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Tornadoes in Romania—from Forecasting and Warning to Understanding Public's Response and Expectations

Simona Andrei [1], Meda Daniela Andrei [2,3,*], Mihăiţă Huştiu [2], Sorin Cheval [2,4] and Bogdan Antonescu [1,3]

1 National Institute of R&D for Optoelectronics INOE2000, Remote Sensing Department, 409 Atomiştilor Str., Măgurele, RO077125 Ilfov, Romania; simona.andrei@inoe.ro (S.A.); bogdan.antonescu@inoe.ro (B.A.)
2 National Meteorological Administration, Weather Forecasting National Center, 97 Bucharest-Ploieşti Ave., RO013686 Bucharest, Romania; hustiumihaita83@gmail.com (M.H.); sorin.cheval@icub.unibuc.ro (S.C.)
3 Faculty of Physics, University of Bucharest, Măgurele, RO077125 Ilfov, Romania
4 "Henri Coanda" Air Force Academy, Faculty of Air Traffic Management, 160 Mihai Viteazul Str., RO5001833 Braşov, Romania
* Correspondence: meda.georgescu@gmail.com

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Abstract: Significant progress in tornado research and management can be claimed over the last few decades worldwide. However, tornado forecasting and warning continue to be permanent challenges for most European national meteorological services because they require particular skills and experience. Moreover, tornado warnings may generate panic. Therefore, one can remark that the main difficulties are related to (1) forecasting the tornado genesis, and (2) finding the most efficient way to communicate to the general public the possibility of tornado occurrence. This article presents the main characteristics of two convective events that occurred in Romania in order to emphasize the similarities and disparities between the tornado event (30 April 2019) and the non-tornado event (6 May 2019), from the warning perspective. Further, we investigate, for the first time in Romania, the general public's comprehension, risk perception and reactions regarding the tornado events. The survey performed in 2020 emphasized that the Romanian public is able to recognize tornadoes (60%), understand the risks (over 80%), can manage the panic (over 70%), and is rather desirous to receive clear (over 90%) and real-time (95%) tornado warnings. The lessons learned may support the further development of tornado forecasting and warning procedures, and foster the public's awareness related to tornado events.

Keywords: tornado; Romania; forecasting; warning; public risk-related perception

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1. Introduction

Tornadoes are one of the most violent meteorological phenomena, responsible for significant damages with impacts on many aspects of society, public health and the economy [1]. As they are associated with severe convective storms, tornadoes are not limited to any specific geographic location. However, the middle latitudes between 30° and 50° north or south provide the most favorable environments for tornado genesis [2].

The interest in convective storms and tornadoes dates from antiquity [3]. Due to the high frequency occurrence in the U.S., the scientific and public interest in this topic has been kept constantly at a higher level than in Europe, for example [4]. As a consequence, tornadoes have been documented mostly in the U.S., which has resulted in a database significantly more consistent [5–7] than the European database [8,9]. In Europe, the interest in this topic has varied depending on regions and historical epochs. The systematic research on tornadoes started during the 19th century and continued during the early 20th century, but the interest declined after the 1950s [10]. Tornadoes in Europe used to be reported based on the on-site damages, which led to a positive bias towards the strongest events. Recent studies [8,9,11–13] have emphasized that the majority of reports and studies came from Northern, Western and Southern Europe, and to a lesser extent from Eastern Europe, where tornado databases were developed after the 1990s. Moreover, in some Eastern European countries, during the 1970s and 1980s, meteorologists considered that "the Coriolis effect does not allow the formation of tornadoes" because the countries are situated too far north [14]. Consequently, it seems that all tornadoes that occurred in the epoch were reported as "high-wind events", and therefore not acknowledged as tornadoes [11,12]. This widespread opinion has recently changed, mainly due to the pan-European efforts of collecting and verifying severe weather reports, including tornadoes, followed by in-depth studies [11–20] and increased public awareness [4,9].

The first successful tornado forecast was conducted by the United States Air Force Severe Weather Warning Centre [21] for an event that occurred on 25 March 1948 in Central Oklahoma. However, the use of the term "tornado" was banned from forecasts until the 1950s to avoid "population's panic" [22,23]. A subsequent tornado outbreak event that occurred in Missouri, Arkansas, and Tennessee between 21 and 22 March 1952 generated public protests and pressure for the issuance of tornado forecasts [22,24]. In Europe, the first known tornado forecast was issued by the Royal Netherlands Meteorological Institute (KNMI) for the tornado outbreak that occurred between 24 and 25 June 1967 [25,26]. For the same reason as in the U.S., the KNMI later that day changed the forecast from "possible tornadoes" to "possible severe wind gusts" [15]. Currently, only a few European meteorological services have developed tornado warning procedures [25,27], but they often use ambiguous terminologies to suggest tornadoes occurrence (e.g., tornado-like winds).

Despite the continuous research and technological advances, forecasting tornadoes remains a real challenge for any weather service [25,27,28]. The rapid development of numerical models and observational techniques could ensure a greater chance of tornado forecasts success, but it is still difficult to issue tornado warnings. In Europe, tornado warnings are not commonly issued because of several reasons. Firstly, the frequency of tornadoes in Europe is lower compared with the frequency of tornadoes in the U.S. Thus, an investment (e.g., observations, technologies, forecasters training) in tornado research will not be justified from the perspective of European meteorological services. Furthermore, European meteorologists need a large number of training events in order to be well prepared and to acknowledge the threat of tornadoes [29]. Secondly, although forecasting the aspects needed and sufficient for deep convection (e.g., supercells) is relatively easy, identifying the environments leading to tornado genesis is still an open problem [4,25,26]. Furthermore, European tornadoes are associated with marginal environmental conditions [30]. Thirdly, there are different approaches of severe weather warning amongst the European meteorological services. In the U.S. there is a unique warning system covering all the states, including outlook, watch and warning activities, while in Europe each country has developed its own warning criteria, and tornadoes are not warned against at all in most countries [25,27]. The time for issuing a tornado warning varies from 0 s, when the criterion is the observation, and reaches up to 20–30 min, when the products of weather radar are used as predictors. There are often false alarms (e.g., tornado warnings with no reported tornado) or missed events (e.g., tornado reports with no warning messages) [31]. Fourth, the majority of tornadoes research has focused on physical processes and climatology, while in Europe far less attention has been paid to the warning communication processes and public behavioral response to tornado warnings [32–36]. A tornado warning process involves institutional action and individual responses, based on conceptual models, numerical weather prediction, remote sensing technologies, forecaster decision making, warning dissemination, and public experience and education [32–35]. Ultimately, in order to be fully efficient, the warnings must be correctly understood by the public.

The hazard perception is a crucial component and plays a fundamental role in all the stages of the risk management chain. Risk perception is part of the decision-making process [37]. Wilde (1988) argues that the accident rate is ultimately dependent only on the level of risk perceived by the target population, which has to intervene before, during and after the event [38]. A sound public awareness related to the potential threats associated with severe weather generates good premises for efficient preparedness, for appropriate reactions during the development of the events, and for post-event recovery. Numerous studies have investigated the prominent role of perception in decisions people make in different risk circumstances [39–42].

In Romania, until the early 2000s it was claimed (even by some senior meteorologists) that tornadoes cannot occur at latitudes of 45° N [14]. The situation changed gradually after a long-track F3+ tornado crossed South-Eastern Romania on 12 August 2002. The damages produced by the tornado event increased the interest and awareness of the Romanian public, scientists and meteorologists. Furthermore, the development of the new weather surveillance system, operational since 2002, persuaded the meteorologists to adjust their opinions about tornado occurrence in Romania, and to approach this topic in a thorough manner [11,14,17]. Currently, the Romanian meteorological service issues tornado warnings using mainly the radar signatures of a supercell [25]. However, for a high probability of tornado occurrence, the preferred phrasing to describe the event are "strong squall", "strong wind", or "tornado-like wind". This is due to (1) the fact that tornados are still challenging to predict with sufficient certainty [27,28], (2) the lack of forecasters' experience concerning tornado occurrences and warnings, and (3) the lack of knowledge on public's perception of tornado warnings and their consequent reactions. The natural hazards perception research in Romania started in early 2000s [43], and was mainly focused on floods [44,45] and earthquakes [46]. Only one study on tornado perception has been conducted since the F3+ Făcăeni tornado [47]. To the best of our knowledge, no updates of this study has been performed since 2004, and the public's perceptions of false alarms has never been rated.

Starting from two recent convective events that occurred in the southern part of Romania during the springtime of 2019, the present work focuses on the analysis of the warning process as it is nowadays, and the public's perception with regards to tornado phenomena in Romania. The aim of this paper is to analyze the public's possible reactions and risk-related perception of severe weather conditions, with focus on tornado events, and, based on this analysis, to provide a recommendation to include tornadoes amongst the severe phenomena for which warnings should be issued in Romania. The paper is organized as follows: in Section 2 an overview of the two convective events is presented, in Section 3 the context and relevance of this study is set up within an up-to-date climatology of tornadoes in Romania. Section 4 presents the warning process chain currently used in Romania and the results of an exploratory empirical inquiry concerning tornado perception and Romanian public expectations. To our knowledge, this is the first time the Romanian general public has been asked to participate in a national level survey with tornadoes as the main topic. Section 5 provides a discussion on (a) how the tornado is perceived by the Romanian public, and (b) the usefulness of issuing tornado warnings in Romania, considering the current public's understanding and preparedness degree in terms of facing this kind of information. Finally, the main conclusions and future work to improve the tornado warning process chain in Romania are presented.

2. General Characteristics of Two Convective Events Occurred in Romania in 2019

On 30 April 2019, around 14:20 UTC, the on-board cameras of the cars traveling on the highway connecting Bucharest with the Black Sea shore captured the image of a tornado that immediately attracted the public's attention. The tornado occurred in the vicinity of Dragalina village, Călăraşi county, in the southern part of Romania (Figure 1a). The media impact was very high, considering the clarity and impressive appearance of the tornado (Figure 1b). The tornado attracted the attention of people travelling nearby and many of them reacted completely inappropriate. For example, they stopped and documented it by taking photos or filming instead of sheltering. The area where the tornado occurred was initially under the meteorological service surveillance, and a warning message for high instability with heavy rain, medium and large hail and severe wind gusts was issued approximately 30 min before the event (Figure 1c).

