DEFY THE TWISTER:

Tornado Resilience in the Age of Climate Change

FM Global®

Introduction

Each year, tornadoes lead to significant property damage in the United States. Increasingly, scientists and engineers are working together to better understand how tornadoes develop and to simulate the effects of tornadoes on buildings. However, the task is daunting due to experimental challenges and the unknowns climate change may bring. Tornado research requires more frequent and effective observations, computer modeling, and wind tunnel experiments as it continues to improve. These research efforts form the basis of existing and emerging loss prevention recommendations that FM Global can offer to clients to help mitigate potentially catastrophic property damage and business interruption.

FIGURE 1: Members of the 2017 FM Global Climate Science Round Table (from left to right): Dr. Harold Brooks, Dr. Joshua Wurman, Professor Yvette Richardson, Professor Greg Kopp, and Professor Horia Hangan.

In November 2017, FM Global hosted the FM Global Climate Science Round Table on Tornadoes. Dr. Harold Brooks (NOAA National Severe Storms Laboratory), Dr. Joshua Wurman (Center for Severe Weather Research), Professor Yvette Richardson (Pennsylvania State University), and Professors Greg Kopp and Horia Hangan (Western University) were invited to present and discuss the state of the art in tornado research with FM Global's Science and Engineering Team (Figure 1). The goal of the Round Table was to discuss practical research that would lead to risk assessment, mitigation and loss prevention solutions and improve business resilience.

In the Round Table discussion, speakers focused on what is currently known about
- the formation of tornadoes
- the economic impact of tornadoes
- risk mitigation and loss prevention strategies.

These research topics were discussed in light of climate change and possible changes in tornado hazard in the future.

The Economic Impact of Tornadoes

Each year, on average, about 1,000 tornadoes occur in the United States and can cause property damage [1]. While even one tornado can cause significant damage, the potential for property damage increases when tornadoes occur in rapid succession or geographical proximity [2] [3]. These outbreaks produce multiple tornadoes within a single weather system [4] and are accompanied by damaging winds, hail and heavy rainfall. Therefore, besides physical damage from intense wind speeds, rainwater intrusions during or after the event can lead to water damage and substantial business interruption.

For example, an outbreak of almost 200 tornadoes across the states of Mississippi, Alabama, Georgia, Tennessee and Virginia on April 27, 2011, caused insured losses exceeding $4 billion [5] [6]. With several other outbreaks in April and May, tornado-related insurance industry losses grew to more than $14 billion in 2011 [6].

TABLE 1: The Enhanced Fujita (EF) tornado intensity scale and associated wind speeds and damage. Wind speeds are estimated based on observed damage. Adopted from [7] and [8].

ENHANCED FUJITA (EF) SCALE	DAMAGE	ESTIMATED 3-SECOND PEAK GUST (MPH)
EF0	Light damage. Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; signboards damaged.	65-85
EF1	Moderate damage. Surface peeled off roads; mobile homes pushed off foundations or overturned; moving autos blown off roads.	86-110
EF2	Considerable damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.	111-135
EF3	Severe damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.	136-165
EF4	Devastating damage. Well-constructed houses leveled; structures with weak foundations blown some distance away; cars thrown and large missiles generated.	166-200
EF5	Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles flung through the air in excess of 109 yards (100 meters); trees debarked; occurrence of extraordinary phenomena.	> 200

Another example of catastrophic destruction and financial loss occurred on May 22, 2011 in Joplin, Missouri, when a tornado with intensity 5 on the Enhanced Fujita (EF) scale (Table 1) and wind speeds inferred to be more than 200 mph left a path of destruction about 1 mile wide and 22 miles long [9]. St. John's Regional Medical Center, an FM Global client, incurred severe damage with caved ceilings, snapped pipes, shattered windows, and expensive medical equipment destroyed (Figure 2) [10].

FIGURE 2: Devastating damage incurred at St. John's Regional Medical Center during the Joplin, Missouri tornado in 2011 [10].

The Formation of Tornadoes

Most strong tornadoes develop in specific types of thunderstorms called supercells. A supercell is characterized by a deep and persistent rotating updraft. The rotating updraft develops from air with horizontal spin in the storm's inflow region, which is carried into the storm by vertically rising air. The supercell produces hail and heavy rainfall, and the rainfall leads to downdrafts and cooling of the air underneath the storm. The cool air in the downdraft develops rotation as it descends through regions of varying temperature. If the conditions are just right, this air can end up in the correct location to get pulled upward into the thunderstorm. As the rotating air is pulled upward, vertically stretched, and horizontally contracted, it also spins faster similar to a figure skater pulling in his/her arms when pirouetting. This dynamic process forms the tornado (Figure 3) [11].

