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Changes in Weather-Related Fatalities in the Czech Republic during the 1961–2020 Period

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Abstract: Fatalities associated with severe weather, collected from newspapers and other documentary sources, were used to create a corresponding database for the 1961–2020 period for the Czech Republic. Fatalities attributed to floods, windstorms, convective storms, snow and glaze ice, frost, fog, and other severe weather, on the one hand, and vehicle accident fatalities connected with rain, snow, glaze ice, fog, and inclement weather, on the other, were analysed separately for two standard periods, 1961–1990 and 1991–2020. The number of weather-related fatalities between these two periods increased in the flood, windstorm, and especially frost categories, and decreased for the convective storm and fog categories. For snow and glaze ice they were the same. Despite significant differences in both 30-year periods, the highest proportions of fatalities corresponded to the winter months, and in individual fatality characteristics to males, adults, direct deaths, deaths by freezing or hypothermia, and to hazardous behaviour. A statistically significant ($p < 0.05$) Spearman rank correlation between fatalities and climate variables was only found in the 1991–2020 period for snow/glaze ice-related fatalities, with the number of days with snow cover depth and frost-related fatalities having days with daily minimum temperatures below −5 °C or −10 °C. Despite the highest proportions of the rain and wet road categories being in the number of vehicle accident fatalities, a statistically significant correlation was only found for the category of snow-related fatalities in the number of days with snowfall. The results and conclusions of this study have to be evaluated in the broader context of climatological, political, economic, and societal changes within the country, and have the potential to be used in risk management.

Keywords: weather fatality; vehicle accident fatality; documentary data; fatality database; spatiotemporal variability; fatality characteristics; climate variability; Czech Republic

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1. Introduction

The WMO Atlas of Mortality and Economic Losses from Weather, Climate, and Water Extremes [1] reports 159,438 fatalities for Europe in the 1970–2019 period. The predominant proportion of deaths was attributed to extreme temperatures (148,109 fatalities, i.e., 92.9%), particularly during the heat waves of 2003 in Western Europe (72,210 deaths in 15 countries) and of 2010 in Russia (55,736 deaths). It strongly influenced the highest decadal numbers of deaths in the 2000s (82,919) and 2010s (66,566) and contrasted with much fewer numbers of fatalities in three preceding decades (from 2275 deaths in the 1970s to 4313 in the 1990s). After the predominant proportions of deaths associated with extreme temperatures, those caused by floods (3%), storms (2%), landslides, and droughts (1% each) were cited. Information in [1], together with other related studies, is of great importance for approaches in risk management. This is underlined by the Sendai Framework for Disaster Risk Reduction

2015–2030 (SFDRR), adopted at the Third United Nations (UN) World Conference on Disaster Risk Reduction in Sendai (Japan) on 18 March 2015, outlining targets and priorities "to prevent new and reduce existing disaster risks" [2,3].

The above dramatic changes in the number of fatalities in Europe in the context of recent climate change has become a frequent topic for many related studies. It was especially reflected in the number of papers dealing with heat waves (e.g., [4–8]), but also with fatal floods (e.g., [9–17]), together with landslides (e.g., [18–20]). A smaller number of studies analysed fatalities during other severe weather events such as cold waves (e.g., [21]), heat and cold waves together (e.g., [22–25]), lightning (e.g., [26–29]), storms (e.g., [30]), tornadoes (e.g., [31]), droughts (e.g., [32]), and those related to more weather factors altogether (e.g., [33–35]).

Inclement weather patterns, however, also represent important circumstances that along with other factors contribute to vehicle accidents, accompanied by high numbers of fatalities and injuries [36–40]. For example, attention has been paid to vehicle-related flood fatalities (e.g., [41,42]), the impacts of severe weather on fatal traffic accidents, snow and winter precipitation (e.g., [43,44]), rainfall (e.g., [45–47]) or to various weather factors in a general overview (e.g., [48]).

Concerning the Czech Republic, the highest attention has been paid to fatalities during heat waves, particularly those that occurred after the year 2000 (e.g., [49–55]), and also during cold waves (e.g., [56,57]), or heat and cold waves together (e.g., [58]). Brazdova and Riha [59] developed a simple model to estimate the number of flood fatalities, tested partly on Czech data. Further Czech studies concentrated on the potential of documentary data to analyse fatalities related to severe meteorological and hydrological events [60], on weather-related fatalities in the Czech Republic during the 2000–2019 period [61], and on fatalities during traffic accidents associated with inclement weather during the 1979–2020 period [62].

An important increase in weather-related mortality between 1970 and 2019 in Europe, reported in the WMO Atlas [1], motivated us to perform such research on a regional scale. The aim of the current study is to compare weather-related fatalities (i.e., those cases in which the weather factors caused direct death or created one of several circumstances resulting in such death) over the Czech Republic in two standard periods, 1961–1990 (with a relatively stable climate) and 1991–2020 (with a dramatic warming), in the context of the whole 60-year time interval, separately analysing those related to the occurrence of severe weather patterns and those connected with inclement weather during vehicle accidents. Our database of weather-related fatalities allows a detailed study of fatality features related to the gender, age, place, time and type of deaths, to direct/indirect fatalities, and the behaviour of the decedent. Section 2 describes the study area, fatality data, and meteorological data used for the study of fatality circumstances, fatality database, and the methods of statistical analysis. Section 3 compares statistical characteristics of weather-related fatalities in the two 30-year normal periods, 1961–1990 and 1991–2020, together with their spatio-temporal variability. Results obtained are discussed in a broader context in Section 4 and briefly summarised in the last section.

2. Materials and Methods

2.1. Basic Information about the Czech Republic

The Czech Republic (henceforth "CR") with a total area of 78,866 km^2 is located in Central Europe (Figure 1a). Historically, it consists of an area extending from Bohemia in the western part to Moravia and Silesia in the eastern part. As a country, it was founded on 1 January 1993 when the former Czechoslovakia split into the CR and the Slovak Republic. Weather and climatic patterns are represented by a mixture of effects by the Atlantic Ocean, the Mediterranean Sea, and the Eurasian continent, determining temperature and humidity features of air masses coming to Central Europe. The Czech territory has altitudes ranging from 115 to 1603 m (mean altitude 390 m a.s.l.) and airflow effects are partly modified by orographic patterns (Figure 1b). The major part of the CR belongs climatically to the category of temperate broadleaf deciduous forest (Cfb) under the Köppen classification, while the remaining areas have a boreal climate, particularly Dfb and, to a lesser extent, Dfc [63].

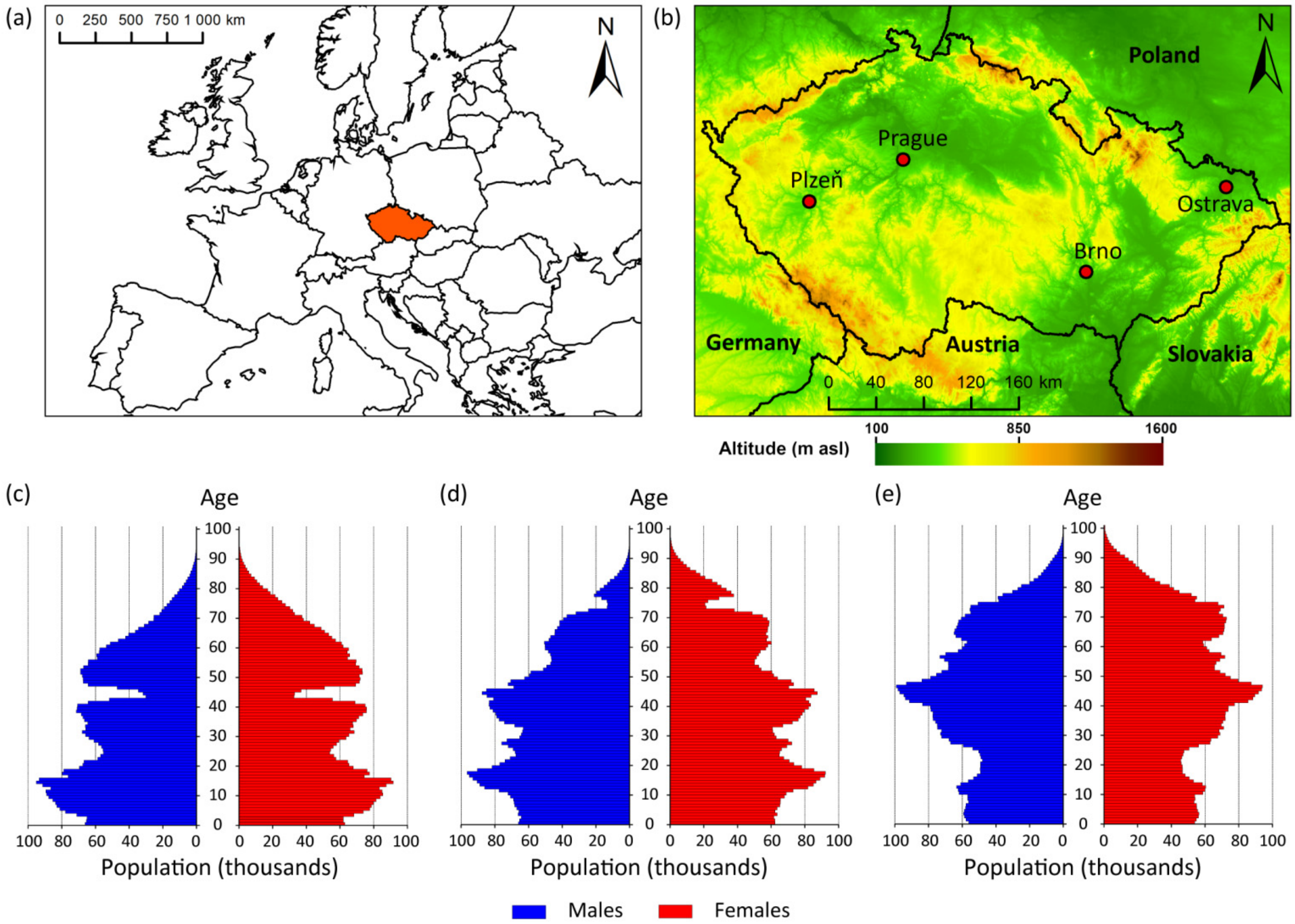

Figure 1. Location of the Czech Republic in Europe (**a**), physical geographical map of the Czech Republic (**b**), and age pyramids for 31 December 1961 (**c**), 31 December 1991 (**d**), and 31 December 2020 (**e**) (data in [64]).

The number of inhabitants in the CR grew from 9,588,016 in 1961 to 10,308,682 in 1991 and to 10,700,155 in 2020. During this period, the proportion of females slightly and gradually decreased from 51.5% (1961) to 51.4% (1991) to 50.7% (2020). The age pyramids for 1961, 1991, and 2020 show an ageing of the population, i.e., a significant decrease in the proportion of children (0–15 years) from 26.6% to 22.3% to 17.0%, and a significant increase in the elderly category (>65 years) from 8.9% to 11.8% to 18.9%. At the same time, the proportion of adults (16–65 years) changed much less (64.5%, 65.9%, and 64.1%) (Figure 1c–e). In the analysed time period, an increased proportion of city dwellers was also recorded from 61.8% in 1961 to 73.1% in 2020 [64,65]. In late 1989, after the Velvet Revolution, the CR experienced a significant societal change from the communist system with a planned socialistic economy to a democratic society with a free-market economy.

2.2. Fatality Data

Information on fatalities associated with severe weather was extracted from different types of documentary evidence, represented especially by newspapers. The central newspaper of the communist era, *Rudé právo* (from 18 September 1995 only *Právo*), was systematically excerpted for the whole 1961–2020 period. Besides the printed version of the newspaper, its electronic form *Novinky.cz* (in cooperation with *Seznam.cz*) was also used after 2000. Moreover, a systematic search of weather-related reports based on a list of 52 keywords (e.g., casualty, died, killed, black ice, flood, windstorm, lightning, frost, heat-wave) and 34 set phrases (e.g., wet road, slippery road, frost casualty, cold casualty, bad weather, bad visibility) from both printed and internet sources of the above newspaper for the 1990–2020 period was conducted by a media analysis method by the Toxin company, from which data of weather-associated fatalities were extracted. References to weather-associated fatalities from the newspaper *Svobodné slovo* from the study by Vintr [66] were used to obtain corresponding information for the 1961–1980 period. A further systematic search in the printed version of *Svobodné slovo* was subsequently conducted to extend the analysed period until 1996. Data of fatalities were further collected systematically from 2005 to 2020 from *iDNES.cz*, the electronic version of the newspaper *Mladá fronta DNES* (published from 1990), and non-systematically from *lidovenoviny.cz*, the electronic version of the newspaper *Lidové noviny* (published from 1990). Information about fatalities before 1990 was also extracted from the non-systematically digitised newspapers *Rovnost* (1964–1966) and *Lidová demokracie* (1976, 1979, 1981–1983, 1986, 1988) from sources of the Moravian Land Library in Brno (for locations of places in the CR see Figure A1).

The basic fatality data collected from the above newspapers were further complemented by reports from local media (mostly found via keyword searching on the internet), tangible monuments/memorials, TV broadcasts, local chronicles, and professional studies reporting hydrometeorological events and their human impacts.

Each extracted fatality was first critically evaluated, then re-worked into a shortened version which included all the necessary analysed parameters of fatal events. This was done in such a way to prepare it for inclusion into a newly-created fatality database (see Section 2.4.1).

2.3. Meteorological Data

With respect to fatalities associated with severe weather, the network of meteorological stations of the Czech Hydrometeorological Institute was used to calculate a mean annual series of selected climate variables for the territory of the CR in the 1961–2020 period. The annual numbers of the corresponding variable were first calculated for each available station, and then averaged over all of them to obtain areal averages. For individual climate variables, the following numbers of meteorological stations were used:

(i) Thunderstorm—72 stations;
(ii) Daily wind gusts ≥20 m s^{-1}—24 stations;
(iii) Glaze ice—11 stations;
(iv) Fog—6 stations;
(v) Snowfall—625 stations;
(vi) Snow cover depth ≥1, 3, 5, 10 and 15 cm—625 stations;
(vii) Precipitation with daily totals ≥1.0 mm—531 stations;
(viii) Frost days (TMIN < 0.0 °C), days with TMIN ≤ −5.0 °C and with TMIN ≤ −10.0 °C —133 stations.

2.4. Methods

2.4.1. Fatality Database

Based on the paper by Petrucci et al. [12], the newly-created Czech fatality database contains the following information from excerpted newspapers and other above-reported documentary sources:

(i) Date of the fatal accident or event;
(ii) Locality (i.e., place of the fatal accident or event);
(iii) Type of weather event (see below);
(iv) Time (hour) of day (morning 0400–0800 Central European Time—CET, forenoon 0800–1200 CET, afternoon 1200–1800 CET, evening 1800–2200 CET, night 2200–0400 CET);
(v) Name of the casualty;
(vi) Gender (male, female);

(vii) Age (exact age in years or estimated age: child 0–15 years, adult 16–65 years, elderly 66 years and more);
(viii) Cause of death (drowning, falling tree/branch, vehicle accident, underlying health reason, freezing to death/hypothermia, lightning strike, other reason);
(ix) Place of death (river/lake/reservoir/bank, within a building, road, open space in a built-up area, countryside, other places);
(x) Type of fatality (direct, indirect);
(xi) Behaviour of fatality (non-hazardous, hazardous);
(xii) Source of information.

As for the type of fatal weather event, the following categories were selected:

(i) Floods

This category includes floods originating from single-day or multi-day rainfall (rainy floods), sudden melts of deep snow cover (snow floods), and a combination of snow-melt and rainfall, sometimes accompanied by ice jams on rivers (mixed floods), as well as flash floods caused by cloudbursts or torrential rains during thunderstorms.

(ii) Windstorms

This category includes strong winds or wind gusts resulting from large horizontal pressure gradients that continue from a few hours to several days.

(iii) Convective storms

This category includes severe phenomena associated with the development of cumulonimbus clouds, particularly lightning strikes, strong winds (e.g., squall, tornado, or downburst) or thunderstorms without detailed specification.

(iv) Snow and glaze ice

This category includes fatal events connected with a large amount of snow or with the occurrence of glaze ice (cleaning of streets and roads, removing snow from roofs or falling snow or ice from roofs, falls on slippery surfaces, avalanches, etc.).

(v) Frost

This category includes deaths during severe frosts occurring during cold waves, and deaths on water bodies insufficiently frozen for the activity undertaken on ice.

(vi) Fog

This category includes cases of fog with very low visibility leading to fatalities other than those by vehicle accidents (train or plane accidents).

(vii) Other weather phenomena

This category includes weather effects leading to fatalities that were not considered in the preceding weather categories, such as heat, landslide, rime, inclement weather, etc.

In the case of fatal vehicle accidents, special consideration was given to the weather categories "rain", "snow (snowfall)", "glaze ice", "fog", and "other inclement weather", since these can contribute to slippery roads and to bad visibility during accidents.

Examples of fatality reports with respect to their projection into the database are shown in Appendix A. As expected, some reports present only incomplete or rather general information, which means that some fatality characteristics in the database remain empty or can be described only in general terms. Those without more specification are labelled as "unknown".