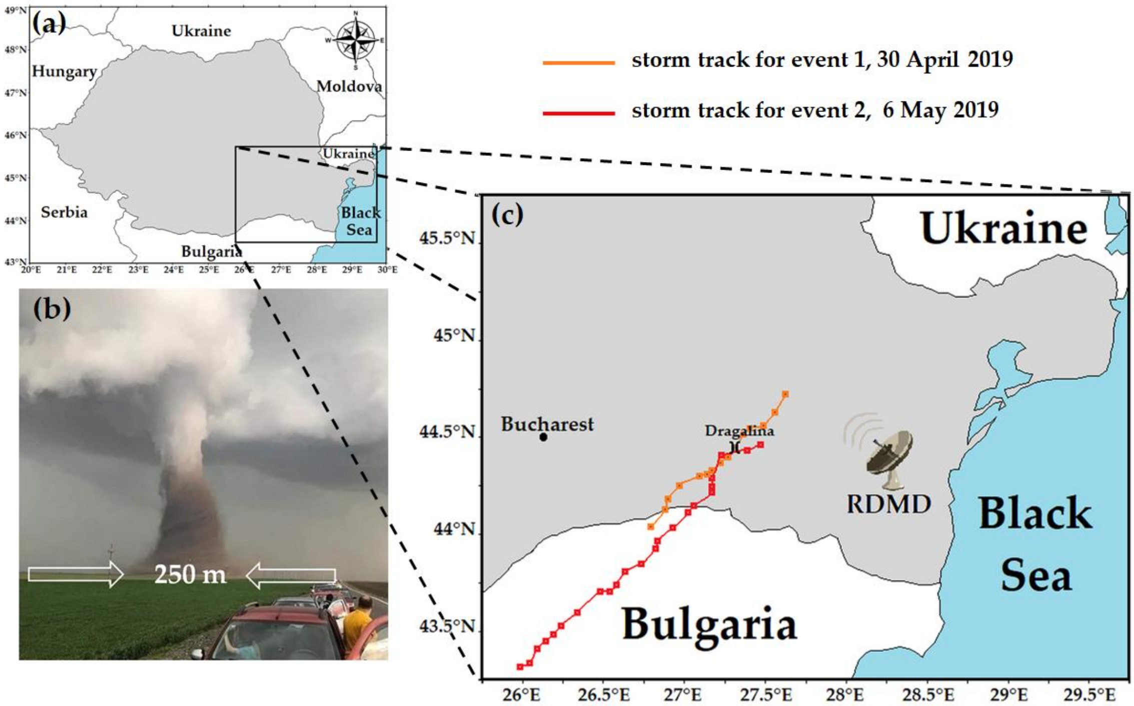

Figure 1. (**a**) Romanian territory (grey) with the watch area marked in black rectangle; (**b**) the tornado evidence for 30 April 2019, image posted on Facebook by Oscar Stanciu [48] (**c**) details of the watch area where the convective events occurred on 30 April 2019, 14:00–15:00 UTC (event 1 storm track, **orange line**) and on 6 May 2019, 14:45–16:30 UTC (event 2 storm track, **red line**); the radar icon marks the location of the Medgidia radar (RDMD) surveying South-Eastern Romania.

Six days later, on 06 May 2019, a second convective event occurred in the very proximity of the event mentioned above, under similar meteorological and environmental conditions (Figure 1c). Still under the influence of the previous event, the meteorological service issued a warning for convective storms and heavy rain, medium and large hail and "tornado-like" winds, but no tornado was reported this time.

It has to be noted that both convective events occurred in South-Eastern Romania within an area well-known for its high numbers of tornado reports [11]. Generally, the convective storms within this area are triggered by the convergence zones resulting from the interactions between the synoptic flows and the local topography (Carpathian Mountains) [17]. The most impactful event occurred in this area on 12 August 2002 at Făcăeni—Ialomița County [14].

The two convective episodes from April–May 2019 showed similarities with respect to synoptic configuration over South-Eastern Europe, namely the presence of surface cyclonic areas of Mediterranean origin accompanied by upper troposphere cut-off lows with their nuclei centered over the Adriatic Sea—Western Balkans (Figure 2). The evolution of both cyclones determined the transport of warm and humid air towards the south-eastern part of Romania, while colder and drier air masses were transported towards the Western Balkans (Figure 2a,b). The upper level cut-off lows coincided with strong positive potential vorticity (PV), displaying values up to 10 PVU at 300 hPa (Figure 2c,d). The high PV values indicated the updrafts' acceleration in front of the PV nuclei, along the path of the cyclonic circulation. Generally, these updrafts are more intense as they are accompanied by a dynamic tropopause fold down to the middle troposphere [49], and play an important role in the production of supercells [50].

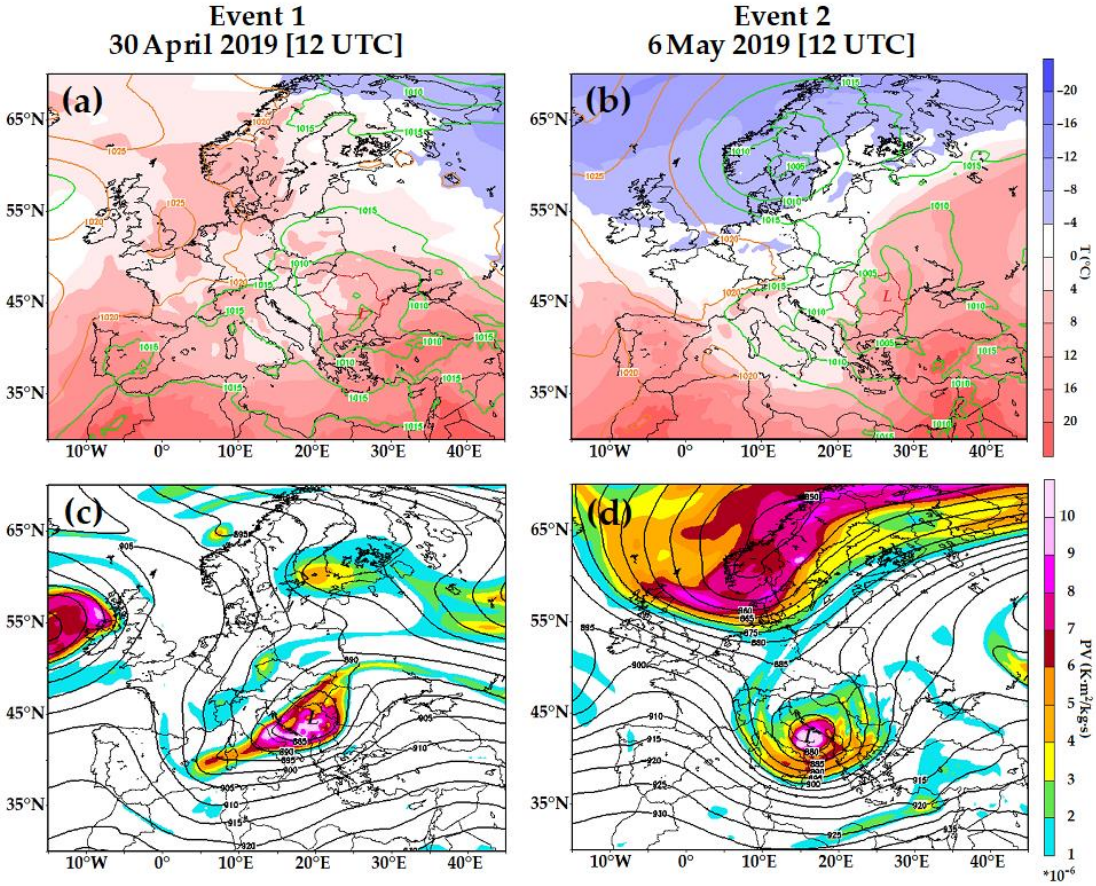

Figure 2. Synoptic context of the convective events derived from ERA5 dataset [51,52]: first row—mean sea level pressure (in hPa) with green contours (low pressure values) and orange contours (high pressure values) and air temperature at the level of 850 hPa (red-blue shades, in °C) (**a**) for 30 April 2019 and (**b**) for 6 May 2019; second row 300 hPa geopotential height (black contours, in gpdam) and potential vorticity $\times 10^{-6}$ (shaded areas, in K·m^2/kg·s) (**c**) for 30 April 2019 and (**d**) for 6 May 2019.

The mesoscale analysis based on data from the Medgidia radar (RDMD, 44.25° N, 28.27° E and 64 m ASL) emphasized the development of the convective storms in both cases (storm tracks in Figure 1c). The RDMD is a WSR-98D S-band radar that operates automatically, providing a volumetric scan every 6 min [17,53]. Radar images of the convective supercells in their maximum evolution stages indicated a series of radar signatures specific to tornado genesis (Figure 3).

During the first event (30 April 2019) the base reflectivity scans at the elevation of 1.5° (approximately 3 km height) displayed a hook echo structure at 13:38 UTC (Figure 3a), while radar algorithms detected the signature of a tornado vortex (TVS). At 14:02 UTC the weak echo region (WER) and high base reflectivity gradients were present (Figure 3b), while at higher scanning elevations the bounded weak echo region (BWER) was evident (not shown here). At 14:15 UTC, the base reflectivity image at the elevation of 0.5° (approximately 1.5 km above the radar level) showed a dry area of descending flow together with a surface gust front generated by the rear flank downdraft (RDF) as well as the outflow of a second convective cell, located southerly (Figure 3c). This marked the moment when the tornado touched the ground in the vicinity of Dragalina village (Figure 1b,c). The mesocyclone was emphasized by the base velocity products (not shown here).

During the second event (6 May 2019), the radar imagery displayed a V-shaped supercell development, while the radar algorithms identified the mesocyclone structure (MESO) and the tornado vortex signature (TVS), indicating strong rotational movements that can be linked with tornado initiation (Figure 3d). The next two scans, at 14:15 UTC and 14:21UTC, detected radar features such as hook echoes and a weak echo region (WER) (Figure 3e,f). The radar algorithms identified again the mesocyclone signature visible on the base velocity product at all elevation scans (not shown here).