The Frequency of Tornadoes and Tornado Outbreaks

It is impossible to predict the number and the approximate locations of tornadoes per year. Tornado activity has become more variable in the United States, particularly since 2000, with a decrease in the number of days per year with tornadoes but an increase in the number of tornadoes on these days [12]. Environmental changes might be related to this increasing variability.

Some climate models project environmental conditions that support an increase in the frequency and intensity of severe thunderstorms which can produce tornadoes, hail, and straight-line winds, especially over regions that are prone to these hazards [13]. Among the environmental conditions known to produce these severe thunderstorms and tornadic supercells are the convective available potential energy (CAPE) and vertical wind shear.

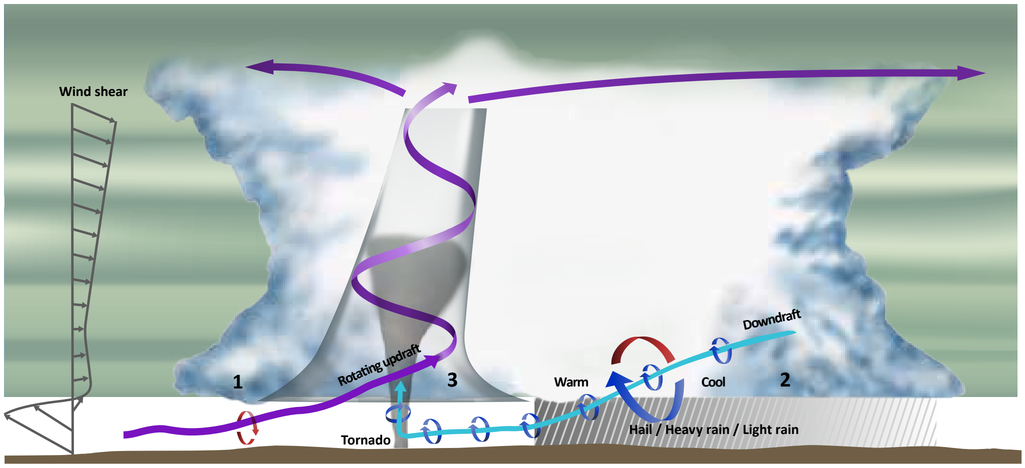

FIGURE 3: Schematic illustration of the anatomy of a supercell and the formation of a tornado. Air with horizontal spin is carried into the storm by vertically rising air (1). As the supercell produces hail and heavy rainfall, this precipitation leads to downdrafts and cooling of the air underneath the storm (2). The cool air in the downdraft develops rotation as it descends through varying temperatures. This air gets pulled upward into the thunderstorm (3). The rotating air is then vertically stretched and horizontally contracted, which accelerates the spinning and forms a tornado.

CAPE can be thought of as an integral measure of how fast buoyant air from near the surface can rise upward in the atmosphere to produce a thunderstorm. All else being equal, the higher the CAPE, the stronger a thunderstorm's updraft can become. The vertical wind shear is associated with the change of wind speed and direction with altitude in the atmosphere. Observations show that thunderstorm severity increases with CAPE and vertical wind shear. Increases in temperature and moisture in a future climate will likely increase CAPE and, thus, create more favorable conditions for strong thunderstorm updrafts [14] [15]. However, vertical wind shear is projected to decrease in a future climate, and this condition is not conducive to strong supercell formation.

The challenge is that the combined effect of these potential future conditions on tornado activity is not well understood. "Changes in the individual environmental parameters are anti-correlated with each other and climate change may bring higher CAPE and lower vertical wind shear. The problem is we know the changes for these individual parameters better than we know the changes in the combinations of parameters. However, the changes in the combinations of parameters are what matters," says Dr. Harold Brooks.

