

CLIMATE CHANGE AND U.S. SEVERE THUNDERSTORM RISK

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EDITOR'S NOTE: 2011 already has set a record for insured losses caused by severe thunderstorms. AIR Director of Atmospheric Science Dr. Peter Dailey and Senior Scientist Dr. Ioana Dima describe how these phenomena develop, their impact, and whether they are increasing in number because of climate change.

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A severe thunderstorm is more than just the sense of excitement brought a flash of lightning and the subsequent clap of thunder. Severe thunderstorms, at their most extreme, are deadly: they can produce pounding hail as large as baseballs, 80 mph straight-line winds, and tornadoes that can achieve wind speeds of 250 mph and cut paths of destruction a mile wide and 50 miles long.

SEVERE THUNDERSTORMS CAUSE SUBSTANTIAL LOSS

This year, according to the National Weather Service, 753 confirmed tornadoes touched ground in April, the most to strike in a single month ever. April 27th became the deadliest day for tornadoes in over half a century: more than 300 people were killed, most of them when several neighborhoods of Tuscaloosa, Alabama, were destroyed. As reported by ISO's Property Claim Service (PCS), 2011 already has set a record for severe thunderstorm losses; PCS has issued 21 Catastrophe Serial Numbers to severe thunderstorm outbreaks this year, five of which had losses greater than \$1 billion. By the beginning of August, total insured losses exceed \$20 billion.

Figure 1 below shows annual losses from severe thunderstorms from 1991 to 2010 as compiled by PCS and expressed in constant (2011) dollars. In addition to the apparent increasing trend, particularly in recent years, Figure 1 clearly demonstrates the volatility of losses from year to year.

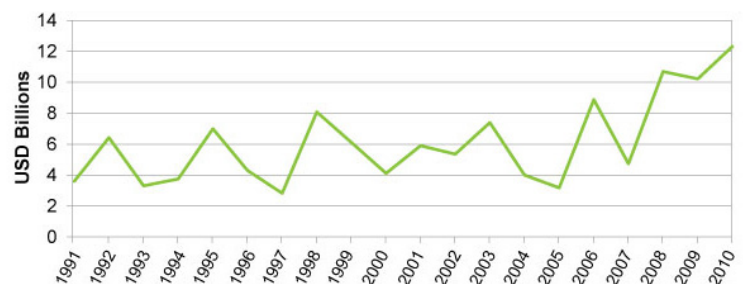


Figure 1. Insured losses from severe thunderstorms, 1991-2010, adjusted to 2011 dollars. (Source: PCS)

Even this brief overview suggests several questions commonly raised by researchers and risk managers alike: what is driving the apparent increase in severe thunderstorm losses? Are severe thunderstorms becoming more frequent or more severe—or possibly both at once? What is the role

of climate change in any possible trend? Or is the apparent increase, after all, driven primarily by increases in the number and value of properties at risk?

To provide answers requires a detailed understanding of the intricate workings of a variety of weather phenomena and their interactions, all of whose specific characteristics are contingent upon constantly changing meteorological conditions—and about which the available data often is not fully adequate or is incomplete.

WHAT CAUSES SEVERE THUNDERSTORMS?

The U.S. National Weather Service describes a severe thunderstorm as a thunderstorm that is capable of producing at least one of three destructive phenomena: wind gusts of 58 miles per hour or greater (straight-line winds), hail of at least 0.75 inches in diameter, or tornadoes. “Tornadic supercell” thunderstorms—potentially the most violent type of thunderstorm—have been observed around the world, but they occur most frequently in the central United States between the Rocky Mountains and the Mississippi River, although they sometimes develop in the western states as well as all the way to the eastern seaboard. Effectively, the entire contiguous United States is at risk from severe thunderstorms.

SEVERE THUNDERSTORM FORMATION

At least three specific meteorological conditions are required for severe thunderstorms to form: (1) atmospheric instability that results in the vertical movement of warm air from the surface; (2) sufficient moisture content (atmospheric water vapor); (3) the presence of a lifting mechanism such as a frontal boundary, an upslope wind, or a “dry line” (a boundary marking two regions of distinctively different moisture content).

Tornadic supercell thunderstorms require one additional and important condition: sufficient wind shear (wind speed and direction that change with height). Wind shear is the chief factor influencing a storm’s movement and, in the case of a tornadic thunderstorm, the storm’s ability to develop a rotating updraft. The first three conditions—instability, moisture, and lifting mechanisms—can affect the storm’s precipitation rate and/or hail generation and size; the development of a rotating updraft marks the storm’s transition to a supercell capable of producing a strong combination of all three perils: downbursts and straight-line winds, large hail—and tornadoes.