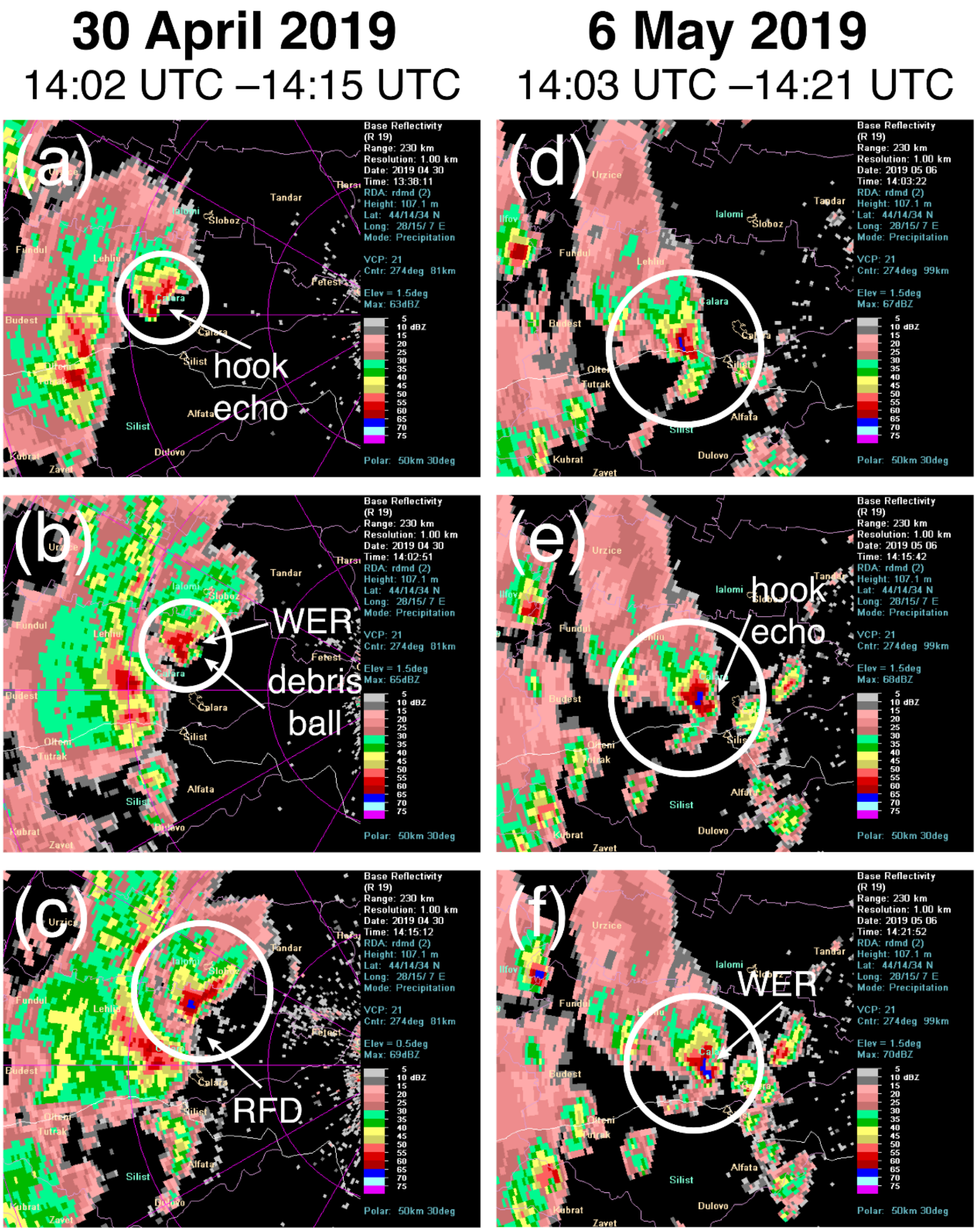

Figure 3. RDMD radar base reflectivity (in dBZ, lower right) of the tornadic supercell that occurred on 30 April 2019 (**left column**), and non-tornadic supercell that occurred on 6 May 2019 (**right column**). The white circle marks the position of the analyzed supercells during their maximum time evolution and the main radar signatures.

Up to this moment the evolution of the supercell was almost similar to the previous one that occurred on 30 April 2019, with one exception: the lack of the bounded weak echo region (BWER), which would precede the tornado's occurrence. While for the first event the intense and persistent updrafts created the potential of strong rear flank downdrafts, during the second event the tornado genesis processes were disturbed by a squall line that developed eastward of the supercell and finally integrated into it.

Generally, the simultaneous presence of the above-mentioned radar signatures (e.g., hook echo, MESO, TVS, WER, BWER) on radar products is considered a relevant clue for issuing tornado warnings [54]. However, previous studies have demonstrated that there is no general rule that ensures tornado occurrence based on these radar signatures [55,56]. Therefore, the warning messages issued by the Romanian meteorological service in both cases were cautious with regards to stating tornado occurrence.

In the end, the issued warnings can be classified as, respectively, missing and a false alarm for tornadoes. For the first event, an orange-level warning [57] for high instability with heavy rain, medium and large hail and severe wind gusts was issued and the tornado occurred, while for the second event, a red-level warning [58] for convective storms producing heavy rain, medium and large hail and "tornado-like" winds was issued, but no tornado was reported. Starting from these two examples, the main problem is to find a feasible strategy of issuing a warning message without omitting to emphasize the possibility of tornado occurrence when the weather situation demands it. To have a solid base for discussions, an update of tornado climatology in Romania is necessary.

3. Updated Climatology of Tornadoes in Romania

The tornado reports recorded after 2014 were integrated within the pre-existing database of tornadoes in Romania [11]. The new dataset used for this research includes a total of 185 tornado reports recorded between 1634 and 2019. The reports were split into four time-intervals: tornadoes that occurred before 1945, between 1945 and 1989, between 1990 and 2005 and after 2005 up to present days.

As expected, the number of tornado reports before 1945 is relatively low but still consistent, compared with the next period between 1945 and 1989, when a smaller number of tornado events was reported. This period overlaps with the period during which both researchers and meteorologists believed that tornadoes could not occur in Romania (Figure 4a). The increasing number of tornado reports during the last 20 years could be attributed both to the increase of public awareness of severe storms and tornadoes, and to the development of national and pan-European severe weather database (ESWD) [58]. Furthermore, continuous technological advance has allowed a better and faster documentation and validation of these events. Within the context of climate change, we could only speculate that tornadoes have turned from "exotic" into "common" phenomena, which raises the issue of taking effective measures for educating the population on how they should react in order to mitigate the effects of these types of severe events.

Tornado occurrence (Figure 4b) displays a similar monthly distribution as in [11], with high values from May to July. The distribution is also similar to the monthly distribution of severe convective events that cause lightning with high numbers of fatalities in Romania [59,60], and hail events [61,62]. The spatial distribution of tornadoes shows similarities with the spatial distribution of severe thunderstorms [59,61–63], with a maximum over the plain region in South-Eastern Romania (Figure 4c), where the reported events have increased since 1990.

Considering the increasing number of tornado events over the last two decades [9,11,14,17], a proper adjustment of the present warning system would be necessary, to include customized procedures for tornado warnings, in order to be efficiently disseminated and to meet the population's needs and expectations.

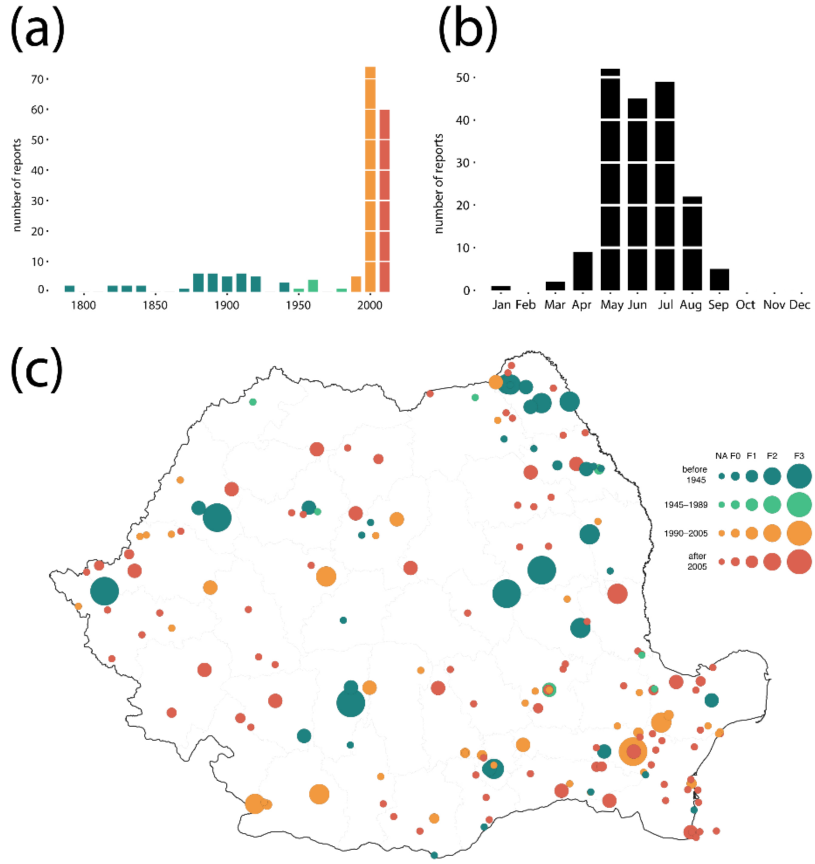

Figure 4. Annual distribution of tornado reports between 1634 and 2019 (**a**), monthly distribution of tornado reports (**b**), and spatial distribution of tornadoes in Romania during 1634 and 2019 (**c**); the colors in (**a** and **c**) attribute the events to different historical epochs: before 1945 (**dark green**), 1945–1989 (**light green**), 1990–2005 (**orange**) and after 2005 (**dark orange**). The tornado intensity is given by the circle's size.

4. The Analysis of Current Warning Processes and Public Perception Assessment of Tornadoes in Romania

For many years, the weather warning system in Europe was non-unitary, being managed by the national meteorological services of each country, usually based on the regional climatology. The first initiative to realize a unitary picture of severe weather in Europe belongs to a small group of young forecasters, working on a voluntary basis. In 2002, they laid the foundations of an active community in the field of forecasting and warning of severe weather phenomena in Europe. Since then, the European Storm Forecast Experiment, ESTOFEX [64], has issued a series of products meant to assist the meteorologists in forecasting severe weather, including tornadoes. Starting in 2007, the first steps have been taken to establish a unitary warning system at the institutional level. The common effort of the all European public weather services network, EUMETNET [65], has been materialized through Meteoalarm [57], a portal offering a universally understood system of color-coded maps with updated severe weather warnings over most of Europe for the next 24 to 48 h. Currently, a four-level color-code for the administrative divisions of each country is indicated on the map depending on the weather severity degree: red—to indicate exceptional risk for dangerous conditions, orange—for dangerous conditions, yellow—for potentially dangerous situations, and green—for no particular awareness. For Romania, the warning system refers to the nomenclature of territorial units for statistics, NUTS-3 level [66].

