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Conference on European Tornadoes and Severe Storms

# Challenges and Opportunities in Tornado Research

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The past several decades have been a period of intense research on tornadoes. Spurred on by the hazard posed by this phenomenon and the development of technologies such as Doppler radar and lidar, progress has been made in understanding the dynamics and predictability of these most intense of nature's columnar vortices. However, many aspects of tornadoes and the interaction of the strong winds they produce with structures and surface features remain enigmatic. This paper will discuss some of the aspects of tornadoes where current understanding is, at best, conjectural or speculative, and point out opportunities for research in the future. Some of these opportunities have important implications for forecasting of these events and enhancing our understanding of how to design structures to maximize shelter opportunities. Other opportunities may have no immediate application, but would better elucidate a physical phenomenon of Earth's atmosphere.

A few examples of topics to be discussed include:

**Inflow Boundary Layer:** While radars of various types have begun to reveal details of the tornado flow field in the interval extending from (roughly) 50 to 1000 meters above local surface, the inflow surface layer (between surface and roughly 50 meters, and extending outward for roughly 1 kilometer) remains largely undocumented. However, laboratory and numerical simulations of tornado-like vortices suggest that this boundary layer may be an important controlling feature of the tornado. There have been intriguing hints of roll vortices in this surface layer (e.g., in the Great Bend, Kansas tornado), which may be associated with some unusual damage phenomena. The occurrence of such boundary layer rolls would not be surprising, given what is known from laboratory work swirling boundary layers beneath end wall vortices, but these have not been well documented in nature.

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**Electrical Phenomena:** Over the years, a small number of credible observers have reported glows, flashes, and other discharge effects that suggest tornadoes have associated electrical phenomena. The possibility of such phenomena occurring is certainly plausible, given a tornado often contains an encircling shroud of swirling dust. However, these have not been well documented.

**Lofting of Detritus and Debris:** That tornadic thunderstorms can transport detritus and debris long distances has been well documented. It is also clear that the mechanism for lofting the material is the flow field in the tornado vortex. However, exactly how a swirling flow is able to lift items 2, 3, or more kilometers aloft without their being centrifuged out of the updraft is not clear.

**Tornado-related Sound:** There has been much speculation over the years concerning the cause of sounds associated with tornadoes. Some tornadoes are reported as being noisy whereas others are reported as relatively quiet or even silent. In some cases the intensity of the sound is apparently enormous. Descriptive reports suggest that some aspects of tornado sounds are common to many events. Overall, there have been very few quantitative investigations of tornado sounds and the producing mechanism(s) remain unknown. Similarly the full spectrum remains unexplored, though it seems clear that some tornado-producing thunderstorms generate significant infra (very low frequency) sounds detectable at great distances.

**Tornado-related Seismic Signals:** Perhaps related to both the inflow boundary layer and tornado sounds are the seismic signals reportedly associated with some tornadoes. While qualitatively one expects the impedance match between the surface and the overlying swirling flow to be poor, so that only a small amount of energy is transferred into ground motion, at least some tornadoes have generated detectable seismic signals. How this happens remains very unclear.