# Past and Future Trends of Severe Storms

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## Focal Area(s)

The objective of this research is to use machine learning methods to establish past trends in the severe storm record and build on this information to provide severe storms projections in a future climate. This objective aligns with Focal Area 3, which emphasizes big data analytics in combination with knowledge-guided AI.

## Science Challenge

Severe storms can be both deadly and destructive. Although they often produce tornadoes, straight-line winds and hail, severe storms also play a significant role in short-term extreme rainfall rates in the central and eastern United States. Extreme rainfall events associated with severe storms have led to both deadly and damaging floods (Smith et al. 2001). Given the potentially devasting consequences from these extreme weather events, it is crucial to understand how severe storms will respond to climate change. However, the impacts of climate change on severe storms have proven difficult to assess and remain uncertain. This is largely due to inconsistencies in the observational record as well as the current limitations of climate models. Machine learning methods, however, provide an alternative approach that can be used to advance understanding of the response of severe storms to climate change.

## Rationale

The severe storm observational record is nonuniform in space and time, due in part to changes in the reporting systems and the population density. Additionally, due to computational restrictions, global and regional climate models are not currently able to adequately resolve severe storms (Brooks et al. 2003; Diffenbaugh et al. 2013). These limitations in both the observational record and model data have hindered progress on understanding the effects of climate change on severe storms. There continues to be uncertainty in how severe storms have changed over the last century and how they will respond to future climate change. To address this uncertainty, machine learning methods can be used to circumvent the limitations of observational and model data. The benefit of this approach is that it can leverage the observational record of known severe storm events. Developing a better understanding of past and future severe storm trends will provide a key input to scientific studies on the resilience of the central and eastern United States and a key test of trends emergent from models such as E3SM. Additionally, local and regional agencies will have the ability to improve disaster planning and preparedness for future extreme


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events. This is particularly important for regions that are likely to experience a future increase in severe storm activity.

## Narrative

Supervised machine learning requires large amounts of labeled data, and is thus well-suited for analyzing the effects of climate change on severe storms. Although the severe storm record is nonuniform in space and time, it provides a wealth of data that is by its nature labeled. A supervised machine learning approach to detect trends in severe storms can be structured around two main goals.

First, historical data can be used to establish multi-decadal trends in the properties and statistics of severe storms over the central and eastern United States. This can be accomplished by using algorithms such as support vector machines, random forests, and neural networks in combination with severe storm data. An advantage of this approach is that it utilizes publicly available datasets and Python modules, such as the widely used Scikit-learn, allowing for greater transparency and reproducibility of the methodology and results. Atmospheric Radiation Measurement (ARM) data, reanalysis data such as ERA5, and climate model data can be used to train and test the machine learning models to provide a robust sample space with as many available features as possible. Hyperparameter optimization can be used to determine which features are the most important for the learning algorithm. This optimization will provide valuable information on which physical processes are the most important for understanding multi-decadal trends in the severe storms historical record.

Second, the machine learning models developed using historical data can be applied to future climate model datasets. This analysis will provide much needed insight into how severe storms over the central and eastern United States will respond to climate change. Due to the inability of climate models to accurately resolve severe storms, there is a large amount of uncertainty in identifying these events under future climate scenarios (Tippett et al. 2015). However, the machine learning models from the historical data will be built on features that represent physical processes that are key to the development of severe storms. These models can therefore provide projections of how trends in severe storms will change in the future climate, a problem that has thus far evaded classical methods due to data and model limitations.

The combined outcome of these two goals will provide an accurate method of detecting trends in the frequency and intensity of severe storms in the historical record, as well as improved predictions of how severe storms will respond to future climate change.

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