CONTRIBUTION TO AN EUROPEAN ADAPTATION OF THE ENHANCED FUJITA SCALE : ANALYSIS OF DAMAGE CAUSED BY TORNADOES IN FRANCE

Pierre MAHIEU, Emmanuel WESOLEK

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

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I. INTRODUCTION

In a general way, a tornado can be defined by three parameters: the width of its path, the length of its path and the wind speeds produced by the vortex. The first two parameters can be quite easily observed by a ground or an aerial survey. But it is a real challenge to determine precisely the speed of the winds generated by a tornado. Indeed, it is not common for an anemometer to be located on a tornado path; and even if it is the case, the anemometer is generally destroyed. The direct measurement of wind speeds in a tornado is consequently almost impossible.

However, wind speed measurements within tornadoes have already been realised by Doppler radar, but it appears that this sort of remote measurement have some limits, essentially because ground level winds are not accuratly measured (Wurman et al., 2007). Furthermore, it is nowadays impossible to proceed to this type of measurements in a systematic way, because of its costs and its technical complexity.

Today, and undoubtedly still for a long time, the only way to evaluate the intensity of a tornado remains to analyse the damage which a tornado causes on the various objects that it hits. It is thus very important to be able to analyse this damage with the highhest degree of accuracy, in order to avoid any mistake. The bases of tornado intensity rating methods have been established in the United States, and they allow high quality tornado ratings on this continent. But the issue here consists in determining if these American bases can be augmented by the analysis of the damage caused by tornadoes in European landscapes, which is slightly different from American landscapes.

II. METHODOLOGY

In order to analyse the damage caused by tornadoes in France, the authors have used the KERAUNOS French tornadoes database as a reference. KERAUNOS is a meteorological team who undertakes on the one hand to seek historical tornado cases, and on the other hand to document all recent tornado cases, especially with site investigations. This database is built on strict rules, in order to ensure the homogeneity of the criteria which are used to collect and validate tornado cases. Indeed, the main objective is to build a reliable database, with only fully verified tornado cases. That's why the KERAUNOS database is divided into two lists: the "main list" with fully verified tornado cases; the "second list" with very probable but not fully verified cases (all the criteria required for a main list validation are not filled).

In order to be in the main list, the tornado case must be sufficiently documented to allow a precise examination of the nature of the damage (suction effects, debris blown away,…) as well as the organisation of the damage (linear organisation, convergent surface flow). If both the nature and the organisation of the damage are clearly established, the case is integrated into the KERAUNOS database as a tornado. The study is based on this database.

III. FROM F-SCALE TO EF-SCALE

When the KERAUNOS database was created, and until 2007, the tornado intensity ratings were realised by using the Fujita scale (Fujita, 1981). Indeed, this scale has been used worldwide and has been the reference scale for intensity ratings of French tornadoes since its implementation. Besides the KERAUNOS database contains all the tornado cases already listed by Prof. Jean Dessens in the 80s' (Dessens et al., 1989) ; all these cases were already rated by using the Fujita scale.

However, in 2007, the publication of the Enhanced Fujita Scale (EF-scale) opened new perspectives. Indeed, it has appeared for a long time that the "original" Fujita scale was not fully adapted to the French and European tornado damage, and this for two reasons: on the one hand the "original" Fujita scale was initially designed as a wind speed scale (which are not directly measurable) ; on the other hand the criteria which are described in the "original" Fujita scale are quite unprecise and more adapted to American urban and rural landscapes. Consequently, many tornado ratings were not very precise in France insofar as the damage observed could not be interpreted directly on the "original" Fujita scale.

Many studies have been realised these last years in order to modulate the "original" Fujita scale and to adapt it more precisely to the European area caracteristics, for example by redefining the various levels of the scale according to the construction standards observed in Central Europe (Feuerstein et al., 2010).

Nevertheless, from our point of view, it could be interesting to propose a new approach, which could be complementary with the aforementioned one. Our way consists of using an EF-scale approach in order to transpose the principles of the EF-scale for the French tornado cases.

Indeed, the "EF approach" appears relevant to us and seems to open promising perspectives, insofar as it distinguishes various damage indicators and thus takes into account in a more precise way the solidity of each sort of building, of each infrastructure or each type of vegetation damaged by the tornadoes.