Necessary Atmospheric Conditions for Tornado Formation

- Sufficient amounts of convective available potential energy (CAPE)
- Strong deep-layer vertical wind shear
- Strong low-level wind shear in the storm's inflow region
- Low cloud base indicating high relative humidity

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>
> PROFESSOR YVETTE RICHARDSON

Predictions about tornado activity are uncertain because of scientific gaps and limitations in observing and simulating tornadoes and their supercell environments. "Factors influencing tornado formation such as low-level wind shear and near-surface moisture are not yet adequately modeled. How these factors change in response to climate change are among the things we don't understand very well," says Brooks. "There are still a lot of uncertainties in the representation of physical processes in climate models, and a lot of people are working on improving them," adds Professor Yvette Richardson.

Impacts of Tornadoes on Buildings

Little in nature can match the wind forces in tornadoes. Tornadic winds differ from straight-line winds (i.e., winds from hurricanes or intense thunderstorms) in terms of their dynamics, spatial and temporal variability and effects on buildings. Tornadic winds can affect the building from multiple directions rapidly (in less than a minute), which increases the destructive forces acting on the building (Figure 4). In addition, when a tornado passes over a building, there is a sudden decline in air pressure and a strong upward suction. The upward suction induced by the pressure drop inside the tornado, combined with the force of the winds, makes tornadic winds more powerful than straight-line winds and structural failure of roofs and walls more likely. Also, flying debris embedded in the tornado vortex is common. The flying debris can strike a building and breach the building envelope. Once the envelope is breached, the wind forces acting on the roof and the interior walls increase dramatically due to the internal pressurization of the building.

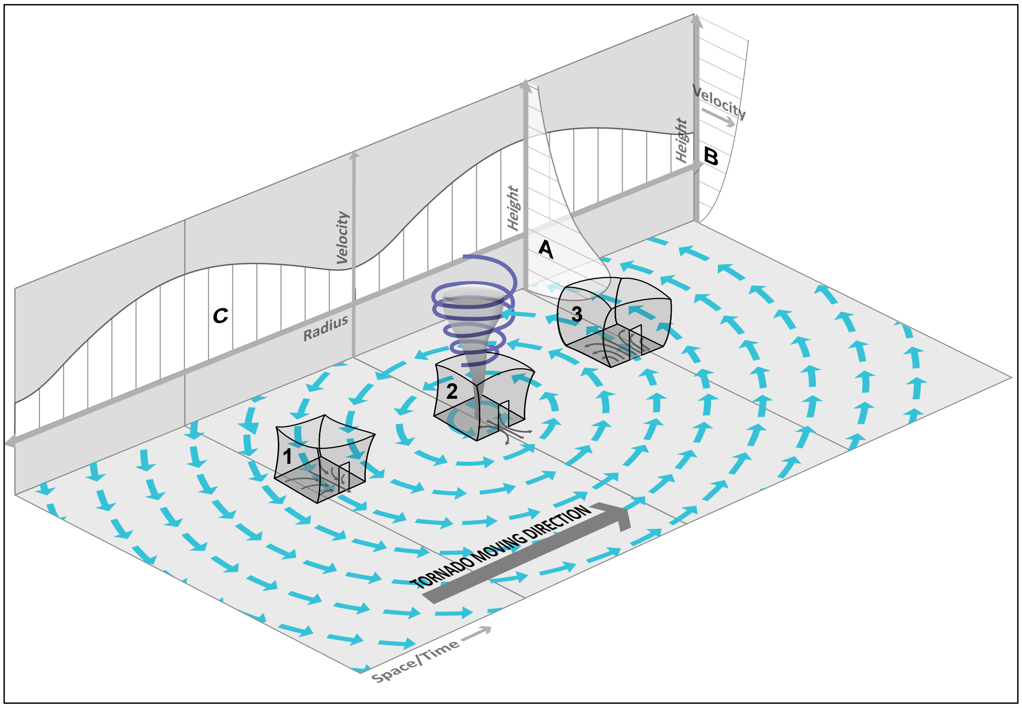

FIGURE 4: Schematic illustration of the effects of tornadic winds on a building. When a tornado passes over a building, its winds can affect it from multiple directions in less than a minute. Openings on the leeward side of the building create suction, leading to caving walls and roof (1). A tornado on top of the building can cause suction and/or billowing depending on the location of the opening with respect to the vortex center (2). Openings on the windward side of the building create internal pressurization leading to billowing walls and roof (3). These effects also depend on the size of the tornado compared to the size of the building. The vertical wind profile in the tornado features maximum wind speeds close to the ground (A). The vertical wind profile far from the tornado is similar to the one from straight-line winds with wind speeds increasing with height (B). The horizontal wind field exhibits maximum wind speeds at some distance from the vortex center (C).

