State of the Science FACT SHEET

Tornadoes, Climate Variability, and Climate Change

Scientists and communication experts from the National Oceanic and Atmospheric Administration (NOAA) developed this assessment of tornado activity and climate.

Tornadoes are intense rotating vertical columns of air that pose a great threat to lives and property. They typically form in an environment where winds are rapidly changing direction and speed with height (referred to as wind shear) and the atmosphere is unstable. Tornado damage has historically been classified according to the Fujita (F) Scale F0-F5, with F0 being the weakest and F5 the strongest.* While tornadoes can occur during any season in the U.S., they are most likely during the spring months of April, May, and June.

Given the right set of atmospheric conditions, tornadoes can occur almost anywhere. However, the areas of the U.S. most susceptible include the Great Plains, Midwest and South. The configuration of the topography of the North American continent (Rocky Mountains, Great Plains, and proximity to the Gulf of Mexico) contributes to the development of large-scale weather systems capable of supporting severe thunderstorms and related tornado events.

Are the frequency and/or intensity of tornadoes increasing?

Underpinning our current understanding of tornado activity is a long-term (1954-present) record of historical tornado counts from NOAA's Severe Events Database (SED). Given that the SED was not intended to be a consistent, homogenous, long-term, definitive record of tornadoes, there are inconsistencies over time as a result of changes in public awareness, tornado reporting practices, Doppler radar technology, and National Weather Service (NWS) guidelines, to name a few.

These inconsistencies have likely introduced artificial trends in the tornado record making attribution of long-term changes in tornado frequency/intensity difficult to determine. This issue is highlighted by a comparison of all tornado counts (F0-F5) with only the F1-F5 tornadoes (Figure 1). Removing the F0 counts from the database nearly eliminates the trend. Despite the potential for spurious trends in the SED, this does not rule out the possibility that a portion of the trend is due to climate change or climate variability.

Even though the annual total of F1-F5 tornadoes has shown little to no trend over the record, there has been a large decrease in the number of days per year with at least 1 F1-F5 tornado since the 1970s, along with a large increase in the number of days per year with numerous F1-F5 tornadoes (Figure 2). Explaining these changes is an area of active research.[1]

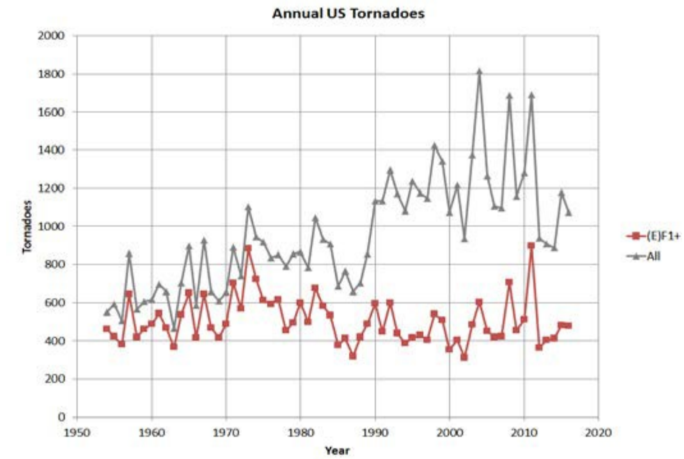

Figure 1: The total number of tornadoes reported in grey and number of F1 or stronger tornadoes reported in red.

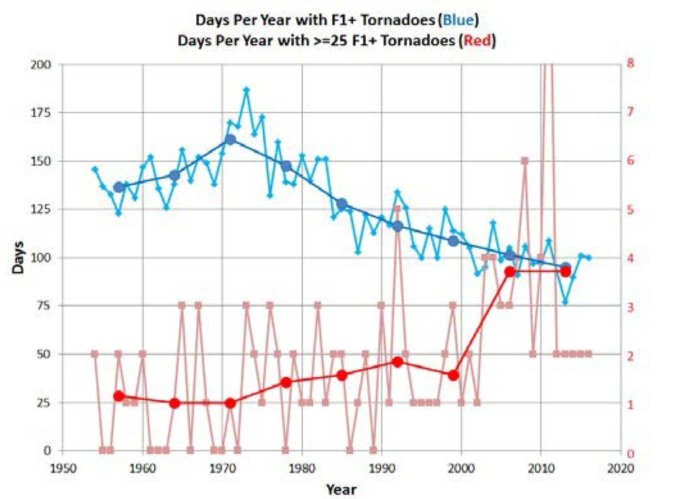

Figure 2: The number of days per year with at least 1 F1 or stronger tornado in the US (blue) and number of days per year with at least 25 F1 or stronger (red). Light lines are annual values. Dark lines with large dots are seven-year averages.

What is the role of natural climate variability in tornado activity?

Emerging evidence suggests natural climate variations like El Niño and La Niña events, and in particular the transition from one to another in spring, have the potential to alter the environment necessary for tornado formation.[2]

Natural variations acting on decadal timescales (e.g., Atlantic Multidecadal and Pacific Decadal Oscillations) have also been similarly implicated. However, uncertainty about their impact is high because the tornado record is too short to verify the impact

***A new Enhanced Fujita scale was adopted in 2007. The F scale is used in this fact sheet to be consistent with the published historical data.**

of potential decadal influences. The link between these interannual-to-decadal natural climate variability modes and variations in tornado activity is typically via shifts in the large-scale upper and lower level jet streams across North America that act as focusing mechanisms for severe thunderstorm development. Shifts in the placement and strength of these jet streams will influence the locations of atmospheric instability and wind shear that promote enhanced or reduced tornado activity.

