CONSEQUENCES OF TORNADIC STORMS IN URBAN AREAS: CASE STUDY OF THE PARIS TORNADO (FRANCE) IN SEPTEMBER 10, 1896

Pierre MAHIEU, Emmanuel WESOLEK

KERAUNOS - Observatoire Français des Tornades et des Orages Violents
97 rue Saint-Sébastien 59000 LILLE, France
e.wesolek@keraunos.org
(26 August 2011)

I. INTRODUCTION

Each tornado presents a threat for goods and people. But the threat is much more serious when a tornado hits a urban or periurban area. The strong population density which is observed nowadays in great cities tends to increase the potential of damage caused by a tornado when it hits them.

In France, tornadoes periodically hit areas with strong population density. Nevertheless, those which hit major cities are not common. On the basis of the KERAUNOS French tornadoes database, which counts 513 tornado cases to date, only 20 tornadoes hit significant agglomerations, i.e. 4% of French tornadoes. The number of strictly urban tornadoes, i.e. which formed and dissipated in an urban environment, are even more uncommon: the Paris tornado of September 10th, 1896, is the only French case in this category.

II. METEOROLOGICAL SITUATION

The meteorological situation which gave rise to the tornado of Paris, this September 10th, 1896, do not have anything exceptional and present a scheme that is frequently associated with severe weather events in France. The authors have reconstituted the synoptic patterns with accuracy thanks to the use of two information sources. The first one - and the most precise one - consists in manual weather observations, which were realised by the French weather stations network and compiled in *Les Annales du Bureau Central Météorologique de France*. The second information source - which corroborates very precisely the first one - consists in the data produced by the reanalysis and research program carried out jointly by the ESRL-PSD (NOAA) and the CIRES.

It appears that the days which preceded the September 10th, 1896 were dominated by a south-western cyclonic flow. A deep high level trough formed on September 9th and 10th on the eastern Atlantic Ocean (FIG. 1). It strenghtened the high level flow on the whole France while taken to northern France a tropical air mass. On the ground level, in the periphery of the main low pressure area positioned on Ireland, a low level trough formed in Spain and moved towards Paris (FIG. 2). The mean sea level pressure data available at the Paris weather center show that a secondary surface low was moving in this surface trough. It concentrated the severe storms which were observed on northern France on September 10th. All these synoptic patterns are consistent with a "spanish plume" configuration, which is known to be regularly associated with severe weather outbreaks in Western Europe, and especially in France.

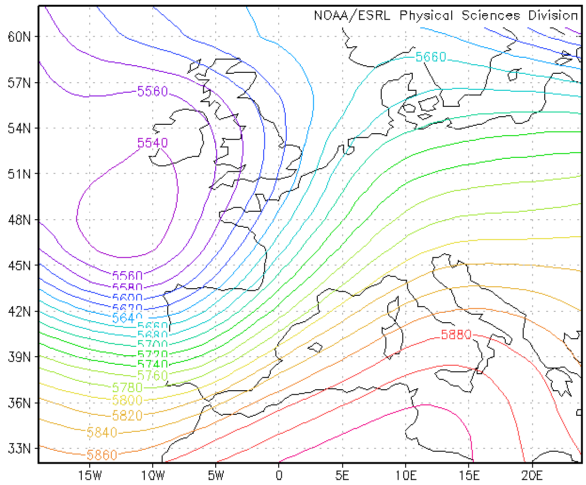

FIG. 1: 500 hPa Geopotential Height (meters). September 10th, 1896, 00h UTC. Source : NOAA/ESRL Reanalysis.

