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# An updated estimate of tornado occurrence in Europe

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## Abstract

Results from a survey on average tornadic activity in Europe conducted among the participants of the ECSS 2002 conference are presented. Compared to Alfred Wegener's 1917 estimate of "at least 100 tornadoes per year in Europe" the present survey shows a total of 329 ± 12 tornadoes over land and water per year based on observations, and more than twice as many cases (697 ± 36) for an estimate of the expected true climatological number, accounting for present underreporting in many European countries. Traditionally, European tornado numbers include waterspouts. For comparison to the current number of 1170 observed tornadoes over land per year in the USA, the European numbers are 169 ± 9 per year based on observations, and 304 ± 25 based on estimates. As European severe weather research is rapidly developing, one can expect less underreporting in the future, leading to an augmented database for upcoming surveys like the present one.

*Keywords:* Tornado; Waterspout; Climatology; Europe

## 1 Introduction

After the European Conference on Tornadoes and Severe Storms (ETSS) held in Toulouse in February 2000 (Snow and Dessens, 2001), one question remained unanswered: How many tornadoes are there in Europe as a whole on average each year?

During the ETSS follow–up, the European Conference on Severe Storms (ECSS 2002) in Prague, the author distributed a survey among the participants coming from 28 different countries, to update an estimate of this important number which has stood for over eight decades: Alfred Wegener (1917, p. 84) gave this estimate of "at least 100 tornadoes per year in Europe" based on his thorough analysis of historical and contemporary tornado reports.

In his book, he stated that “Tornadoes and waterspouts are identical phenomena, only that the former term is used over land, while the latter is used over the sea. Should it happen that small underlying differences between the two are discovered, something that has certainly not happened until now, these will presumably be attributable to the differences in surface friction” (Wegener, 1917, p. 3, cf. App. A).

Further, he defined tornadoes and waterspouts alike as “large vortices with vertical axis extending from the base of a cumulonimbus cloud to the surface, visible completely or in part through condensation or, in the lower part through dust, in the form of a pendant cone, funnel, hose or column. In a track typically on the order of hundreds of meters wide, with intense convergence towards the region of strongly reduced air pressure around the vortex axis, they in general cause damage of a kind not observed in even the strongest larger scale storms” (Wegener, 1917, p. 5, cf. App. A).

These definitions were well ahead of their time. The often–cited, but not very helpful, definition of the Glossary of Meteorology’s first edition (Huschke, 1959) has been a subject of criticism for many years. Only recently, the second edition of the Glossary (Glickman, 2000) provided a similar definition to Wegener’s given 83 years before. In this paper, the notion is adopted that tornadoes and waterspouts represent the same basic physical phenomenon described by Wegener’s and Glickman’s definitions.

To address the question on how many tornadoes there are in Europe, Sec. 2 reviews the data from the ECSS 2002 survey, while Sec. 3 briefly discusses the data and current European severe weather research activities. Sec. 4 presents the conclusions.

## 2 Survey data

A total of 26 survey forms were returned, including two slightly differing ones from Germany. All names of participants were given on the forms. Usually one, but up to five people contributed to each form. These participants were well–acquainted with their national tornado climatology or even keepers of the national tornado record.

The survey data are outlined in Table 1 for tornadoes over land surfaces, and in Table 2 for tornadoes over water surfaces, i. e. waterspouts. Both tables give two different sets of numbers. First, the survey participants were asked to give the average number of tornadoes and waterspouts per year based on historical or recent observations. Second, the survey asked for any available estimate of the "true" number of events per year, in order to get an impression of the expected current underreporting of events in the participating countries.

Both Tables 1 and 2 give the numbers per year per country. For Norway and Sweden, Denmark, and the Mediterranean Isles Malta and Cyprus no first–hand information on tornado observations was available among the ECSS participants. However, from the Tornado and Storm Research Organisation (TORRO) database, Terence Meaden provided estimated numbers for these countries. Therefore, it should be kept in mind that observational data are available from 25 countries, while estimates of tornado occurrence are provided for 28 locations here. Whenever on a survey form ranges for the observed or estimated numbers of tornadoes and waterspouts per year were given, the minimum and maximum values in Tables 1 and 2 indicate the lower and upper bound of that range. In this way, at least a proxy for the real uncertainty in the data could be obtained. However, as this short survey did not explicitly ask for lower and upper bounds of observations and estimates, most survey forms only contained average values without any standard deviation $\sigma$. Other options to approximate $\sigma$ for observed and estimated numbers of reports, like Poisson's uncertainty, where $\sigma$ corresponds to the square root of the reported numbers $n$, were not chosen for this survey evaluation.