The differences between the flow fields produced by tornadic winds and those from straight-line winds are important for structural response predictions. To address this issue, new methods and techniques are being developed in collaboration with FM Global's research partners, Professors Horia Hangan and Greg Kopp (Western University), to explore how tornadic winds affect buildings and how to calculate tornadic wind loads to facilitate more robust building designs and retrofits.

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PROFESSOR GREG KOPP

Improving Tornado Resilience

There are a few specific and well-tested loss prevention solutions for hurricanes or straight-line winds that are also applicable for tornadoes. “Recommendations should be based on observed weaknesses. We should use the same approach for tornadoes. The first step for loss prevention is to know the weak links and get rid of those,” says Kopp. Current practical recommendations to prevent wind damage are based on the loss experiences from hurricanes and are available in FM Global Property Loss Prevention Data Sheet 1-28 [18]. Some recommendations are:

1. **Harden the building envelope:** When the building envelope is breached, the tornadic winds can blow out ceilings and damage building contents. Keeping the exterior building envelope intact is therefore critical to minimize damage. The use of reinforced concrete, stone and brick yields stronger and more projectile-proof building envelopes than the use of synthetic, lightweight exterior cladding.
    - **Design and build more resilient roof decks:** Metal deck roofs are not strong enough to withstand tornadic wind forces. Ballast or gravel used to hold down ballasted roof systems can be blown away, become projectiles, and should not be used. Instead, concrete roof decks and double-roof systems with waterproof membrane are more suitable and more resistant to wind damage. If steel decks are used, they should be designed for higher wind design pressures. As a mitigation effort, more resilient roof decks could be achieved by using shorter deck spans, decks that are stiffer, deeper or thicker, and more robust securement to joists and purlins. Wind loss experience demonstrates that steel joists may buckle due to the transfer of lateral loads or compressive stresses developing in the lower chords of the joist while uplift pressures are applied to the roof deck. This transfer of force could be mitigated by enhancing the joist resistance, improving the joist bridging, and/or adding lower chord extensions.
    - **Use wind-rated dock and garage doors:** Dock and garage doors are most vulnerable to wind damage, and among the building envelope components that receive the least attention with respect to wind design outside of hurricane-prone areas. The use of wind-rated doors is critical in buildings designed for tornado resistance. Normally the vertical guides and end-locks that attach the door slats to those guides are smooth and are designed to allow vertical movement of the door, but do not resist strong forces. Such doors bow under wind loading and act like catenaries, thus allowing the door slats to pull out of the vertical guides. Wind-rated doors have guides and end-locks that are interlocked to resist large lateral loads.
    - **Upgrade windows:** When windows are shattered, the interior of the building becomes vulnerable to wind forces, wind-borne debris and water damage. Certain types of laminated glass and impact-resistant windows can withstand wind speeds of about 250 mph and projectiles hitting at 100 mph. The use of these types of windows can improve the resistance of the building envelope. Annealed, heat-strengthened (partially tempered) or even fully tempered glass should not be used. While tempered glass may meet safety glass criteria, it is not adequately resistant to wind-borne debris. These glass types have the greatest potential to break, compromise the enclosure of the building, increase wind pressure on the structure, and directly expose the interior of the building to wind, wind-borne debris, and rain.

Differences Between Tornadic and Straight-Line Winds

Straight-line winds differ from tornadic winds in several ways. Tornadic winds have a vortex core with low static pressure, sometimes strong vertical wind speeds, and horizontal wind fields with a rotational component. In non-tornadic winds, the wind speed increases with height, whereas in tornadoes, the wind speed maximizes near the ground [16, 17]. Often the maximum wind speeds in a tornado are found several meters above ground or at about the height of roofs of a typical low-rise building, making damage to roofs more likely (A and B in Figure 4). Furthermore, the spatial extent of the tornadic wind field in comparison to the size of the building matters. “Differences between tornadic and straight-line winds are probably small when the tornado is large and the building is small. However, the differences could be larger if the tornado and the building are of about the same size. For a large building such as a hospital or a chemical facility and a tornado on that scale, we just don’t know much yet about the wind loads, but more research is being done,” says Kopp.

