-78	EF-0	65-85
F-1	79-117	EF-1	86-110
F-2	118-161	EF-2	111-135
F-3	162-209	EF-3	136-165
F-4	210-261	EF-4	166-200
F-5	262-317	EF-5	Over 200

Source: NOAA Storm Prediction Center, at http://www.spc.noaa.gov/faq/tornado/ef-scale.html.

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96 Dr. Ted Fujita developed the scale in 1971.

97 NOAA Storm Prediction Center, at http://www.spc.noaa.gov/faq/tornado/index.html#f-scale3.

98 NOAA Storm Prediction Center, at http://www.spc.noaa.gov/faq/tornado/ef-scale.html.