2.4.2. Statistical Analysis

Fatalities in each category of fatal weather events were analysed separately for the 1961–1990 and 1991–2020 periods using their annual numbers, complemented with linear trends and their significance, distribution (variation) during the year, spatial distribution over the CR territory and particular features including the cause of death, type of fatality, place of death, time of death, age, gender, and behaviour (Figures 2–6). The same analysis was performed for all weather categories together (Figure 7) and separately for fatalities in vehicle accidents (Figure 8). The presence of a significant linear trend ($p < 0.05$ or $p < 0.10$) in the analysed time series was evaluated using the non-parametric Mann-Kendall test [67,68]. Parameters of linear trends were estimated applying the non-parametric Theil-Sen method, which is more robust to outliers in time series [69,70]. Linear trends in related figures for any of the 30-year or 60-year periods were marked only in the case that their slopes were equal to zero. The two-proportion Z-test [71] was used to test the significance of differences in relative proportions of fatalities in annual distributions and in their special characteristics between the 1961–1990 and 1991–2020 periods. In the case that they were statistically significant, related pairs of figures were marked by asterisks. Relationships between different fatality categories to corresponding climate variables in two standard 30-year periods were expressed by box plots and scatter plots, being complemented by the calculation of the non-parametric Spearman rank correlation coefficient with the *p*-value calculated via the asymptotic t-approximation (Figures 10 and 11).

3. Results

3.1. Fatalities Associated with Severe Weather

3.1.1. Floods

The numbers of flood fatalities in the CR significantly increased between 1961–1990 and 1991–2020, from 130 to 217 deaths. The related numbers of flash flood fatalities reached 65 (50.0% of all flood fatalities) and 58 (26.7%) respectively. Differences in the relative proportions of flash floods between 30-years periods are statistically significant (as well as for the remaining floods). The years 1970 with 52 fatalities and 1997 with 63 fatalities appeared as outstanding during the entire period analysed (Figure 2a). In the first case these were caused by the tragic flash flood of 9 June 1970 at Šardice, in southern Moravia, when a lignite mine collapsed due to a water torrent (34 fatalities). In the second case, they were related to the disastrous rainy flood of July 1997 (61 fatalities) in Moravia and Silesia [60]. As for other years, related annual deaths did not exceed 10 fatalities during 1961–1990, but in the following 30-year period fatalities reached 22 in 2002 (17 deaths during the disastrous August flood [72]) and fatalities above 15 also occurred in 2009, 2010, and 2013 (cf. Table A1).

The two above-mentioned extreme flood events also influenced the annual distribution of flood fatalities with the maximum in June (36.9%) in the first 30 years and in July (37.8%) in the second, both months with statistically significant differences (Figure 2b). The spatial distribution of flood fatalities (Figure 2c), significantly different from random, is associated with watercourses and settlements and to the territorial extent of some important floods. Particularly expressed is a cluster of flood fatalities in the north-eastern part of the CR for 1991–2020, which was less pronounced in the previous 30 years, though appearing in southern Moravia. The analogous clusters of fatality occurrences were more distinct around the River Vltava and in northern and western Bohemia during 1991–2020.

In terms of the characteristics of flood fatalities, a variety of differences appear between both periods. As expected, drowning was the main cause of deaths (72.3% and 77.9% respectively), but there are a relatively higher proportion of “other reasons” due to the collapse of the mine that occurred in 1961–1990 (Figure 2d). While in the first period nearly all fatalities were characterised as “direct” deaths caused by flood events, in the second period the proportion of “indirect” deaths (mainly health complications) reached 18.4% (Figure 2e). Concerning the places of deaths, they appeared most frequently in rivers/lakes/reservoirs/riverbanks (56.2% and 62.7%), but 26.2% of deaths in 1961–1990 were classified as “other place”, i.e., the lignite mine in Šardice (Figure 2f). For approximately half of the flood fatalities, the time of day in which they died is unknown. In the first period, 35.4% of them died in the afternoon, clearly reflecting fatalities during flash floods in 1970 (Figure 2g). Concerning the age of deaths, besides maxima in the adult category (50.8% and 54.8%), a distinctly higher proportion for the children category appears in the first period (25.4% to 7.8%), while an opposite ratio occurs for the senior category (4.6% to 19.4%); both differences were statistically significant (Figure 2h). As for gender, a clear prevalence of the male category (70.0% and 73.7%) compared to the female category (20.0% and 24.4%) was detected (Figure 2i). The comparable proportions of flood fatalities (37.7% and 38.2%) were classified as "hazardous" (Figure 2j).

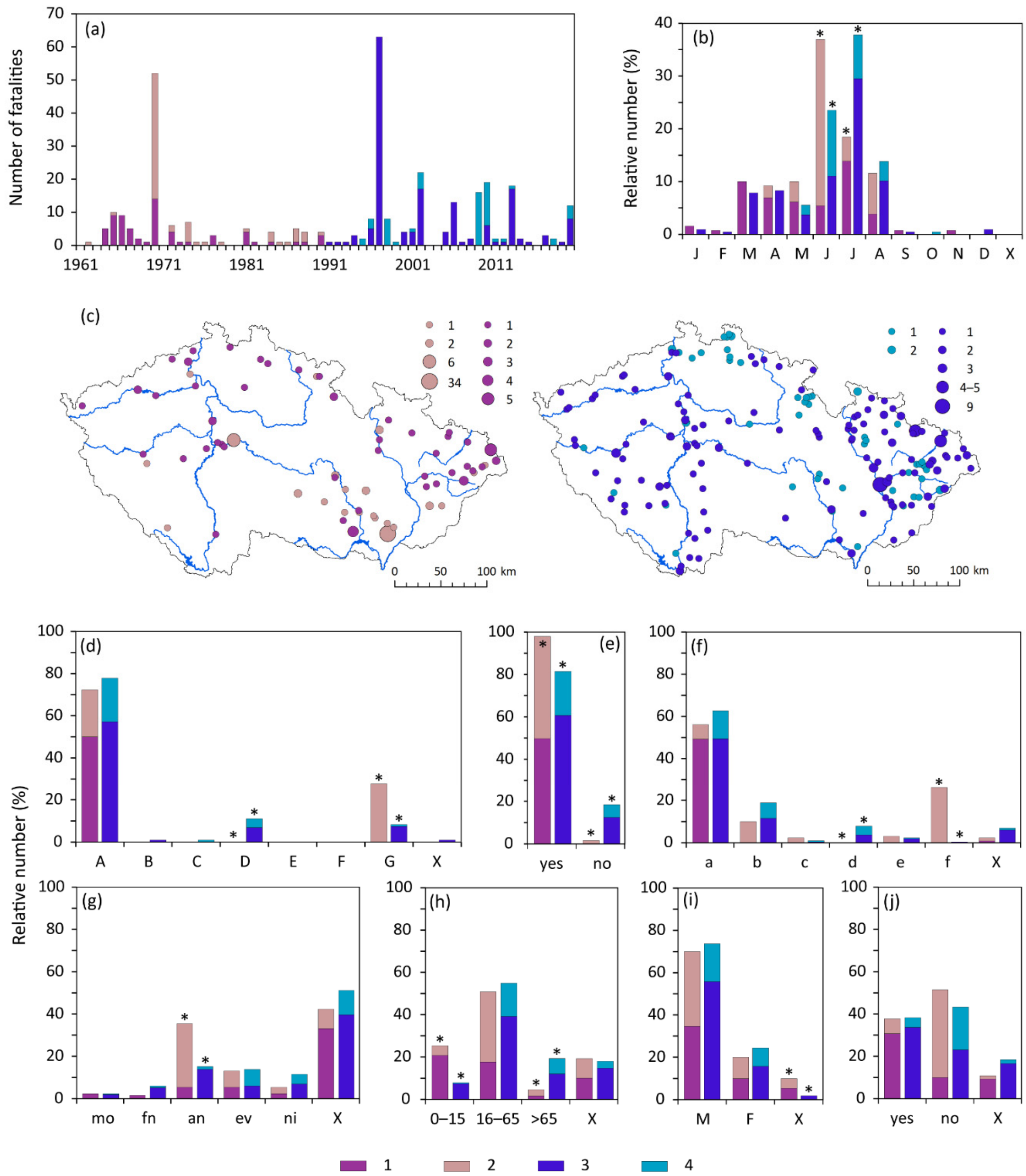

Figure 2. Characteristics of flood-related fatalities in the Czech Republic during the 1961–1990 (1—flood, 2—flash flood) and 1991–2020 (3—flood, 4—flash flood) periods. (**a**) Fluctuations in 1961–2020; (**b**) annual variation; (**c**) spatial distribution (seven fatalities in 1961–1990 and two fatalities in 1991–2020 lack exact locations); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). Symbols * identify statistically-significant differences ($p < 0.05$) in corresponding relative numbers between two 30-year periods in parts (**b**) and (**d**–**j**). Symbols and abbreviations: A—drowning, B–tree/branch fall, C—vehicle accident, D—underlying health reason, E—freezing to death/hypothermia, F—lightning strike, G—other reason; a—river/lake/reservoir/river bank, b—within a building, c—road, d—open space in a built-up area, e—open countryside, f—other places; mo—morning, fn—forenoon, an—afternoon, ev—evening, ni—night; M—males, F—females; X—unknown.

3.1.2. Windstorms

Between the 1961–1990 and 1991–2020 periods, the number of windstorm-associated fatalities increased from 41 to 60, with the highest number of nine deaths occurring in 2017, followed by six fatalities in 2007, 2008, and 2020 (Figure 3a). Worthy of mention are the windstorms Kyrill on 18–19 January 2007 [73], with six fatalities, and Herwart on 29 October 2017 [74] with four fatalities. In the annual distribution, the highest proportion of fatalities in 1961–1990 appeared in November (22.0%) followed by February (14.6%), while over the next 30 years it was in October (18.3%) followed by January and March (16.7% each). Differences between both periods were statistically significant in November (Figure 3b). The spatial distribution of fatalities shows a rather random distribution over the CR territory (Figure 3c).

Both 30-year periods were similar in their highest proportions of fatalities occurring as direct victims (65.9% and 91.7% respectively, with a statistically significant difference between them—Figure 3e), on an open space in a built-up area (36.6% and 31.7%—Figure 3f), in the afternoon (26.8% and 38.3%—Figure 3g), in the adult category (48.8% and 75.0%, the difference statistically significant—Figure 3h), with clear prevalence of males over females (75.6% to 22.0% in 1961–1990 and 83.3% to 13.3% in 1991–2020—Figure 3i), and in non-hazardous behaviour (70.7% and 71.7%—Figure 3j). Only in the case of death (Figure 3d), "tree/branch fall" fatalities with 58.3% were dominant in 1991–2020 (compared to 17.1% in the preceding period, the difference is statistically significant), compared to "other reasons" in 1961–1990 (34.1%). In some cases, however, the reported differences in relative proportions can be influenced by high proportions of "unknown" information, such as in time of day (Figure 3g) and the age of the decedent (Figure 3h).

3.1.3. Convective Storms

Compared to 102 identified fatalities associated with convective storms in the 1961–1990 period, their number in the following 30 years dropped to 62. While their maximum number reached 15 fatalities in 1962, the following highest values appeared in 1964 and 1968 (nine fatalities each). This was reflected in a statistically significant ($p < 0.05$) decreasing linear trend of −3.0 fatalities/10 years in 1961–1990, appearing with a much smaller slope in 1991–2020 ($p < 0.10$) also, as well as in the whole 60-year period ($p < 0.05$) (Figure 4a). Both 30-year periods were different in their proportions of meteorological events causing fatalities. For deaths by lightning strike, it was 82.4% and 50.0%, for strong wind 14.7% and 37.1%, and the rest of the fatalities during a thunderstorm created 2.9% and 12.9%, respectively. Differences in the relative proportions of all three variables between both 30-years were evaluated as statistically significant. In the annual distribution, fatalities that occurred from May to August clearly predominated, with a maximum in June (34.3% in 1961–1990) and in July (27.4% in 1991–2020); statistically significant differences appeared only in September (Figure 4b). The spatial distribution of fatalities in the two periods has a rather random character (Figure 4c).

The highest proportions of fatalities during the two 30-year periods exhibit similar patterns. For cause of deaths, this is valid for lightning strikes (79.4% and 48.4%, the difference between them is statistically significant—Figure 4d). For type of fatality, those in the "direct" category were dominant (87.3% and 82.3%—Figure 4e). The open countryside was the most frequent place of death (40.2% and 30.6%, with the same proportion of deaths in open spaces in built-up areas—Figure 4f). People often died in the afternoon (23.5% and 35.5%, but for 59.8% of fatalities in 1961–1990 the time of their deaths was unknown—Figure 4g). The adult fatalities predominated according to age (52.9% and 75.8%, the difference was statistically significant—Figure 4h). This was similar to males according to gender (49.0% and 67.7%, i.e., with a statistically significant difference), while proportions of female fatalities were nearly the same, 31.4% and 32.3% (Figure 4i). The non-hazardous behaviour of fatalities was more frequent in the first 30 years (50.0% and 43.5%), while hazardous behaviour increased in the following 1991–2020 period (29.4% and 38.7%—Figure 4j).

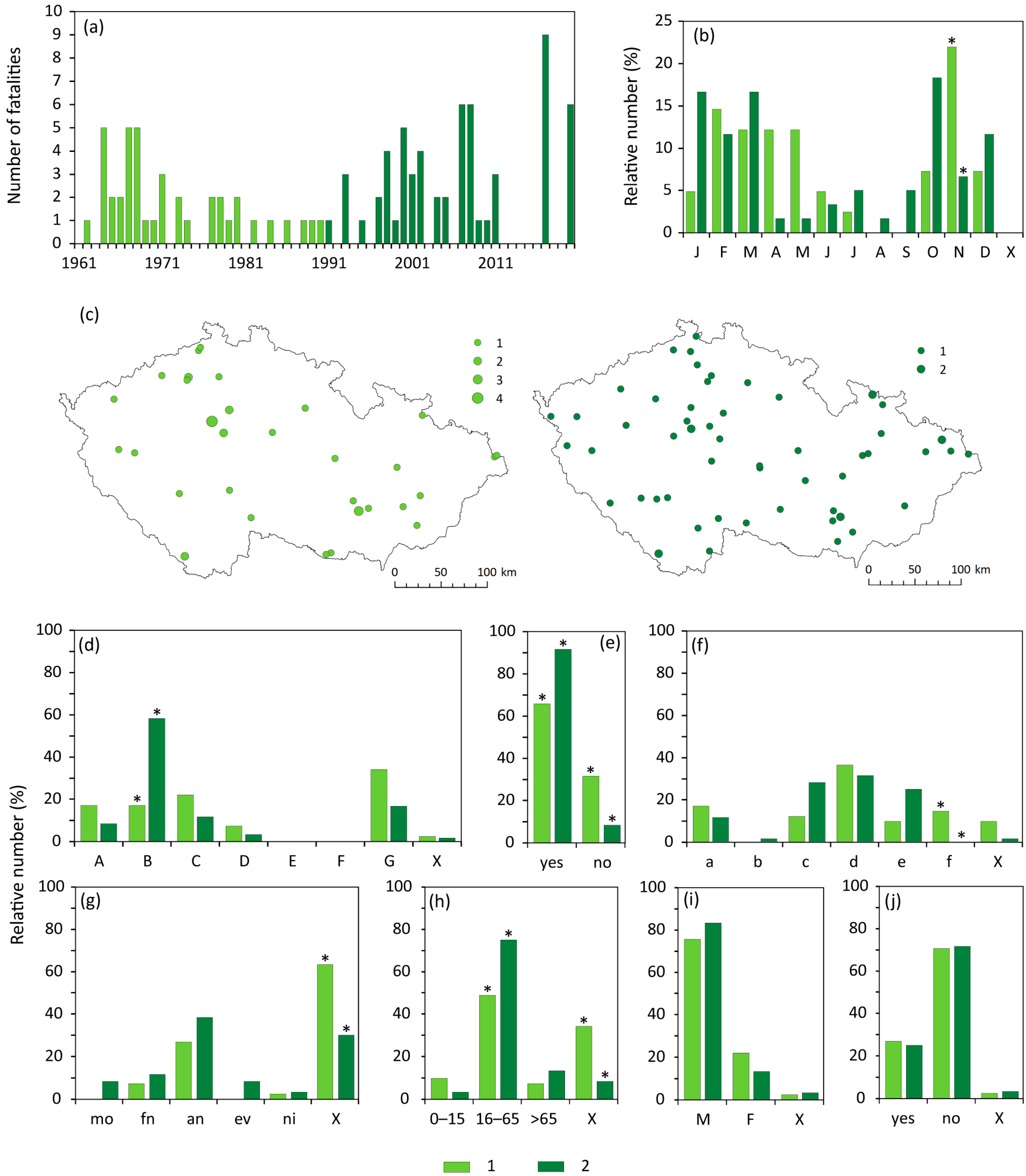

Figure 3. Characteristics of windstorm-related fatalities in the Czech Republic during the 1961–1990 (1) and 1991–2020 (2) periods. (**a**) Fluctuations in 1961–2020; (**b**) annual variation; (**c**) spatial distribution (one fatality in 1961–1990 and two fatalities in 1991–2020 lack exact location); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). For an explanation of symbols and abbreviations see Figure 2.