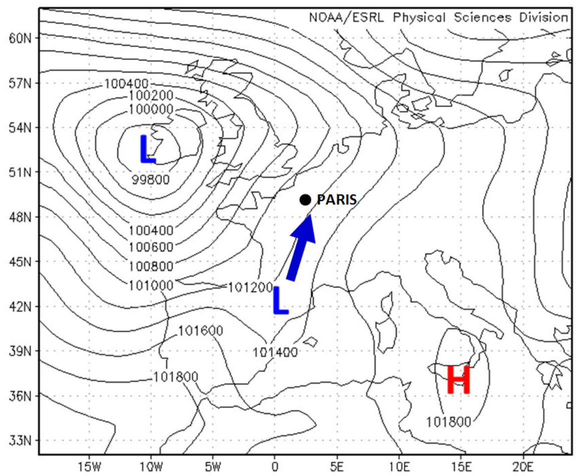

FIG. 2: Mean sea-level pressure (Pa). September 10th, 1896, 00h UTC. Source : NOAA/ESRL Reanalysis. L = low pressure ; H = high pressure.

III. CHARACTERISTICS OF THE TORNADO

The path and the intensity of this tornado could be reconstituted thanks to the many testimonies which were described in the newspapers.

The authors have realise a precise inventory of the damage caused by this tornado, in order to analyse its characteristics. It appears that the tornado hits Paris at 2:30 p.m.. It reached a F2 intensity on its 6.500 meters path, between the *Jardin du Luxembourg* and the old public dump (current *Adolphe Mille* street). It followed a linear track, from south-west to north-east, and struck 6 different districts of Paris (FIG. 3). But, as other urban tornadoes (Wesolek, 2010), its path was affected by discrete deviations and by variations in the width of the damage area (average width of 300 meters, with minimum width of 100 meters and maximum width of 400 meters). The devastation area represents 195 hectares, i.e. 2,5% of the territory of Paris in 1896.

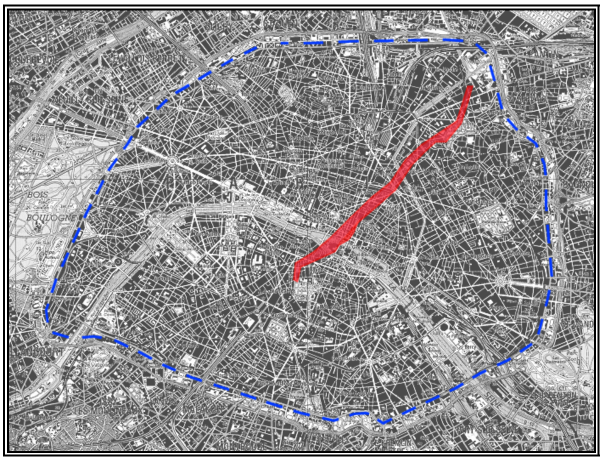

FIG. 3: Map of Paris city, with borders of the city in blue ; the tornado track and damage area is indicated in red

It is worth noting that the tornado hit the barograph of the meteorological observatory of the Saint-Jacques Tower. This barograph recorded a quick drop of sea-level pressure, which is quite uncommon for this sort of instrument. The sea-level pressure suddenly dropped from 748 mm (997 hPa) to 742 mm (989 hPa) at 14:43. Thanks to this information, the precise hour at which the tornado hit Paris could be determined.

IV. DAMAGE ANALYSIS AND IMPACT ON THE POPULATION

The analysis of this tornado case brings several interesting conclusions as far as the impact of tornadoes in urban areas is concerned.

The first conclusion deals with the vulnerability of urban areas when they are hit by tornadoes. Indeed, even if it is possible that great urban centres could have a negative influence on the formation of the weakest tornadoes (F0-F1) (Elsom, 1982), it appears that the probability for a tornado to kill people is significantly higher in a urban area than in other areas. Indeed, the Paris tornado of 1896, in spite of a relatively common intensity (F2), killed five people, who all succumbed to their wounds. This tornado is thus the 9th deadliest tornado in France, as far as the number of killed people is concerned, on the 513 cases which are listed in the French tornado database. Furthermore, it is the deadliest F2 tornado in France. This tornado also caused a wide number of injuries (more than 70 people were severely injured). Indeed, the analysis of urban French tornadoes shows that they cause about 3,2 deaths by occurrence in France, whereas the tornadoes in rural areas cause only about 0,1 death by occurrence (FIG. 4). In addition, 1 urban tornado out of 3 causes at least one death in France, whereas hardly 1 rural tornado out of 20 causes a death (FIG. 5). Thus, even if the urban tornadoes are not very common, they present a significant risk of death, even for moderate intensity tornadoes.