The dissemination of alerts for exceptionally risky and dangerous weather conditions in Romania is performed throughout the RO-ALERT system, managed by the Ministry of Internal Affairs [67]. The system is fast and accessible, allowing it to send Cell Broadcast messages to warn and alert citizens in cases of emergency, according to the legal provisions. The new system is better than previous ones, but still there is room for improvements. Despite all efforts to improve the weather forecast performance, the warning system and the dissemination methods, even now some issues remain unsolved. For instance, the term "tornado", as it is defined by meteorological glossaries [68,69], is not clearly mentioned by the Romanian meteorological service in its warnings. This is because although the supercells' signatures or the mesocyclones are relatively easily detectable by weather radars, it is difficult to decide whether or not a tornado will form. The poor collaboration between the national meteorological service and the community of severe weather spotters has also contributed to this situation. As a result, in the situation of the emergence of a supercell, because it is not certain that a tornado will form, in most cases the expression "strong squall" or "tornado-like wind" is preferred.

According to the recent research [20,25,27], many European national meteorological services do not hold comprehensive tornado warning concepts or procedures for tornado warning. Considering the potential threat of tornadoes in Romania [4,9,11,14,17], the inclusion of tornadoes on the list of severe phenomena for which warnings are issued has to be considered, and relevant knowledge about the Romanian public perception of tornadoes is needed.

Based on the information provided by the media for the 30 April 2019 event (e.g., Figure 1b), one can remark that in Romania, "risk culture" is a at a very low level [45], at least in relation to tornadoes, and there is still much work to do with respect to educating the Romanian general public in terms of understanding the threat and having a correct reaction when facing a tornadic event [70,71]. The scientific literature emphasized that a general problem of many weather services involves coping with the relatively small amount of information regarding the social and behavioral data on the population using the weather and climate services [35,36]. Therefore, a proper approach to this topic requires an in-depth understanding of the knowledge level among the different social categories of the general public. To assess the usefulness of tornado warnings and their perception in Romania, an exploratory survey was performed.

A 21-items questionnaire, built in Google forms, was addressed to the Romanian general public and disseminated via Facebook, which is likely the most used social media platform at the national level [72]. The inquiry was built around the premise that even though many people have access to the warning messages and also to the basic information, some people's reactions during the tornado event that occurred on 30 April 2019 were inappropriate. For example, the drivers traveling nearby stopped their cars and filmed the phenomenon (Figure 1b), or went as close as possible to catch the best image instead of sheltering themselves or moving far away from the tornado. A series of questions addressed the following topics:

- How does the public perceive the occurrence of a tornado in Romania?
- How does the public perceive the meteorological warnings?
- Is the public sufficiently educated and prepared to react correctly?
- What are the public expectations from the experts and the authorities in such situations?

The questionnaire (Appendix A, questions are denoted Q1 to Q21) was disseminated via Facebook, and advertised by the authors between 27 June and 8 July 2020. During this short period of time, a number of 707 responses was collected and further analyzed. The structure of the questionnaire supported four categories of answers, as follows: (1) the assessment of the basic knowledge on tornado as phenomenon (through question Q1 to Q5); (2) the information sources, the level of trust and understanding of these sources (Q6 to Q9); (3) the personal experience, possible reactions and preventive measures in the case of a tornado event (Q10 to Q12); and (4) the level of interest and expectation with regards to warnings of tornadoes (Q13 to Q16). Questions Q17 to Q21 were meant to assess the demographic profile of the respondents (e.g., age, gender, residence, education and the linkage of their daily activities with the atmospheric sciences domain). The investigation unfolded within a period unbiased by a recent tornado event.

The first part of the questionnaire was focused on the assessment of the basic knowledge of tornadoes. We were interested to find out whether the respondents are able to recognize this phenomenon (Q1), how they perceive it (Q2), how convinced they are about tornado occurrence in Romania (Q3), where they think the tornadoes occur (Q4), and which is the most dangerous weather phenomenon associated with a tornado (Q5). From the provided images in Q1 (Appendix A), 88.1% of respondents were able to recognize tornadoes and 64.4% chose waterspouts, while 29.8% chose funnel clouds and 26.2% chose the dust devil image (Figure 5a). As the results of multiple-choice questions could be ambiguous, the responses were "filtered" according to the following combinations: if the respondent chose option 2 (tornado), option 3 (waterspout) or both (option 2 and 3), we considered that the respondent made the correct choice (blue square in Figure 5b); if the respondent chose option 1 (dust devil) and/or option 4 (funnel cloud), chose all the four options, or if two of their choices out of three were options 1 and 4, the response was considered incorrect (red squares in Figure 5b), while if one of two options or two of three options were correct, the response was considered confusing (grey squares in Figure 5b). It is to be noted that we considered both tornadoes and waterspouts correct answers, since in Europe and in the ESWD database the two phenomena are not differentiated.

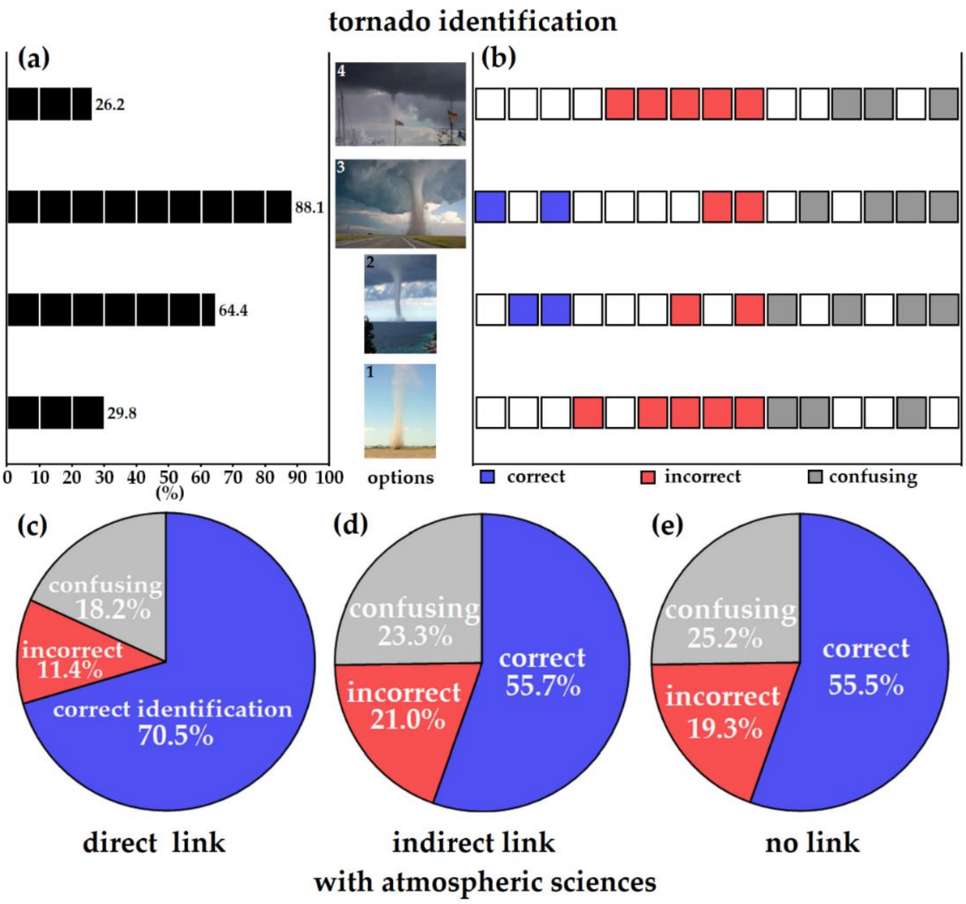

Figure 5. The initial results of the multiple choice question Q1 for testing the ability of respondents to identify tornadoes (**a**), the filter for discerning correct (full blue squares), incorrect (full red squares) and confusing (full grey squares) choices; each column of four squares represents a choices type identified within the survey; full white squares represent those options not taken into consideration by the respondents for each series of four options within the columns (**b**), and the final results after applying the filter to the three sub-sets containing the responses from people with professions directly (**c**), indirectly (**d**) and not (**e**) linked with the atmospheric sciences.

The answers were split into three sub-sets, based on the declared level of professional linkage of the respondents with the atmospheric sciences, as follows: sub-set 1—containing 176 responses from people with activities directly linked with atmospheric sciences; sub-set 2—containing 210 responses from people whose activities have indirect links with atmospheric sciences; and sub-set 3—containing 321 responses from persons who declare no connection with this domain. The ability to identify tornadoes amongst the three sub-sets was analyzed. The filtered results emphasized that people with activities connected to the atmospheric sciences are more able to identify correctly tornadoes and waterspouts (70.5%) compared with the group with no connection to the atmospheric sciences (55.5%), while the percentages of confusing and incorrect responses increased from the sub-set 1 to sub-set 3 (Figure 5c–e).

The provided images were associated with the term "danger" or similar terms (e.g., disaster, damage, fury, horror, threaten or fear) by 87.4% of the respondents. The perception of danger was higher amongst the respondents in sub-set 3 (Figure 6a), who reported as possible reactions a high level of fear (6.2%), low calm (31.2%), looking for shelter (74.1%) or choosing to go far away (53%) (Figure 8). In total, 9.6% of all respondents associated the term "spectacular" or similar terms (e.g., fascinating, impressive or curiosity), and 2.3% provided a realistic feedback (e.g., tornado, vortex, special or extreme weather phenomenon, storm) or associated the images with America and Wizard of Oz (Figure A1a). Of all the respondents, 60.7% were convinced that tornadoes can occur in Romania (Figure A1b), of which the highest percentage includes people form sub-set 1 (79% in Figure 6b). The occurrence locations of tornadoes were identified by 56.2% of all respondents within the lowlands as the area where the chance of occurrence is very high (Figures A1c and 6c), and 93.1% of all respondents identified strong winds as the most dangerous characteristic of a tornado (Figure A1d), with the highest percentage being within sub-set 1 (99.4% in Figure 6d).

