9.3 A CLIMATOLOGY OF TORNADOES IN FINLAND

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1. INTRODUCTION

Only a decade ago the general assumption among meteorologists was that severe thunderstorms do not occur in Finland and that if they occur, they are very rare. No research on the topic was published from 1960's until recent years, nor were reports collected. However, during the last decade, severe thunderstorms and especially tornadoes have gained a lot of attention in the media. Besides property damage, severe thunderstorms have caused several injuries and fatalities in Finland. Low population density has contributed to the lack of casualties, but as stated by Doswell (2001), in the case of a significant severe thunderstorm event, the risk of hazard becoming a disaster is bigger in the areas where the events are relatively rare.

This study is a first attempt to define a tornado climatology in Finland. The definition of a tornado, methods to collect reports, and the credibility evaluation process are discussed. The study summarizes general features of the tornado statistics such as the monthly, diurnal and geographical distributions.

Collecting severe thunderstorm records is part of the groundwork for thunderstorm-related disaster mitigation. In the future, the climatological risk assessment presented here may provide a basis for tornado-related disaster preparedness.

2. DATA

2.1 Tornado definition and criteria

According to the Glossary of Meteorology a tornado is defined as "*a violently rotating column of air, in contact with the ground, either pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud*" (Glickman 2000). Forbes and Wakimoto (1983) suggested that a vortex would be classified as a tornado if it is strong enough to cause at least F0-damage. This has been adapted in the United States where all tornadoes are classified by the F-scale, even if there is no damage. On the other hand, waterspouts that do not hit land are not classified as tornadoes. In this work a different tornado definition (Teittinen 2001) is used: *A tornado is a vortex between cloud and land or water surface, in which the connection between the cloud and surface is visible, or the vortex is strong enough to cause at least F0-damage*. This definition thus allows all waterspouts to be included under the definition. Similarly, those tornadoes over land that do not cause damage, but with a visible connection between ground and the cloud base, are included.

In this work, we will also make use of the concept of a "tornado case." In one tornado case there might be many tornadoes. For example, several tornadoes might be situated in close proximity to each other (e.g., within the same storm or boundary), but this is still one tornado case. This helps the recording since, for example, in several waterspout cases the exact number, location or timing of each individual tornado is not known. Since waterspouts often occur in groups of 5-20 single tornadoes, recording each of them as an individual event, the monthly, diurnal, intensity and geographical distribution of waterspouts would dominate in this relatively small database.

On the other hand, if tornadoes are known to be situated in separate storms, they are considered to be separate cases. There is often not enough information to split a report into several cases. Particularly in the historical data, the path length would often indicate a series of tornadoes, but the event is still recorded as one case, due to the lack of detailed information on damage tracks. The problem of distinguishing between long track tornadoes and series of short-track tornadoes is discussed in more detail in Doswell and Burgess (1988). The starting point of the first tornado path in each event characterizes the case on geographical maps. In several cases, the same tornado moves over both water and land surfaces. If a tornado is first observed over land, it is classified as a tornado over land; if first over water, as a waterspout.

2.2 Collecting tornado records

This study includes two datasets. The historical dataset is from the period 1796-1996. The new dataset, 1997-2003, covers the period when the Finnish Meteorological Institute has been actively collecting information on tornadoes in Finland. The methods of collecting, evaluation and classification of tornado reports have been different for these two datasets.

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In the new 1997-2003 dataset the preliminary reports were obtained from the general public by phone, web pages or email. In addition, reports from news media were collected, including related newspaper articles and reporter information. In almost all cases, eyewitnesses were interviewed. The credibility of a report was evaluated based on the information available on the event. The type of the observation determined whether the case could be categorized as: confirmed, probable, or possible (Table 1). Only confirmed and probable tornado cases were accepted to be included into the official tornado statistics. Radar pictures were also studied for the data of the last four years (2000-2003). If there was no radar echo during or after a reported tornado, the case was not included in the statistics.

The 1796-1996 historical data set covers the time period when no systematic tornado documentation was maintained at the Finnish Meteorological Institute. The tornado reports were collected mainly from old newspapers and only occasionally were there documented reports obtained from the general public. Only in a few cases, mainly from the 1930's, was there a meteorological description of the event. Due to the lack of detailed information of the tornado cases, these historical data did not go through an extensive quality control and most of the reported tornadoes were included in the statistics.

