

RELIABILITY OF TORNADO ECOLOGICAL HAZARD ESTIMATE IN UKRAINE AND EUROPE

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Purpose. To estimate the relative quantity and reliability of tornado reports in Ukraine in comparison to other European countries. **Methodology.** Based on European Severe Weather Database data the tornado reporting reliability in Ukraine was compared to 27 other countries of Eastern and Central Europe. **Results.** European Severe Weather Database contains 2643 tornado and other atmospheric twisters reports in 2009 – 2019 in 28 European countries analyzed in the paper. The total quantity of tornadoes and other atmospheric twisters reports in 2009 – 2019 in Ukraine was 186, or 31 tornado per 100 thousand square kilometers which is twice smaller than Europe average. However, the quantity of tornadoes appearing over land in Ukraine is 23 reports per 100 thousand square kilometers, which corresponds to European average value. The quantity of tornado reports per square kilometer correlation with country geographic location was not found except for obvious larger quantity of waterspouts reports in near-sea countries. The fraction of sufficient-quality reports (QC1 and QC2 quality status) in Ukraine was found to be 94% of all the reports. This value is greater than average 84% for 28 European countries. The calculated tornado intensity distribution according to Fujita-Pearson scale corresponds well with tornado intensity distribution in Eastern Europe. Therefore, it was shown that the data available in European Severe Weather Database for Ukraine territory is satisfactory to provide reliable estimates of tornadoes ecological hazard. **Originality.** For the first time the quantity and quality of available tornadoes and other atmospheric twisters reports in Ukraine were estimated and were shown to correspond to average values for other European countries. **Practical value.** The results of the research can be used to justify the adequateness level of tornado ecological hazard estimate in Ukraine territory. *References 8, tables 2, figure 1.*

Keywords: tornado, Europe, Ukraine, ecological safety, quality assessment.

НАДІЙНІСТЬ ОЦІНОК ЕКОЛОГІЧНОЇ НЕБЕЗПЕКИ СМЕРЧІВ НА ТЕРИТОРІЯХ УКРАЇНИ І ЄВРОПИ

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У статті на основі даних Європейської бази даних екстремальних погодних явищ аналізується рівень надійності повідомлень про смерчі на території України у порівнянні з 27 іншими країнами східної і центральної Європи. У 2009 – 2019 рр загальна кількість повідомлень про смерчі та інші типи атмосферних вихорів в Україні складала 186, або 31 смерч на 100 тисяч квадратних кілометрів, що відповідає середньому показнику для усіх розглянутих країн. Показано, що 94% від усіх повідомлень про смерчі на території України мають достатню якість (рівень достовірності QC1 і QC2). Цей показник перевищує середнє значення, яке для 28 країн Європи складає 84% якісних повідомлень. Розподіл повідомлених смерчів у 1999 – 2019 рр за класами потужності за шкалою Фудзіти-Пірсона добре узгоджується із розподілом смерчів за класами потужності у східній Європі. Таким чином, показано, що дані, представлені у Європейській базі даних екстремальних погодних явищ на території України достатні для забезпечення надійних оцінок екологічної небезпеки смерчів.

Ключові слова: смерч, Європа, Україна, екологічна небезпека, оцінка якості.

PROBLEM STATEMENT. Tornadoes and other types of powerful atmospheric twisters pose a high ecological hazard, leading to damage and destruction of man-made and natural objects, long-range transport of debris and contaminated aerosol, disruption of ecosystems. Recent research on tornadoes ecological hazard in Ukraine [1-3] showed that tornado threat in Ukraine is significantly underestimated [1, 4] just as in other European countries [5].

Therefore the *aim* of this article is to estimate the quantitative parameters of tornado reporting reliability in Ukraine in comparison to other European countries based on European Severe Weather Database (ESWD) data [6, 7].

EXPERIMENTAL PART AND RESULTS OBTAINED. For the analysis made in this paper, a total of 2643 tornado and other atmospheric twisters records in January 1, 2009 – January 1, 2019 were analyzed. These reports originated from 28 European countries roughly

within 8° – 40° E; 42° – 71° N. The analysis results are presented in table 1.