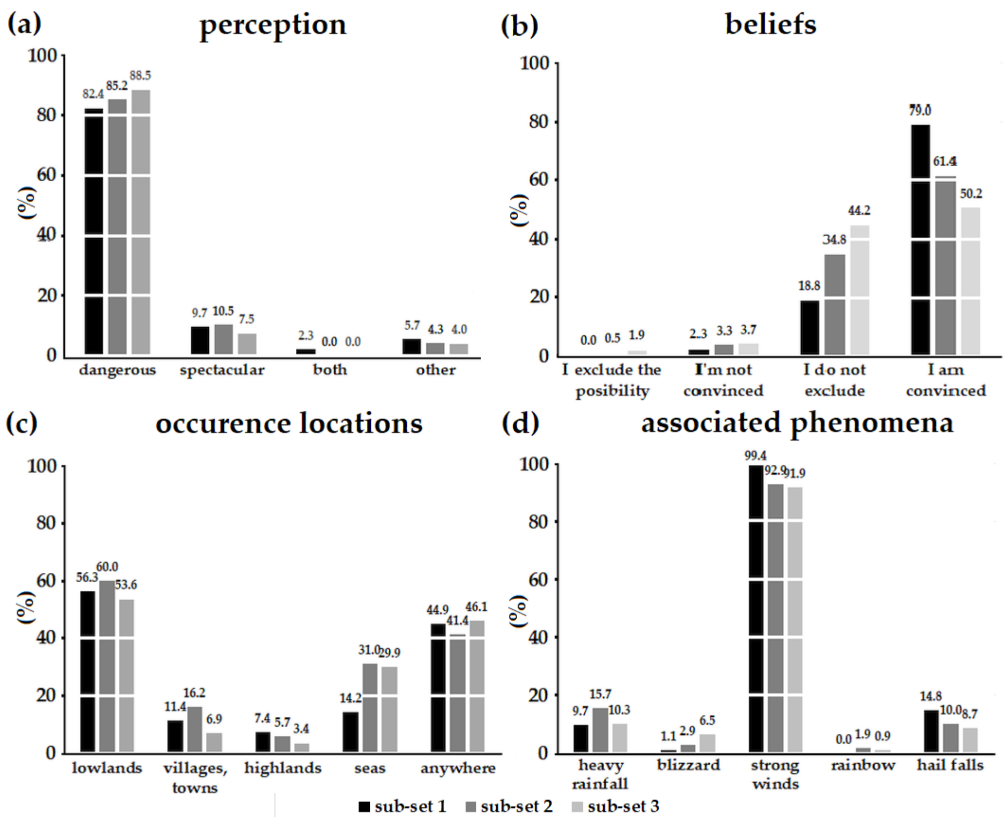

Figure 6. The distribution of results in sub-sets for questions Q2 to Q5 regarding: the respondents' perceptions (**a**), their beliefs (**b**), their knowledge on occurrence locations (**c**) and the most dangerous associated phenomena (**d**).

The next questions' slot (Q6 to Q9) aimed to identify the most reliable weather information sources (Q6), the respondents' understanding level of the provided information (Q7, Q8) and the assertiveness concerning the messages provided by the weather services (Q9). The top three most reliable information sources are the National Weather Service (84.3%), the General Inspectorate for Emergency Situations (55%) and weather smartphone apps (30.3%). The National Weather Service receives the greatest trust from people with activities directly related to atmospheric sciences (92.6% in Figure 7a), while the General Inspectorate for Emergency Situations is more trustable for people in sub-sets 2 and 3 (63.3% and 57% in Figure 7a). The weather apps seem to be more popular amongst sub-sets 2 and 3 (30% and 30.8% in Figure 7a). Surprisingly, media channels (TV, radio, online, social media) are trustable only for 13.6% of all respondents (Figure A2a), with the lowest level being amongst sub-set 1 (6.8% in Figure 7a). This could be explained by the excessive breaking of news on weather phenomena that some Romanian news channels broadcast without discernment. A high percentage of the interviewed people (44.4%) understand very well the information provided through icons, maps or radar and satellite images (Figure A2b), of which the highest percentage is represented by the respondents from sub-set 1 (67.6% in Figure 7b). In total, 90.1% of all respondents could discern amongst different types of weather messages (Figure A2c) and 95% of the respondents chose to be informed as soon as possible (Figure A2d) in the case of a high probability of tornado occurrence in the proximity. The highest percentage was given by the respondents from sub-set 1 (96% and 98.3% in Figure 7c,d).

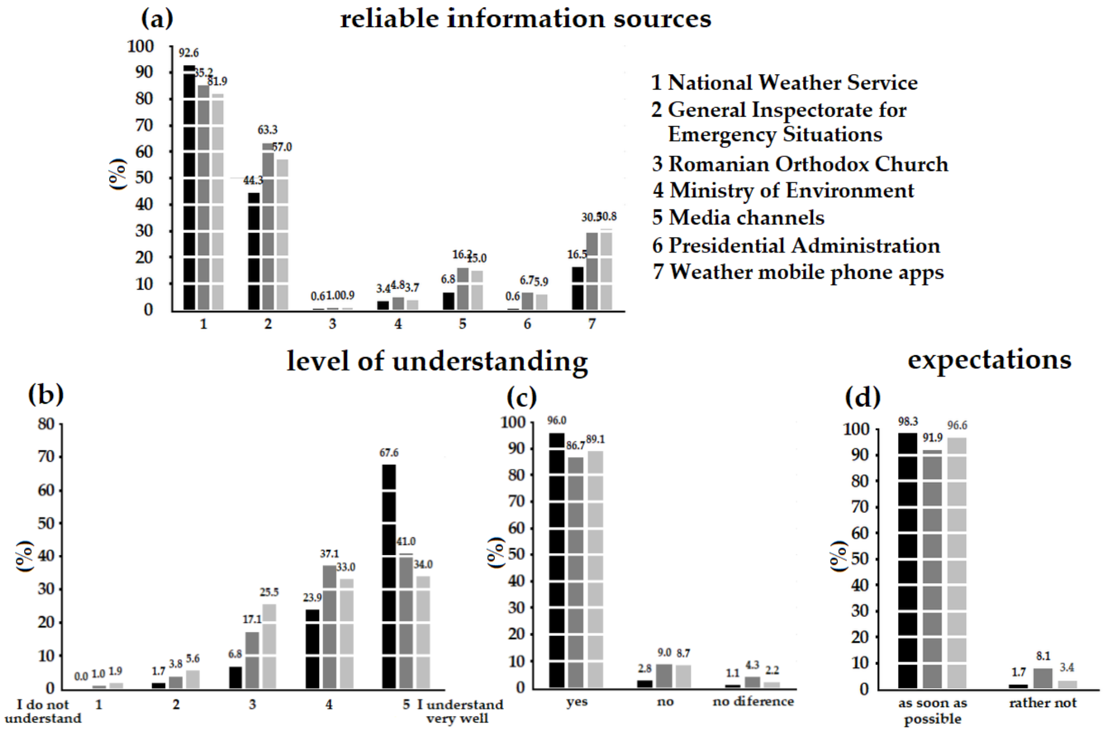

Figure 7. The distribution of results from sub-sets for questions Q6 to Q9 regarding: the most reliable information sources (**a**), understanding level of weather apps information (**b**), understanding level of weather service messages, (**c**) and peoples' expectations regarding the warning messages (**d**).

Questions Q10 to Q12 intended to assess people's experience regarding tornadoes (Q10), their possible reactions (Q11) and preventive measures to take in the case of experiencing a tornado event (Q12). Only 6.8% of all respondents declared a direct experience with tornado events and 3.7% found later on that they have been in the vicinity of a tornado, while 78.1% categorically declared the lack of such an experience (Figure A3a, Figure 8a). In a hypothetical case of tornado occurrence, 72.4% of all respondents would look for shelter as soon as possible with the highest rate in sub-set 3

(Figure 8b), 33.7% would keep calm waiting to see the storm evolution and decide later, 4.8% would be scared, and 4.4% would stay outside and document the tornado (to see/photograph/film it). Only 1.4% specified different reactions (Figure A3b), such as “I don’t know how I would react”, “I would follow the authorities’ indications”, I would “chase it”, being aware of the dangers, etc. As a possible choice for sheltering, 50.5% of all respondents would choose to go as far away as possible and 30.7% would shelter inside the house, while 10.5% of all respondents indicated the basements as the safest places (Figure A3c), with the highest percentage in sub-set 1 (15.3% in Figure 8c). From the 48 respondents who declared that they had a direct experience with tornado events, 36 indicated sheltering as their first reaction, 19 would keep calm and only 5 would stay outside to document the event. As a shelter choice, 26 would choose to go far away from the active area, 10 would shelter inside the house, 5 under a bridge, and 7 would choose the basement as the safest place. The interest level for this domain was high and very high for 41 of the respondents, but only one of them declared that he is a tornado chaser.

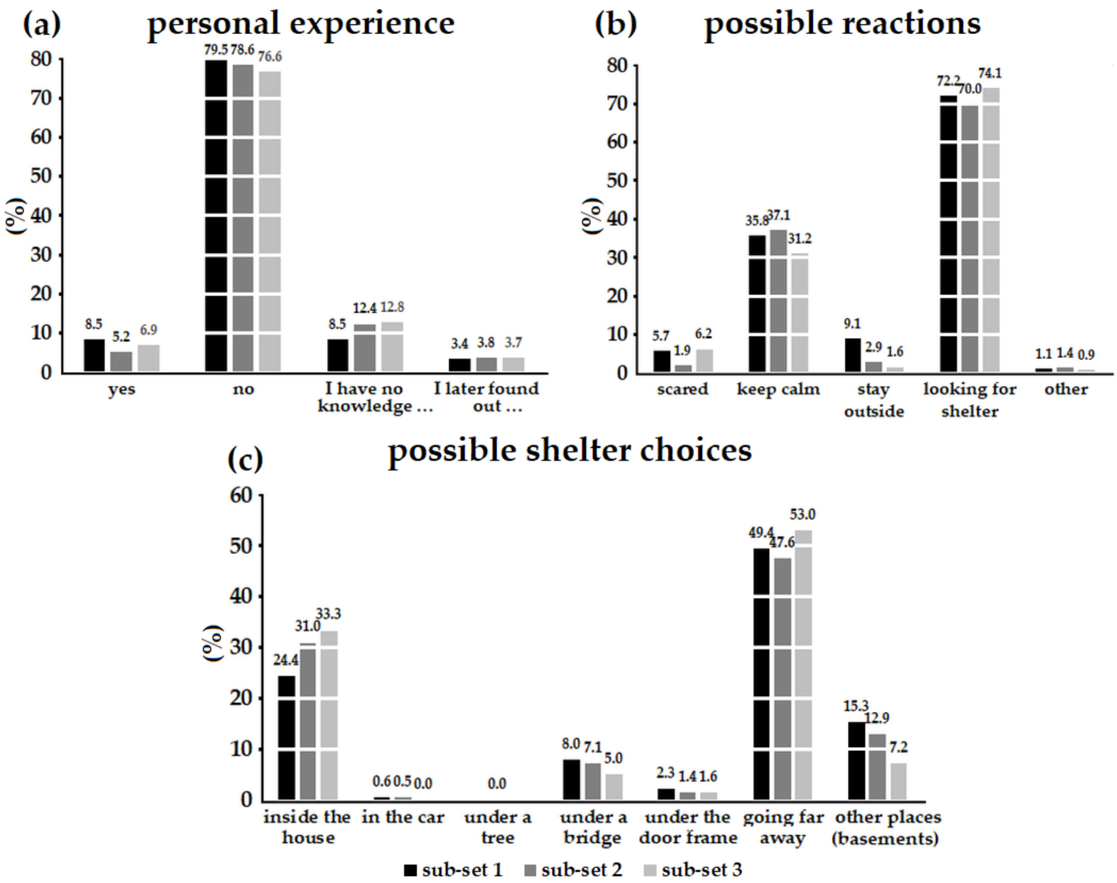

Figure 8. The distribution of results in sub-sets for questions Q10 to Q12 regarding: the respondents’ personal experience with tornadoes (**a**), their possible reactions (**b**) and their shelter choices in the case of tornado experience (**c**).