Turning first towards the data for tornadoes over land in Table 1, we see that country size is not the only determining criterion for number of observed tornadoes: Larger European countries like France report only 8 tornadoes a year, while the Netherlands report 20 observed tornadoes a year. And the European part of Russia, by far the largest country in this survey, reports only 4 to 5 tornadoes a year.

So, aside from country size alone, other factors contribute to the numbers given here, e. g.:

- Climatology,
- Length of historical record,
- Population density and mass media availability.

The first point is rather obvious. The analysis by Wegener (1917) already showed that e. g. the North Sea coastal plains in France, Belgium, the Netherlands, and Germany are regions of enhanced tornadic activity. Therefore, in this region, even a small country like the Netherlands may well experience a rather high number of tornadoes each year.

The second point, length of historical record, is more subtle. Some of the countries have started to analyze their tornado reports only very recently. It is not surprising that they cannot give very robust average numbers from only few recorded events during the last years. Countries with longer time series like the United Kingdom, Germany, and Estonia, provide well–based and usually higher numbers, despite their not too large size.

The third point, in close connection to the previous one, addresses probability of detection and probability of nationwide reporting of a tornado. In general, the number of weak tornado observations suffers most from low population density and a sparse communication network.

Despite these issues, a total of $169 \pm 9$ tornadoes over land surfaces per year are observed in Europe, based on 25 countries.

Looking at the estimated numbers in Table 1, we see that all countries estimate at least as many tornadoes a year as indicated by their observational records. Russia, again, apparently gives a very conservative estimate, taking into account the large size of the country and the proximity to countries with rather high tornado occurrence, like Estonia (cf. Peterson, 2000). For the countries which give higher estimates, i. e. which believe in some kind of underreporting of tornadic storms, the factor of increase from observations to estimates is usually between 1 and 2. Only Spain expects a factor of 3 between their estimate and current observations.

In total, $304 \pm 25$ tornadoes over land surfaces per year are estimated to occur in Europe, based on 28 countries. Using only the 25 countries for which observations were available yields an estimate of $295 \pm 25$ tornadoes over land surfaces per year. This leads to an overall estimate of the current underreporting by roughly 43%.

Table 2 gives a similar impression for tornadoes over water surfaces. Of course, countries without coastlines give no or only very few reports from large lakes (tornadoes which merely cross a river or a small lake should not be classified as waterspouts). Ireland also gives no waterspout observations at all, which is caused by the fact that, as indicated in the survey form, most tornadoes in Ireland are waterspouts coming onshore. These were already included in the numbers given in Table 1, and pure offshore waterspouts have apparently not been reported.

Not surprisingly, the highest number of observed waterspouts come from the Netherlands (already Wegener, 1917, mentions the well–developed waterspout spotter network in the Netherlands). Spain, Italy, and the United Kingdom also report substantial numbers. All of these countries have long coastlines relative to their size. The Mediterranean Sea also provides high sea surface temperatures, which further helps to explain the numbers from Spain and Italy. The data for Switzerland, on the other hand, are well–based, too. Even though there is no coastline in Switzerland, its larger lakes, especially Lake Constance, are reliable producers of waterspouts in Summer, probably enhanced by orographic boundary layer convergence lines near the Alps.

In total, 160 $\pm$ 3 waterspouts per year are observed in Europe (25 countries), and the estimated numbers are usually higher than the number of observations. The main difference between this and the estimates of tornadoes in Table 1 is that some countries now give much bigger estimates in comparison with the available observations. Apparently, the amount of underreporting is believed to be considerably larger for waterspouts than for tornadoes over land. For most countries with likely underreporting, this factor is about 2 to 3. Germany, however, estimates three to five times, and Spain even six times higher waterspout numbers compared to present observations. For Germany at least, waterspouts over the North and Baltic Seas are common phenomena from July to September, but as of yet, no systematic recording takes place. Therefore, a significant underreporting of waterspouts over coastal waters might indeed be reasonable at this time.