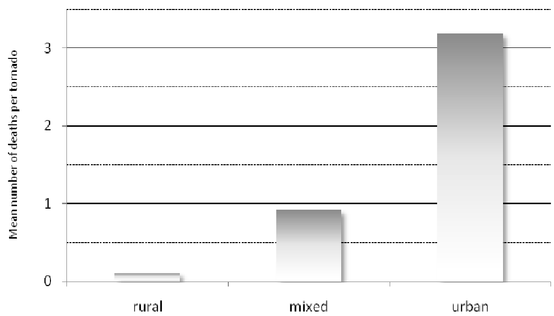

FIG. 4: median number of death per occurrence of tornado, in France, according to the type of environment (rural/mixed/urban).

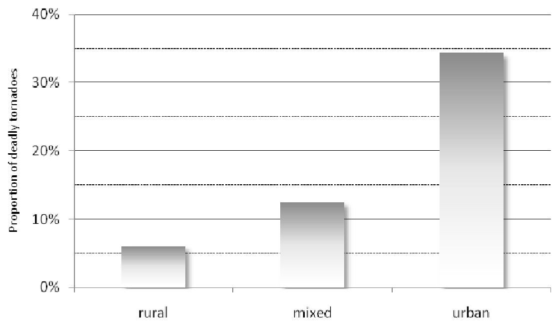

FIG. 5: proportion of deadly tornadoes, in France, according to the type of environment

The second conclusion deals with the type of wounds which were observed in the population. It appears that the five deaths caused by this tornado have all been the consequence of a fracture of the skull. These fractures were the result of the fall of heavy objects (pieces of roofs or street furniture) or of the violent thrown of the victims on the ground or on the walls of nearby buildings. Various fractures, especially on the legs, are regularly noted among the injuries. These reports are not surprising : head injuries and fractures have been already identified as main causes of death during the 3 May 1999 tornado outbreak (Brown, 2001). Most of these severe injuries could probably be avoided with simple public safety recommendations, especially to protect one's head and to go in the nearest solidly built building

The third conclusion deals with the caracteristics of tornado damage in an urban environment. Indeed, it appears that the track of the Paris tornado was straight when it hit the oldest districts. These districts are composed of a very tightened and very dense habitat, and the damage which is observed there is strongly concentrated, with little peripheral damage. Inversely, the tornado track seems to become more irregular when it hits more modern districts. These districts are characterized by many open spaces, with large avenues and public gardens. The peripheral damage is much more numerous there and the width of the damage area is almost doubled. This behavior of the tornado is probably caused by significant disturbances in the surface flow produced by large avenues, the river *Seine* or other large squares. It is thus probable that urban areas with a very dense, homogeneous and tightened habitat are less exposed to wide devastations than an urban area with large avenues, streets, squares and multiple public gardens. Even if this conclusion needs to be confirmed by the analysis of other tornado cases in urban areas, this assumption could be taken into account in order to identify the urban environments which are supposed to be more exposed to severe tornado damage. This could be useful in order to adjust the public safety procedures in urban areas.

V. REFERENCES

Brown S., Archer P., Kruger E., Mallonee S., 2001 : Tornado-Related Deaths and Injuries in Oklahoma due to the 3 May 1999 Tornadoes. *Weather and Forecasting, 17*, 343-353.

Elsom D.T., Meaden G.T., 1982 : Suppression and Dissipation of Weak Tornadoes in Metropolitan Areas: A Case Study of Greater London. *Monthly Weather Review, 110,* 745-756.

Wesolek E., Mahieu P., 2010 : The F4 tornado of August 3, 2008, in Northern France: Case study of a tornadic storm in a low CAPE environment. *Atmospheric Research, 100, 4*, 649-656.