2. **Reduce sources of wind-borne debris:** Reducing the potential sources of wind-borne debris is important because flying debris can damage windows and breach building envelopes. Generally, gravel surfacing of any type should not be used. This includes large stone ballast such as used on loose-laid ballasted roofs, or pea gravel used on built-up or modified-bitumen roof types. While pea gravel is usually embedded into a full mop of hot bitumen, in practice only the bottom half of the pea gravel gets embedded and the top half remains loose and nested and, thus, is subject to becoming wind-borne debris in an extreme wind event. Stone ballast used for loose-laid roof systems may be larger, but it still contains a large percentage of stone small enough to become wind-borne debris. Anchoring rooftop equipment is recommended to prevent it from becoming wind-borne debris.
3. **Create interior safe zones:** Walls, ceilings and floors that are connected with extra structural support, well-anchored light fixtures and heavy doors with stronger frames create interior safe zones. These structural features also provide robustness against tornadic winds.
4. **Establish robust power sources:** The availability of power is essential for disaster recovery efforts. In a hardened, concrete, partially buried structure, build a separate central utility plant with power generators for backup power supply. Install underground fuel tanks that can hold fuel for several days. Build an additional battery backup or uninterruptible power supply.

Recommendations for Mitigating Tornado Damage

- Harden the building envelope
- Reduce sources of wind-borne debris
- Create interior safe zones
- Establish robust power sources

Ongoing Research

FM Global can offer guidance to clients on how to design buildings that are more resistant to tornadoes. However, there are challenges. First, the wind fields in tornadoes are non-stationary, which means they change rapidly in space and time. Since traditional wind tunnel experiments use stationary flows for testing, it is difficult to estimate tornadic wind loads from these experiments because they are not representative of real-world tornadoes. New techniques need to be developed to create non-stationary flow conditions in wind tunnels that are more representative of tornadoes. Second, the large natural variability of tornadoes makes it difficult to predict and quantify the effects of tornadic wind fields on all building types. The same building can experience different wind loads depending on the structure and size of the tornado and its interactions with the building.

These gaps in science and the limitations of current tornado modeling offer opportunities for intensive research. A multi-year collaborative project between FM Global and Western University has begun with the objective of improved understanding of the effects of tornadic winds on large industrial and commercial buildings. In this project, the interaction between tornadic winds and buildings with different configurations is analyzed by leveraging non-stationary wind tunnel experiments in the Wind Engineering, Energy and Environment (WindEEE) Research Institute at Western University (Figure 5) [19].

> *"There is merit in investigating a broad combination of tornado and building parameters based on wind tunnel experiments."*
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> PROFESSOR HORIA HANGAN

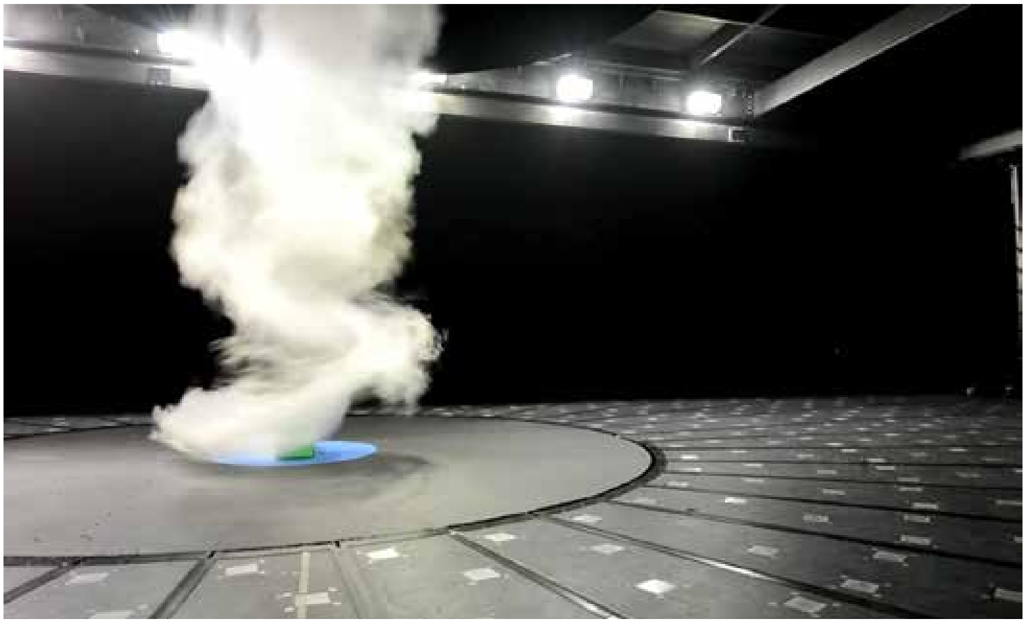

FIGURE 5: A lab tornado interacting with a model building. Picture provided by the WindEEE Research Institute at Western University.