Figure 1 shows the tornado reports per decade in Finland. The old dataset is probably very incomplete, particularly the records of weak tornadoes. Before the 1930's, there are only a few, if any, known reports per decade. In the 1930's, several significant tornadoes affected Finland, which awoke the interest of meteorologists during that period. Both the attention paid to the problem and the availability of documented cases are reflected in the statistics with a larger numbers of reports during the 1930's, 1990's and 2000's. In the modern period 1997-2003 there has been an average of 10 confirmed and probable tornado cases each year.

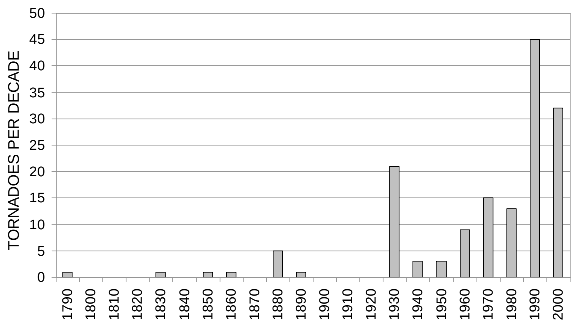

Fig. 1. Tornado reports per decade in Finland.

2.3 Estimation of tornado intensity

The tornado intensity assessment is based on a damage survey, photographs or eyewitness description of the damage. The estimation is based on the Fujita scale (Fujita 1981) and guidance tables for assigning tornado damage to buildings (Bunting and Smith 1993, Appendix C; Minor et al. 1977, Table 4). The estimates are made by a single person, the first author, so the data should not contain some of the inhomogeneties discussed by Doswell and Burgess (1988), although systematic biases may occur. The information available on events in the old dataset was often so limited that an accurate F-scale estimation could not be derived. For the historical data, the F-scale estimation is instead the minimum intensity that could cause the described or photographed damage. In this work tornadoes without damage are not classified by the Fujita scale.

Table 1. Credibility categories of tornado reports. The report is attributed to a certain class if any of the guidelines are satisfied.

Category	Observation type
Confirmed	-A photograph or videotape of a tornado -Damage survey indicates a tornado damage
Probable	-Credible eyewitness observation of a tornado -Credible eyewitness report of typical tornado damage. -A photograph of a typical tornado damage
Possible	-No eyewitnesses -The cause of the damage is not confirmed by the observations of a eyewitness

3. RESULTS

3.1 Geographical distribution

Geographically, tornado density is highest in eastern Finland, in south central parts of the country, and over the Gulf of Finland. Figure 2a shows the geographical location of 151 observed tornadoes in Finland with the corresponding intensity using the F-scale. The density is lowest in Lapland and in some inland areas of western Finland. The density of waterspouts is high over the Gulf of Finland, but also in the lake district of eastern Finland. If each waterspout was recorded separately instead of grouping them into cases, the high density over sea areas would dominate. Since there are numerous inland lakes in Finland, several tornadoes are over water and land at various times during their lifetime. Altogether, 24% of all the tornadoes spent some time over both land and water.

a) b)