Figure 2. The classic funnel-shaped cloud of a tornado (Source: NOAA)

MACRO-SCALE INFLUENCES

The distinctive geography of the North American Great Plains—an almost level surface stretching for thousands of miles from the Arctic to the Gulf of Mexico and unbroken by any east-west mountain range—ensures that there is no significant physical barrier to the flow and interaction of air masses up and down and across the center of the continent.

Two other large-scale phenomena additionally contribute to the high likelihood of thunderstorm activity over the Great Plains. The first is an abundance, especially in the Spring, of low-level atmospheric moisture that originates in the Gulf of Mexico (and to a lesser degree, the Atlantic Ocean). This warm, moist air clashes with the cooler, drier air from the north, thereby setting in play the local conditions described above that are necessary for severe thunderstorms to form. Second, about five miles above and traveling from west to east, is the northern polar jet stream. When the jet stream is situated above a developing thunderstorm, its intense winds act to “vent” the storm, pulling its rising inner air up and away from the main body of the storm, thereby helping the updraft to strengthen and its speed to increase. This venting process is critical to the storm’s development because it creates a positive feedback loop.

The rising warm moist air from the surface is cooled as it rises and, as a result, water vapor begins to condense into liquid cloud droplets, and potentially rain. As water changes state from vapor to liquid, there is a release of “latent heat,” the heat that was stored when the still-liquid water evaporated from the ocean. This heat feeds the already warm buoyant air, making the air not only rise, but to accelerate in its movement upwards.

With sufficient “venting” out the top, the latent heat supply will be replenished as long as humid air is available at the surface—thereby leading to a continuing cycle of more intense vertical motion, more condensation and heat release, more vertical motion and so on, until the storm cell is enormous and very intense.

OTHER INFLUENCES

While jet stream patterns of movement are more or less regular, the “jet” is subject to seasonal and other climate variations, in particular, to the quasi-periodic phenomenon known as ENSO, or the El Niño/La Niña-Southern Oscillation. ENSO is a climate pattern—anomalous warmer or cooler ocean surface temperatures (El Niño/La Niña) that are coupled to higher and lower air surface pressure (the Southern Oscillation)—that occurs across the tropical Pacific Ocean in roughly five- to seven-year cycles. During *El Niño* conditions, the jet stream over the U.S. generally is positioned farther south, and during *La Niña* conditions farther north.

Changes in the position of the jet stream induced by ENSO in the spring and summer months can have a significant impact on thunderstorm development, not only directly by providing a venting mechanism, but because the jet stream also initiates and influences the tracks of extratropical cyclones and frontal systems, both of which are potential lifting mechanisms in thunderstorm development.

Earlier this year, for example, a weakening *La Niña* resulted in a persistent passage of the jet stream over the United States, thereby allowing cold air from the north to come into direct contact with warm moist air from the Gulf of Mexico. As a result, very favorable and sustained conditions for severe weather developed—conditions that finally erupted into the especially deadly outbreaks in April and May.

It should be kept in mind, however, that the development of severe thunderstorms is the result of numerous complex and even chaotic atmospheric interactions, and that their manifestation is thus also subject to a great deal of natural year-to-year and even day-to-day variability.

THE EFFECTS OF CLIMATE CHANGE

Climate is always changing. A primary indicator of climate change is the observed trends of global surface temperatures, which over the past century have been on the rise and which are expected to continue. How, then, will a warming climate affect the conditions and mechanisms that lead to the development of severe thunderstorms?

WEAKER WIND SHEAR → FEWER SEVERE THUNDERSTORMS

As the earth’s average global surface temperature rises, the polar regions are expected to become warmer. As a result, at the lower reaches of the atmosphere, nearer the surface, the difference between the temperature of the air masses coming from the poles and the temperature of the air moving up from the equator is expected to decrease (that is, the temperature gradient between the poles and the equator will weaken). In turn, vertical wind shear should weaken, since the generation of shear depends on temperature differences (the smaller the temperature difference, the less shear). Given the importance of vertical wind shear to the development of severe thunderstorms, especially supercells, weaker vertical shear reduces the probability that severe thunderstorms will develop and intensify.