A primary objective of the research collaboration between FM Global and Western University is to continue developing knowledge of the wind loads for different scenarios of tornado sizes and foster the understanding of structural impacts on various building types. This research translates into potential loss prevention solutions, helps refine recommendations that can be offered to FM Global clients, and provides guidance for designing buildings that are more robust to tornadoes. "There has been a lot of testing to understand what can be transferred from hurricanes in terms of loss prevention solutions. However, the solution could be different depending on the size of the tornado when compared to the size of the structure. If the wind loading patterns change, then the loss prevention solutions change as well," says Kopp. "Design guidelines for tornado wind loads should be more building-specific or specific for classes of buildings. There is merit in investigating a broad combination of tornado and building parameters based on wind tunnel experiments. This research could serve many communities and have a significant impact," says Professor Horia Hangan, director of the WindEEE Research Institute.

Another goal of the research collaboration is to improve the scientific basis for moving building codes forward and work towards tornado-resistant design standards. "The goal of current building codes is to design for a couple of worst-case scenarios. For tornadoes, this approach is insufficient because we don't know the worst case. Therefore, the question is what is the best approach for building codes and design guidelines and for moving the code forward. It is important to get some checkpoints from field observations whenever possible," says Hangan.

Elsewhere, atmospheric scientists are creating models to better understand the formation of tornadoes and thereby improve the ability to predict tornado occurrence. "We have a good knowledge of the large-scale environmental conditions in which tornadoes form. One of the things that we don't understand is why tornadoes don't form and why certain supercells do not make tornadoes," says Brooks. What differentiates tornadic from non-tornadic supercells is the potential to intensify low-level rotation to tornadic strength. The temperature and humidity of the air also affect tornado formation. Typically, warmer and moister air is more conducive to tornado formation.

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>
> DR. JOSHUA WURMAN

Also, the structure of rotation in the air mass beneath a storm is not well understood. A tornado may have more than one vortex, and configurations with multiple small vortices have been observed to be more damaging. "Most often, larger tornadoes do have stronger, enhanced regions with multiple small vortices and these embedded smaller vortices can be responsible for much of the damage," says Dr. Josh Wurman. "We don't know what fraction of tornadoes have multiple vortices or how intense they are on average. Sometimes the small vortices are unstable but they can last for a significant part of the rotation of a tornado. We have seen cases where they lasted 20 minutes. These multiple vortices can exist at all tornado intensity levels. We need more observations to get a better understanding of the internal structure of tornadoes," Wurman adds.

According to Richardson, "Models, observations, and wind tunnel experiments are all potentially valuable for addressing scientific gaps in our understanding of tornadoes." "Regarding improving our understanding of tornado structure, we would like to collect more and more comprehensive observations by combining proximate radars, in situ measurements, and observations aloft," adds Wurman.

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Moving Forward

Risk and damage to property from tornadoes continues to increase in the United States. New research partnerships are exploring more accurate modeling of tornadoes through wind tunnel testing and observations. This ground-breaking research will shape cost-effective solutions to engineer against tornado damage. FM Global will continue to partner with scientists and engineers, as it provides up-to-date and effective strategies that protect properties from tornado damage, minimize business interruption and help clients to become more resilient.