In total, 393 $\pm$ 11 waterspouts per year are estimated to occur in Europe, based on 28 countries. Using again the subset of 25 countries as for the tornadoes over land yields an estimate of 382 $\pm$ 11 waterspouts per year. This leads to an overall estimate of the underreporting by about 58%.

Table 3 reviews the general findings of this survey done at the ECSS 2002 conference. At this point in time, observations of tornadoes and waterspouts differ by less than 10% on average. In the estimates, the number of waterspouts exceeds that of tornadoes by roughly 30%. The available observations lead to 329 $\pm$ 12 tornadoes and waterspouts per year in the 25 European countries for which surveys were returned. The estimated numbers for 28 countries are 697 $\pm$ 36, and for the subset of 25 countries, 677 $\pm$ 36. The overall estimate of the underreporting is then roughly 51%.

# 3 Discussion

When interpreting the numbers from this first survey on tornadoes in Europe since the work of Wegener (1917), some care must be taken. For example, some countries have just initiated tornado research and base their observations and estimates on rather short or intermittent time series. Other countries have homogeneous records going back many centuries. The level of uncertainty in the survey results is therefore much larger than indicated by the quite tight “errorbars” in Table 3. Yet as severe weather awareness is strongly rising in Europe, surveys of this sort should be much more robust and reliable in the near future.

Nevertheless, the statement by Wegener (1917) that there are “at least 100 tornadoes a year in Europe” is well corroborated. And even the most conservative conclusion from the current numbers should now be: At least some hundreds of tornadoes (including waterspouts) a year in Europe. Even though these do not present the main severe weather threat in Europe, they are not at all negligible.

On average, there is only a factor of about 2 between observed and estimated "true" numbers of tornadoes in Europe. For individual countries, and especially in the case of waterspouts, this factor can however be much larger and attain a value of 6 as for waterspouts in Spain. All this variety will make it very interesting to watch the European number of tornado reports converge to more stable climatological values in the near future.

The current best estimate for tornadoes (without waterspouts) in the USA is 1170 per year. Not taking into account the different area sizes of Europe (where tornadoes can occur practically everywhere) and the tornado–prone part of the USA, one can diagnose that currently seven times less tornadoes are observed in Europe (169/1170). Taking into account the estimated numbers from 28 countries we end up with only a factor of four times fewer tornadoes than in the USA (304/1170).

It is unfortunate that waterspout observations in the USA are not recorded routinely. Waterspouts are indeed less likely to be observed than tornadoes over land surfaces. This holds true for both the USA and for Europe. Nevertheless, waterspouts can be hazardous to ships or aircraft. So, from a climatological point of view, a waterspout record is valuable as well, and these tornadoes should be a point of interest for European tornado research in the future.

The statement above that severe weather awareness is rising strongly in Europe can easily be substantiated. Aside from the two successful European Conferences on Severe Storms in 2000 (Snow and Dessens, 2001) and 2002, and private research networks like TORRO in the United Kingdom or TorDACH in Germany, Austria, and Switzerland, there are currently several other research initiatives on the European level.

This includes the concept of a European Severe Storms Laboratory (ESSL) developed by the author, the European Severe Weather Directory (ESWD) introduced at the ECSS 2002 by Fulvio Stel and Dario Giaiotti from Italy, the European Storm Forecast Experiment (ESTOFEX) involving researchers from the Netherlands and Germany, and the initiation of a Skywarn Europe storm spotters network currently under way in several countries.

Within this framework, an ESSL could be achieved by first establishing a web–based center for conducting and coordinating severe weather research on a European level. After some years of continuing research the ESSL could switch over to a real center with permanent facilities in Central Europe. Work using the web–based ESSL is currently in progress.

The ESWD is intended for Europe–wide reporting of various severe weather events on a convenient internet platform. Its primary purpose is to raise awareness of a progressing synoptic severe weather situation by publishing severe weather events which could take place the next day in a neighboring country as the synoptic pattern propagates. Aside from this primary purpose, the ESWD data could enter climatological data records of individual countries or of an ESSL after some quality control procedure.

