IN-VENTO 2026
International Conference of the Italian Association for Wind Engineering
Bari, September 13th – 16th, 2026

BARI

Towards hazard wind maps of non-synoptic extreme winds for fragility curves of structures: from thunderstorm downburst and tornadoes

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SUMMARY
The identification of areas prone to being affected by strong winds represents valuable knowledge for the structural design of buildings and result of interest to diverse sectors of the society. While synoptic winds are well-documented, non-synoptic extreme winds such as tornadoes and thunderstorm downbursts are harder to characterize due to their short duration and limited area of impact. Due to these characteristics, reports based on direct observation of events and/or induced damages represent a valuable source of data for more in-depth analysis. The present research project analyzes reports from the European Severe Weather Database (ESWD) and complements this database with the Meteonetwork Storm Report database. Areas affected by tornadoes and thunderstorm downbursts will be identified along with structural archetypes particularly vulnerable to this type of events. This will tribute to a wider PhD research aimed at developing fragility curves for typical Italian low-rise buildings subjected to non-synoptic extreme wind events.

Keywords: downburst, structural archetypes, fragility

1. INTRODUCTION

The identification of geographic areas prone to being affected by strong wind incidents is a very valuable knowledge for the structural design of buildings. The availability of hazard distribution maps can be of great importance not only to structural engineers, but also to other sectors of the society involved in the managing of the risk (e.g., community-based organizations, academic institutions) (Pedoth et al., 2025). They are a very useful tool to raising risk awareness among key stakeholders such as emergency managers and government agencies (MacPherson-Krutsky et al., 2020). While wind hazard maps for structural design rely on complex statistical characteristics of the extreme wind velocities such as the return period, a map overview taking into account simpler parameters as the event occurrence rate can be useful towards a later development of a more comprehensive hazard map.

Progress have been made in the past thirty years toward defining a wind hazard map in Italy with reference to synoptic winds (i.e. Ballio et al., 1999; Picozzi et al. 2022, Raffaele et al., 2024; Ricciardelli et al., 2025). However, these maps have not explicitly addressed the identification and mapping of non-synoptic winds, for which only limited efforts have been made in recent years (Miglietta & Matsangouras, 2018). This is because, while synoptic winds can be properly characterized due to their larger spatiotemporal occurrence, non-synoptics winds (e.g., tornadoes, thunderstorm downbursts) are much more difficult to identify and characterize even with advanced field-measurement techniques given their short duration and limited spatial extent ((Solari et al., 2020)). Nevertheless, more informal reporting methods, such as direct observation of the phenomenon described by volunteers, can be suitable as a first approximation to a more complete description of the incidence of such events. On this subject, since 2006 the European Severe Storms Laboratory (ESSL) has been operating the European Severe Weather Database (ESWD) (Dotzek et al., 2009). This database is dedicated to centrally registering information on severe weather across all European territory, supported by the collaboration of several national meteorological agencies, observer networks and volunteers. This paper describes one work package of a wider PhD research project aimed at developing fragility curves for typical Italian low-rise buildings subjected to non-synoptic extreme wind events. The present work package will focus on the identification of areas affected by tornadoes and thunderstorm downbursts along with structural archetypes particularly vulnerable to this type of events. Data available for Italy in the ESWD such as the geographical location of events and damages caused to structures will be analyzed. In particular cases where the information from the ESWD is not complete, it will be complemented with information from the database operated by the non-profit organization Meteonetwork (MNW) (Giazzi et al., 2022).

2. DATABASE ANALYSIS

Among the categories included in the ESWD (ESSL, 2021), a general classification can be found: lesser whirlwinds, gustnadoes, tornadoes, severe wind gusts, large hail, heavy rain, heavy snowfalls, ice accumulations, avalanches and damaging lightning. The definition of the above-mentioned categories are broad enough to facilitate the incorporation of reports from individuals who are not necessarily meteorological field experts but they often do not make it easy to distinguish between subtypes of events. A few examples are reported as follows. *Tornadoes* category includes both landspouts and waterspouts. *Severe wind gusts* category is defined as a gust with a speed of at least $25\ m/s$ or one doing such damage that a wind speed of 25 m/s or higher is likely to have occurred. Events reported in this last category can be originated by thunderstorms, downbursts, extratropical cyclones or another phenomenon. As mentioned above, all reports of ESWD database are based on the direct observation of the event or the damage caused by the reported event. The same event can be reported several times if it causes damage in different locations. This was found to be particularly common in the *severe wind gusts* category, as such wind develop over a larger area, impacting on multiple nearby towns in densely populated areas. In the first stage, the *tornadoes* and *severe wind gusts* categories have been analyzed. Particularly, 4058 tornado damage reports from the period between the years 1900 to 2025 have been analyzed, as shown in Fig. 1a. Most reports are from events that occurred in this century, as the democratization of internet makes easier to share information and provides a platform to amateur groups to collaborate, as noted by Miglietta & Matsangouras (2018). Previous reports, especially the older ones, tend to be high-impact events with enough available information in historical records to reconstruct the incident.

Reports for the *severe wind gusts* category have been issued from 1930 (with two isolated cases) up to 2025 (Fig. 1b), with most reports released in the last 15 years for the same reasons explained above. Even if there is a visible gap in the reports of this category between 1990 and 2010, the number of reports issued in recent years is significant. Specifically, thunderstorm downburst records are included in the *severe wind gusts* category without distinguishing them as a stand-alone sub-category. One crucial step of this research (still ongoing) consists of the classification of events through the report description and attached links in the cases where they are available. A cross-reference is also possible in some cases using the Meteonetwork database.