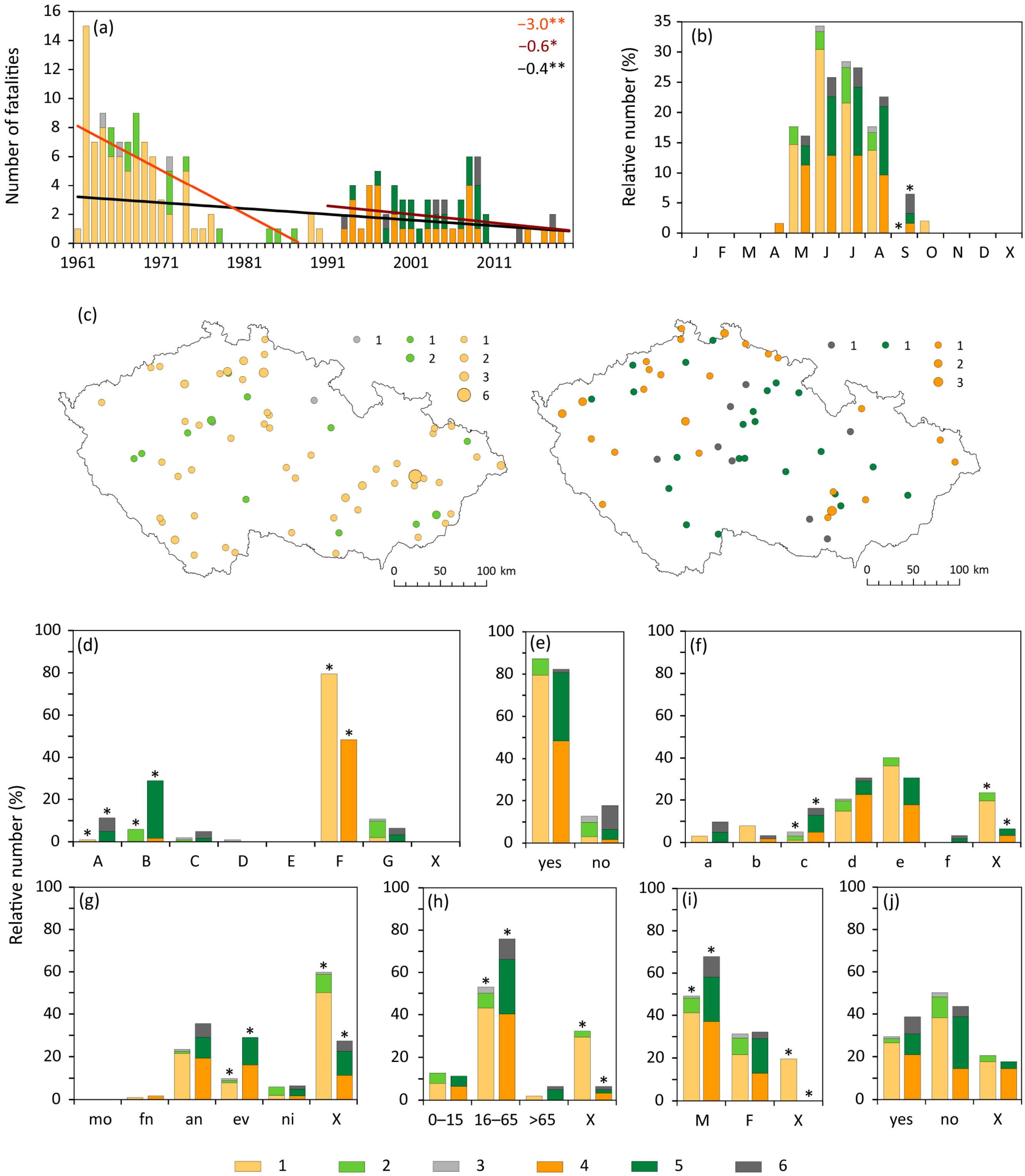

Figure 4. Characteristics of fatalities associated with convective storms in the Czech Republic during the 1961–1990 (1—lightning strike, 2—strong wind, 3—during a thunderstorm) and 1991–2020 (4—lightning strike, 5—strong wind, 6—during a thunderstorm) periods. (**a**) Fluctuations with linear trends (top right in fatalities/10 years for both 30 years and 1961–2020, trends with ** are significant for $p < 0.05$ and with * for $p < 0.10$); (**b**) annual variation; (**c**) spatial distribution (20 fatalities in 1961–1990 lack exact location); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). For an explanation of symbols and abbreviations see Figure 2.

3.1.4. Snow and Glaze Ice

In this category, the total number of 47 fatalities was the same in both 30-year periods. The proportions of deaths differed in the case of snow (59.6% in 1961–1990 to 51.1% in 1991–2020) and avalanche (10.6% to 19.1%), while for glaze ice they were similar with 29.8%. The highest number of nine fatalities was recorded in both 1962 and 2006, followed by the years 1970 and 2010 with six fatalities (Figure 5a). On the night of 28 to 29 January 1962 in Tábor, a train ran into a heavy snowstorm on a blind track and derailed; nine people died and 36 were injured (Table A1). In both 30-year periods, January fatalities dominated with 63.8% and 42.6%, respectively, followed by 25.5% in February during the second period (Figure 5b). In the spatial distribution of fatalities, the Krkonoše Mts. in northern Bohemia is a more consistent area for their occurrences (Figure 5c).

A greater proportion of fatalities belonged to the category "other reasons", such as deaths in avalanches, a great amount of snow falling from a roof, a slip on snow or glaze ice on the street or road and subsequent fall, etc. (61.7% and 76.6%); significantly different were the proportions of deaths in "transport accidents" (31.9% in 1961–1990) and "underlaying health reasons" (19.1% in 1991–2020) (Figure 5d). More than half of the associated fatalities were classified in the "direct" category (61.7%) in the second period compared to the "indirect" category (53.2%) in 1961–1990 (Figure 5e). Fatalities were often recorded in the open countryside (44.7% in 1961–1990, while a maximum of 31.9% in 1991–2020 was also reached in "other places"—Figure 5f). Information about time of day of death is biased by a high proportion of unknown cases (48.9% and 38.3%), but 25.5% of deaths occurred at night during the first 30 years, and the same proportion in the afternoon during the second 30 years, with statistically significant differences in both cases (Figure 5g). Adults predominated in both periods (42.6% and 55.3%, but with 40.4% being of unknown age in 1961–1990—Figure 5h) as well as males in the gender category (53.2% and 72.3%—Figure 5i). While in 1961–1990 hazardous behaviour by the fatalities dominated the non-hazardous (68.1% to 29.8%) category, in 1991–2020 it was the opposite (46.8% to 53.2%); differences in non-hazardous proportions were statistically significant (Figure 5j).

3.1.5. Frosts

The number of frost-related fatalities grew substantially from 198 in 1961–1990 to 522 in 1991–2020. The maximum of 63 fatalities was recorded in 2010, followed by 44 in 2012. These two years had severe cold waves with 25 fatalities each (1–22 December 2010 and 31 January–16 February 2012—Table A1). While a statistically significant decreasing trend (−2.8 fatality/10 years, $p < 0.05$) appeared in the first 30-year period, for the whole 60 years the significant positive linear trend had a slope of 1.5 fatality/10 years ($p < 0.05$) (Figure 6a). While relative January maxima in the annual distribution of fatalities nearly agreed in both 30-year periods (31.3% and 31.4%), they were followed by 27.8% in February (1961–1990) and by 29.3% in December (1991–2020) (Figure 6b). Differences in relative proportions between both periods were statistically significant in February, March and November. Despite the rather random spatial distribution of frost-related fatalities (Figure 6c), some areas with a higher concentration in the mountain areas, such as northern or north-western Bohemia, are complemented by large cities and their surroundings. Particularly, an increase of fatalities in Moravia and Silesia is remarkable.

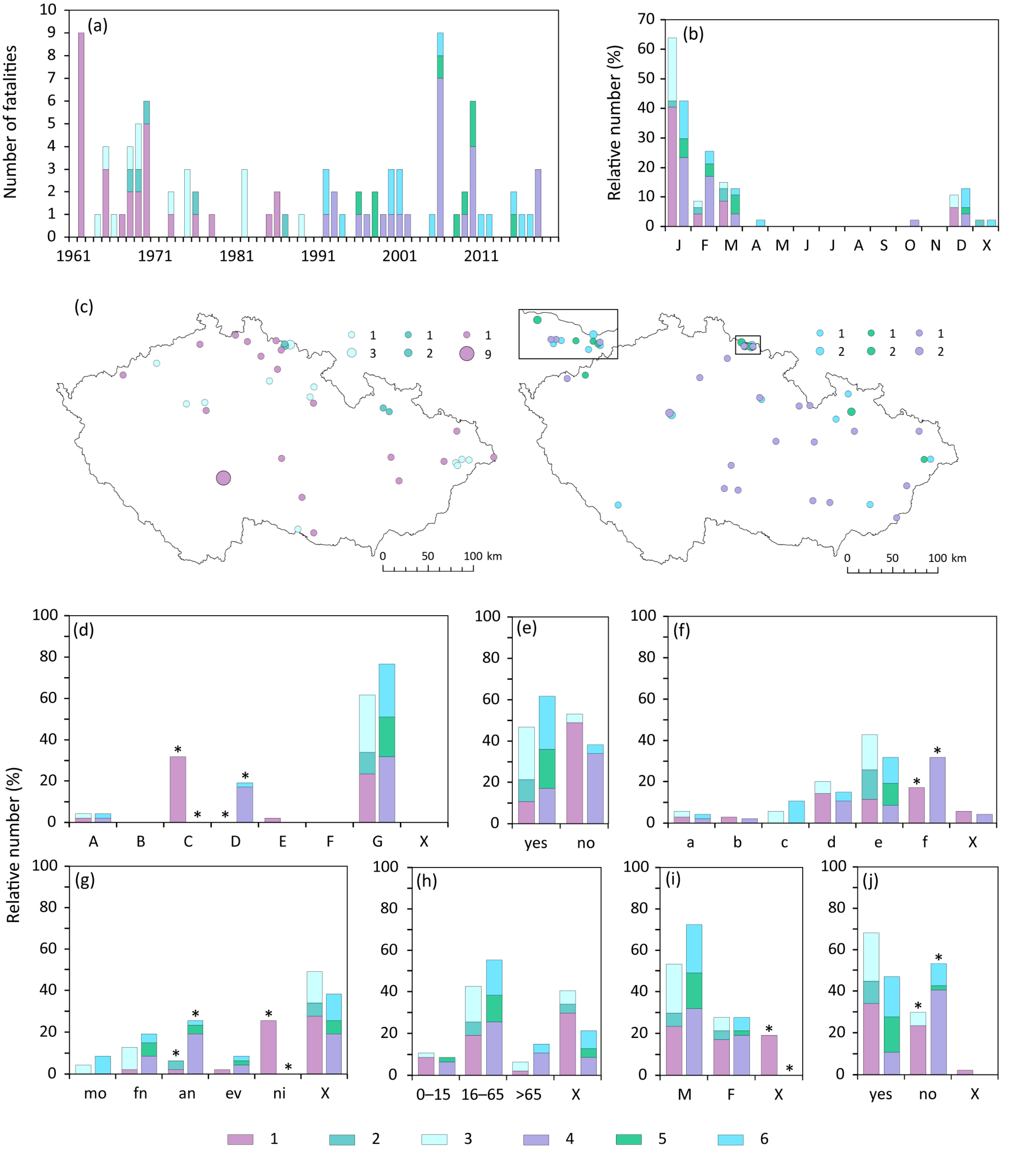

Figure 5. Characteristics of fatalities associated with snow and glaze ice in the Czech Republic during the 1961–1990 (1—snow, 2—avalanche, 3—glaze ice) and 1991–2020 (4—snow, 5—avalanche, 6—glaze ice) periods. (**a**) Fluctuations in 1961–2020; (**b**) annual variation; (**c**) spatial distribution (two fatalities in 1991–2020 lack exact location); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). For an explanation of symbols and abbreviations see Figure 2.

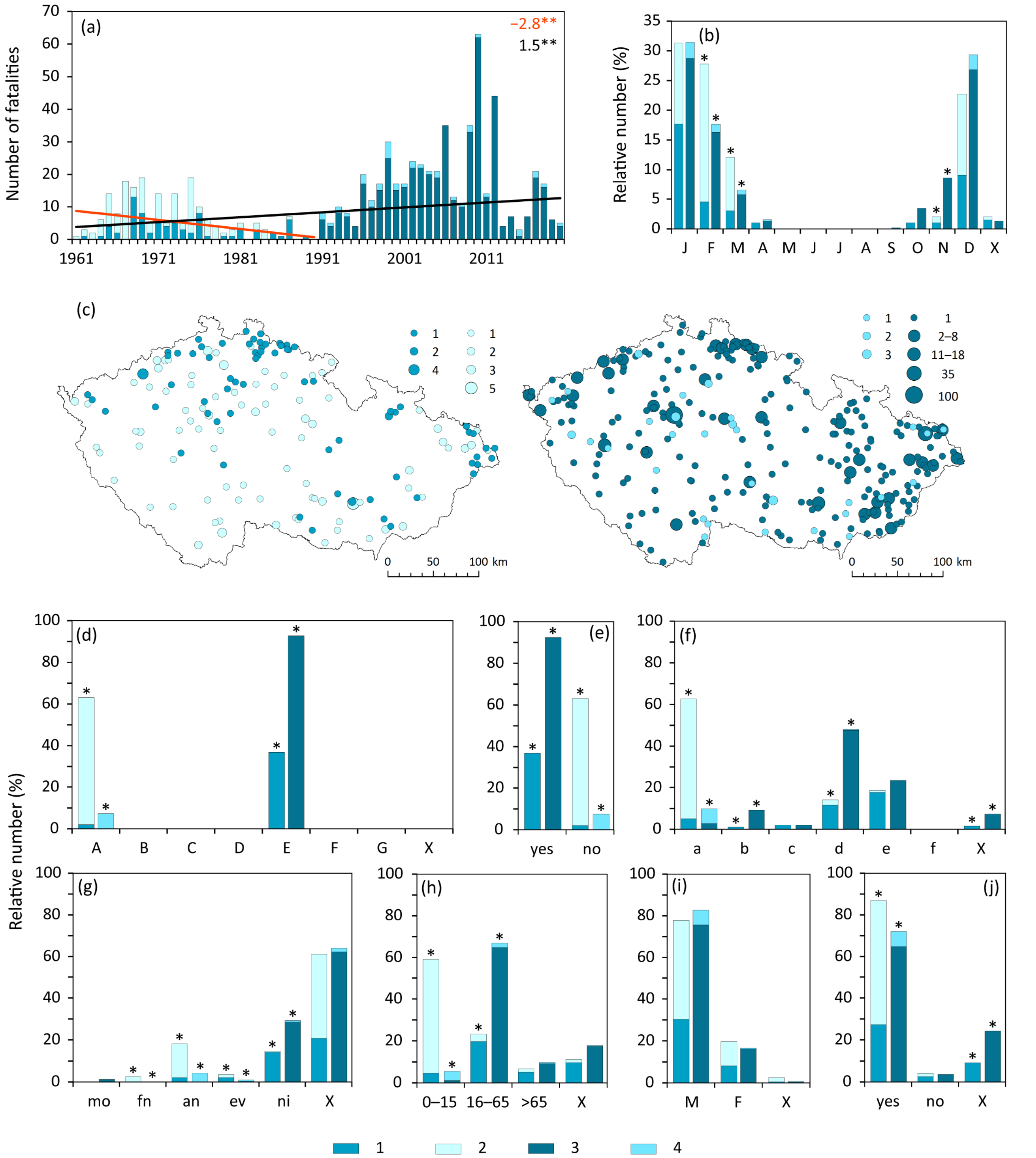

Figure 6. Characteristics of frost-related fatalities in the Czech Republic during the 1961–1990 (1—cold spell, 2—ice) and 1991–2020 (3—cold spell, 4—ice) periods. (**a**) Fluctuations with linear trends (top right in fatalities/10 years for 1961–1990 and 1961–2020, trends with ** are significant for $p < 0.05$); (**b**) annual variation; (**c**) spatial distribution (seven fatalities in 1961–1990 and nine fatalities in 1991–2020 lack exact location); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). For an explanation of symbols and abbreviations see Figure 2.

Concerning the reason for deaths (Figure 6d), a dramatic change in structure is shown: while in the first period 63.1% of fatalities died during drowning after the activity was undertaken in freezing bodies of water, in the second period 92.7% of related fatalities died of hypothermia during cold waves (differences are statistically significant). Statistically significant differences in corresponding fatality proportions also appear in other characteristics. They concern the proportions in direct/indirect fatalities (36.9/63.1% and 92.3/7.5%—Figure 6e), in the place of deaths (river/lake/reservoir/river bank by 62.6% and 9.8% and open spaces in built-up areas and the countryside together by 32.8% and 71.5%—Figure 6f), in children (59.1% and 5.6%) and adults (23.2% and 66.9%) (Figure 6h), and in hazardous behaviour (86.9% and 72.0%—Figure 6j). Males comprised around 80% of fatalities (77.8% and 82.8%—Figure 6i). Less representative is information about the time of day with respect to the high proportions of cases with an unknown time (61.1% and 64.0%—Figure 6g).