The level of expectation concerning severe weather and tornado warnings, and the level of interest in tornadoes as phenomena, were assessed through questions Q13 to Q16. A significant number of respondents would be satisfied, even relieved, in the case that the warned-against severe phenomena did not occur, despite the forecast (Figure A4a). The highest degree of contentment was given by sub-set 1 respondents (49.4% in Figure 9a) and those in sub-set 3 (45.2% in Figure 9a). Although the probability of a severe weather phenomenon (e.g., tornado) would be low, approximately 90% of all respondents prefer to be informed even though the tornado may not occur, or to be prepared for any contingency (Figure A4b). The most eager to receive tornado warnings even though it might be a false alarm were the respondents from sub-set 1 (55.1% in Figure 9b), while the reluctant respondents belonged to sub-set 3 (12.5% in Figure 9b). Based on these results, we may assume that the majority of the Romanian public is eager to receive tornado warnings, without taking into consideration the potential influence of a high number of false alarms, which might generate later a "crying wolf effect" [73,74]. The importance of specifying clearly the term "tornado" within the warning message if the possibility of occurrence does exist was approved by over 90% of all the respondents (Figure A4c), with the highest percentage in sub-set 1 (93.8% in Figure 9c). The population's interest in tornadoes is high (Figure A4d), the highest interests being reported by the respondents from sub-set 1 (72.7% in Figure 9d).

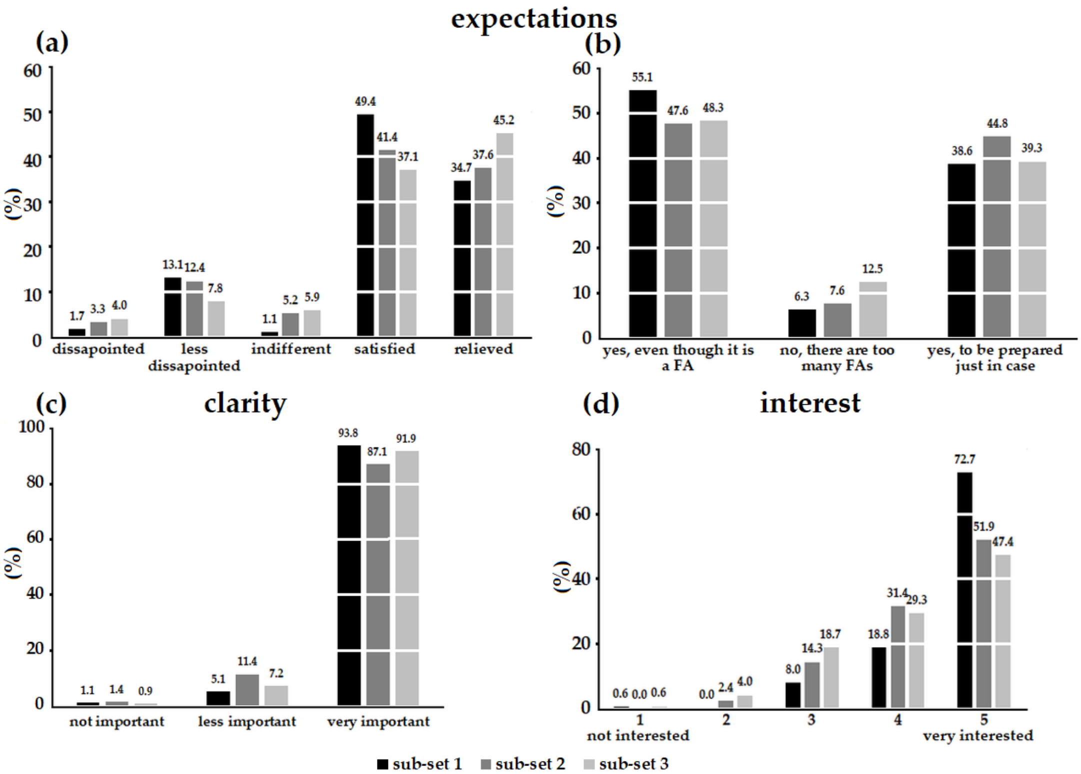

Figure 9. The distribution of results in sub-sets for questions Q13 to Q16 regarding the expectations in case of false alarms (**a**) and issuing messages although the probability of a tornado is low (**b**), how important is the word tornado to be clearly specified in a warning message (**c**), and the respondents' interests in tornadoes as severe/extreme phenomena (**d**).

Questions Q17 to Q21 provide the demographical profile of the respondents. The majority of people involved with this inquiry (97.4%) belong to the active population segment (18–54 years old), of which 59.1% are women and 37.6% are male; they live in urban areas (82.6%), and 85.9% have academic degrees (Figure A5a–d). In total, 24.9% declared that their profession is directly linked with atmospheric sciences in different ways, such as weather forecasting, scientific research or dedicated journalism. For 29.7% of them, the link with atmospheric sciences is indirect (insurance companies, emergency services, hobbies), and 45.4% declared no connection with this domain (Figure A5e).

5. Discussions and Conclusions

This paper has examined several challenges related to tornado forecast and warning procedures, as well as the public's understanding, response and expectations related to tornado forecasting in Romania. The analysis was performed one year after the occurrence of two severe convective events in the south-eastern part of the country, one being a tornado event on 30 April 2019, and one being a non-tornado event on 6 May 2019. These events raised significant interest from scientists, the general public and mass media. Based on scientific evidence and documentation, the frequency of such events in Romania is lower compared to other areas (e.g., Tornado Alley in the U.S. or even Western Europe), such that the media's coverage and public's interest are always amplified.

Two almost similar convective events were briefly presented as a preamble for discussions on the use of the term "tornado" in plain language within the warning messages issued by the National Meteorological Service. Such discussions used to be opened only after major events [20,23]. To the best of our knowledge, only the U.S. and Canada have implemented a dedicated tornado warning system [75–77], while in Europe the problem is still under debate [19,20,25]. As tornado forecasting is one of the most demanding tasks of any meteorological service, the low frequency of such phenomena may add supplementary pressure for inexperienced forecasters. In addition, important decisions to inform and warn the public and authorities must be taken in a very short time, and the result may be different, as demonstrated by the analyses of the two convective events presented in this study.

An update of the climatology of tornadoes in Romania was performed in order to emphasize the most susceptible areas affected, and the seasons with a higher frequency of the phenomena. The increasing number events reported in the last 20 years indicates that, even though tornadoes have a low frequency compared to other convective phenomena (e.g., torrential rain, hail, high wind speeds or electric discharges), they can no longer be considered exotic phenomena. Moreover, such a long-term picture at country level may explain the degree of understanding, the knowledge about reactions and the expectations of the forecasting service and authorities.

An exploratory investigation aiming to capture Romanians' perceptions, beliefs and attitudes in relation to tornado events was performed between 27 June and 8 July 2020, using a sample of 707 answers collected from an internet-based survey. The results refer mainly to the urban population with a relatively high level of education and information, who were randomly selected; the size of the sample sustains pertinent conclusions.

Generally, the respondents were well informed. For example, approximately 60% of the respondents were convinced that tornadoes occur in Romania, were able to identify tornadoes and waterspouts, set the danger as the main effect (over 80%), located the main occurrence over plain areas (over 55%), and identified the strong winds as the most dangerous associated phenomenon (over 90%). However, the distribution of percentages amongst the sub-sets underlines the need to concentrate more efforts on education relating to severe weather, and especially to the tornado topic, not only for people whose activities have an indirect or no linkage with atmospheric sciences but also for those directly involved in this domain. The most reliable information sources are the National Meteorological Administration (over 80%) and the General Inspectorate for Emergency Situation (approx. 55%). The public's trust should put even more pressure on the institutions to provide clear information as soon as possible (95%). On the other hand, the unexpectedly low trust in media channels needs an in-depth evaluation, which is envisaged for a future research. Only 7% of the respondents declared that they had experienced tornadoes. In the case of a tornado event, the majority of the respondents are expected to have a correct reaction; over 70% would look for shelter inside (30%) or in the basement (10%) of a house, or would go far away from the area of warning (50%). These responses contradicted the latest event reactions (on 30 April 2019), when people continued to drive towards the tornado [69,70]. This discrepancy might be due to the fact that the respondents had a relatively high education level. Therefore, this study should have a follow up, oriented towards people with lower education and/or who do not have internet access, and, based on the overall results, towards investigating and deciding on the most suitable methods to inform and educate the public. The interest in tornadoes is high and the importance of specifying clearly the word "tornado" within the warning messages was approved by more than 90% of the respondents, even in cases of a low possibility of occurrence. Moreover, in the case of a "false alarm", they would be satisfied, even relieved, that the warned-of phenomena did not occur. However, more research is needed in order to understand the people's perceptions and possible decisions related to tornado warnings, and to assess the sensitivity of the Romanian public to the "cry wolf" effect.