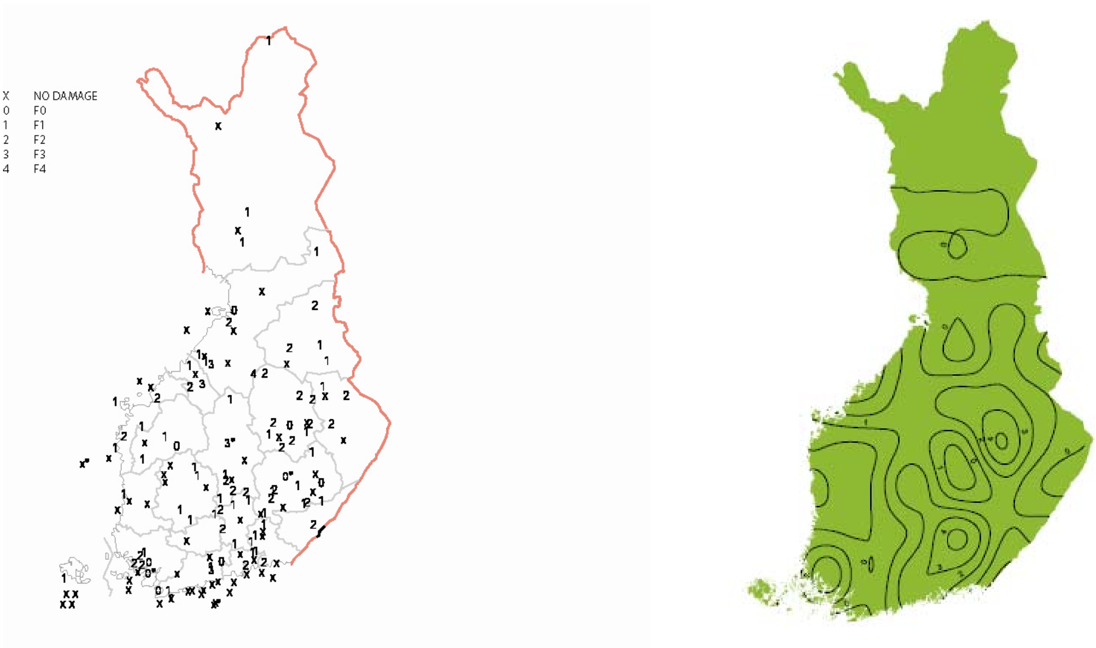

Fig. 2. Geographical distribution of a) all reported tornadoes during the period 1796-2003 in Finland. b) Annual risk probability (in percent) of at least one significant tornado in an 80 km*80 km area based on the 1930-2003 statistics.

The concentration of cases in the eastern half of the country is more evident when only the significant tornadoes (F2 or stronger) are considered (Fig. 2b).The annual risk probability of significant tornadoes was calculated from 1930-2003 statistics. The climatological probability of at least one significant tornado within an 80 km*80 km area during the course of a year in several areas in central southern and eastern central Finland is 2-4 %. This means that a F2 or stronger tornado occurs in the maximum threat area once every 25-50 years. The belt of highest risk extends from the Gulf of Finland over central Finland to the Gulf of Bothnia.

The number of days with thunderstorms could be related to the tornado frequency. The frequency of thunderstorm days in Finland is highest in southwestern Finland where the yearly average is around 20 days. This area does not coincide with the high tornado density areas. In eastern Finland, where the tornado density is high, the average annual number of thunderstorm days is 10-15, the same as in the rest of continental Finland. Thus, the geographical distribution of thunderstorm days does not explain the tornado density in Finland. One cannot find much of explanation to the geographical distribution from the orography either. Finland is a relatively flat country, where only small areas of central Finland and northern Finland have an elevation of more than 200 m above sea level. On the regional scale, this dataset does not seem to display any effect on the concentration of tornado occurrence due to differences in elevation. At a smaller scale, on the other hand, the land-sea and land-lake induced boundaries near the coast and near lakes in eastern Finland may provide a favourable environment for tornadogenesis.

Low population density may lead to underreporting of events and the population bias may affect the geographical distribution of tornado reports in Finland. There were indeed more reports in areas of regionally high population density. In the northern parts of Finland, where the population density is much lower (2 inh/km2), the frequency of tornado reports was low.

3.2 Intensity distribution

The strongest tornado recorded in Finland was of F4 intensity. Besides this case, there were only four F3 cases. A total of 34 significant (F2 or stronger) tornadoes were observed. Most (75%) of the observed tornadoes were of F1 intensity or less. There are differences in the intensity distribution between the two datasets (Fig. 3). From the reports of 1796-1996, 45 % of the tornadoes and from 1997-2003 only 8 % were significant. The large number of weak tornadoes (maximum F1-strength) in the new dataset can be explained by more efficient collecting reports. Stronger tornadoes typically have bigger effects to the society and influence larger area, which leads to better recording of the cases in the statistics.

This can be seen in the large portion of significant tornadoes in the historical dataset.

Tornadoes and waterspouts occurring at coast were of F1 intensity or weaker. Almost all tornadoes that started over water were weak. In central eastern Finland the fraction of tornadoes that were significant was higher than elsewhere in Finland. In Lapland and in large parts in western Finland, significant tornadoes have not been observed. If all waterspouts were recorded as single events, the portion of non-damaging or weak tornadoes would be bigger, especially in the new dataset.

There is uncertainty in estimating the intensity of tornadoes using F-scale. Damage is not equivalent to intensity, since even for the same wind speeds, the damage depends on the object receiving damage (Doswell and Burgess 1988) e.g. terrain, building codes, debris or rapidly fluctuating winds can contribute to the consequent damage and have an effect on the intensity estimation. For example in this dataset, tornadoes without damage are classified as weak, although often the true intensity could not be resolved because there was not anything to be damaged. Doswell and Burgess (1988) considered that by using F-scale, many tornadoes have inappropriate F-ratings, perhaps by two categories or more. On the other hand the Fujita-scale is largely based on damage for buildings and the construction standards in Finland may differ from these in the United States.