3.1.6. Fog

In the "fog" category, 124 fatalities in 1961–1990 and 17 fatalities in 1991–2020 were reported. They were often caused by plane accidents when pilots in dense fog in bad visibility lost their orientation and crashed into the terrain. On 30 October 1975 at 0920 CET, a Yugoslavian McDonnell Douglas DC-9 airplane, mostly transporting Czech tourists, crashed into the surface in a cottage colony above the River Vltava valley in Prague-Suchdol while preparing to land at the Prague-Ruzyně airport. The pilots did not include fog in their altitude profile of the flight. A total of 79 persons on the plane died (a further 41 injured) together with an older woman in the cottage colony [75,76]. Similarly, on 10 October 1962 around 1000 CET, an Il-14M airplane operated by Czechoslovak airlines flying from Košice (Slovakia) to Prague crashed into a hill (280 m a.s.l.), 6 km before the intermediate landing at Brno airport. The pilot in a dense fog did not keep the altitude and heading of the flight. A total of 13 persons died and 29 persons were seriously injured [77].

Cases of other documented plane accidents, usually with one to four casualties, were connected with personal transport ("aerotaxis"), commercial flights, military activities, or sport flying. Among them was an interesting case that occurred on 23 April 1992 in the Jizerské hory Mts. in northern Bohemia. Two French sport planes during a humanitarian flight from Germany to Opole (Poland) got lost in the fog and strayed from their original course to Bohemia. At 1732 CET both planes crashed into the northern slope of the Smědavská hora Mt. at an altitude of 1050 m, and in each plane the pilot and the navigator were killed [78–80]. Besides plane accidents with a total of 122 fatalities in both periods, 15 deaths were attributed to railway accidents (14 of them in 1961–1990). In two cases, tourists in the mountains lost their orientation in the dense fog and died after falling down the slope.

3.1.7. Further Severe Weather Categories

Fatalities not included in any of the six preceding categories are reported here under "further severe weather". Their numbers reached 15 deaths in 1961–1990 and 37 in 1991–2020. In the second period, fatalities appeared that were especially caused by extremely high temperatures or heat waves, which were connected mainly with fatal heart attacks. Such data started to appear in documentary sources from 1998, with a total of 22 such fatalities registered from which nine occurred in 2006. Because 20 of them were already analysed by Brázdil et al. [61], we only refer to that paper and do not repeat the corresponding results here.

Other fatalities in this category were represented by the effects of downpours or long rainy periods (five fatalities), followed by landslides and non-specified inclement weather (four fatalities each) in 1961–1990, while in the next 30 years, besides 22 heat-wave-related fatalities, ten people died in non-specified severe weather and three in landslides.

3.1.8. Synthesis of Severe Weather Fatalities

Totaling all fatalities associated with severe weather in the CR from Section 3.1.1, Section 3.1.2, Section 3.1.3, Section 3.1.4, Section 3.1.5, Section 3.1.6 to Section 3.1.7 together, 657 fatalities were recorded in 1961–1990 and 962 fatalities in 1991–2020 (Table 1), representing 40.6% and 59.4%, respectively, from the total of 1619 fatalities associated with severe weather in 1961–2020. While in the second period fatalities attributed to frost (54.3%) and floods (22.6%) represented more than three-quarters of all fatalities, frost-related fatalities were also the most frequent in the first 30 years, but with less than one-third of all fatalities (30.1%), being followed by the flood (19.8%), fog (18.9%), and convective storms (15.5%) categories (Table 1). Differences in proportions of fatalities related to convective storms, frost, and fog between two 30-year periods were statistically significant ($p < 0.05$). Some catastrophic deadly events (Table A1) caused the highest annual numbers, with 70 fatalities in 1970 (flash flood), 105 in 1975 (plane crash in fog), 86 in 1997 (flood) and 95 in 2010 (floods, frost) (Figure 7a). A statistically significant decreasing linear trend of −11.2 fatality/10 years ($p < 0.05$) was detected for 1961–1990, while a decreasing trend for 1991–2020 and an increasing trend for the whole 60-year period was non-significant.

Table 1. (a) Numbers of weather-related fatalities (1—flood, 2—windstorm, 3—convective storm, 4—snow and glaze ice, 5—frost, 6—fog, 7—other severe weather), and (b) their proportions to all related fatalities (%) in the Czech Republic in the 1961–1990, 1991–2020 and 1961–2020 periods.

Period	Char.	Weather Category							Total
		1	2	3	4	5	6	7	
1961–1990	(a)	130	41	102	47	198	124	15	657
	(b)	19.8	6.2	15.5	7.2	30.1	18.9	2.3	100.0
1991–2020	(a)	217	60	62	47	522	17	37	962
	(b)	22.6	6.2	6.4	4.9	54.3	1.8	3.8	100.0
1961–2020	(a)	347	101	164	94	720	141	52	1619
	(b)	21.4	6.3	10.1	5.8	44.5	8.7	3.2	100.0

The annual distribution of fatalities (Figure 7b) was maximal during the winter (49.8%, with the maximum in January 20.6%) in 1991–2020, while in 1961–1990 the corresponding proportion of winter months had only 33.4% of all fatalities, when the January value of 15.1% was slightly lower than that of October at 15.8%. Further maxima in the summer months occurred in July (11.1%) during 1991–2020 and in June (13.5%) during 1961–1990. In the spatial distribution of fatalities (Figure 7c), their substantially higher number in 1991–2020 compared to 1961–1991 is reflected in dense spatial coverage as well as in the accentuation of core regions, such as around large cities and in some mountain regions.

Concerning further fatality characteristics, differences in proportions between both analysed periods were statistically significant in nearly all cases. This was already valid for the differences appearing in the proportions of "cause of death" (Figure 7d): 34.9% drowning and 22.8% transport accidents in 1961–1990, and 50.3% freezing to death/hypothermia and 23.0% drowning in the following 30 years. Proportions of "direct" fatalities were not too different from "indirect" in 1961–1990 (51.8% to 47.9%), while in 1991–2020 "direct" fatalities dominated (84.9% to 15.0%) (Figure 5e). As for the place of death, comparable proportions of fatalities died in open countryside (32.6%) and on rivers/lakes/reservoirs/riverbanks (32.0%) in the first 30 years, while open spaces in built-up areas (34.7%), open countryside (22.0%) and rivers/lakes/reservoirs/river banks (20.9%) were the most frequent in the second 30 years (Figure 7f). The distribution of fatalities during the day (Figure 7g) is biased by high proportions of unknown cases (46.9% and 54.0%). Significantly lower proportions of fatalities in the "adult" category appear in 1961–1990 compared to 1991–2020 (35.2% and 64.6%), which can also be related to higher proportions of unknown age of fatalities (32.7% and 16.7%). On the other hand, the proportion of child deaths was significantly higher (27.4% and 6.2%) (Figure 7h). According to gender, the "male" category clearly predominated (59.2% and 79.0%, the difference being statistically significant—Figure 7i). Proportions of hazardous behaviour by fatalities (48.9% and 56.3%) were higher than non-hazardous (42.8% and 24.5%) with statistically significant differences (Figure 7j).

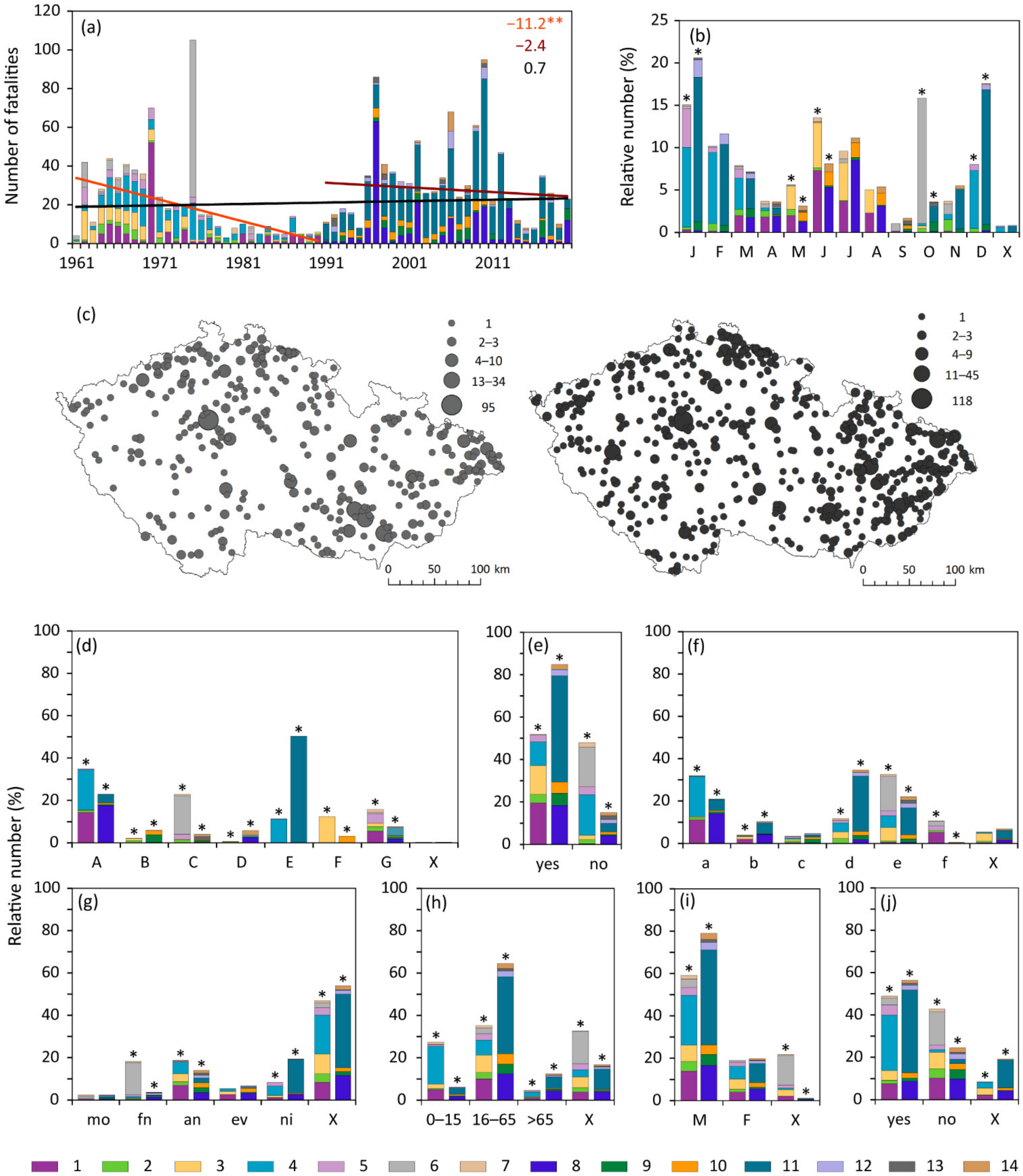

Figure 7. Characteristics of weather-related fatalities (1, 8—flood, 2, 9—windstorm, 3, 10—convective storm, 4, 11—snow and glaze ice, 5, 12—frost, 6, 13—fog, 7, 14—other severe weather) in the Czech Republic during the 1961–1990 and 1991–2020 periods. (**a**) Fluctuations with linear trends (top right in fatalities/10 years for both 30 years and 1961–2020, trends with ** are significant for $p < 0.05$); (**b**) annual variation; (**c**) spatial distribution (36 fatalities in 1961–1990 and 18 fatalities in 1991–2020 lack exact location); (**d**) cause of death; (**e**) type of fatality (direct); (**f**) place of death; (**g**) time of day; (**h**) age; (**i**) gender; (**j**) behaviour (hazardous). For an explanation of symbols and abbreviations see Figure 2.

3.2. Vehicle Accident Fatalities Associated with Inclement Weather

The created database also contains data about fatal vehicle accidents caused or affected by inclement weather conditions. Comparable numbers of fatalities were identified in both 30-year periods: 899 fatalities in 1961–1990 and 935 fatalities in 1991–2020 (Table 2). The absolute maxima were 58 fatalities in 2007, 56 fatalities in 1976, and 55 fatalities in 2001; more than 50 fatalities were also recorded in 1999 and 2005 (Figure 8a). Fatalities during rain and wet roads were the most frequent in both periods (30.7% and 38.4%, respectively), but the proportions of fatalities in 1961–1990 were higher than in 1991–2020 during snow/snowfall (28.1% and 21.5%) and fog (14.5% and 4.8%); the opposite situation occurred with fatalities during glaze ice (26.6% and 33.8%) (Table 2). For all categories, differences in the relative proportions of corresponding pairs between both 30-year periods were evaluated as statistically significant ($p < 0.05$). The two 30-year periods show non-significant trends (positive and negative, respectively) (Figure 8a). As for individual categories, statistically significant trends were detected only for "snow (snowfall)" in 1961–1990 (3.3 fatality/10 years) and for "fog" in 1991–2020 and 1961–2020 (−0.4 and −0.7 fatality/10 years respectively) (not shown).

Table 2. (a) Numbers of vehicle accident fatalities associated with inclement weather (1—rain and wet roads, 2—snow (snowfall), 3—glaze ice, 4—fog, 5—other inclement weather), and (b) their proportions to all related fatalities (%) in the Czech Republic in the 1961–1990, 1991–2020 and 1961–2020 periods.

Period	Char.	Weather Conditions					Total
		1	2	3	4	5	
1961–1990	(a)	276	253	239	130	1	899
	(b)	30.7	28.1	26.6	14.5	0.1	100.0
1991–2020	(a)	359	201	316	45	14	935
	(b)	38.4	21.5	33.8	4.8	1.5	100.0
1961–2020	(a)	635	454	555	175	15	1834
	(b)	34.6	24.8	30.3	9.5	0.8	100.0

In annual variations (Figure 8b), fatalities were attributed, in particular, to January and December (18.7% and 18.1% in 1961–1990, 17.0% and 18.1% in 1991–2020); a proportion of fatalities above 12% was also recorded in November and February. As expected, the spatial distribution of fatalities follows the road network of the CR (Figure 8c). However, an obvious concentration of fatalities is noticed on the main highway connection between Prague and Brno in the second period.

A great majority of fatalities died in vehicle accidents (small proportions, 1.1% and 0.4%, represent cases when after an accident the vehicle fell into a river and people drowned) and were classified as "indirect" victims. For place of death (Figure 8d), roads dominated (86.9% and 90.5%—the difference being statistically significant), being followed by open spaces in built-up areas (10.7% and 8.6%). The proportion of fatalities during the day is the highest in the morning (10.3% and 25.5%), but for more than two-thirds of fatalities (67.5%) in 1961–1990 the time of the accident was not reported (Figure 8e); the differences between two 30-years periods are all statistically significant. Adults represent the most frequent fatality category according to age (57.1% and 62.4%—the difference is statistically significant, but with a high proportion of unknown ages—Figure 8f), similar to males according to gender (65.4% and 63.9%—Figure 8g). The behaviour of the dominant number of fatalities was classified as "hazardous" (99.1% and 97.5%, the difference is statistically significant—not shown).