ESTOFEX was initiated to focus the recently established different severe weather forecast initatives giving convection forecasts ("convective outlooks") for Europe for a period of two or three days. The synergy of merging the individual outlooks to a single one with evaluation afterwards by the ESTOFEX group provides a promising way to gain severe weather forecasting experience. Eventually, ESTOFEX may become one of the nuclei for a European Storm Prediction Center hosted by the European weather services.

Even more focused on the operational nowcasting level is the European Skywarn storm spotters network. Similar to Skywarn in the USA, real time spotter reports are expected to enter a database to provide guidance to weather services and the media to enable them to issue more timely and accurate warnings to the public. The Skywarn Europe effort also involves spotter training courses. During or after a severe weather day in Europe, the Skywarn data record may enter the ESWD and help to evaluate ESTOFEX convective outlooks after some initial quality control, e. g. to eliminate multiple reports.

Furthermore, it is worth mentioning that the last five years have seen a vividly growing storm chaser community all over Europe who already documented many interesting severe weather cases which otherwise may have passed without notice by the atmospheric sciences.

# 4 Conclusions

The climatological survey on tornadoes in Europe during the European Conference on Severe Storms in Prague showed the following:

- Based on data from 25 countries, about 170 tornadoes over land, and 160 waterspouts are currently observed in Europe each year on average.
- The number given by Alfred Wegener (1917) was reasonable, given the data available at the time.
- Estimated numbers from 28 countries indicate roughly 300 cases per year for tornadoes and 390 per year for waterspouts.
- Total numbers for all cases are 330 per year based on observations, and about 700 per year based on estimates that account for the current underreporting.
- The level of uncertainty in these numbers is still substantial. Nevertheless, the numbers given here appear to be quite conservative for many countries, and future numbers significantly below these are not likely. For some countries even a substantial increase of reports can be expected for longer periods with careful observations, e. g. for Russia.

Hopefully, and with support by the described current severe weather research initiatives in Europe, a similar survey to this one during the next ECSS in Léon in 2004 will lead to an even broader perspective on tornadic storms in Europe. This should then probably also include downbursts, where an even more serious underreporting problem is likely to exist today.


## Acknowledgments

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Information on mentioned projects and groups is available for the ESSL: www.essl.org, ESWD: www.eswd.osmer.fvg.it, ESTOFEX: www.estofex.org, Skywarn Europe: www.skywarn.eu, and TorDACH: www.tordach.org.

# A Wegener's tornado definitions

As his book is not readily available today, here are the original German text excerpts with the definitions by Alfred Wegener (1917) translated to English above:

**p. 3:** "Windhosen und Wasserhosen sind gleichartige Erscheinungen, nur ist erstere Bezeichnung auf dem Lande, letztere auf See gebräuchlich. Sollte es einmal gelingen, geringe grundsätzliche Unterschiede zwischen beiden zu entdecken, was bisher mit Sicherheit nicht möglich ist, so werden sich solche vermutlich ohne weiteres auf die verschiedene Reibung am Untergrunde zurückführen lassen."

**p. 5:** "... Wind- und Wasserhosen sind große Luftwirbel mit vertikaler Achse, die vom Rande einer Cumulo–Nimbus–Wolke meist bis zum Erdboden herabreichen, in ihrem Inneren durch Kondensation in Form eines herabhängenden Zapfens, Trichters, Schlauches oder Säule, im unteren Teil auch durch Staub, ganz oder teilweise sichtbar sind und in einer meist nach Hektometern zählenden Spurbreite durch stürmisches Hinzuströmen der Luft zu dem stark luftverdünnten Raum um die Wirbelachse gewöhnlich derartige Verwüstungen verursachen, wie sie auch bei den schwersten Stürmen größerer Ausdehnung nicht beobachtet werden."