The atmospheric twisters reports in table 1 are distinguished according to ESWD classification as dust devils (including steam devils, sand devils and other lesser whirlwinds), gustnadoes and tornadoes appearing over land and water surface.

20 of 28 countries have tornado reporting frequency of 10 – 70 reports per 100000 km² of the country area. The map, plotted in fig. 1 shows no distinctive correlation of the tornado reporting frequency and the country geographical location. Therefore, the tornado reporting frequency is rather stipulated by the government authorities and civilians involvement in tornado reporting, and cannot be unambiguously explained by local climate peculiarities of the considered regions. This implies that the frequency of actual tornado events considering unreported tornadoes may be considered approximately homogeneous around most European countries.

Table 1 – Quantity and quality of tornadoes and other atmospheric twisters reporting in 28 Europe countries according to [6, 7] in 2009 – 2019.

Country	Dust devils	Gustnadoes	Total tornadoes	Fraction of waterspouts	Country total area, km ²	Total reports per 100000 km ²	QC0 (+) quantity	QC0 (+) fraction	QC2 quantity	QC2 fraction
Albania	0	0	7	86%	28750	24	1	14%	0	0
Austria	14	3	38	3%	83880	66	15	27%	1	2%
Belarus	4	1	37	3%	207600	20	5	12%	1	2%
Bosnia and Herzegovina	0	0	4	25%	51130	8	1	25%	0	0
Bulgaria	0	0	11	36%	110990	10	2	18%	0	0
Croatia	0	2	198	70%	56590	353	22	11%	8	4%
Czech Republic	22	0	12	0	78870	43	12	35%	4	12%
Denmark	2	1	103	64%	42930	247	19	18%	9	8%
Estonia	5	0	37	65%	45230	93	6	14%	0	0
Finland	4	0	29	72%	338420	10	6	18%	1	3%
Germany	51	5	443	32%	357390	140	80	16%	49	10%
Hungary	5	0	39	0	93030	47	13	30%	0	0
Italy	8	2	815	69%	301340	274	120	15%	18	2%
Latvia	4	0	19	58%	64590	36	5	22%	0	0
Liechtenstein	0	0	0	0	160	0	0	0	0	0
Lithuania	0	0	16	25%	65300	25	1	6%	0	0
Moldova	0	0	4	25%	33850	12	1	25%	0	0
Montenegro	0	0	9	100%	13810	65	0	0	0	0
North Macedonia	0	0	1	0	25710	4	0	0	0	0
Norway	7	2	63	62%	385210	19	8	11%	7	10%
Poland	40	4	126	37%	312700	54	31	18%	2	1%
Romania	3	0	68	6%	238400	30	15	21%	0	0
Serbia and Kosovo	0	1	23	0	88360	27	6	25%	0	0
Slovakia	1	0	6	0	49040	14	4	57%	1	14%
Slovenia	2	0	9	33%	20270	54	3	27%	0	0
Sweden	5	0	121	55%	450300	28	29	23%	4	3%
Switzerland	1	0	20	80%	41290	51	3	14%	4	19%
Ukraine	8	5	173	21%	603630	31	12	6%	7	4%

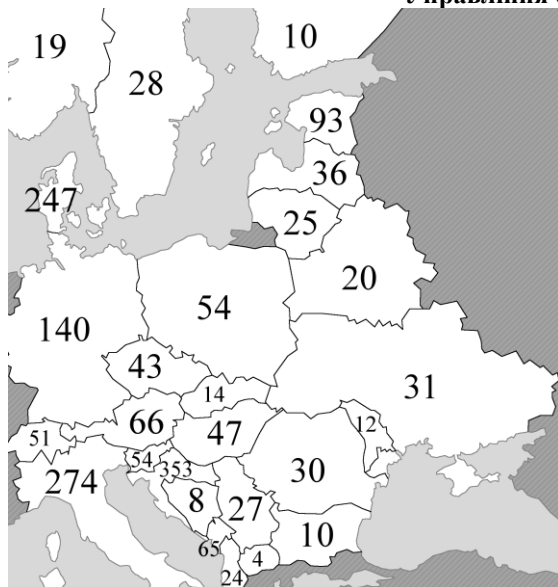


Figure 1 – Quantity of tornadoes reports per 100000 km² in 28 European countries in 2009 – 2019.