The comparative analysis of the three sub-sets reveals the following resemblances and differences:

- In terms of basic knowledge, the ability to identify the tornadoes increases with direct experience in the atmospheric sciences, and the same trend can be observed with regards to the belief that tornadoes occur in Romania. The perception of danger, occurrence locations and the most dangerous associated phenomena show a similar pattern. It is very likely that the background level of knowledge and interest in tornadoes is a major triggering factor both for identifying the danger and for the immediate reaction of a person.
- In terms of trust in information sources, although in general the most reliable source is the National Weather Service, a decreasing trend is visible from sub-set 1 to sub-set 3, while the opposite trend is evident for mobile phone weather apps. One can assume that the level of literacy in meteorology is also important for using and trusting official sources (e.g., National Meteorological Administration).
- There are notable differences regarding the possible reactions and shelter choices. People in sub-set 3 would be less calm, would not stay outside and would be more focused on looking for a shelter (preferably inside the house), or going far away, more so than people from sub-sets 1 and 2.
- With regards to receiving warning messages, people in sub-set 3 gave contradictory responses. In the case of a false alarm, they would be less satisfied but more relieved that the severe phenomenon did not occur compared with people in sub-sets 1 and 2. Moreover, they still want to be informed even if the probability of a tornado event is lower.
- Regardless of the sub-set, the majority expect to be informed as soon as possible even in cases of high probability of a tornado occurrence, and are categorically supportive of the use of the term "tornado" clearly within the warning messages.

This study is an exploratory contribution to the better understanding of public perceptions of tornadoes in Romania. The methodology may be improved (e.g., by a better structure of the survey, scientifically sound sampling or more elaborate questions), but it is very likely that the conclusions remain valid. For the appropriate use of these results, one should acknowledge several inherent limitations of this study. The sampling was selected by random, and it may be biased by the authors' network. However, considering the number of authors who spread the survey, this limitation was addressed. The analysis was performed using the entire set of respondents in order to use all the information collected. By splitting the sample into sub-sets, we tried to make the results more meaningful.

To the best of our knowledge, this is the first survey of this size conducted to investigate the public's perception of tornadoes in Romania. It has an exploratory meaning, and further refinements are needed in order to get the full relevance of the results. For example, future work will include a relevant sample of responses from a sample of lower education people and/or those who do not have access to the internet. Another study is also foreseen involving researchers, experts in meteorology and communication, policy-makers and emergency managers in order to improve the tornado warning procedures and to find the best way to communicate them to the Romanian general public.

Author Contributions: Conceptualization, S.A., M.D.A. and B.A.; methodology, S.A., M.D.A. and S.C.; software, S.A. and M.H.; formal analysis, S.A., M.D.A., M.H., B.A. and S.C.; investigation, M.D.A., S.A., M.H., B.A. and S.C.; resources, M.H., M.D.A., B.A., S.A. and S.C.; writing—original draft preparation, S.A. and M.D.A.; writing—review and editing, S.A., M.D.A., M.H., B.A., and S.C.; visualization, S.A., B.A. and M.H.; supervision, B.A. and S.C. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Perception of Tornadoes in Romania

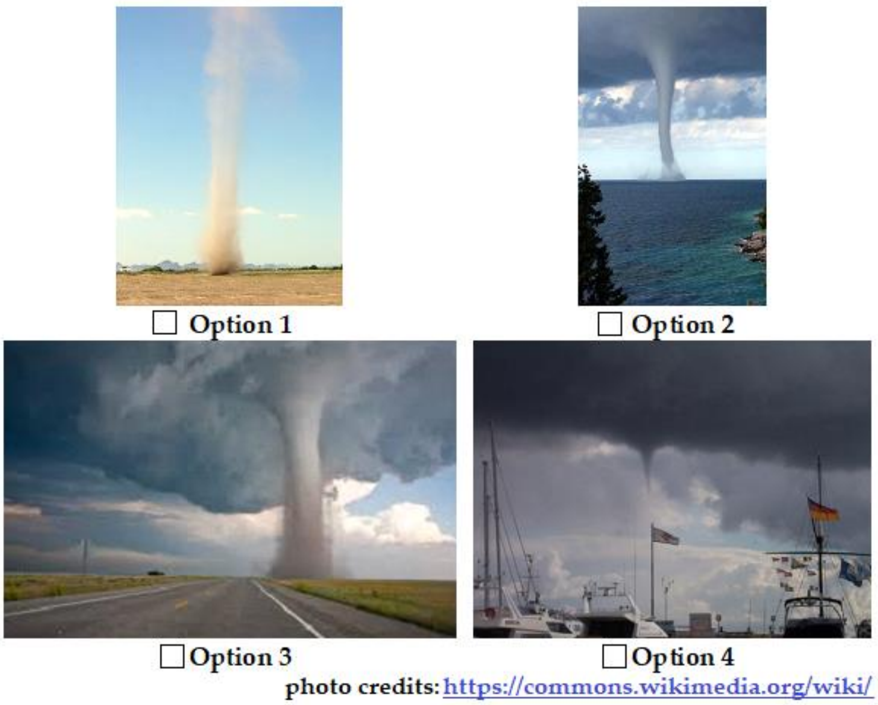
https://docs.google.com/forms/d/e/1FAIpQLSd8YZAnXVUZOc9yWvUN5gUocq3uQG23o4XUApysTnQT7JnTgw/viewform?usp=sf_linkTornado (*In Romanian*).

Given the increasing number of severe weather events, we would like to assess how familiar is the Romania public with the presence of tornadoes in Romania. Your answers will only be used for that purpose. According to the GDPR policy, the identity and personal data will not be made public by us under any circumstances.

**Mandatory answer*

Q1. In which of the images below can you identify a tornado? *

Select all applicable choices



Q2. What is the first word that comes to your mind when you look at the images above? *

Select a single choice

- ○ spectacular
- ○ dangerous
- ○ other

Q3. How convinced are you that tornadoes can occur in Romania? *

Select a single choice

- ○ I exclude this possibility
- ○ I am not convinced that tornadoes can occur in Romania

- ○ I do not exclude this possibility
- ○ I am convinced that tornadoes can occur in Romania

Q4. In which area tornadoes can occur? *
Select all applicable choices

- ○ lowland areas
- ○ inhabited areas (e.g., villages or towns)
- ○ highlands
- ○ over the seas
- ○ anywhere

Q5. The most dangerous weather phenomenon associated with a tornado is: *
Select all applicable choices

- ○ heavy rainfalls
- ○ blizzard
- ○ strong winds
- ○ rainbow
- ○ hail falls

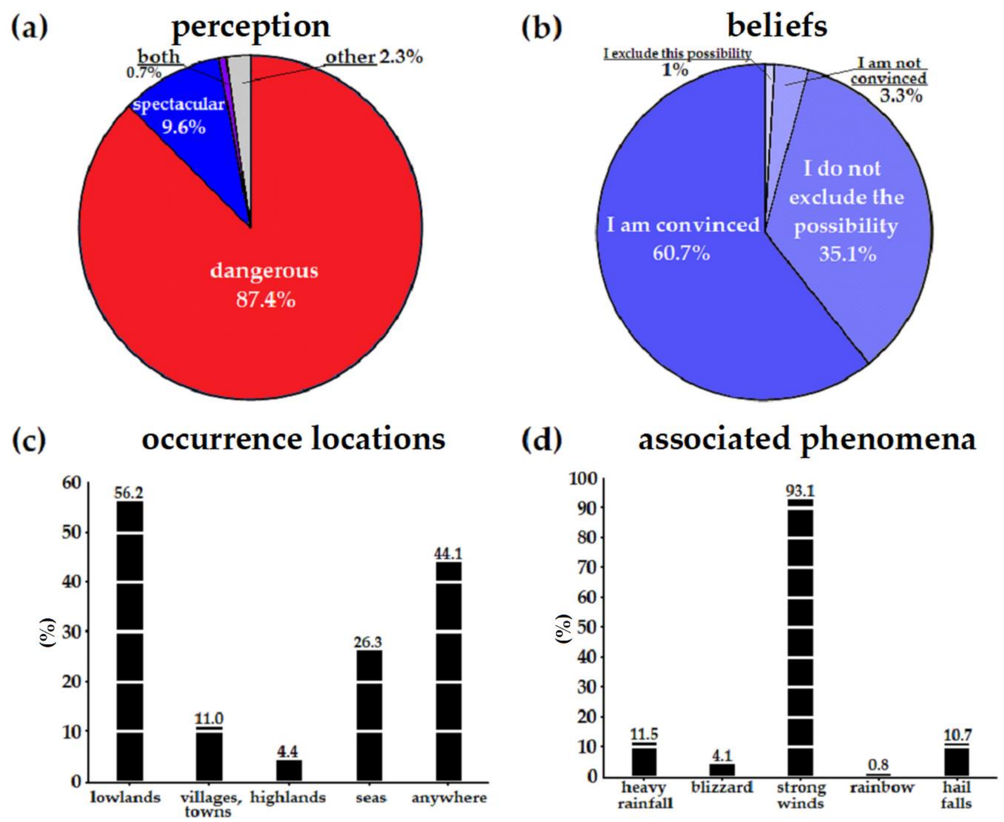


Figure A1. The summary results of questions Q2 to Q5 regarding: the respondents' perceptions of tornadoes (**a**), their beliefs (**b**), their knowledge of tornado occurrence locations (**c**) and the most dangerous associated phenomena (**d**).