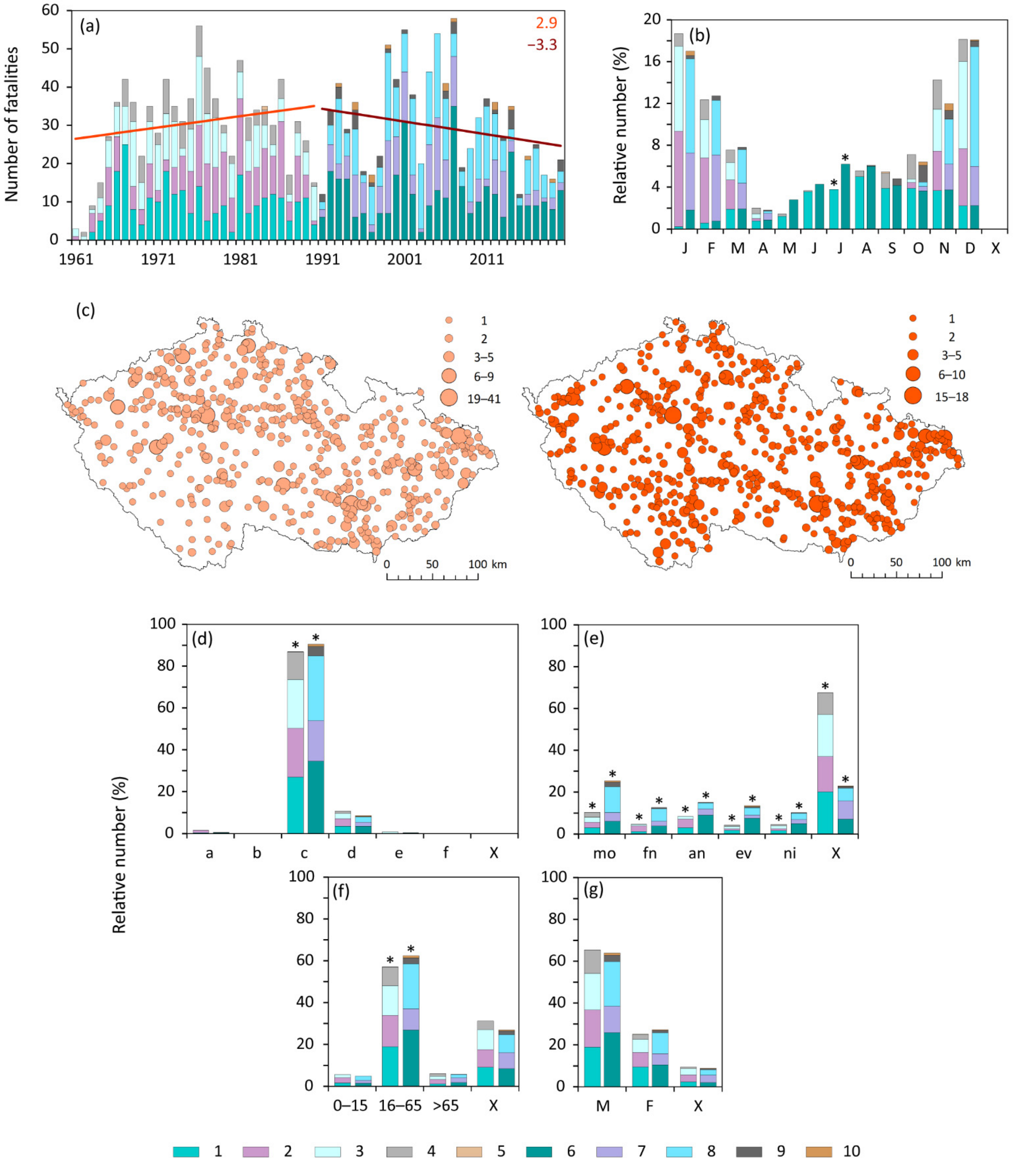

Figure 8. Characteristics of vehicle accident fatalities associated with inclement weather (1, 6—rain and wet road, 2, 7—snow (snowfall), 3, 8—glaze ice, 4, 9—fog, 5, 10—other inclement weather) in the Czech Republic during the 1961–1990 and 1991–2020 periods. (**a**) Fluctuations with linear trends (top right in fatalities/10 years for both 30-year periods); (**b**) annual variation; (**c**) spatial distribution (27 fatalities in each of 30-year periods lack exact location); (**d**) place of death; (**e**) time of day; (**f**) age; (**g**) gender. For an explanation of symbols and abbreviations see Figure 2.

3.3. Climatic Factors and Related Fatalities

Each fatality event is a result of different simultaneously affecting factors of which the weather is one, while in the long-term development of the number of fatalities climate variability can be inferred. Figure 9 shows fluctuations and statistically significant linear trends in mean annual series of selected climate variables in the CR during the 1961–2020 period, which are further used in Figures 10 and 11. Despite a relative great interannual variability, the series of mean annual numbers of days with wind gusts ≥20 m s^{-1}, thunderstorms and TMIN ≤ −10.0 °C showed statistically significant ($p < 0.05$) decreasing trends in the both 1991–2020 and 1961–2020 periods, while for days with snow cover depths ≥ 15 cm and with snowfall it was valid only for 1961–2020 (Figure 9). None of climatic series presented showed any statistically significant trends during 1961–1990.

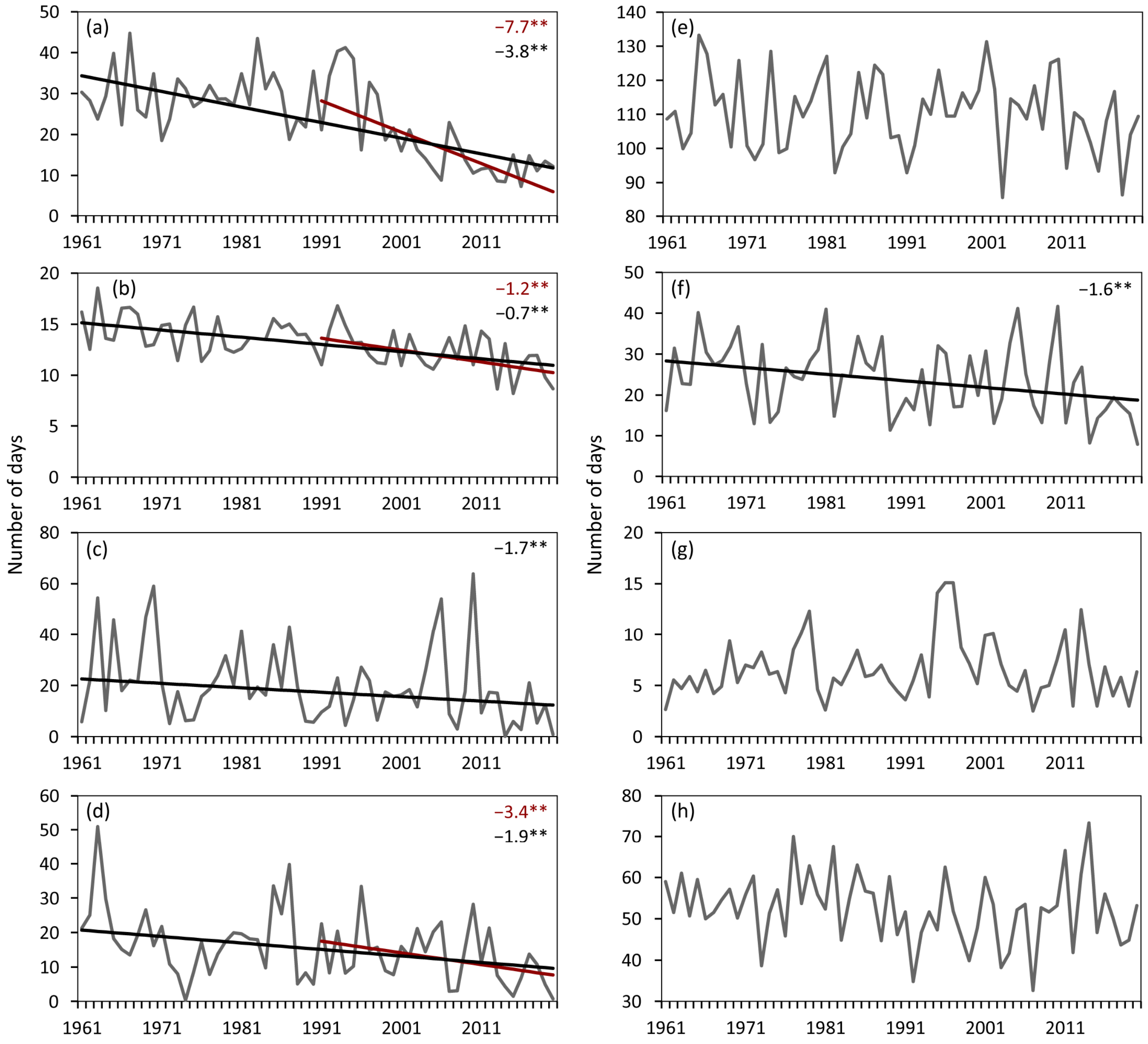

Figure 9. Fluctuations in mean annual numbers of days with selected climate variables in the Czech Republic and their statistically significant linear trends (top right in days/10 years; ** statistically significant for $p < 0.05$) in the 1991–2020 and 1961–2020 periods. (**a**) Days with wind gusts ≥ 20 m s^{-1}; (**b**) days with thunderstorm; (**c**) days with snow cover depth ≥15 cm; (**d**) days with TMIN ≤ −10.0 °C; (**e**) precipitation days with daily total ≥ 1.0 mm; (**f**) days with snowfall; (**g**) days with glaze ice; (**h**) days with fog.

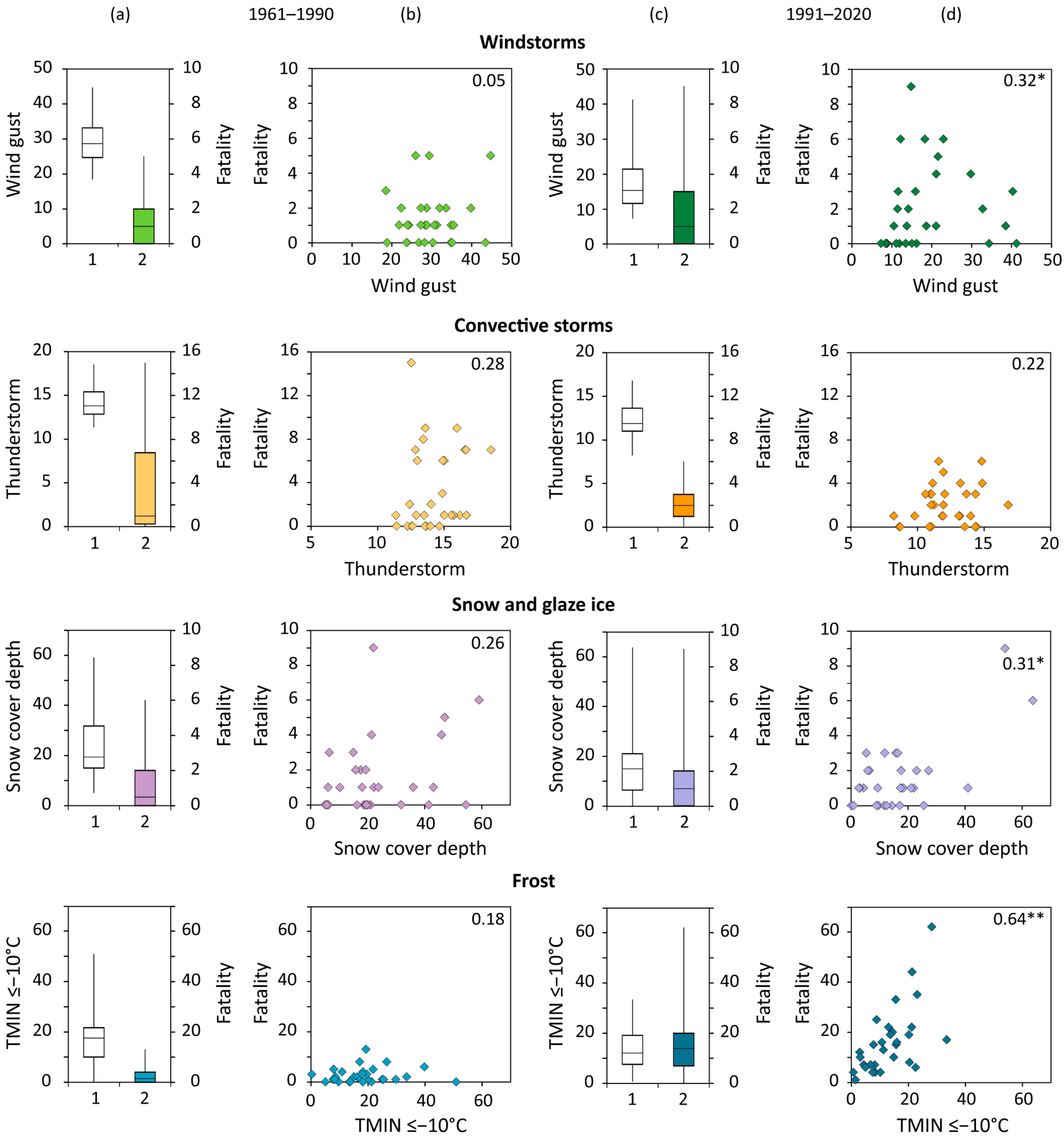

Figure 10. Comparison of selected climate variables (days with wind gust ≥ 20 m s^{-1}, thunderstorm, snow cover depth ≥ 15 cm, TMIN ≤ −10.0 °C) with weather-related fatalities (windstorms, convective storms, snow and glaze ice, frost) in the Czech Republic during the 1961–1990 (**a**,**b**) and 1991–2020 (**c**,**d**) periods, expressed as box plots (median, upper and lower quartile, maximum and minimum; 1—climate variable, 2—fatalities) (**a**,**c**) and scatter-plots between corresponding pairs (**b**,**d**). Values of Spearman correlation coefficients are in the top right (* significant for $p < 0.10$, ** for $p < 0.05$).

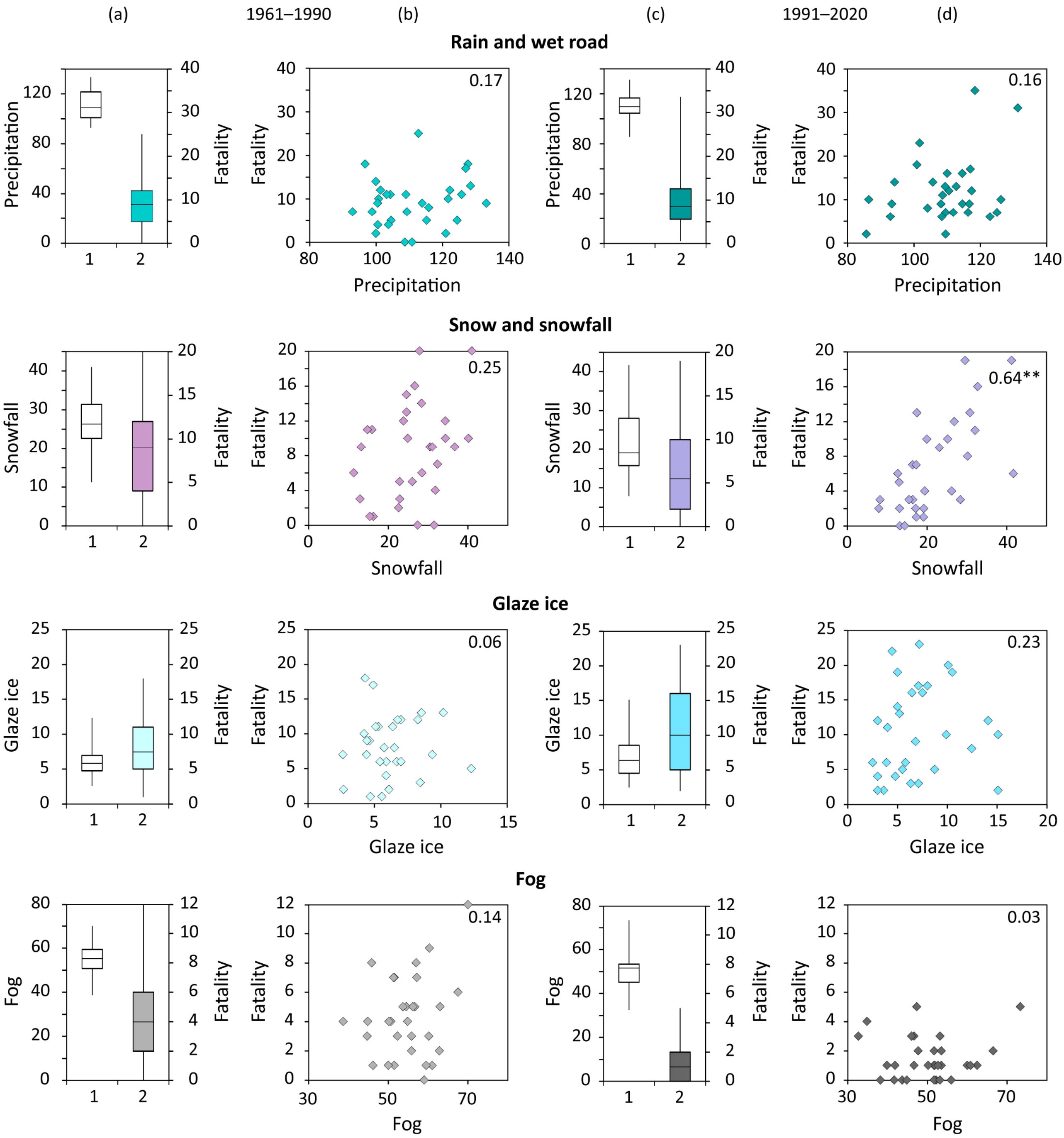

Figure 11. Comparison of selected climate variables (precipitation days with daily total ≥ 1.0 mm, days with snowfall, glaze ice and fog) with related vehicle fatalities (categories rain and wet road, snow and snowfall, glaze ice, fog) in the Czech Republic during the 1961–1990 (**a**,**b**) and 1991–2020 (**c**,**d**) periods, expressed as box plots (median, upper and lower quartile, maximum and minimum; 1—climate variable, 2—fatalities) (**a**,**c**) and scatter-plots between corresponding pairs (**b**,**d**). Values of Spearman correlation coefficients are in the top right (** significant for $p < 0.05$).

