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Downburst winds and the directionality of their extreme values

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SUMMARY:
The strong winds due to thunderstorms are a hazard that affects a significant portion of the built environment across the globe and so are of primary concern for strength design in wind engineering. To predict the impact of these winds, it is important to know how to identify them, their directionality, and their magnitude. Challenges exist in extreme wind analysis of thunderstorms due to the short duration and small area covered by these events, as well as how they are identified in the long-term records. By manually identifying thunderstorm events during data recorded at 1-minute intervals, we have determined the wind directions associated with the most severe winds produced by thunderstorm downbursts at several locations. This directionality is shown to differ from that of the overall wind climate. Relying solely upon the lightning-detection-based thunderstorm “flags” provided in weather records is shown to bias the directionality towards that of the synoptic climate.

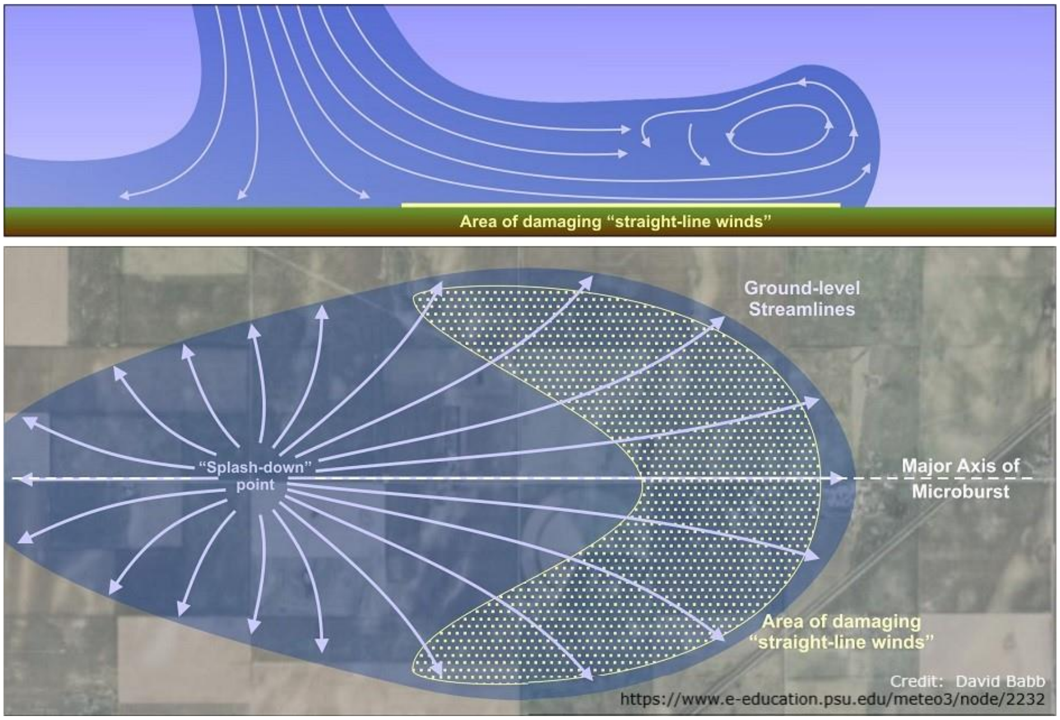
Keywords: wind directionality, thunderstorm downbursts, extreme winds

1. BACKGROUND: EXTREME WINDS FROM THUNDERSTORM DOWNBURSTS

For the purposes of this research, “downburst” is defined as “the general term for all localized strong wind events that are caused by a strong downdraft within a thunderstorm” (NSSL), which includes microbursts, macrobursts, and other types of downdrafts but does not include derechos or straight-line winds, which have unique characteristics not discussed here.

Cumulonimbus clouds, frequently associated with thunderstorms, can form when warm, humid air rises into an environment with cooler air, cooling and condensing water vapor as it rises. Once the air is cooler than its environment, it descends until it is warmer than its environment again, and the process restarts. The convective process continues to build in this manner, which can sometimes lead to a downburst of air that spreads out in all directions as it reaches the earth’s surface.

While the highest wind speeds tend to be along the major axis (see Figure 1) of the downburst ahead of the storm’s touchdown point, damaging winds can occur in a wide swath of directions as the effects of the downburst radiate outwards. Wind speeds and directions associated with a downburst are typically variant from the overall storm motion, hence, the major axis of the downburst is not necessarily related to the synoptic wind direction at the time of occurrence. Severe downbursts will produce a sudden spike in wind speed and, often, a rapid change in wind direction as the severe winds flow outward from the translating splashdown point (see Figure 2).



Credit: David Babb
https://www.e-education.psu.edu/meteo3/node/2232

Figure 1. Illustration of Thunderstorm downburst outflow in profile view above and plan view below.

The “T” symbols in Figure 2 indicate the presence of a “thunderstorm flag” in the data. The data are ASOS (Automated Surface Observing System) data, and the flags are based on automated lightning detection (ASOS User’s Guide, 1998). Since these flags do not directly identify downbursts, it is common to find flags with no downbursts and downbursts with no flags, examples of which will be provided in the full paper.