INCREASED MOISTURE AND VERTICAL INSTABILITY → MORE SEVERE THUNDERSTORMS

At the same time, increased warming at the earth’s surface is expected to produce at least two other major effects. First, it would increase the amount of moisture in the air: more water would evaporate from the surface of the ocean in warmer conditions, and warmer air can hold more water vapor. Additionally, vertical instability would increase, because of both direct thermal effects (warm air rises) and because warm, moist air is more unstable than cool, dry air. Since both of these conditions—abundant moisture and vertical instability—promote the generation of severe thunderstorms, climate change characterized by rising temperature could increase the probability that severe thunderstorms will develop.

CONSENSUS OF CURRENT RESEARCH

While the above conclusions appear to be contradictory—one pointing to elevated risk and the other to reduced risk under conditions of global warming—the anticipated conditions upon which those conclusions are based are not independent of the totality of changes that may develop in the end. While changes in the jet stream and moisture and instability conditions are indeed expected to change in a changing environment, there is no consensus at present as to which of these effects will “win.”

How climate change will affect the development of severe thunderstorms in the coming years is a question whose answer remains unclear. The United Nations’ “Intergovernmental Panel on Climate Change” (IPCC) 2007 Report states: “There is insufficient evidence to determine whether trends exist in small-scale phenomena such as tornadoes, hail, lightning, and dust storms.”

Part of the difficulty, over and above the competing effects, is that changes in small scale weather phenomena like tornados are difficult to attribute directly to changes in larger-scale climate phenomena like ENSO and jet stream patterns. Additionally, as the scale of the peril is reduced, the amount of data needed to address the various impacts of climate change increases. Consequently, a very long historical record of thunderstorm activity is needed in order to provide a sufficiently large sample from which statistical significance can be established. Today, the historical record is simply not long enough to reach firm conclusions.

Indeed, the occasional mile-wide tornado with a 50-mile long track notwithstanding, individual severe thunderstorm events remain, as the IPCC report states, “small-scale phenomena.” Most tornadoes touch ground only briefly; most straight-line winds last less than an hour; and large-size hail storms are similarly circumscribed in their duration and the area they affect. These storms occur irregularly, tend to have relatively small footprints, and are easily overlooked (or are not observed at all in unpopulated areas).

For these reasons—together with progressively uncertain data prior to the 1990s—the effort by researchers to determine how severe thunderstorm activity may be influenced by climate change is daunting. Aside from disasters like Tuscaloosa in April and Joplin, Missouri, in May this year, the impact of severe thunderstorms is mainly felt because of their cumulative effect—because of the large number of individual occurrences that take place within a single over-arching event or over an entire season.

WHAT OF THE OBSERVED INCREASE IN LOSSES?

While a consensus on the effects of climate change on the generation and intensity of severe thunderstorms remains elusive, the historical record does demonstrate an increase in losses caused by these storms in recent years. Several explanations, unrelated to climate change, are highly credible.

Prominent among these is the fact that patterns of living and behavior have changed over the past several decades. The Great Plains, which as late as the 1950s were predominantly rural and had few large cities (and those

with populations in the few hundreds of thousands), in recent years have become more densely populated, more urban, and the farms and ranches more corporatized and more highly valued. In brief, the total insured value at risk in areas where severe thunderstorms are known to occur is on the rise.

Where fifty years ago hail might fall (unnoticed) in uninhabited scrub, today, with almost equal likelihood, it could strike a suburban car dealership with hundreds of cars on display, or a large multi-use shopping mall.

Consequently, at least three factors have contributed to increasing losses from severe thunderstorms: increased population in formerly rural areas, increasing exposure values in today's urban and suburban areas, and severe storm activity that has directly impacted urban areas, many of which extend much further away from city “downtowns” than in decades past.

CONCLUSION

The United States is particularly susceptible to severe thunderstorm outbreaks. No other country experiences as many and as intense thunderstorm cells in a typical year. When all of the contributing conditions come together— atmospheric instability, moist warm air, and a mechanism capable of lifting the air and releasing its latent heat—the risk is clear.

The latest research on the influence of climate change points in two conflicting directions and further study is needed for scientists to be able to reach a consensus. In the near term—which may extend for decades or longer—which of the competing factors “wins out” may change from one year to the next, making it nearly impossible to attribute specific changes in the hazard to changes in climate until a very long and dependable historical record becomes available.

What is clear, in the United States and in most parts of the world, is that people are moving to and building homes in areas of higher risk. In comparison to climate impacts, these trends are more easily quantified and can more readily explain some part of the upward trend in losses.

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