IV. PROPOSALS OF COMPLEMENTARY DAMAGE INDICATORS

In order to determine the possibility of using an EF-scale approach for the French cases, the damage caused by each one of the 513 tornado cases of the KERAUNOS database have been compiled in order to build an exhaustive list of damage. Then, the damage list was sorted, in order to give a synthetic vision of the elements which are regularly affected by the French tornadoes. The list of these main sorts of damage is the following one:

- vegetation (trees, vines,…);
- rivers;
- fields;
- buildings (houses, barns or factories);
- civil and religious monuments (churches), castles;
- high-rise buildings;
- retail buildings;
- cemeteries;
- vehicles (cars, agricultural carts, trucks,...);
- electrical transmission lines;
- street furniture;
- humans and animals.

Then the issue has been to determine the damage indicators which are relevant in order to efficiently represent the whole list of known damage.

The EF-scale already counts 28 damage indicators, which constitute as many references which allow a precise tornado intensity rating. The current limit of this approach is due to the fact that the damage indicators which compose the EF-scale are to some extent typical American indicators. All these indicators are not applicable in Europe, and some of them have to be adapted to the characteristics of the European habitat. Our work thus consisted in determining the EF-scale damage indicators which are likely to be applied in France without modification ("common" indicators), and isolating the others ("specific" indicators).

It appears that a little number of damage indicators can be directly applied in France. These indicators can be qualified as "common", insofar as we can considered that their characteristics are sufficiently similar in the U.S.A. and in Europe so that a degree of damage is not rated on a different level in the United States or in France. The possible differences in construction standards for these indicators appear indeed to be too marginal to cause different classifications. The "common indicators" are for example : small barns or farm outbuildings, manufactured home, automobile showroom, trees, luminary poles, family residences (some of them),... Other damage indicators can be partly applied in France. These are for example high-rise buildings or warehouse buildings.

The other indicators which are listed in the EF-scale can be qualified as "specific indicators". The use of these indicators is probably limited to the United States, insofar as none of them has been observed in any tornado case in France.

But some of the "common indicators" do not cover all the families of damage identified in France. Our proposal thus consists in adding specific indicators which are not specific to the United States, but specific to France - and probably to Europe in a general way. These specific indicators are the following:

HOUSES :

- cottages, cob houses ;
- urban adjoining houses (stone and/or brick);
- urban apartments (18^{th} or 19^{th} centuries) built in large avenues;
- farms.

OTHER BUILDINGS :

- mills ;
- manufactures and factories ;
- churches ;
- medieval castles ;
- other castles (Renaissance style).

OTHERS :

- tombstones and other components of cemeteries
- rivers

This list of specific damage indicators could be augmented by four complementary indicators:

- humans or light animals (lifted off the ground or not)
- heavy animals (lifted off the ground or not)
- light vehicles (lifted off the ground or not)
- heavy vehicles (lifted off the ground or not)

Each one of these specific indicators has been analysed in order to determine the relevant degrees of damage for each indicator. The last stage finally consisted in determining, for each degree of damage, the level associated on the EF-scale. The method consisted in gauging each degree of damage of a specific indicator while referring to the damage undergone by a common indicator hit at the same time by the same tornado. For example, it was possible to determine that a tornado which remove large sections of roof structures, on houses which correspond to the common indicator known as "family residences", and which thus has an EF2 intensity, generally collapse the summit of the bell-tower of the churches located on its path. Consequently, the degree of damage "collapse of the summit of a bell-tower" could be associated with an EF2 intensity. This calibration principle of the specific indicators on the basis of the common indicators was applied to all the French tornado cases, in order to establish a reliable relationship between the degrees of damage of each indicator and a precise tornado intensity rating.

V. FURTHER RESEARCH

Our aim would be to widen these proposals on a European scale and thus to be able to validate, on an international level, all the specific indicators which are relevant for Europe, in complement of those already defined in the current EF-scale. Tornado ratings would undoubtedly gain in precision and homogeneity with such a method, and would make it possible to carry out more rigorous climatological comparisons on the two sides of the Atlantic.

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