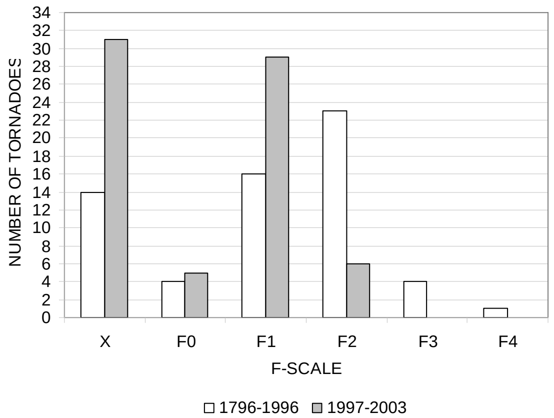

Fig. 3. Intensity distribution.

3.3 Monthly distribution of tornadoes

Figure 4 shows monthly distribution of tornadoes in Finland in 1796-2003. Tornadoes occur in Finland from May till October. More than two thirds of the events (68 %) occur during the statistically warmest moths, in July and August. In comparison, the lightning activity is highest in Finland in July. Over sea areas thunderstorms develop most frequently in July and August.

The distribution of waterspouts is shifted towards late summer compared to all tornadoes. The maximum month is in August, when half of the tornadoes start over water. In July 35 % are waterspouts. There are only few known waterspout cases in late spring and early summer.

For all tornadoes that start on land, the maximum is in July. July is characterized by weak tornadoes over land. Of all tornadoes in July, almost half are weak and start on land surface. The maximum for significant tornadoes is in August when more than one-fourth of all observed tornadoes are significant.

With this dataset significant differences in the monthly distribution between different geographical locations cannot be found. In western inland areas of the country, tornadoes seem to occur mostly in June and July; in the east, they occur during the whole season. Most tornado cases offshore occur in August or September. By reporting each waterspout as a single case, the monthly distribution of tornadoes in Finland would shift more towards late summer and early autumn.

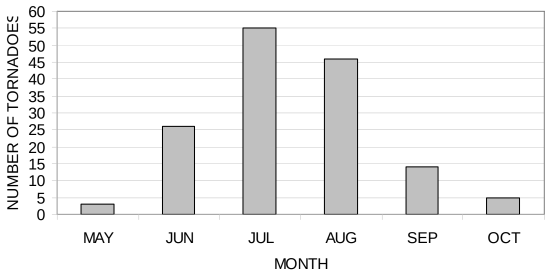

Fig. 4. Monthly distribution of tornadoes in Finland in 1796-2003.

3.4 Diurnal distribution of tornadoes

Most of the tornadoes occurred between 11-21 local standard time (Figure 5). The peak was at 17-19 local time. There were only few observations at night, between 21 and 7 local time. Most (67 %) of the tornadoes over land occurred in the late afternoon and evening, between 15-21 local time. The diurnal distribution of waterspouts was more scattered throughout the day than tornadoes over land. The maximum of the waterspouts was approximately from noon to the early afternoon. If single waterspouts were recorded separately, the diurnal maximum of tornadoes in Finland would be in the morning and before noon.

These results suggest that the diurnal occurrence of tornadoes depends on the destabilization due to solar heating. Typically the seasonal maximum in lightning activity in mainland Finland is also in afternoon, the peak is typically around 15-17 local time. The seasonal lightning activity over the sea is somewhat more evenly distributed throughout the day, than over land areas, but there is still a distinct afternoon maximum and minor morning maximum. A possible explanation is that the warm water surface may be a favorable location for the development of convection at any time of the day or night. It is possible that the lack of tornado reports at night is influenced by the darkness (in the late summer) or a smaller number of people outdoors.

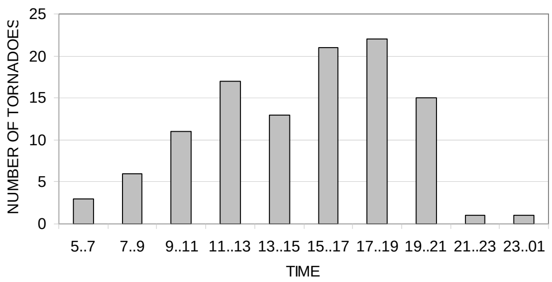

Fig. 5. Diurnal distribution of tornado cases in Finland.

4. CONCLUSIONS

This study summarizes some features of tornado statistics in Finland from 1796 to 2003. Altogether 151 Finnish tornado reports were studied, of which 34 were of F2 intensity or stronger. Reports for the period 1796-1996 show that 45 % of the tornadoes were significant (F2 or stronger) while 8 % were significant during 1997-2003. Tornadoes occur from May till October in Finland. July and August are the months when the frequency is the maximum. July is characterized by weak tornadoes over land, August by waterspouts. The peak season for significant tornadoes is in August. The diurnal peak of tornadoes is between 15-19 local time.

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