The analysis of downburst wind conditions is further complicated by their short duration and small spatial and temporal footprint in comparison to other storm types. Downbursts can last only a few minutes, so they are not always captured in hourly records. Downbursts also have a small spatial extent (the downburst jet can be as little as 1 km in diameter, though the outflow’s full impact can extend further), so the location of the downburst relative to the location of the anemometer will impact the wind speed and direction that is recorded. However, if the goal is to characterize extreme wind conditions at a point location (as in this paper and in determining site-specific design wind speeds), these “indirect hits” are appropriate to include in the analysis.

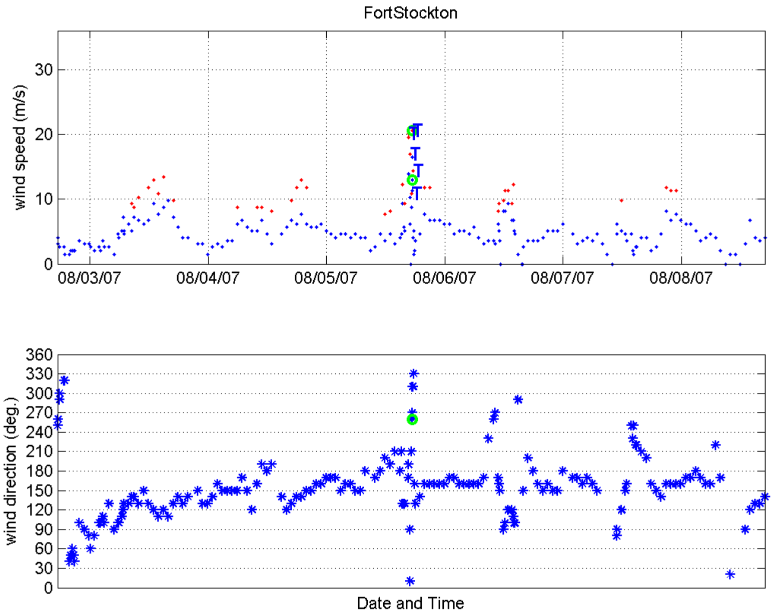


Figure 2. Example of thunderstorm downburst time series signature.

The high winds due to thunderstorm downbursts have been recognized as being critical for structural design (Letchford et al., 2002), and the need to explicitly evaluate design wind speeds from each type of storm has long been recognized (Gomez and Vickery, 1978). There are also advantages in identifying sub-annual independent maxima for extreme value analysis as proposed by Cook (1982), and we do so in this paper. Since the indicators present in weather reports are not always coincident with the highest winds, various methods are employed to identify and ultimately automate storm classification for separate extreme value analyses. Letchford & Ghosalkar (2004) considered the "thunder-day", where daily peak wind events were classified as thunderstorms when a thunderstorm observation was made on the same day. Lombardo (Lombardo et al, 2009) leveraged the start and end of thunderstorm reports in METAR remarks to further narrow the duration of thunderstorm classifications.

The methods presented above can be effective in addressing the lack of coincidence between high wind and thunderstorm flag and have the advantage of being readily automated. However, these methods assume any high wind that occurs surrounding thunderstorms flags should fall into the same storm classification for analysis as "thunderstorm winds". As noted above, there is no guarantee that thunderstorm flags in weather records are accompanied by high downburst winds, which is ultimately the condition we intend to identify for explicit analysis.

2. METHODS

Several long-term weather station data sets that contain both 1-minute wind data and thunderstorm flags in the United States and Australia were leveraged to compare the occurrences of downbursts that were manually identified by Atmospheric Scientists to those identified solely using the thunderstorm flags for classification. The manual identification relies on wind speed and directional behaviour, time of day, location of climate, and radar imagery in addition to thunder flags to classify storms as downbursts or synoptic storms. While more time-intensive than automatic storm separation by thunder flags, manual separation allows for a broader look at the storm's climate and other characteristics, which can lead to higher accuracy in determining the peak winds by storm type.

3. RESULTS

From the manual identification process, both false negatives and false positives associated with thunder flags were noted. False positives, i.e., thunder flags associated with storms that are not downbursts, tend to increase the frequency of lower speed wind events in the dataset and overrepresent the frequency of downbursts in an area. False negatives, i.e., downbursts that do not have an associated thunder flag, tend to underrepresent the frequency of such events in an area and can either increase the speeds in the dataset (if only high-speed events happen to be flagged) or decrease the speeds in the dataset (if only low speed events happen to be flagged). False negatives can also act to increase the speeds associated with synoptic storms, as high-wind downbursts may be classified as synoptic if they do not have an associated thunder flag.

The results of the manual and automated methods are compared in terms of thunderstorm frequency, distribution of peak wind speeds, and directional distribution of the peak speeds. Additionally, the wind speeds from each dataset were fit to a Gumbel (Type I) extreme value distribution, and the impacts on the fit and the resulting predicted wind speeds are presented.

The downburst directionality is shown to differ from that of the overall wind climate. Relying solely upon the lightning-detection-based thunderstorm "flags" provided in weather records is shown to bias the directionality towards the synoptic storm directionality. Recommendations are made for extending the criteria to identify thunderstorms and for how to incorporate their directionality into comprehensive directional statistical models.

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