In order to find possible relationships to climate variability, the fatality series were compared with a series of selected climate variables using their box plot expression and scatter-plots in both 30-year periods. While box plots of climate variables do not show significant differences in the two periods analysed (rather their shift to lower values in 1991–2020), box plots of related fatalities show higher variability in 1961–1990 for convective storms and lower variability for the categories "windstorms" and "frost" (Figure 10a,c). As these box plots also demonstrate quite a large asymmetry in the fatality distribution (e.g., for windstorms) or the occurrence of outliers (snow and glaze ice), their relationships to climate variables were quantified with non-parametric rank correlation. Non-significant Spearman correlation coefficients between fatalities and climate variables appear in 1961–1990 (Figure 10b) except for the comparison of fatalities in the category "snow/glaze ice" with the number of days with snowfall for the 1961–1990 period (0.33, $p < 0.10$, not shown). On the other hand, in the 1991–2020 period, significant correlations were found in the "frost" category (0.64, $p < 0.05$) and also in those of "windstorm" and "snow/glaze ice" (0.32 and 0.31 respectively, $p < 0.10$) (Figure 10d). Some signal was also detected when comparing "snow/glaze ice" fatalities with the number of days with snow cover depth: correlations were statistically significant for the depth $\geq$ 1 cm in 1961–1990 (0.32, $p < 0.10$) and for the depth $\geq$5 cm and $\geq$15 cm in 1991–2020 with the significant correlations 0.31 ($p < 0.10$) in both cases. As for fatalities in the category "frost" (after removing those caused by drowning when the ice broke on frozen water bodies), they exhibit the highest correlations with the number of days with TMIN ≤ -10.0 °C: statistically significant in 1991–2020 (0.64, $p < 0.05$), but non-significant in 1961–1990 (Figure 10b,d). A similar situation also occurred when comparing the number of days with TMIN ≤ -5.0 °C, but the significant correlation coefficient was slightly lower (0.53, $p < 0.05$).

In the case of fatalities related to vehicle accidents during inclement weather, differences in the box plots of climate variables between the two 30-year periods are not significant, with some higher interquartile ranges for the categories "snow and snowfall" and "glaze ice" in 1991–2020 (Figure 11a,c). This range increased especially for fatalities related to "glaze ice" in 1991–2020 and those related to "fog" in 1961–1990. Non-significant correlations appear in both 30-year periods for three of four groups: fatalities during "rain and wet road" and the numbers of precipitation days with a daily total $\geq$ 1.0 mm, fatalities during "glaze ice" and the number of days with glaze ice, and fatalities during "fog" and the number of days with fog (Figure 11b,d). Only correlations between fatalities during "snow (snowfall)" and the number of days with snowfall were statistically significant in 1991–2020 (0.64, $p < 0.05$), but non-significant in 1961–1990 (0.25).

4. Discussion

4.1. Data Uncertainty

Weather-related fatalities are frequently reported in newspapers, which is reflected in their use to create corresponding fatality databases for follow-up analyses (e.g., [15,18,34,81–83]). Although the particular newspaper could have been published during the long period analysed (as *Rudé právo/Právo* in our case for the whole 60 years), different circumstances such as political and societal changes, changes in the media market or internal changes in the newspaper may create a complex range of influences such as space devoted to certain kinds of information, the perceived interest of target readers, the political orientation of the newspaper, the reduction of regional editorial staff, different quantities of space given to regional and countrywide reporting, advertising space, competition in reporting, reader fatigue, availability of regional/local news taken from other bodies (e.g., police, press agencies, state and regional administration), etc. Despite complementing our database from other newspapers and sources, it represents rather lower estimates of weather-related fatalities as well as vehicle accident fatalities during inclement weather, characterised by some spatial and temporal non-homogeneity, which is typical when working with documentary evidence [60,61].

In the case of weather-related fatalities, some data seem to be lacking, especially *c.* 1961–1963 and 1978–1991 (Figure 7). Less information about fatal events in the early 1960s is clearly related to less newspaper attention to such fatal events, similar to 1990–1991 after the Velvet Revolution (1989) in the CR with the main focus having been on political, economic, and societal changes in the country. The open question is how much the lower numbers of weather-related fatalities in the late 1970s–1980s should be attributed to less weather severity, because despite the clear decline in the number of total vehicle fatalities in the CR in the 1980s, fatal vehicle accidents during inclement weather do not appear for that time (Figure 8) [62]. Similarly, the numbers of weather/climate-related fatalities in Europe in the 1980s remained lower than fatalities in the subsequent decades, despite being higher than in the 1970s [1].

On the other hand, these potential database drawbacks can be partly addressed by the unique database character, allowing one to analyse many additional features of fatalities besides their inter-annual fluctuations, annual distributions, or spatial patterns. Other "official" Czech fatality sources used in the preceding papers (e.g., Czech Statistical Office (CSO) database or police yearbooks—see [61,62]) suffer by shorter series and by containing only part (the CSO database without clearly distinguishing individual weather categories) or have no additional fatality information provided in our database (police yearbooks).

4.2. Severe Weather Fatalities

As reported in Section 3.1.8, the number of fatalities attributed to severe weather increased in 1991–2020 compared to 1961–1990 by nearly half of all cases (46.4%). The highest increases occurred in the "frost" (163.6%) and "flood" (66.9%) categories, while the opposite occurred in "convective storms" with a decrease in fatalities of 39.2%.

In the case of frost-related fatalities (Figure 6), a much higher proportion and number of deaths by drowning on broken ice occurred in 1961–1990 compared to the next 30 years (121 to 39 fatalities). This especially affected the children category, which demonstrates that children spend more time in nature ice skating, but also sliding on ice or crossing frozen water bodies, very often without any careful supervision by their parents. According to Sharma et al. [84], who investigated over 4000 winter drowning events on frozen bodies of water in ten countries in the northern hemisphere in the 1991–2017 period, children and adults aged up to 39 years were at the highest risk. Contrary to significant warming trends in winters over the CR territory during 1961–2020 [85,86], we recorded a dramatic increase in deaths by freezing or hypothermia, increasing from 77 fatalities in 1961–1990 to 483 in 1991–2020. This increase is explained by an enormous increase in the homeless population after 1990, particularly in the larger cities; until that time such people were very rare. Many homeless people do not have the opportunity to spend the night indoors during cold waves and die in the open air or in provisional shelters by hypothermia, often after the consumption of excessive alcohol.

Concerning flood-related fatalities (Figure 2), their increase in 1991–2020 compared to 1961–1990 (from 65 to 159 fatalities) was caused by the frequent occurrence of disastrous rainy floods as reported in Section 3.1.1. This corresponds to Brázdil et al. [87], who recognised a notable flood period during 1997–2010 and a relative respite from floods between 1966 and 1992 (except 1981), analysing the most important floods (peak discharge $\geq$ 20-year return period) in the CR during the 1900–2000 period. These occurred in at least one of twenty-eight representative profiles (stations) for river catchments over 2000 km^2. Petrucci et al. [12] also reported an increasing trend in flood fatalities in Greece, Italy, and southern France for 1980–2018. Moreover, Blöschl et al. [88] identified the 1990–2016 period among the most flood-rich periods in western and central Europe within the past 500 years. Although Franzke and Torelló i Sentelles [89] found significantly increasing flood fatalities for worldwide aggregated data (1960–2019), for Europe they detected a significant downward trend. Concerning the Czech flash flood fatalities, if we remove 34 such fatalities from the event of 9 June 1970 (Table A1), their number grew from 31 in the first 30 years to 58 in the second 30-year period. While papers presenting any flash flood series for the CR are very limited (e.g., [90]), the statistically non-significant linear trends in the annual numbers of days with daily precipitation totals over thresholds 30.0, 50.0, 70.0, 100.0 and 150.0 mm for the 1961–2019 period [91] do not support a detected increase in flash flood fatalities.

As for "convective storm" fatalities (Figure 4), the most dramatic decrease appeared for deaths by lightning strikes, responsible for 84 fatalities in 1961–1990 and only 23 in 1991–2020. Because of non-significant correlations with the number of days with thunderstorms (cf. Figure 10), this must be explained by socio-economic factors. Brázdil et al. [60] reported an especially higher number of people working in agriculture and forestry in the past than at present, being more frequently outdoors and exposed in the open landscape. Influential, also, have been the increased use of lightning conductors, vast improvements in medical services, an increase in the availability of immediate emergency help with rapid transport to hospitals, and a broader public awareness of how to behave during a thunderstorm. Similar to our study, Holle [28] reported a large reduction in lightning fatality rates in Western Europe and for other countries that changed from a mainly rural agricultural society to a primarily urban one. Badoux et al. [33] found a considerable decline in the number of lightning fatalities in Switzerland between the 1946–1975 and 1976–2015 periods. Antonescu and Cărbunaru [29] reported for Romania a decrease in the annual number of lightning fatalities from 65 fatalities/year in 1999–2003 to 23.2 fatalities/year in 2011–2015, with the highest risk being for males aged 10–39 years in rural areas. However, Singh and Singh [92] reported an increase in lightning fatalities in India between 1979 and 2006 and a subsequent decrease from 2007 to 2011. Among them, males comprised 89% of victims (compared to females with 5% and children with 6%) clearly predominated, most likely as a consequence of much higher numbers of males working and moving outdoors.

Concerning the other weather categories, snow and glaze ice fatalities had the same numbers in both 30-year periods (Section 3.1.4), while for windstorm fatalities the number grew from 41 in 1961–1990 to 60 in 1991–2020 with a statistically significant increase in deaths caused by "tree/branch fall" (Figure 3). An increase in windstorm fatalities between the two 30-years is contrary to a decrease in the number of days with wind gusts $\geq$20 m s^{-1} (Figure 10). A clear dominance of the 1961–1990 period appears in the number of fog-related fatalities (Section 3.1.6) because their numbers were more than seven times higher than in 1991–2020; this is a result of several fatal plane and train accidents before 1990, which after that year became less frequent (Table A1).

Because the weather is only one of the factors contributing to fatal events, and climate variability represents some general frame of its variability, it is difficult to determine close relationships between weather-related fatalities and climate variables on the annual scale, usually reflected in non-significant correlation coefficients. A statistically significant relationship appeared only for "snow and glaze ice" fatalities, correlated with the number of days with snow cover depths $\geq$15 cm, and "frost" fatalities correlated with the number of days with TMIN below -5 °C or -10 °C during the 1991–2020 period (Figure 10). This was a period of milder winters than in the previous 30 years.

One reflection of the historical political changes in the CR is the increase of weather-related fatalities from foreign visitors from 13 in 1961–1990 to 68 in 1991–2020, resulting from increased international contacts and better conditions for travelling, particularly for business or holiday. They were represented mainly by fatalities from neighbouring countries such as Germany (28.4%), Slovakia (18.5%), and Poland (12.3%). Besides the not-stated country of foreigners (12.3%), the rest of the corresponding fatalities covered 12 countries.

4.3. Vehicle Accident Fatalities

The lower annual numbers of vehicle accident fatalities during inclement weather in 1961–1990 compared to 1991–2020 are related to highly underestimated values in 1961–1963 (Figure 8). Comparing the numbers of fatalities in absolute values, more frequent in 1961–1990 were the categories of "snow (snowfall)" (253 to 201 fatalities) and "fog" (130 to 45 fatalities), while in 1991–2020 higher fatality numbers were achieved for "rain and wet road" (359 to 276 fatalities) and "glaze ice" (316 to 239 fatalities). Although proportions of individual categories between both periods differed in statistical significance, the proportions of fatalities in the categories "snow (snowfall)" and "glaze ice" could especially be influenced by distinguishing vehicle accidents between snow and glaze ice because snow on a road can quickly change into a slippery beaten layer reported in newspapers as an "icy road", and the corresponding fatality with snow on the road is then attributed to the category of "glaze ice" instead of "snow (snowfall)".

A comparison of vehicle accident fatalities with related climate variables showed statistically significant correlations only between the "snow (snowfall)" fatalities and the annual numbers of days with snowfall (Figure 11). This fact can be related to underestimated values in our database because Brázdil et al. [62], using data from the CR police yearbooks for 1979–2020, found statistically significant correlation coefficients for all-weather categories comparing "rain" fatalities with the number of days with rain (0.57), "snow" fatalities with the number of days with snowfall (0.76), "glaze ice and rime" fatalities with the number of days with glaze ice (0.62), and "fog" fatalities with the number of days with fog (0.33). This corresponds to Tobin et al. [93], who reported a significantly higher risk of casualties in freezing rain and snow than in rain in an analysis of the influence of precipitation type on relative crash risk estimates for Kansas (USA) in 1995–2014.

The numbers of vehicle-related fatalities during inclement weather in the CR showed the opposite non-significant trends in both 30-year periods (Figure 8). A downward trend in 1991–2020 was already confirmed in some preceding Czech studies [61,62], but it also appears in other countries. For example, Andrey et al. [94] disclosed a downward trend in the relative risk of casualties during rainfall for 1984–2002 based on data of weather-associated crash risk in automobile transport for ten Canadian cities, but no significant change concerned cases during snowfall. Han and Sharif [47] found a decrease in rain-related fatal crashes for Texas (USA) in 1994–2018.

Vehicle accident fatalities during inclement weather in the CR have to be evaluated in the broader context of changes during the whole 60-year period. As follows from Figure 12a, the annual numbers of vehicle accidents fatalities show two waves, with the first maximum in the late 1960s–early 1970s and with the second one in the 1990s, while minima occurred in the 1980s and 2010s. This generally corresponds to the numbers of fatalities during inclement weather according to police data since 1979 (Figure 12b), with annual proportions of inclement weather fatalities reaching 10–30% of their total numbers [62]. Although a similar two waves as in total fatalities can be found in our vehicle accidents fatalities related to inclement weather (Figure 8a), their annual proportions remained far behind the previous values, fluctuating mainly between 1–5% with the maximum proportion of 5.6% occurring in 2014. This shows that our data are considerably undervalued compared to official police data.

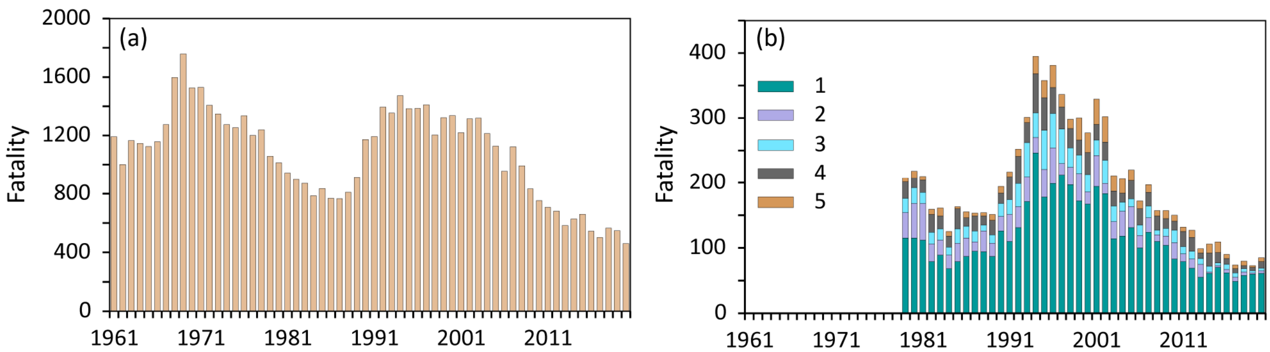

Figure 12. Annual numbers of all vehicle accident fatalities in the 1961–2020 period (**a**) and those related to inclement weather in the 1979–2020 period (**b**) in the Czech Republic according to police data [95,96]: 1—rain, 2—snow, 3—glaze ice, 4—fog, 5—other inclement weather.

Although there are no doubts about the effects of severe weather conditions on vehicle accidents and their fatalities and injuries (e.g., [38,39]), many other factors are also reflected, which may explain corresponding fluctuations and trends. For example, Zou et al. [40] demonstrated the importance of non-climatic variables (i.e., beer consumption, the proportion of rural vehicle miles travelled, and vehicle performance), as well as climatic conditions (temperature, precipitation), in fatal traffic accidents in California and Arizona

(USA). Concerning the CR, political, economic, and societal changes after 1989 created new conditions for the extension of vehicle ownership and consequent increases in traffic density. For example, between 1990 and 2000 alone, the number of cars grew from 2.41 million to 3.44 million. Many more cars, including more powerful ones, and loosely policed traffic offences in the road network of the time contributed to a significant increase in traffic accidents and fatalities in the 1990s [97]. Despite the continuous growth of the number of cars (6.05 million in 2020) and small changes in the length of the road network (55,500 km in 1995 and 55,792 km in 2020), a substantial decrease in the number of fatalities appears from the 1990s (Figure 12a), similar to other European countries [98]. This decreasing tendency can be associated, among other factors, with the development of safer cars, better roads and their maintenance, weather forecasting, general media warnings before dangerous weather, the raising of public awareness regarding road safety, and improved emergency services and health systems [62].

5. Conclusions

An analysis of fatalities related to severe weather over the territory of the CR in the 1961–2020 period allows the formulation of the following conclusions:

(i) Based on documentary sources, particularly newspapers, a unique database of fatalities related to severe weather and vehicle accidents during inclement weather over the territory of the CR for the 1961–2020 period was created. Despite the database representing the lower estimate of all weather-related fatalities, it allows studying the spatio-temporal variability of fatalities and their special characteristics.

(ii) The annual numbers of weather-related fatalities between 1961–1990 and 1991–2020 increased in the flood, windstorm, and particularly frost (cold waves) categories, and decreased for convective storms and fog. There were also statistically significant changes in the internal structure of these fatality categories. The 30-year linear trends in individual fatality categories are prevailingly zero or non-significant.

(iii) Although the basic features of weather-related fatalities generally indicated the highest percentages for their occurrence in the winter months (the secondary maximum in the summer months), males, adults, direct deaths, deaths by freezing or hypothermia, and hazardous behaviour, relative proportions between both 30-years periods and individual fatality categories were often very different and in many cases statistically significant.