Research Challenges

- Development of new techniques to generate non-stationary wind fields in wind tunnels experiments that are more representative of real-world tornadoes
- Development of knowledge spanning the range of possible combinations of tornado and building properties
- Finding the best approach for improving current design guidelines and building codes

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>
> DR. HAROLD BROOKS

References

1. National Centers for Environmental Information. U.S. Tornado Climatology. [Online]. https://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornado-climatology
2. M. K. Tippett, C. Lepore, and J. E. Cohen, “More tornadoes in the most extreme U.S. tornado outbreaks,” Science, vol. 354, no. 6318, pp. 1419-1422, 2016.
3. T. W. Moore, “On the temporal and spatial characteristics of tornado days in the United States,” Atmospheric Research, vol. 184, pp. 56-65, 2017.
4. American Meteorological Society. Meteorological Glossary. [Online]. http://glossary.ametsoc.org/wiki/Tornado_outbreak
5. K. R. Murphy, T. A. Coleman, T. A. Wade, R. A. Mullins, C. J. Schultz, E. V. Schultz, L. Carey, A. Sherrer, E. W. Mc Caul Jr, and B. Carcione, “Meteorological overview of the devastating 27 April 2011 tornado outbreak,” Bulletin of the American Meteorological Society, vol. 95, no. 7, pp. 1041-1062, 2014.
6. Swiss Re, “Natural catastrophes and man-made disasters in 2011: Historic losses surface from record earthquakes and floods,” 2012.
7. NOAA/NWS Storm Prediction Center. Enhanced F Scale for Tornado Damage. https://www.spc.noaa.gov/faq/tornado/ef-scale.html
8. NOAA/NWS Storm Prediction Center. Fujita Tornado Damage Scale. https://www.spc.noaa.gov/faq/tornado/f-scale.html
9. E.D. Kuligowski, F.T. Lombardo, L.T. Phan, M.L. Levitan, and D.P. Jorgensen, “Final Report, National Institute of Standards and Technology (NIST) Technical Investigation of the May 22, 2011, Tornado in Joplin, Missouri,” 2014.
10. FM Global, “The morning after: The tragic destruction and remarkable rebirth of Mercy Hospital,” Reason, no. 1, pp. 34-43, 2016.
11. P. Markowski and Y. Richardson, Mesoscale Meteorology in Midlatitudes. John Wiley & Sons, 2011.
12. H. E. Brooks, G. W. Carbin, and P. T. Marsh, “Increased variability of tornado occurrence in the United States,” Science, vol. 346, no. 6207, pp. 349-352, 2014.
13. J. P. Kossin, T. Hall, T. Knutson, K. E. Kunkel, R. J. Trapp, D. E. Waliser, and M. F. Wehner, “Extreme storms,” in Climate Science Special Report: Fourth National Climate Assessment, Volume I, D.J. Wuebbles, Fahey D.W., Hibbard K.A., D.J. Dokken, Stewart B.C., and Maycock T.K., Eds.: U.S. Global Change Research Program, 2017, pp. 257-276.
14. R. J. Trapp, N. S. Diffenbaugh, and A. Gluhovsky, “Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations,” Geophysical Research Letters, vol. 36, no. L01703, pp. 1-6, 2009.
15. J. T. Seeley and D. M. Romps, “The effect of global warming on severe thunderstorms in the United States,” vol. 28, no. 6, pp. 2443-2458, 2015.
16. J. Wurman, K. Kosiba, and P. Robinson, “In situ, Doppler radar, and video observations of the interior structure of a tornado and the wind–damage relationship,” Bulletin of the American Meteorological Society, vol. 94, no. 6, pp. 835-846, 2013.
17. K. Kosiba and J. Wurman, “The three-dimensional structure and evolution of a tornado boundary layer,” Weather and Forecasting, vol. 28, pp. 1552-1561, 2013.
18. FM Global, “DS 1-28: Wind Design,” 2016.
19. H. Hangan, M. Refan, C. Jubayer, D. Romanic, D. Parvu, J. LoTufo, and A. Costache, “Novel techniques in wind engineering,” Journal of Wind Engineering and Industrial Aerodynamics, vol. 171, pp. 12-33, 2017.

Acknowledgment

Thank you to those who took part in the preparation of this document: Dr. Andreas Muehlbauer, Dr. Lakshmana Doddipatla, Dr. Shangyao Nong, Dr. Franco Tamanini, Dr. Louis Gritzo and Dr. Hosam Ali.

About FM Global

Established nearly two centuries ago, FM Global is a mutual insurance company whose capital, scientific research capability and engineering expertise are solely dedicated to property risk management and the resilience of its client-owners. These owners, who share the belief that the majority of property loss is preventable, represent many of the world's largest organizations, including one of every three Fortune 1000 companies. They work with FM Global to better understand the hazards that can impact their business continuity in order to make cost-effective risk management decisions, combining property loss prevention with insurance protection.

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