Atmospheric Research 100 (2011) 649–656

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

The F4 tornado of August 3, 2008, in Northern France: Case study of a tornadic storm in a low CAPE environment

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ARTICLE INFO

Article history:
Received 15 February 2010
Received in revised form 1 September 2010
Accepted 7 September 2010

Keywords:
Tornado
France
Case study

ABSTRACT

A strong tornado hit seven cities of northern France in the late evening of Sunday, 3 August 2008, causing severe damage along its 19 km path from Pont-sur-Sambre to Boussois. Three people were killed in the collapse of their house and 18 were injured. More than 1000 houses were damaged and several thousand trees were uprooted or fallen down.

The authors led a damage survey in the hours that followed the disaster, then investigated this case, in order to determine the characteristics of this tornado precisely and to better understand the conditions that led to its formation. Weather radar analysis shows that the convective cell that gave rise to the tornado took on a fairly pronounced S-shaped structure, with a persistent mesocyclone in the central part of the convective system. The synoptic and mesoscale pattern associated with this severe storm was very dynamic, and characterized by a coupling between a low-level jet and a highly divergent jet-stream. The authors have reconstructed a vertical profile for this case study, in order to describe the tornadic environment precisely. The reconstructed profile reveals two main elements, namely an environment having a very modest vertical instability on one hand, and the presence of intense wind shear, notably in the lowest layers of the atmosphere on the other hand. This conclusion is supported by the analysis of many instability and shear parameters.

1. Introduction

The powerful tornado that struck northern France on August 3, 2008 was probably the most violent tornado to hit Europe in 2008. Despite its remarkable power, it is worth noting that this tornado developed within an air mass whose vertical instability was quite normal for the summer months in France. In fact, cases of tornadoes in low Convective Available Potential Energy (CAPE) environments have already been the subject of studies in the United States and in Europe: e.g., Clark (2008); Geerts et al. (2009) and Groenemeijer et al. (2009), have studied the subject quite recently. Nevertheless, most of these case studies generally deal with low to moderate intensity tornadoes (<F3). The fact that the Hautmont tornado, a F4 intensity tornado, was produced despite a very limited CAPE, makes it unique from this standpoint, insofar as tornadoes of this intensity are more commonly associated with strong vertical instability, especially in the lowest 3 km above the level of free convection (Rasmussen and Blanchard, 1998). The purpose of this study therefore consists of detailing the meteorological governing the formation of this tornado and identifying the key atmospheric elements in this situation, in particular to improve the forecastability of this type of event.

2. Damage survey

The site investigation shows that the tornado first touchdown occurred in a corn field at 20.28 UTC with an F1 intensity. A few houses suffered minor damage and large branches of hard wood were broken.

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0169-8095/$ – see front matter
doi:10.1016/j.atmosres.2010.09.003

Only 2 min later, the tornado reached an F2 intensity (many uprooted trees and several damaged houses), then, at 20.31 UTC, an F4 intensity, causing the total destruction of one solidly built house (see Fig. 1). Many trees were uprooted and some of them were completely debarked.

Keeping its F4 intensity for 2.5 km (up to 20.33 UTC), the tornado crossed the Fayt Wood, uprooting and debarking all the trees on its 150 m wide path. Then, it hit the city of Hautmont, where 3 people were killed by the total destruction of their house. Hundreds of houses were severely damaged all around the tornado path (sometimes as far as 500 m from it), some of them were demolished down to the foundations in the central part of the path. Many cars were thrown to significant distances, and one was lifted up to the first floor of a severely damaged house. Some trees were thrown to more than 500 m. Little objects, like photographs or chequebooks, were thrown to more than 30 km.

A few minutes later, the tornado weakened to F2 intensity, causing significant damage on the boroughs of Maubeuge. The bell-tower of a church collapsed. Many other infrastructures (factories, hospitals, the city-hall, the zoo) sustained moderate damage. Hundreds of trees were knocked down at the Public Garden and all around.

About 12 km after its touchdown, the tornado weakened to F1 intensity. It hit the Military Cemetery of Assevent, where large branches of hard wood were broken. Many little trees were also uprooted. Finally, at 20.40 UTC, the tornado weakened to F0 intensity on a 50 m wide path. Two minutes later, it caused little damage on trees again, then it dissipated at 20.42 UTC near the Belgian border.

The damage survey reveals that this tornado case is of the greatest significance, because it hit a wide variety of terrain with a wide variety of intensities (see Fig. 2), from corn fields and woods to highly populated areas, from a narrow F0 vortex to a 150 m wide severe F4 tornado.

3. Radar echo features

In order to identify the mechanisms involved at the local scale in the production of the Hautmont tornado, a detailed analysis was performed using images produced by weather radar.