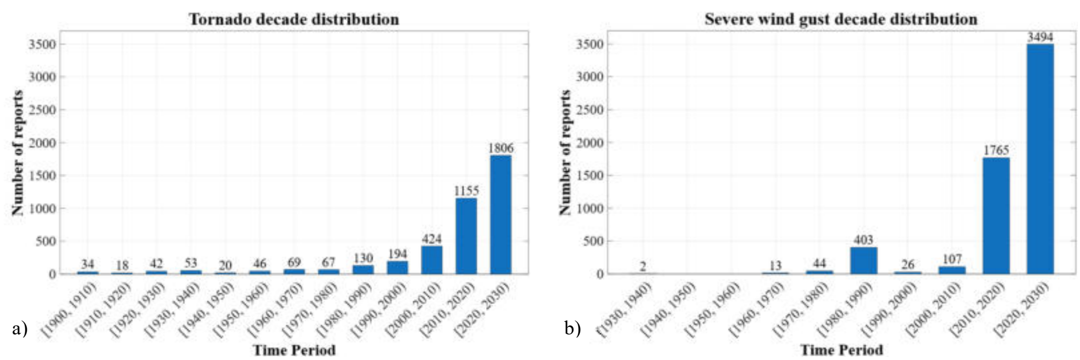

Figure 1. ESWD reports by decade of (a) tornadoes and (b) severe wind gusts categories.

3. PRELIMINARY RESULTS AND CONCLUSIONS

This section presents the results of the initial phase of analysis, which is still ongoing. Tornado reports, differentiated by their origin over land (i.e., landspout) or water (i.e., waterspout), are shown in Fig. 2. These two sub-categories refer only to the location where the vortex originated, but they do not preclude the tornado moving from land to water or vice versa. However, as this mechanism can heavily affect the degree of damage of specific archetypes in coastal cities, it will be investigated more in depth. Fig. 3 shows the location of reports of *severe wind gusts* identified as downbursts. A trend can be noticed in the higher number of reports from densely populated northern Italian regions, as Lombardia and Veneto. From this preliminary analysis, the high velocities observed during these events may not be fully reflected by the CNR-DT 207 R1/2018 (2018), where these zones have the lower basic reference wind velocity based in estimations for synoptic winds which could lead to an underestimation of the peak wind velocity due to non-synoptic winds.

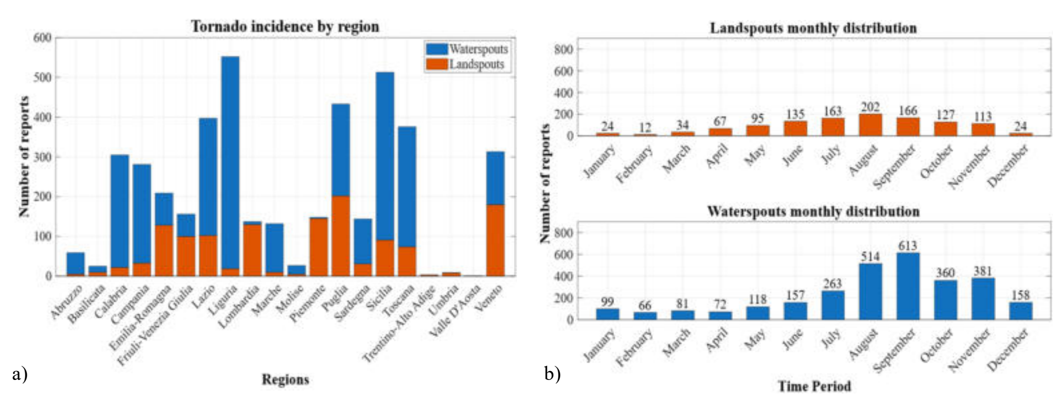

Figure 2. Waterspout and landspout reports by Italian region (a) and total reports per month (b).

A more comprehensive characterization of the regions affected by tornadoes and downbursts, along with a classification of the types of damage caused by these events, will be presented in the full paper and presentation. Additionally, the significance of other wind events recorded in the database (e.g., gustnadoes, extratropical cyclones, etc.) will be assessed in comparison with the damage reported from downbursts.

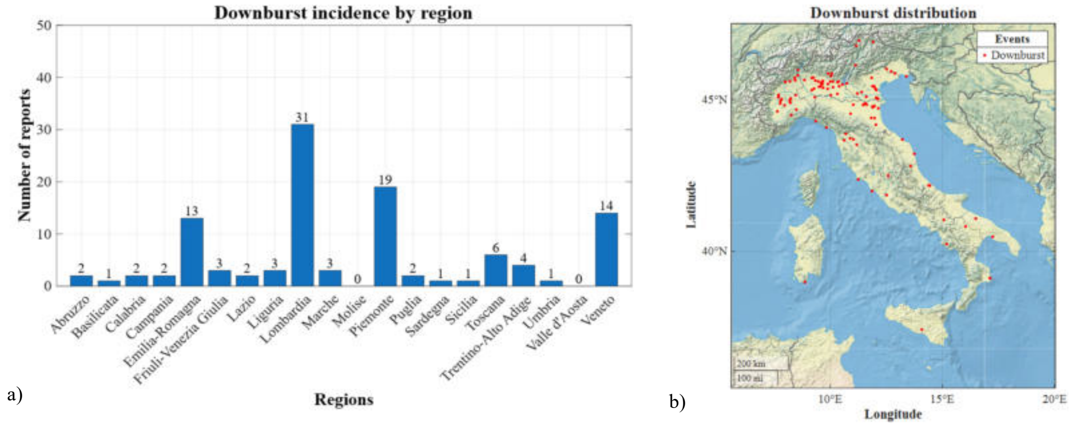

Figure 3. Downburst reports in each Italian region (a) and map location (b)

ACKNOWLEDGEMENTS

ESSL are acknowledged for the management and updating of the ESWD and for kindly providing access to this data.

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