Thunderstorm outflows in the Northern Mediterranean area

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SUMMARY:
The relative few observations of thunderstorm winds in nature due to their space and time small-scale characteristics, their drastic impacts on the manmade and natural habitat all over the world, and their strengthening associated to recent trends in climate changes, lead to a growing demand of full-scale records of this kind from the engineering and atmospheric science communities. The large wind monitoring network installed in the main ports of the Northern Mediterranean Sea has been providing an enormous number of wind records. An automated algorithm, comprised of systematic quantitative controls on selected parameters related to wind signals as well as qualitative inspections and cross-checking with meteorological data, allows to separate and classify the events into homogeneous subclasses. Following this procedure, 29 verified thunderstorm outflows were extracted from multiple ultrasonic anemometers in the period 2010–2015 and collected in a newly published open-access dataset. It is expected that such records will provide essential help to further understanding the dynamics of thunderstorm downbursts, particularly through calibration and validation of experimental, numerical, and analytical models. Under a more industrial view, the database here presented will greatly assist companies involved in the risk management and loss reductions related to thunderstorm events.

Keywords: database, thunderstorm outflows, Northern Mediterranean

1. INTRODUCTION

Downbursts and gust fronts are severe windstorms that strike the mid-latitudes areas of vast part of the globe. They originate from high and localized thunderstorm clouds, namely cumulonimbus, and vigorously descend towards the ground through buoyant mechanisms. Once the downdraft of air hits the ground, an horizontal radial outflow of impinging-jet type forms (Canepa et al., 2022). This produces an acceleration of the flow at the near-ground level that is reflected in the characteristic nose-like shape of the horizontal velocity vertical profile (Canepa et al., 2020). The time and space extent of this extreme wind, in the order of tens of minutes and few kilometres on the horizontal respectively, makes the recorded signals highly transient and non-Gaussian. It follows that thunderstorm winds are hardly measurable through classic anemometric instruments in nature, which makes their study and modelling at least challenging. A number of experimental, numerical, and analytical approaches have been developed over the last decade. However, the lack of full-scale records implicitly enhances uncertainties related to thunderstorm models that make them still not set to describe the real scenario in civil and meteorological standards. The European projects "Wind and Ports" (WP) (Solari et al., 2012) and "Wind, Ports and Sea" (WPS) (Repetto et al., 2018) have provided the installation of a one-of-its-kind large wind monitoring network in the main ports of the Northern Mediterranean Sea. This has produced an unprecedent number of wind records that are separated and classified into homogeneous families according to the methodology described in Section 2. The climatology of this area, characterized by important orographic connotations and by the mixing between southern warm air currents, further heated up by the sea surface temperature (SST), and cold air descending from the north sector (Italian alps) (Fig. 1), is prone to the development of important convective systems. Furthermore, recent trends in climate change forecast increases in severity and frequency of occurrence of extreme wind events. The Northern Mediterranean basin is expected to be among the geographical areas more affected in this sense (Rädler et al., 2019). With these premises, it is not surprising that the wind monitoring network introduced above has been recording quite many thunderstorm events since the last decade. This paper describes the recently published database of thunderstorm records acquired during the early-stage operation of the monitoring network (2010–2015) (Canepa et al., 2023). It will serve as fundamental tool both to the academic and industrial world. The mutual interchange of statistical outcomes between full-scale and experimentally- or numerically-reproduced signals will allow, on the one hand, to calibrate and validate models and, on the other hand, to further understand the dynamics of an increasing number of full-scale records. The large variability in their characteristics is indeed difficult to interpret without the support of ad-hoc models. The combination of these studies will contribute to advance frontier knowledge in the atmospheric science as well as civil engineering fields, to describe the effects of thunderstorm winds on nature and structures (or infrastructures).

2. THUNDERSTORM EXTRACTION AND METEOROLOGICAL VALIDATION

The extraction criterion adopted involves systematic quantitative controls and qualitative expert judgments. First, the method set by De Gaetano et al. (2014) was used to preliminarily extract potential thunderstorm events. The quantitative control sets two lower thresholds on the peak wind speed, $\hat{V}$ > 15 m s^{-1}, and on the 10-min gust factor, $G_{10} = \hat{V}_{10}/\bar{V}_{10}$ > 1.25, where $\bar{V}$ is the mean wind speed over a 10-min interval. This implies relatively small mean wind speed and large isolated peaks. This first automated procedure is followed by qualitative inspections of the wind speed and direction signals. In general terms, the thunderstorm downburst dynamics is governed by the passage of a leading vortex, called primary vortex (PV), over the measuring instrument. This produces a sudden ramp-up of the wind speed, simultaneous to a rapid change of wind direction, followed by a decrease as the vortex travels away from the station and thunderstorm dissipates. An accurate meteorological survey enabled to verify the actual nature of the events extracted. Particularly, the following meteorological data were investigated for each event: (1) Cloud top height distribution from cloud analysis performed by Eumetsat; (2) In-cloud hydrometeors from radar analysis performed through CAPPI (Constant Altitude Plan Position Indicator) and VMI (Vertical Maximum Intensity) representations; (3) Lightning occurrence. Thunderstorm phenomena are usually characterized by high top height of the parent cumulonimbus cloud (typically up to the top of the troposphere, approximately 11 km above ground level, AGL), precipitations (wet downbursts cover the majority of thunderstorm events, especially in the Northern Mediterranean region), and lightning occurrences.