It appears that the convective cell that gave rise to the Hautmont tornado was part of a series of prefrontal convective storms, and took on a fairly pronounced S-shaped structure in the 45 min before the tornado formed (see Fig. 3). Analysis of images from a Doppler radar located 40 km from Hautmont (images provided by Météo France) shows the presence of a persistent mesocyclone in the central part of this S-shaped convective system, during more than 30 min. The radial velocity dipole gradually becomes more pronounced, reaching its maximum intensity at the time of the tornado. Moreover, it is worth noting that during this 45-minute pre-tornadic period, the convective system took on a gradual deviation of 15 to 20° to the right of the average flow. These elements in fact suggest a possible supercell structure embedded in an S-shaped convective system.

Furthermore we note a perceptible increase in the storm system's precipitation activity around ten minutes before the tornado touched down. The convective system is characterized by a double heavy precipitation core, the first and main one imbedded in the northern part of the system and the second one, later, in the southern part of the system. Both produced heavy rain, but a major axis of 30 to 80 mm hourly rain accumulation is noticeable about 4 km north of the tornado path, i.e. under the northern precipitation core. During this period, witnesses reported nonstop intracloud electrical activity. Analysis of lightning strikes detected by the METEORAGE detection system shows a small number of cloud-to-ground lightning strikes, but which were distinguished by being mostly positive in polarity.

The tornado touched the ground during the mature stage of the convective system, at the beginning of the outflow-dominated phase of the storm. Indeed, we note that the cell began breaking down within minutes of the tornado touchdown, forming a dying and disorganized convective cell just fifteen minutes later (see Fig. 4).

All of these characteristics suggest the pattern of a high-precipitation supercell embedded in an S-shaped convective system. The result in terms of radar reflectivity is fairly similar to that observed by Wolf (1998), even if the

Fig. 1. Total destruction of a solidly built house in Boussières-sur-Sambre (F4 intensity).

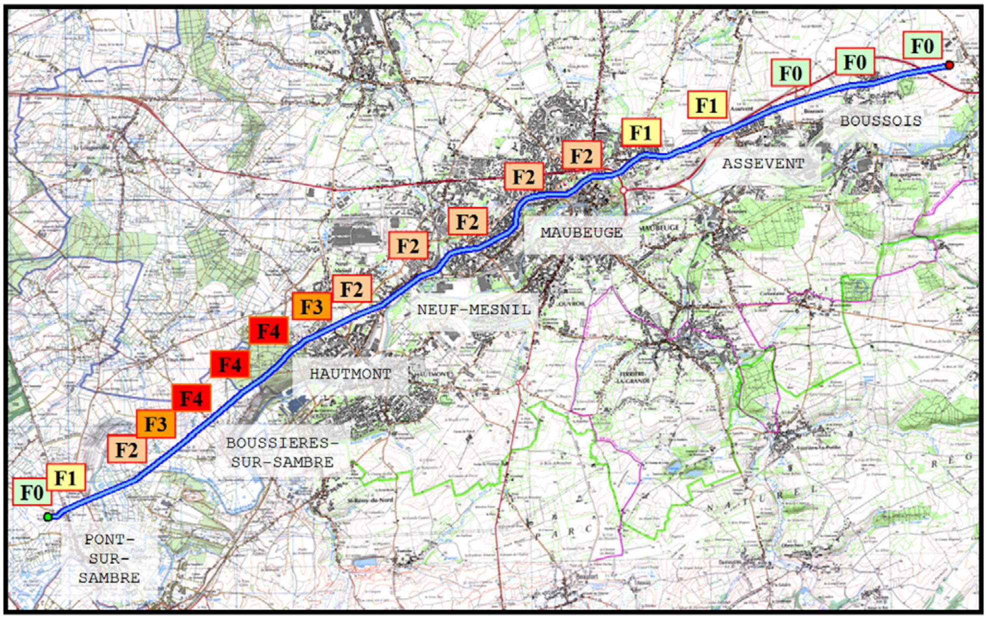

Fig. 2. The 19 km path of the "Hautmont tornado", from Pont-sur-Sambre (south-west) to Boussois (north-east) with F-scale intensities and cities names.

origin of the convective system studied then was markedly different.

4. Synoptic and mesoscale patterns

From a synoptic point of view, this severe tornado was generated during a prefrontal convective event.

That Sunday, August 3, 2008, the meteorological situation was dominated at the surface by a string of depressions stretching from the Atlantic Ocean to the British Isles, Scandinavia, and Russia. All of these depressions displayed modest lows, between 1000 hPa and 1005 hPa. We note the presence of a vast front extending from the tropical Atlantic (Azores) to Benelux, and across northern France. This almost stationary front separated two very distinct air masses: polar oceanic air on its northern flank, and hot, humid tropical air on its southern flank. Fig. 5 superimposes mean sea-level pressure and precipitable water for the evening of August 3 rd. We may clearly detect the presence on the Atlantic of a depression well-supplied with moist air; this moist, mild air was then taken by WSW flows to northwestern France and northern Germany. The air mass present in the Hautmont region on August 3, 2008 thus came from tropical latitudes and was carried by a depressionary, contrasting flow that had its source far away on the Atlantic.