It should be noted that the countries in the considered region with most tornadoes reports per square kilometer (Denmark, Croatia and Italy) have more than 60% of tornadoes registered over sea water surface (see table 1). Such tornadoes (also called waterspouts) are easier to observe because they are not obstructed by landscape and other objects, and are usually opaque due to water content which is favorable for such tornadoes visual identification and thus reporting.

The quantity of atmospheric twisters reports per 100000 km² per 10 years in Ukraine is 31 (14th position out of 28 analyzed countries), which is twice smaller than 63 Europe average. However, considering only tornadoes appearing over land, this value is 23 which approximately corresponds to Europe average 29.

This means, that tornado ecological hazard estimate of in Ukraine territory based on ESWD dataset has adequate quantitative characteristics comparing to other European countries.

Quality of tornado reports in Ukraine. European Severe Weather Database offers three gradations of report confirmation status [6, 7].

The unassessed tornado sighting report is assigned QC0 quality status. After the report passed a basic plausibility check by European Severe Storms Laboratory (ESSL) quality control, it is either discarded or assigned QC0+ quality status. In table 1 we sum both of the reports quality types in column labeled "QC0 (+) quantity". These reports otherwise denote lower-reliability reports, which were not reviewed thoroughly and event parameters, such as tornado intensity, were not assessed.

When the report has been analyzed and confirmed by European Severe Storms Laboratory or its official partners (National or Regional Hydrometeorological or Meteorological Services, trusted Voluntary Observer Networks or trusted Voluntary Observer Persons) it is assigned QC1 quality status. The report source quality is considered reliable if there are quality photo/video materials available with accurate metadata, or the reporter is certified by ESSL. As seen from the table 1, reports

of QC1 quality status constitute almost 80 % of total tornado records.

According to ESSL recommendations [6, 7], the records with quality status QC1 and higher are advised for tornado statistical studies and thus estimation of ecological hazard.

The highest quality status of tornado report in ESWD is QC2, which is usually preceded by a thorough scientific analysis and verification of all the information presented in the report.

The total fraction of QC1 and QC2 quality status records is 94% which is above average 84% for 28 European countries considered. Ukraine has the lowest relative quantity of low-quality atmospheric twisters reports (6% of all the reports) among 16 countries with total quantity of tornadoes reports 20 and higher.

Ukraine is in the 9th place out of 28 analyzed countries by relative quantity of QC2 quality status reports (4% of all the reports).

Intensity distribution of reported tornadoes in Ukraine. The comparison of tornadoes reports distribution in Eastern Europe (21° – 65° E; 44° – 71° N) and over Ukraine territory by Fujita-Pearson intensity in 1999 – 2019 is given in table 2. The calculations were made by a specialized GIS system developed by the authors in Free Pascal, Lazarus and Castle Game Engine [8].

Table 2 – Comparison of relative reported atmospheric twisters intensities frequencies in Eastern Europe (21° – 65° E; 44° – 71° N) and Ukraine according to merged tornado catalog [1] in 1999 – 2019.

Tornado intensity	Quantity of tornadoes in Eastern Europe	Fraction of tornadoes in Eastern Europe	Quantity of tornadoes in Ukraine	Fraction of tornadoes in Ukraine
EF3 (F3)	38	0.02	7	0.02
EF2 (F2)	219	0.10	33	0.09
EF1 (F1)	379	0.18	58	0.16
EF0 (F0)	160	0.07	32	0.09
Unknown	1354	0.63	226	0.63
Total:	2150		356	

The numbers in the table 2 represent the sum of tornadoes assessed according to Fujita-Pearson (F) and Enhanced Fujita (EF) scales. Note that while they are similar, there is no strict relation between those scales.