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# Tables

Table 1: Tornadoes over land, per country per year. First two data columns give the average number based on observations, the second two give an estimate of the expected "true" number. For the last countries in the list, only estimates by T. Meaden were available.

| | Observation | | Estimations | |
|---|---|---|---|---|
| Country | min | max | min | max |
| Albania | 0 | 0 | 2 | 2 |
| Austria | 3 | 3 | 5 | 5 |
| Belgium | 2 | 5 | 5 | 10 |
| Bulgaria | 1 | 3 | 2 | 2 |
| Czech Republic | 7 | 7 | 10 | 10 |
| Estonia | 8 | 11 | 8 | 11 |
| Finland | 5 | 5 | 10 | 10 |
| France | 8 | 8 | 10 | 30 |
| Germany | 10 | 10 | 30 | 30 |
| Greece | 6 | 6 | 8 | 10 |
| Hungary | 8 | 9 | 10 | 13 |
| Ireland | 10 | 10 | 10 | 11 |
| Italy | 15 | 15 | 12 | 18 |
| Latvia | 1 | 4 | 3 | 7 |
| Lithuania | 1 | 1 | 3 | 5 |
| Netherlands | 20 | 20 | 35 | 35 |
| Poland | 4 | 4 | 5 | 6 |
| Portugal | 1 | 2 | 3 | 3 |
| Romania | 1 | 1 | 3 | 3 |
| Russia (Europ.) | 4 | 5 | 8 | 10 |
| Slovakia | 1 | 1 | 4 | 4 |
| Slovenia | 1 | 1 | 1 | 1 |
| Spain | 8 | 12 | 30 | 30 |
| Switzerland | 2 | 2 | 3 | 3 |
| United Kingdom | 33 | 33 | 50 | 50 |
| Norway and Sweden | n/a | n/a | 5 | 5 |
| Denmark | n/a | n/a | 2 | 2 |
| Malta and Cyprus | n/a | n/a | 2 | 2 |
| Total | 160 | 178 | 279 | 328 |
| Average $\pm \Delta$ | $169 \pm 9$ | | $304 \pm 25$ | |

Table 2: As Table 1, but for tornadoes over water surfaces, i. e. waterspouts. The numbers given for Ireland are zero because most waterspouts come onshore there and are already included in Table 1.

| | Observation | | Estimations | |
|---|---|---|---|---|
| Country | min | max | min | max |
| Albania | 0 | 0 | 1 | 1 |
| Austria | 1 | 1 | 1 | 1 |
| Belgium | 2 | 2 | 5 | 5 |
| Bulgaria | 2 | 2 | 3 | 3 |
| Czech Republic | 0 | 0 | 0 | 0 |
| Estonia | 2 | 3 | 6 | 8 |
| Finland | 5 | 5 | 10 | 10 |
| France | 2 | 5 | 2 | 5 |
| Germany | 4 | 5 | 15 | 25 |
| Greece | 5 | 5 | 10 | 10 |
| Hungary | 1 | 1 | 1 | 2 |
| Ireland * | 0 | 0 | 0 | 0 |
| Italy | 25 | 25 | 23 | 27 |
| Latvia | 1 | 1 | 1 | 1 |
| Lithuania | 1 | 1 | 1 | 1 |
| Netherlands | 60 | 60 | 100 | 100 |
| Poland | 2 | 2 | 4 | 4 |
| Portugal | 0 | 0 | 0 | 1 |
| Romania | 1 | 1 | 2 | 2 |
| Russia (Europ.) | 1 | 2 | 3 | 4 |
| Slovakia | 0 | 0 | 0 | 0 |
| Slovenia | 1 | 1 | 1 | 1 |
| Spain | 25 | 25 | 150 | 150 |
| Switzerland | 1 | 1 | 2 | 2 |
| United Kingdom | 15 | 15 | 30 | 30 |
| Norway and Sweden | n/a | n/a | 5 | 5 |
| Denmark | n/a | n/a | 3 | 3 |
| Malta and Cyprus | n/a | n/a | 3 | 3 |
| Total | 157 | 163 | 382 | 404 |
| Average $\pm \Delta$ | $160 \pm 3$ | | $393 \pm 11$ | |

Table 3: Data for average total tornado number in Europe per year, based on Tables 1 and 2. First data column gives average number per year and uncertainty based on observations in 25 countries, the second gives the corresponding estimates of the expected “true” average number per year. The last column includes the additional estimates provided by T. Meaden.

| Type | Observation (25) | Estimations (25) | Estimations (28) |
|---|---|---|---|
| Tornadoes $\pm \Delta$ | $169 \pm 9$ | $295 \pm 25$ | $304 \pm 25$ |
| Waterspouts $\pm \Delta$ | $160 \pm 3$ | $382 \pm 11$ | $393 \pm 11$ |
| All | $329 \pm 12$ | $677 \pm 36$ | $697 \pm 36$ |