(iv) It is difficult to find, on the annual and whole-republic scales, a clear relationship between the numbers of weather-related fatalities and climate variables, despite substantial changes appearing in many of them due to global warming, being enhanced especially in 1991–2020. The correlation analysis only proved a statistically significant relationship for "snow and glaze ice" fatalities with the number of days with some snow cover depth and "frost" fatalities with the numbers of days with a minimum temperature below −5 °C or −10 °C. Enhanced flood activity of the past decades was reflected in a substantial increase of "flood" fatalities.

(v) The "rain", "snow (snowfall)", "glaze ice", and "fog" categories are the most important weather factors influencing the annual numbers of vehicle accident fatalities during inclement weather. However, their small proportion of all annual fatalities, achieving only 1–6%, signal highly undervalued data excerpted from newspapers and internet sources. Only "snow (snowfall)" fatalities are significantly correlated with the number of snowfall days, while for other fatality categories their correlations with corresponding climatic variables are non-significant.

(vi) Results of the analysis of fatalities related to severe weather or vehicle accidents during inclement weather reflect different climatological, political, economic, and societal changes. It is a great challenge for further research to go from annual and whole-republic scales to higher spatio-temporal resolutions, which may enhance the importance of this and similar studies for risk management, not only in the CR.

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Appendix A

Below are some examples from the fatality database (for the reported locations see Figure A1):

(i) *Lidová demokracie*, 12 July 1968, p. 5; *Rovnost*, 13 July 1968, p. 1; *Rudé právo*, 12 July 1968, p. 2; *Svobodné slovo*, 12 July 1968, p. 3 (source): On 11 July 1968 (date) around midday (time of day), 48-year-old (age) pilot Miloš Funk (name and gender) from Brno arrived with an AN-2 plane to the airport (place of death) at Kunovice (locality). He fixed the plane and remained there to be saved before the rain. A sharp whirlwind—tornado (event)—took a hangar away, tore off the plane from the ropes and brought it out of the hangar into the open. The plane turned over several times (cause of death) and the pilot died.

(ii) *Svobodné slovo*, 18 August 1978, p. 7 (source): On Wednesday 16 August 1978 (date) in the early evening (time of day), a torrent of water (event) at Velké Žernoseky (locality) lifted a car with a 36-year-old driver, carried it a 50-m distance on the road (place of death) and dropped it into a ditch. The driver and his wife with three children were in the car. Additionally, a 4-year-old (age) little girl (gender) was taken away by the torrent (cause of death) and died.

(iii) https://cs.wikipedia.org/wiki/Soubor:Kocaba-2007-05-19-PomnikJirihoKrysla.JPG (accessed on 20 December 2021) (source): Memorial plaque of Jiří Krýsl with the inscription: "First sergeant of the fire brigade Jiří Krýsl (* 28 December 1949, † 20 July 1981) died tragically here at an intervention during an anti-flooding action. Honour to his memory." Circumstances: After a four-day rain, on 20 July 1981 (date), the dam of Strž pond collapsed and caused a flood (event). Five firemen were in a lifeboat in the Kocába valley (place of death) at Velká Lečice (locality) which after a sudden and sharp hit of a water wave turned over (cause of death). Four men were saved, but 31-year-old (age) Jiří Krýsl (name, gender) died in the flood.

(iv) *Právo*, 1 July 1994, p. 3 (source): In the afternoon (time of day) of 29 June 1994 (date), two 16-year (age) students (gender) playing basketball on the playing field at Tuhnice in Karlovy Vary (locality) hid before a thunderstorm (event) under a tree (place of death), which was struck by lightning (cause of death). One of the students fell dead into the brook, the second in shock crawled up to Poštovní Street and was transported to the hospital.

(v) *Právo*, 27 March 2006, p. 6 (source): Half-past-two p.m. (time of day) on 25 March 2006 (date) at Vilémov (locality), a layer of snow (cause of death) from a lean-to of the house (place of death) fell on a seven-year-old (age) boy (gender). He died after being transported to the hospital.

(vi) https://www.idnes.cz/liberec/zpravy/jablonec-nad-nisou-autobusove-nadrazi-garaz-mrtvy-muz-svazane-nohy-podchlazeni-bezdomovec.A180130_174216_liberec-zpravy_fer, (accessed on 20 December 2021) (source): A 46-year-old (age) homeless person (gender), who was found dead on Monday 29 January 2018 (date) at a garage (place of death) near the bus terminal in the centre of Jablonec nad Nisou (locality). He died of exposure (cause of death) (confirmed by post-mortem examination).

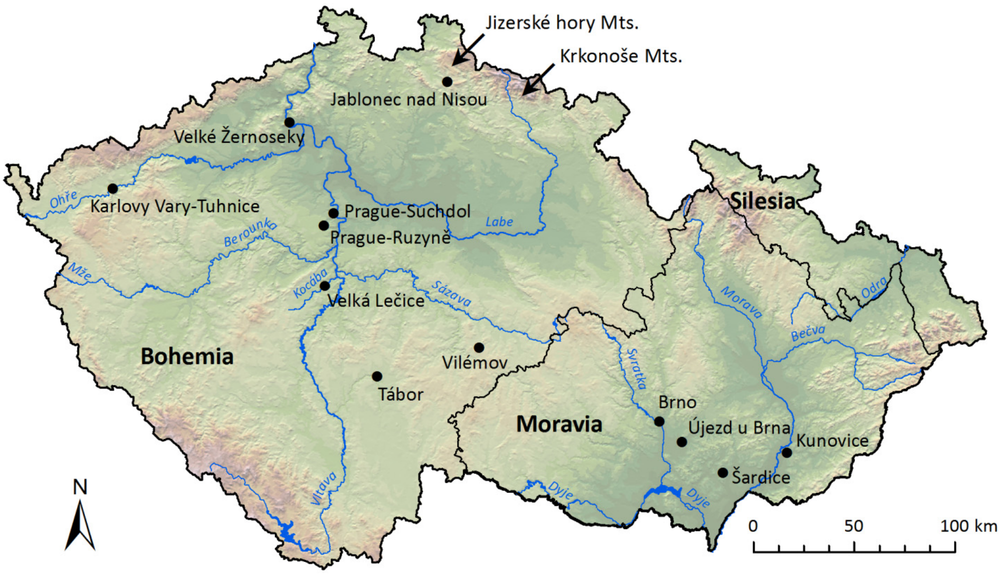

Figure A1. Location of places, mountains, and rivers in the Czech Republic reported in this study.

Figure A2. Memorial plaque of Jiří Krýsl who died on 20 July 1981 in the valley at Velká Lečice during a response to flooding (Photo Miloš Hlávka, available under CC BY-SA 3.0 at [99]).

Appendix B

Table A1 below provides an overview of events with the highest numbers of fatalities derived from our fatality database related to the CR during the 1961–2020 period. With a dominance of flood- and frost-related fatalities, this demonstrates an increasing number of such events during this period, particularly after 2000.

Table A1. Deadly events (with at least eight fatalities) associated with weather in the Czech Republic during the 1961–2020 period (N—number of fatalities).

Date	Place	Event	N	Reason	Type of Death
28–29 January 1962	Tábor	Snowstorm	9	Entry of train on a blind track in the night	Derailment of the train
10 October 1962	Újezd u Brna	Fog	13	Loss of pilot orientation during landing	Crash of the plane into a hill
9 June 1970	Šardice	Flash flood	34	Breakthrough of a torrent of water into a lignite mine	Collapse of mine and torrent of mud
30 October 1975	Prague-Suchdol	Fog	80	Loss of pilot orientation during landing	Crash of the plane into terrain
19 March 1982	Central Bohemia	Winter weather	9	Snow and ice on roads	Vehicle accidents
20–22 December 1986	Bohemia	Snow	8	Snow on roads	Vehicle accidents
July 1997	Moravia and Silesia	Flood	61	Extreme river discharges, flooding	Drowning, collapse of buildings, rescue work, health complications
7–8 February 1999	CR	Snow	8	Snow and ice on roads	Vehicle accidents
5–mid-February 1999	CR	Cold wave	8	Frost, bad weather in the mountains	Freezing to death/hypothermia
August 2002	Bohemia	Flood	17	Extreme river discharges, flooding	Drowning, collapse of buildings, rescue work, health complications, other
20 January–1 February 2006	CR	Cold wave	18	Extreme frosts	Freezing to death/hypothermia
March–April 2006	Bohemia and Moravia	Flood	8	Extreme river discharges, flooding	Drowning, rescue work, health complications
7–17 January 2009	CR	Cold wave	11	Extreme frosts	Freezing to death/hypothermia
24–27 June 2009	Moravia and Silesia	Flash floods	14	Water torrent	Drowning, rescue work, health complications
16–20 December 2009	CR	Cold wave	11	Extreme frosts	Freezing to death/hypothermia
23–31 January 2010	CR	Cold wave	12	Extreme frosts	Freezing to death/hypothermia
7 August 2010	Northern Bohemia	Flash flood	8	Water torrent	Drowning, health complications
1–22 December 2010	CR	Cold wave	25	Extreme frosts	Freezing to death/hypothermia
16 February 2012	CR	Cold wave	25	Extreme frosts	Freezing to death/hypothermia
5–11 December 2012	CR	Cold wave	8	Extreme frosts	Freezing to death/hypothermia
June 2013	Bohemia	Flood	17	Extreme river discharges, flooding	Drowning, collapse of buildings, rescue work, health complications, other
6–10 January 2017	CR	Cold wave	8	Extreme frosts	Freezing to death/hypothermia
21–28 February 2018	CR	Cold wave	10	Extreme frosts	Freezing to death/hypothermia

References

1. WMO. *WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2019)*; WMO-No. 1267; World Meteorological Organization: Geneva, Switzerland, 2021.
2. UN Office for Disaster Risk Reduction: Sendai Framework for Disaster Risk Reduction 2015–2030. Available online: https://www.unisdr.org/we/inform/publications/43291 (accessed on 21 February 2022).
3. Wright, N.; Fagan, L.; Lapitan, J.M.; Kayano, R.; Abrahams, J.; Huda, Q.; Murray, V. Health emergency and disaster risk management: Five years into implementation of the Sendai framework. *Int. J. Disaster Risk Sci.* **2020**, *11*, 206–217. [CrossRef]
4. Robine, J.-M.; Cheung, S.L.K.; Le Roy, S.; Van Oyen, H.; Griffiths, C.; Michel, J.-P.; Herrmann, F.R. Death toll exceeded 70,000 in Europe during the summer of 2003. *C. R. Biol.* **2008**, *331*, 171–178. [CrossRef] [PubMed]
5. de Castro, M.; Gomez-Gesteira, M.; Ramos, A.M.; Álvarez, I.; de Castro, P. Effects of heat waves on human mortality, Galicia, Spain. *Clim. Res.* **2011**, *48*, 333–341. [CrossRef]
6. Vyberčki, D.; Švec, M.; Faško, P.; Savinova, H.; Trizna, M.; Mičietova, E. The effects of the 1996–2012 summer heat events on human mortality in Slovakia. *Morav. Geogr. Rep.* **2015**, *23*, 58–70. [CrossRef]
7. Graczyk, D.; Kundzewicz, Z.W.; Choryński, A.; Førland, E.J.; Pińskwar, I.; Szwed, M. Heat-related mortality during hot summers in Polish cities. *Theor. Appl. Climatol.* **2019**, *136*, 1259–1273. [CrossRef]
8. Vicedo-Cabrera, A.M.; Scovronick, N.; Sera, F.; Royé, D.; Schneider, R.; Tobias, A.; Astrom, C.; Guo, Y.; Honda, Y.; Hondula, D.M.; et al. The burden of heat-related mortality attributable to recent human-induced climate change. *Nat. Clim. Chang.* **2021**, *11*, 492–500. [CrossRef]
9. Diakakis, M. Have flood mortality qualitative characteristics changed during the last decades? The case study of Greece. *Environ. Hazards* **2016**, *15*, 148–159. [CrossRef]
10. Diakakis, M.; Deligiannakis, G. Flood fatalities in Greece: 1970–2010. *J. Flood Risk Manag.* **2017**, *10*, 115–123. [CrossRef]
11. Pereira, S.; Diakakis, M.; Deligiannakis, G.; Zêzere, J.L. Comparing flood mortality in Portugal and Greece (Western and Eastern Mediterranean). *Int. J. Disaster Risk Reduct.* **2017**, *22*, 147–157. [CrossRef]
12. Petrucci, O.; Aceto, L.; Bianchi, C.; Bigot, V.; Brázdil, R.; Pereira, S.; Kahraman, A.; Kiliç, Ö.; Kotroni, V.; Llasat, M.C.; et al. Flood fatalities in Europe, 1980–2018: Variability, features, and lessons to learn. *Water* **2019**, *11*, 1682. [CrossRef]
13. Petrucci, O.; Papagiannaki, K.; Aceto, L.; Boissier, L.; Kotroni, V.; Grimalt, M.; Llasat, M.C.; Llasat-Botija, M.; Rosselló, J.; Pasqua, A.A.; et al. MEFF: The database of MEditerranean Flood Fatalities (1980 to 2015). *J. Flood Risk Manag.* **2019**, *12*, e12461. [CrossRef]
14. Vinet, F.; Bigot, V.; Petrucci, O.; Papagiannaki, K.; Llasat, M.C.; Kotroni, V.; Boissier, L.; Aceto, L.; Grimalt, M.; Llasat-Botija, M.; et al. Mapping flood-related mortality in the Mediterranean basin. *Results from the MEFF v2.0 DB. Water* **2019**, *11*, 2196. [CrossRef]
15. Grimalt-Gelabert, M.; Rosselló-Geli, J.; Bauzà-Llinàs, J. Flood related mortality in a touristic island: Mallorca (Balearic Islands) 1960–2018. *J. Flood Risk Manag.* **2020**, *13*, e12644. [CrossRef]
16. Špitalar, M.; Brilly, M.; Kos, D.; Žiberna, A. Analysis of flood fatalities—Slovenian illustration. *Water* **2020**, *12*, 64. [CrossRef]
17. Petrucci, O. Factors leading to the occurrence of flood fatalities: A systematic review of research papers published between 2010 and 2020. *Nat. Hazards Earth Syst. Sci.* **2022**, *22*, 71–83. [CrossRef]
18. Hilker, N.; Badoux, A.; Hegg, C. The Swiss flood and landslide damage database 1972–2007. *Nat. Hazards Earth Syst. Sci.* **2009**, *9*, 913–925. [CrossRef]
19. Haque, U.; Blum, P.; da Silva, P.F.; Andersen, P.; Pilz, J.; Chalov, S.R.; Malet, J.-P.; Auflič, M.J.; Andres, N.; Poyiadji, E.; et al. Fatal landslides in Europe. *Landslides* **2016**, *13*, 1545–1554. [CrossRef]
20. Salvati, P.; Petrucci, O.; Rossi, M.; Bianchi, C.; Pasqua, A.A.; Guzzetti, F. Gender, age and circumstances analysis of flood and landslide fatalities in Italy. *Sci. Total Environ.* **2018**, *610–611*, 867–879. [CrossRef]
21. Analitis, A.; Katsouyanni, K.; Biggeri, A.; Baccini, M.; Forsberg, B.; Bisanti, L.; Kirchmayer, U.; Ballester, F.; Cadum, E.; Goodman, P.G.; et al. Effects of cold weather on mortality: Results from 15 European cities within the PHEWE Project. *Am. J. Epidemiol.* **2008**, *168*, 1397–1408. [CrossRef] [PubMed]
22. Fonseca-Rodríguez, O.; Sheridan, S.C.; Lundevaller, E.H.; Schumann, B. Effect of extreme hot and cold weather on cause-specific hospitalizations in Sweden: A time series analysis. *Environ. Res.* **2021**, *193*, 110535. [CrossRef]
23. Grigorieva, E.A.; Revich, B.A. Health risks to the Russian population from temperature extremes at the beginning of the XXI century. *Atmosphere* **2021**, *12*, 1331. [CrossRef]
24. Petkova, E.P.; Dimitrova, L.K.; Sera, F.; Gasparrini, A. Mortality attributable to heat and cold among the elderly in Sofia, Bulgaria. *Int. J. Biometeorol.* **2021**, *65*, 865–872. [CrossRef]
25. Folkerts, M.A.; Bröde, P.; Botzen, W.J.W.; Martinius, M.L.; Gerrett, N.; Harmsen, C.N.; Daanen, H.A.M. Sex differences in temperature-related all-cause mortality in the Netherlands. *Int. Arch. Occup. Environ. Health* **2022**, *95*, 249–258. [CrossRef] [PubMed]
26. Elsom, D.M. Deaths and injuries caused by lightning in the United Kingdom: Analyses of two databases. *Atmos. Res.* **2001**, *56*, 325–334. [CrossRef]
27. Elsom, D.M.; Webb, J.D.C. Deaths and injuries from lightning in the UK, 1988–2012. *Weather* **2014**, *69*, 221–226. [CrossRef]
28. Holle, R.L. A summary of recent national-scale lightning fatality studies. *Weather Clim. Soc.* **2016**, *8*, 35–42. [CrossRef]
29. Antonescu, B.; Cărbunaru, F. Lightning-related fatalities in Romania from 1999 to 2015. *Weather Clim. Soc.* **2018**, *10*, 241–252. [CrossRef]