Q6. Indicate the most reliable information sources in case you receive a severe weather message (e.g., tornado) *
Select all applicable choices

- ○ National Weather Service
- ○ General Inspectorate for Emergency Situations
- ○ Romanian Orthodox Church
- ○ Ministry of Environment
- ○ Media channels (TV, radio, online, social media)
- ○ Presidential Administration
- ○ Weather mobile phone apps

Q7. Weather websites and smartphone apps use icons, maps, radar and satellite images. On a scale of 1 to 5, how well do you understand the information? *

Select a single choice

	1	2	3	4	5	
I do not understand it	O	O	O	O	O	I understand it very well

Q8. Weather forecasters issue several types of messages: information, notice (yellow code) and warning (orange and red code). Is the difference between them clear to you? *

Select a single choice

- ○ Yes
- ○ No
- ○ There is no difference

Q9. In case of a high probability of tornado occurrence in the proximity of your area, would you like to be informed, *

Select a single choice

- ○ As soon as possible
- ○ Rather not

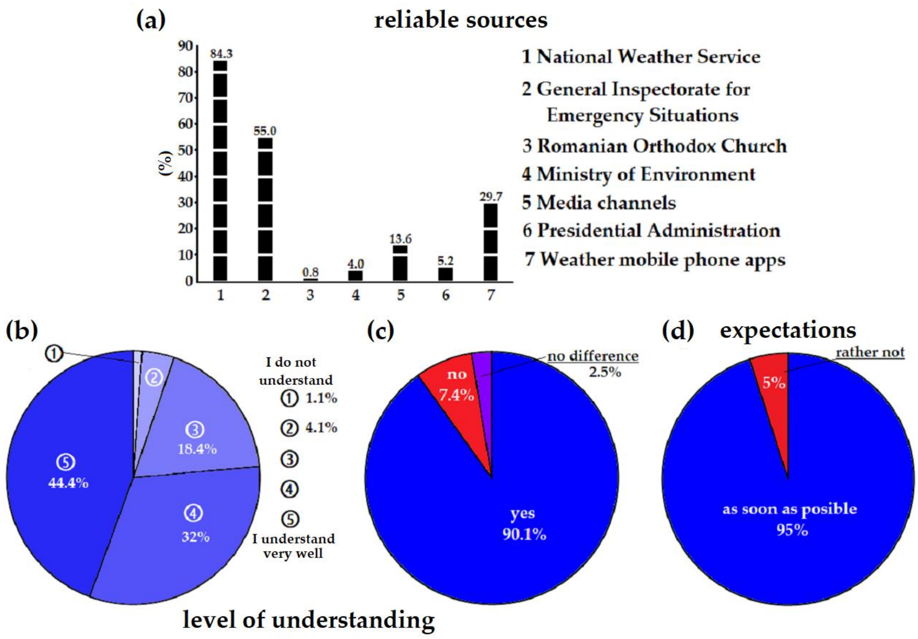


Figure A2. The summary results of questions Q6 to Q9 on: the reliable information sources (**a**), understanding level of weather apps (**b**), understanding level of weather service messages (**c**), and peoples' expectations regarding the warning messages (**d**)

Q10. Have you ever been in the vicinity of a tornado? *
Select a single choice

○ Yes
○ No
○ I have no knowledge that I have ever been in this situation
○ I later found out that I was in a nearby area

Q11. How would you react if you received a message that a tornado might occur in the proximity your area? *
Select all applicable choices

○ I would be really scared
○ I would keep calm and wait to see how situation evolves
○ I would stay outside and see/photograph/film it
○ I would look for shelter as soon as possible
○ Other reaction

Q12. Where do you think would be the safest place to take shelter in case of a tornado? *
Select a single choice

○ Inside the house
○ In the car
○ Under a tree
○ Under a bridge
○ Under the door frame*
○ I would try to go as far away as possible
○ Other places

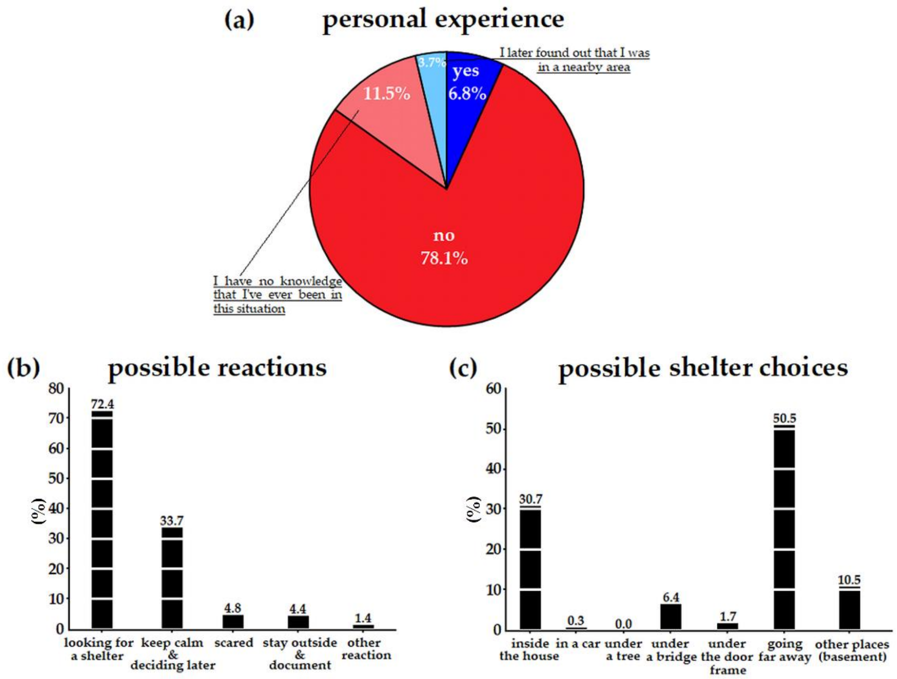


Figure A3. The summary results of question Q10 to Q12 regarding: the respondents' personal experience with tornadoes (**a**), their possible reactions (**b**) and their shelter choices in case of tornado experience (**c**).

Q13. How disappointed would you be if the warned severe phenomena did not occur? *
Select a single choice

- ○ disappointed due to the false alarm
- ○ a little disappointed due to the false alarm
- ○ I wouldn't care
- ○ satisfied that the reported phenomena were not as severe as the message
- ○ relieved that no dangerous phenomena occurred

Q14. If the probability of a severe weather phenomenon (e.g., tornado) is low, do you still want to be informed? *
Select a single choice

- ○ yes, even though it may not occur
- ○ no, there are too many false alarms
- ○ yes, I want to know to be prepared for any contingency

Q15. How important do you think it is to receive warning messages that CLEARLY specify the possibility of a tornado occurrence? *
Select a single choice

- ○ it is not important
- ○ it is less important
- ○ it is very important

Q16. On a scale of 1 to 5 your interest in severe phenomena (e.g., tornadoes) is: *
Select a single choice

	1	2	3	4	5	
I am not interested	O	O	O	O	O	I am very interested

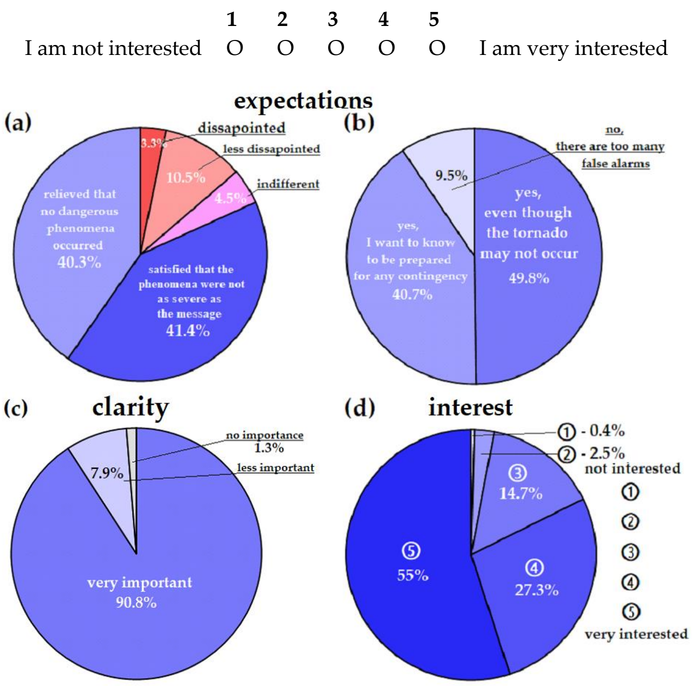


Figure A4. The summary of results from Q13 to Q16 regarding the expectations in cases of false alarms (**a**) and issuing messages although the probability of a tornado is low (**b**), how important is the word tornado to be clearly specified in a warning message (**c**), and the respondents' interests in tornado as severe/extreme phenomenon (**d**).

Q17. What is your age? *
Select a single choice

- ○ 18 to 24 years
- ○ 25 to 34 years
- ○ 35 to 44 years
- ○ 45 to 54 years
- ○ 55 to 64 years
- ○ 65 to 74 years
- ○ Over 75 years

Q18. Your gender is: *
Select a single choice

- ○ Female
- ○ Male
- ○ Unreported

Q19. Your residential area is: *
Select a single choice

- ○ Urban
- ○ Rural

Q20. Your educational degree is: *
Select a single choice

- ○ elementary school
- ○ middle school
- ○ high school
- ○ post-secondary school
- ○ university
- ○ post-graduate

Q21. Your connection with the atmospheric sciences is: *
Select a single choice

- ○ direct (by profession: meteorology, scientific research, dedicated journalism)
- ○ indirect (hobby, education, emergency services, insurance)
- ○ there is no connection

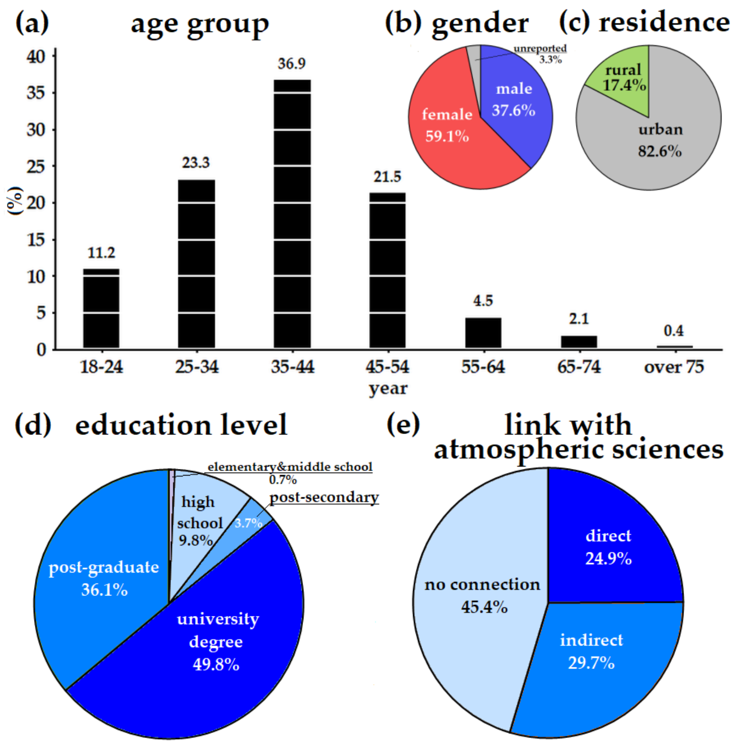


Figure A5. The summary of demographic profiles of the respondents (Q17 to Q21) regarding the age (**a**), gender (**b**), residence (**c**), education (**d**) and their connection with the atmospheric sciences (**e**).

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