Does anthropogenic climate change impact tornado activity?

Despite the existence of artificial trends in the SED there is still a potential role for changes in tornado activity due to human-caused climate change. Given that tornado activity is dependent upon two things: the strength of atmospheric instability, which promotes rising air and thunderstorm formation; and vertical wind shear, which provides the necessary rotation for tornadic thunderstorms (Figure 3), the best approach is to assess the likely impact human-caused climate change will have on these proxy indicators. In general, human-caused climate change is expected to increase atmospheric instability by increasing temperature and humidity in the lower atmosphere, while simultaneously weakening vertical wind shear through a reduction in the surface pole-to-Equator temperature gradient. While early indications suggested a likely tug-of-war between these two mechanisms, recent studies have shown an overall increase in projected number of days where sufficient instability and wind shear occur in tandem[3]. Dynamical downscaling work has begun to explore how the initiation of thunderstorms will change in the future and the role of enhanced convective inhibition in this process[4].

Can we predict tornado activity on monthly-to-seasonal time scales?

Emerging evidence suggests it may be possible to provide subseasonal prediction of anomalous tornado activity over the U.S[5], and experiments to predict severe weather conditions on 2-4 week time-scales have begun[6]. However, the viability of providing monthly and seasonal outlooks of tornadoes has not yet reached a level needed to provide actionable information. Because current versions of climate models do not have the resolution necessary for explicitly representing the extremely small-scale tornado structures, other techniques are being explored. The current strategy focuses on the prediction of local proxy indicators (atmospheric instability and wind shear) and remote climate signals (El Niño/La Niña transitions and other climate variability modes, such as the Madden-Julian Oscillation and the Global Wind Oscillation). An effort is underway to develop a quantitative monthly-to-seasonal prediction system that exploits new insights and knowledge as they are discovered.

The potential for predicting even longer-term tornado activity (i.e., decadal-to-centennial) is much less clear given the inherent uncertainties in the model-based prediction of decadal-to-centennial regional climate change. To be sure, there is much room for improvement, and large gaps exist in current understanding on all timescales. However, it is widely believed in the scientific community there is great potential for research to fill these gaps.

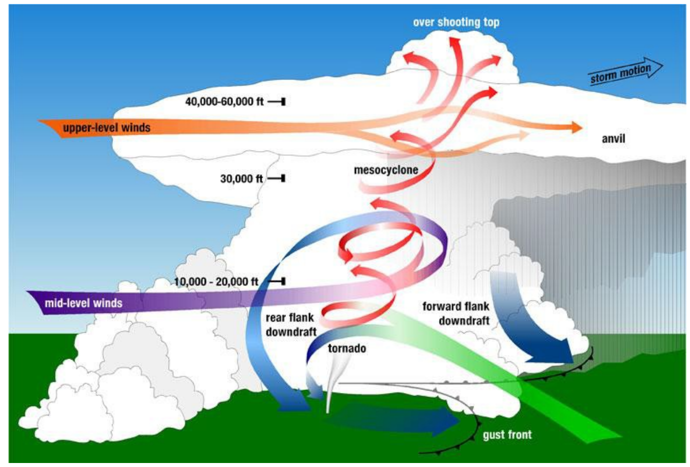

Figure 3: This schematic of a supercell thunderstorm shows how instability and wind shear influences tornado formation. The unstable rising air (red arrows) is forced to rotate by the increased wind speed between the lower (green) and mid-to-upper levels

How should research be directed to improve understanding?

Near-term research should target several crucial areas:

- Improve understanding of the influence of large-scale natural climate variations on tornado activity;
- Improve understanding of potential climate change impacts on the frequency and/or intensity of tornadoes;
- Advance modeling and downscaling strategies;
- Explore ways to develop consistent assessments that exploit recent technological advances in remote sensing.

Additional Resources

[1] Brooks, H. E., G. W. Carbin, and P. T. Marsh, 2014: Increased variability of tornado occurrence in the United States. *Science*, **346**, 349–352, doi:10.1126/science.1257460.

[2] Lee, S-K, R. Atlas, D. Enfield, C. Wang, and H. Liu, 2013: Is there an optimal ENSO pattern that enhances large-scale atmospheric processes conducive to tornado outbreaks in the United States? *J. Climate,* **26,** 1626-1642, doi: 10.1175/JCLI-D-12-00128.

[3] Tippett, M. K., J. T. Allen, V. A. Gensini, and H. E. Brooks, 2015: Climate and Hazardous Convective Weather. *Current Clim. Change Reports,* **1,** 60-73, doi:10.1007/s40641-015-0006-6.

[4] Hoogewind, K. A., M. E. Baldwin, and R. J. Trapp, 2017: The Impact of Climate Change on Hazardous Convective Weather in the United States: Insight from High-Resolution Dynamical Downscaling. *J. Climate,* **30,** 10081-10100, doi: 10.1175/JCLI-D-16-0885.1.

[5] Tippett, M. K., A. H. Sobel, and S. J. Camargo, 2012: Association of U.S. tornado occurrence with monthly environmental parameters. *Geophys. Res. Lett.,* **39,** L02801, doi: 10.1029/2011GL050368.

[6] Gensini, V. A., D. Gold, J. T. Allen, and B. S. Barrett, 2019: Extended U.S. Tornado Outbreak During Late May 2019: A Forecast of Opportunity. *Geophys. Res. Letters.,* **46**, 2019GL084470. https://doi.org/10.1029/2019GL084470.