30. Trigo, R.M.; Ramos, C.; Pereira, S.S.; Ramos, A.M.; Zêzere, J.L.; Liberato, M.L.R. The deadliest storm of the 20th century striking Portugal: Flood impacts and atmospheric circulation. *J. Hydrol.* **2016**, *541A*, 597–610. [CrossRef]
31. Taszarek, M.; Gromadzki, J. Deadly tornadoes in Poland from 1820 to 2015. *Mon. Weather Rev.* **2017**, *145*, 1221–1243. [CrossRef]
32. Salvador, C.; Nieto, R.; Linares, C.; Díaz, J.; Gimeno, L. Short-term effects of drought on daily mortality in Spain from 2000 to 2009. *Environ. Res.* **2020**, *183*, 109200. [CrossRef] [PubMed]
33. Badoux, A.; Andres, N.; Techel, F.; Hegg, C. Natural hazard fatalities in Switzerland from 1946 to 2015. *Nat. Hazards Earth Syst. Sci.* **2016**, *16*, 2747–2768. [CrossRef]
34. Petrucci, O.; Salvati, P.; Aceto, L.; Bianchi, C.; Pasqua, A.A.; Rossi, M.; Guzzetti, F. The vulnerability of people to damaging hydrogeological events in the Calabria Region (Southern Italy). *Int. J. Environ. Res. Public Health* **2018**, *15*, 48. [CrossRef] [PubMed]
35. Psistaki, K.; Paschalidou, A.K.; McGregor, G. Weather patterns and all-cause mortality in England, UK. *Int. J. Biometeorol.* **2020**, *64*, 123–136. [CrossRef]
36. Bergel-Hayat, R.; Debbarha, M.; Antonioub, C.; Yannis, G. Explaining the road accident risk: Weather effects. *Accident Anal. Prev.* **2013**, *60*, 456–465. [CrossRef]
37. Chakrabarty, N.; Gupta, K. Analysis of driver behaviour and crash characteristics during adverse weather conditions. *Procedia–Soc. Behav. Sci.* **2013**, *104*, 1048–1057. [CrossRef]
38. Vajda, A.; Tuomenvirta, H.; Juga, I.; Nurmi, P.; Jokinen, P.; Rauhala, J. Severe weather affecting European transport systems: The identification, classification and frequencies of event. *Nat. Hazards* **2014**, *72*, 169–188. [CrossRef]
39. Mohammed, A.A.; Ambak, K.; Mosa, A.M.; Syamsunur, D. A review of the traffic accidents and related practices worldwide. *Open Transp. J.* **2019**, *13*, 65–83. [CrossRef]
40. Zou, Y.; Zhang, Y.; Cheng, K. Exploring the impact of climate and extreme weather on fatal traffic accidents. *Sustainability* **2021**, *13*, 390. [CrossRef]
41. Sharif, H.O.; Hossain, M.M.; Jackson, T.; Bin-Shafique, S. Person-place-time analysis of vehicle fatalities caused by flash floods in Texas. *Geomat. Nat. Hazards Risk* **2012**, *3*, 311–323. [CrossRef]
42. Enríquez-de-Salamanca, Á. Victims crossing overflowing watercourses with vehicles in Spain. *J. Flood Risk Manag.* **2020**, *13*, e12645. [CrossRef]
43. Eisenberg, D.; Warner, K.E. Effects of snowfalls on motor vehicle collisions, injuries, and fatalities. *Am. J. Public Health* **2005**, *95*, 120–124. [CrossRef] [PubMed]
44. Black, A.W.; Mote, T.L. Effects of winter precipitation on automobile collisions, injuries, and fatalities in the United States. *J. Transp. Geogr.* **2015**, *48*, 165–175. [CrossRef]
45. Jackson, T.L.; Sharif, H.O. Rainfall impacts on traffic safety: Rain-related fatal crashes in Texas. *Geomat. Nat. Hazards Risk* **2016**, *7*, 843–860. [CrossRef]
46. Tobin, D.M.; Kumjian, M.R.; Black, A.W. Characteristics of recent vehicle-related fatalities during active precipitation in the United States. *Weather Clim. Soc.* **2019**, *11*, 935–952. [CrossRef]
47. Han, Z.; Sharif, H.O. Investigation of the relationship between rainfall and fatal crashes in Texas, 1994–2018. *Sustainability* **2020**, *12*, 7976. [CrossRef]
48. Han, Z.; Sharif, H.O. Vehicle-related flood fatalities in Texas, 1959–2019. *Water* **2020**, *12*, 2884. [CrossRef]
49. Kyselý, J.; Kříž, B. Decreased impacts of the 2003 heat waves on mortality in the Czech Republic: An improved response? *Int. J. Biometeorol.* **2008**, *52*, 733–745. [CrossRef] [PubMed]
50. Kyselý, J.; Plavcová, E. Declining impacts of hot spells on mortality in the Czech Republic, 1986–2009: Adaptation to climate change? *Clim. Chang.* **2012**, *113*, 437–453. [CrossRef]
51. Knobová, V.; Hůnová, I.; Malý, M.; Braniš, M. Vliv vln vedra v létě 2003 a 2006 na úmrtnost obyvatel Prahy (Heat wave effect on mortality in Prague in summer 2003 and 2006). *Meteorol. Zpr.* **2014**, *67*, 33–40.
52. Hanzlíková, H.; Plavcová, E.; Kynčl, J.; Kříž, B.; Kyselý, J. Contrasting patterns of hot spell effects on morbidity and mortality for cardiovascular diseases in the Czech Republic, 1994–2009. *Int. J. Biometeorol.* **2015**, *59*, 1673–1684. [CrossRef]
53. Urban, A.; Hanzlíková, H.; Kyselý, J.; Plavcová, E. Impacts of the 2015 heat waves on mortality in the Czech Republic—A comparison with previous heat waves. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1562. [CrossRef]
54. Arsenović, D.; Lehnert, M.; Fiedor, D.; Šimáček, P.; Středová, H.; Středa, T.; Savić, S. Heat-waves and mortality in Czech cities: A case study for the summers of 2015 and 2016. *Geogr. Pannonica* **2019**, *23*, 162–172. [CrossRef]
55. Urban, A.; Kyselý, J.; Plavcová, E.; Hanzlíková, H.; Štěpánek, P. Temporal changes in years of life lost associated with heat waves in the Czech Republic. *Sci. Total Environ.* **2020**, *716*, 137093. [CrossRef]
56. Kyselý, J.; Pokorná, L.; Kyncl, J.; Kříž, B. Excess cardiovascular mortality associated with cold spells in the Czech Republic. *BMC Public Health* **2009**, *9*, 19. [CrossRef] [PubMed]
57. Plavcová, E.; Urban, A. Intensified impacts on mortality due to compound winter extremes in the Czech Republic. *Sci. Total Environ.* **2020**, *746*, 141033. [CrossRef]
58. Hanzlíková, H.; Kyselý, J.; Plavcová, E. Vliv horkých a studených vln na kardiovaskulární úmrtnost a nemocnost v České republice (Hot and cold spell effects on cardiovascular mortality and hospital admissions in the Czech Republic). *Meteorol. Zpr.* **2016**, *69*, 74–82.
59. Brazdova, M.; Riha, J. A simple model for the estimation of the number of fatalities due to floods in central Europe. *Nat. Hazards Earth Syst. Sci.* **2014**, *14*, 1663–1676. [CrossRef]

60. Brázdil, R.; Chromá, K.; Řehoř, J.; Zahradníček, P.; Dolák, L.; Řezníčková, L.; Dobrovolný, P. Potential of documentary evidence to study fatalities of hydrological and meteorological events in the Czech Republic. *Water* **2019**, *11*, 2014. [CrossRef]
61. Brázdil, R.; Chromá, K.; Dolák, L.; Řehoř, J.; Řezníčková, L.; Zahradníček, P.; Dobrovolný, P. Fatalities associated with the severe weather conditions in the Czech Republic, 2000–2019. *Nat. Hazards Earth Syst. Sci.* **2021**, *21*, 1355–1382. [CrossRef]
62. Brázdil, R.; Chromá, K.; Zahradníček, P.; Dobrovolný, P.; Dolák, L. Weather and traffic accidents in the Czech Republic, 1979–2020. *Theor. Appl. Climatol.* **2022**. [CrossRef]
63. Tolasz, R.; Míková, T.; Valeriánová, A.; Voženílek, V. *Atlas podnebí Česka (Climate Atlas of Czechia)*; Český hydrometeorologický ústav, Univerzita Palackého v Olomouci: Praha, Olomouc, Czech Republic, 2007.
64. Český statistický úřad (Czech Statistical Office). Available online: https://www.czso.cz/ (accessed on 20 February 2022).
65. Český statistický úřad—Veřejná databáze (Czech Statistical Office—Public Database). Available online: https://vdb.czso.cz/vdbvo2/ (accessed on 20 February 2022).
66. Vintr, J. Analýza hydrometeorologických extrémů v České republice na základě novinových článků (Analysis of hydrometeorological extremes in the Czech Republic based on newspaper reports). Master's Thesis, Masarykova Univerzita, Brno, Czech Republic, 2020.
67. Mann, H.B. Non-parametric tests against trend. *Econometrica* **1945**, *13*, 163–171. [CrossRef]
68. Kendall, M.G. *Rank Correlation Methods*, 4th ed.; Charles Griffin: London, UK, 1975.
69. Theil, H. A rank-invariant method of linear and polynomial regression analysis. In *Henri Theil's Contributions to Economics and Econometrics*; Advanced Studies in Theoretical and Applied Econometrics, 23; Raj, B., Koerts, J., Eds.; Springer: Dordrecht, Switzerland, 1992; pp. 345–381. [CrossRef]
70. Sen, P.K. Estimates of the regression coefficient based on Kendall's tau. *J. Amer. Stat. Assoc.* **1968**, *63*, 1379–1389. [CrossRef]
71. Sprinthall, R.C. *Basic Statistical Analysis*, 9th ed.; Pearson Education: New York, NY, USA, 2011.
72. Hladný, J.; Krátká, M.; Kašpárek, L. *August 2002 Catastrophic Flood in the Czech Republic*; Ministry of the Environment of the Czech Republic: Prague, Czech Republic, 2004.
73. Hostýnek, J.; Novák, M.; Žák, M. Kyrill a Emma v Česku—Meteorologické příčiny, průběh bouří s hodnocením větrných extrémů (The Kyrill and Emma storms in Czechia—Meteorological causes and the course of the storms, with evaluation of wind extremes). *Meteorol. Zpr.* **2008**, *61*, 65–71.
74. Hujslová, J.; Šimandl, P. Bouře Herwart v Česku (The storm Herwart in Czechia). *Meteorol. Zpr.* **2018**, *71*, 60–63.
75. Poláček, D.; Švec, P. Fatální chyba v mlze. Jak se odehrála největší letecká katastrofa v historii Česka (Fatal error in fog. These were the conditions of the largest airplane catastrophe in the history of Czechia). Available online: https://zpravy.aktualne.cz/domaci/foto-unikatni-snimky-uplynulo-45-let-co-prazsky-suchdol-zdev/r~{}0d10bfd01ab411eb9d74ac1f6b220ee8/ (accessed on 15 December 2021).
76. Krupka, J. Jsou to jatka, volali zdravotníci. Pád letadla v Suchdole nepřežily desítky lidí (It is carnage, declared the paramedics. Dozens of people were killed in a plane crash in Suchdol). Available online: https://zdarsky.denik.cz/zpravy-z-ceska/havarie-letadla-v-suchdole.html (accessed on 15 December 2021).
77. V Újezdu u Brna odhalili pomník jedné z největších leteckých katastrof (The memorial to one of the largest plane disasters was unveiled at Újezd u Brna). Available online: https://ct24.ceskatelevize.cz/archiv/1095541-v-ujezdu-u-brna-odhalili-pomnik-jedne-z-nejhorsich-leteckych-katastrof (accessed on 15 December 2021).
78. Havárie dvou letadel z Francie (An accident of two planes from France). *Rudé právo*, 25 April 1992; p. 2.
79. Smrt v 17.32 (A death at 17:32). *Rudé právo*, 27 April 1992; p. 4.
80. Smrtící past pod Smědavou (A death trap under Smědava). *Rudé právo*, 29 April 1992; p. 4.
81. Zêzere, J.; Pereira, S.; Tavales, A.; Bateira, C.; Trigo, R.; Quaresma, I.; Santos, P.; Santos, M.; Verde, J. DISASTER: A GIS database on hydro-geomorphologic disasters in Portugal. *Nat. Hazards* **2014**, *72*, 503–532. [CrossRef]
82. Vinet, F.; Boissier, L.; Saint-Martin, C. Flashflood-related mortality in southern France: First results from a new database. In: 3rd European Conference on Flood Risk Management (FLOODrisk 2016). *E3S Web Conf.* **2016**, *7*, 06001. [CrossRef]
83. Aceto, L.; Pasqua, A.A.; Petrucci, O. Effects of damaging hydrogeological events on people throughout 15 years in a Mediterranean region. *Adv. Geosci.* **2017**, *44*, 67–77. [CrossRef]
84. Sharma, S.; Blagrave, K.; Watson, S.R.; O'Reilly, C.M.; Batt, R.; Magnuson, J.J.; Clemens, T.; Denfeld, B.A.; Flaim, G.; Hori, Y.; et al. Increased winter drownings in ice-covered regions with warmer winters. *PLoS ONE* **2020**, *15*, e0241222. [CrossRef]
85. Brázdil, R.; Zahradníček, P.; Dobrovolný, P.; Řehoř, J.; Trnka, M.; Lhotka, O.; Štěpánek, P. Circulation and climate variability in the Czech Republic between 1961 and 2020: A comparison of changes for two "normal" periods. *Atmosphere* **2022**, *13*, 137. [CrossRef]
86. Zahradníček, P.; Brázdil, R.; Řehoř, J.; Lhotka, O.; Dobrovolný, P.; Štěpánek, P.; Trnka, M. Temperature extremes and circulation types in the Czech Republic, 1961–2020. *Int. J. Climatol.* **2022**. [CrossRef]
87. Brázdil, R.; Řezníčková, L.; Havlíček, M.; Elleder, L. Floods in the Czech Republic. In *Changes in Flood Risk in Europe*; IAHS Special Publication, 10; Kundzewicz, Z.W., Ed.; IAHS Press and CRC Press/Balkema: Wallingford, UK, 2012; pp. 178–198.
88. Blöschl, G.; Kiss, A.; Viglione, A.; Barriendos, M.; Böhm, O.; Brázdil, R.; Coeur, D.; Demarée, G.; Carmen Llasat, M.; Macdonald, N.; et al. Current European flood-rich period exceptional compared with past 500 years. *Nature* **2020**, *583*, 560–566. [CrossRef] [PubMed]
89. Franzke, C.L.E.; Torelló i Sentelles, H. Risk of extreme high fatalities due to weather and climate hazards and its connection to large-scale climate variability. *Clim. Chang.* **2020**, *162*, 507–525. [CrossRef]

90. Halásová, O.; Brázdil, R. Flash floods in Moravia and Silesia during the nineteenth and twentieth centuries. *Geografie* **2020**, *125*, 117–137. [CrossRef]
91. Brázdil, R.; Zahradníček, P.; Dobrovolný, P.; Štěpánek, P.; Trnka, M. Observed changes in precipitation during recent warming: The Czech Republic, 1961–2019. *Int. J. Climatol.* **2021**, *41*, 3881–3902. [CrossRef]
92. Singh, O.; Singh, J. Lightning fatalities over India: 1979–2011. *Meteorol. Appl.* **2015**, *22*, 770–778. [CrossRef]
93. Tobin, D.M.; Kumjian, M.R.; Black, A.W. Effects of precipitation type on crash relative risk estimates in Kansas. *Accident Anal. Prev.* **2021**, *151*, 105946. [CrossRef]
94. Andrey, J.; Karlis, D.; Wets, G. Long-term trends in weather-related crash risks. *J. Transp. Geogr.* **2010**, *18*, 247–258. [CrossRef]
95. Police of the Czech Republic. Statistika nehodovosti (Statistics of Accidents). Available online: https://www.policie.cz/clanek/statistika-nehodovosti-900835.aspx (accessed on 14 June 2021).
96. Vývoj počtu usmrcených osob od roku 1961 (The development of the number of fatalities since 1961). Available online: https://www.policie.cz/soubor/1-2015-12-grafy-pdf.aspx (accessed on 15 February 2022).
97. Skácal, L. Hloubková analýza mezinárodního srovnání dopravní nehodovosti v ČR (The detail analysis of traffic accidents in the CR in the international comparison). Observatoř bezpečnosti silničního provozu, říjen 2007. Available online: https://www.czrso.cz/clanek/hloubkova-analyza-mezinarodniho-srovnani-dopravni-nehodovosti-v/?id=1402 (accessed on 14 June 2021).
98. ETSC—European Transport Safety Council. Road Deaths in the European Union—Latest Data. Available online: https://etsc.eu/euroadsafetydata/ (accessed on 10 March 2021).
99. Pomník Jiřího Krýsla (Memorial of Jiří Krýsl). Available online: https://cs.wikipedia.org/wiki/Soubor:Kocaba-2007-05-19-PomnikJirihoKrysla.JPG (accessed on 20 December 2021).