The analysis of different intensity tornadoes fractions presented in table 2 concludes that tornadoes reports intensity distribution in Ukraine and Eastern Europe is similar. Therefore the quality of tornado intensity determination in Ukraine corresponds to that in other Eastern European countries.

It should also be noted that in contrary to expected log-normal distribution of tornadoes by intensity, the quantity of EF0 (F0) tornadoes in Eastern Europe and Ukraine is smaller than that of EF1 (F1) tornadoes. This fact may be caused by observation bias, as EF0 torna-

does cause significantly less damage than tornadoes of higher intensities and thus are more likely to be unreported, especially in low-populated areas.

Therefore according to three quantitative and qualitative criteria Ukraine tornado reporting reliability corresponds to average in Central and Eastern Europe. This enables of investigation tornado physics and ecological hazard relative to climate and hydrological conditions and Ukraine can provide a significant contribution to development of tornado science in Europe.

On the other hand, it is necessary to further increase the quantity and quality of tornadoes reports accompanied by high-quality data (official reports, photographic and video records, damage estimates, eyewitness testimonies, etc) on the observed tornadoes and their ecological consequences. More reliable estimates allow for development of tornado forecasting methods and high-resolution mapping of tornado hazard in regions of Ukraine.

CONCLUSIONS. European Severe Weather Database contains 2643 tornado and other atmospheric twisters reports in 2009 – 2019 in 28 European countries analyzed in the paper. This includes 186 reports in Ukraine.

There are average 29 tornadoes over land reported per 100000 km² per 10 years in Ukraine, which corresponds to average value for other European countries.

The quantity of tornadoes reports per square kilometer correlation with the country geographic location was not found except for obvious larger quantity of waterspouts reports in near-sea countries.

The relative quantity of sufficient quality reports (QC1 and QC2 quality statuses) in Ukraine is 94% of total quantity of reports in European Severe Weather Database which is higher than Europe average 84%.

The tornado distribution by intensity according to Fujita-Pearson scale corresponds to average in East Europe (21° – 65° E; 44° – 71° N) in 1999 – 2019.

Therefore the quantity and quality of tornadoes and other atmospheric twisters reporting is sufficient for estimation of ecological hazard of tornadoes in Ukraine as compared to other European countries.

Only 7 cases of tornadoes reports (4% of all reports) in Ukraine have undergone a thorough scientific investigation in 2009 – 2019. While this value is higher than average for European countries, it is reasonable to give more attention to careful investigations and scientific descriptions of specific cases of tornadoes and their ecological consequences in Ukraine.

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НАДЁЖНОСТЬ ОЦЕНОК ЭКОЛОГИЧЕСКОЙ ОПАСНОСТИ СМЕРЧЕЙ НА ТЕРРИТОРИЯХ УКРАИНЫ И ЕВРОПЫ

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В статье на основе данных Европейской базы данных экстремальных погодных явлений анализируется уровень надёжности сообщений о смерчах на территории Украины по сравнению с 27 другими странами восточной и центральной Европы. В 2009 – 2019 гг общее количество сообщений про смерчи и другие типы атмосферных вихрей в Украине составила 186, или 31 смерч на 100 тысяч квадратных километров, что соответствует среднему показателю для всех рассмотренных стран. Показано, что 94% от всех записей про смерчи на территории Украины имеют достаточное качество (уровень достоверности QC1 и QC2). Этот показатель превышает среднее значение, которое для 28 стран Европы составляет 84% качественных сообщений. Распределение сообщённых смерчей в 1999 – 2019 гг по классам мощности по шкале Фуджита-Пирсона хорошо согласуется с распределением смерчей по классам мощности в восточной Европе. Таким образом, показано, что данные, представленные в Европейской базе данных экстремальных погодных явлений на территории Украины достаточны для обеспечения надёжных оценок экологической опасности смерчей.

Ключевые слова: смерч, Европа, Украина, экологическая опасность, оценка качества.