3. DATABASE DESCRIPTION

The comprehensive methodology mentioned in Section 2 allowed to extract a set of 29 thunderstorm events that occurred in the period 2010–2015. All events were recorded by means of ultrasonic anemometers located in the ports of Genoa, Livorno and La Spezia (Fig. 1). While Genoa and La Spezia are equipped with bi-axial anemometers to measure the two horizontal wind speed components, *u* and *v*, three-axial anemometers are installed in the port of Livorno and measure also the vertical wind component *w* (except for bi-axial anemometers LI06 and LI07). Fig. 1 also reports a list of the anemometers involved in the study. The acquisition frequency of all instruments was 10 Hz and their sensitivity 0.01 m s^{-1} (except LI06 and LI07 with sensitivity 0.1 m s^{-1}). The installation height varies among the anemometers, ranging from 13 to 75 m AGL. It is worth noting that most events presented were recorded by multiple anemometers in the same port area (total of 99 records in the database), encouraging the user to perform cross-correlation analyses in space and time. Also, each record in the database is 10-h long (360.000 samples) to allow a better understanding of the background atmospheric conditions before and after the thunderstorm. Other than the dataset itself, the dedicated repository webpage includes a content description and two additional files (Canepa et al., 2023). One file lists the thunderstorm records collected, in terms of date, place, and measuring anemometer(s); the other file reports the anemometer locations in the form of ellipsoidal WGS84 coordinates.

Figure 1. Geographical map of ultrasonic anemometers involved in the study and their list (bottom-left table). Schematics of the main air streams producing convective mechanisms and thunderstorm phenomena.

As an example, Fig. 2 illustrates the database cataloguing procedure applied on the thunderstorm event that occurred in La Spezia on 25 June 2014 around 06:20 UTC time. Fig. 2a-d shows the meteorological characterization of the phenomenon in a 30-min interval, from 06:00 to 06:30 UTC. A large amount of lightnings stroke the area of the port of La Spezia (Fig. 2a), while the time evolution of high localized clouds (Fig. 2b-d) suggests a southwest-northeast movement of the storm. Fig. 2e-h shows the horizontal velocity ($U = \sqrt{u^2 + v^2}$) and direction timeseries in 1-h interval as recorded by the two bi-axial ultrasonic anemometers SP02 and SP03. Their time, kinematic, and direction differences, along with the information on the instrument coordinates, can be crucial to reconstruct the space and time variation of the phenomenon.

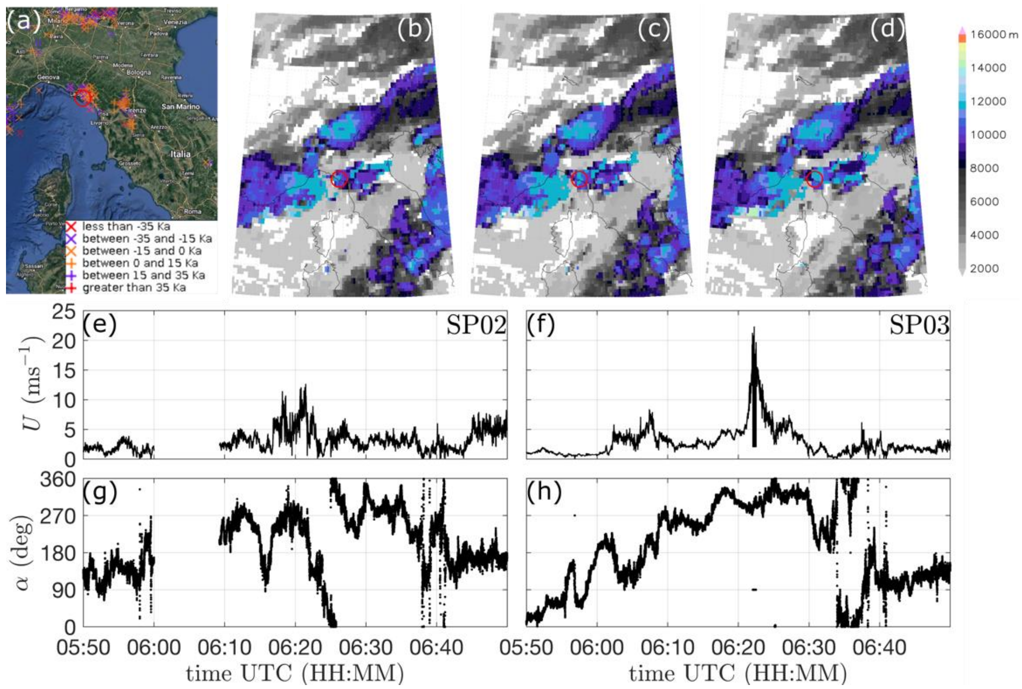

Figure 2. Thunderstorm event in La Spezia, 25 June 2014. Lightning strikes between 06:00 and 06:30 (a); Cloud top height distribution at 06:00 (b), 06:15 (c), and 06:30 (d); 1-h time series of 10-Hz horizontal velocity U (e,f) and direction α (g,h) for anemometers SP02 (e,g) and SP03 (f,h). Red circles show the position of La Spezia.

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