During the evening, a baroclinic mesoscale wave moved rapidly toward northern France, with an associated low-level jet (see Fig. 6). The head of this wave developed a fast moving surface mesolow just ahead of the front, which caused a strong backing of surface winds on northern France.

Meanwhile, the cut-off low positioned over the North Sea since morning developed a trough on its southwestern flank. This short trough advected aloft a cold air mass coming directly from the island regions and simultaneously caused an acceleration of the winds in the mid layers of the atmosphere, as well as an increase in the divergence aloft over northern France. Furthermore we observe a split, then a break in the jet-stream in the evening, again over northern France, associated with a rapidly moving upper-level potential vorticity anomaly (see Fig. 7). Wind speeds in the upper-level west/south-west flow were in excess of 45 m/s, with mid- and upper-level storm-relative winds from 8 to 20 m/s. Kerr and Darkow (1996) showed that these storm-relative

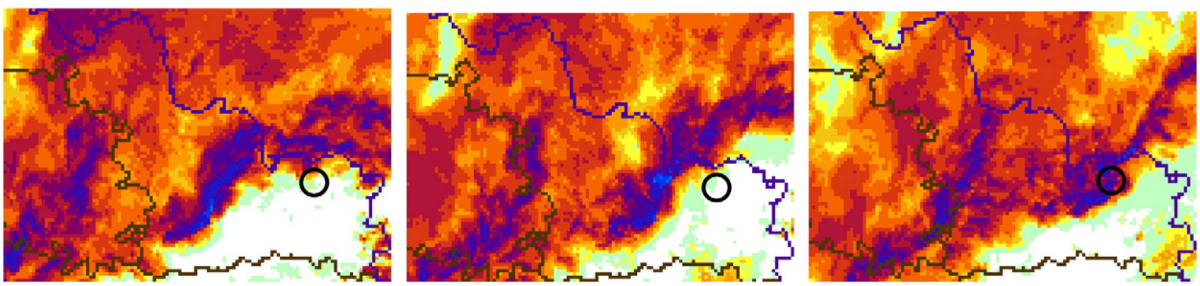

Fig. 3. Radar echo patterns associated with the S-shaped convective system (20:00 UTC, 20:15 UTC, 20:30 UTC). The tornado touched the ground a few minutes before 20:30 UTC. Hautmont is pointed out with a circle. Images provided by Météo France.

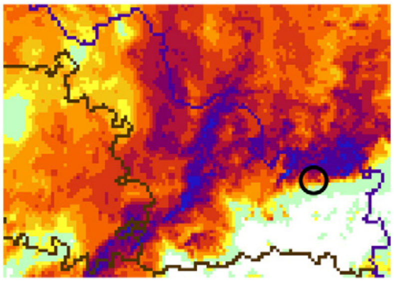

Fig. 4. Radar echo shows a disorganized convective system at 20:45 UTC, a few minutes after the end of the tornadic activity. Hautmont is pointed out with a circle. Image provided by Météo France.

wind values constitute a favorable element in the formation of tornado-producing mesocyclones.

This synoptic pattern, characterized by a coupling between a low-level jet and a highly divergent jet-stream, is known to be severe weather conducive, by forcing deep convection and by insuring high deep shear and high low-level storm-relative helicity values Uccellini and Johnson (1979). Therefore the storm system that gave rise to the tornado developed in a very dynamic situation, marked by a strong convergence in the low layers, and a rapid accentuation of the divergence aloft.

5. Vertical profile reconstruction

5.1. Methodology

A vertical profile was reconstructed for the town of Hautmont on August 3, 2008 at 20:30 UTC (see Fig. 8). This profile was made using three complementary sources: all altitude levels greater than 850 hPa are from the GFS 0.5° forecast at 3 h intervals (21:00 UTC) in a run initialized at 18:00 UTC on August 3, 2008. Between 975 and 900 hPa, the data used are those from a WRF-NMM model at 10 km horizontal resolution, nested into the GFS 0.5° and initialized August 3, 2008 at 18:00 UTC. Lastly, the surface data are those from the Météo France observation network, in particular the Valenciennes, Cambrai and Saint-Hilaire-sur-Helpe stations. These three stations are located within a radius of less than 30 km around the area hit by the tornado and help to precisely integrate surface conditions into the vertical profile.

The sum of these three sources helps to construct as realistic a representation as possible of the atmosphere at the local scale, at the time of the tornado, in terms of temperature, hygrometrics, and wind.

5.2. Vertical profile analysis

The reconstructed profile reveals two main elements, namely an environment having a very modest vertical instability on one hand, and the presence of intense wind shear, notably in the lowest layers of the atmosphere on the other hand.

With regard to vertical instability, it is worth noting that the Most Unstable CAPE value calculated on this profile (444 J/kg) normally is not very favorable to the development of consequential storms. The convective energy is especially concentrated in the mid layers of the atmosphere, where narrow vertical thermal gradients are observed in particular between levels 850 and 700 hPa (6.9 °C/km). Instability in the lower layers is also relatively modest (0–3 km CAPE barely exceeds 80 J/kg). Despite a fairly high Level of Free Convec-

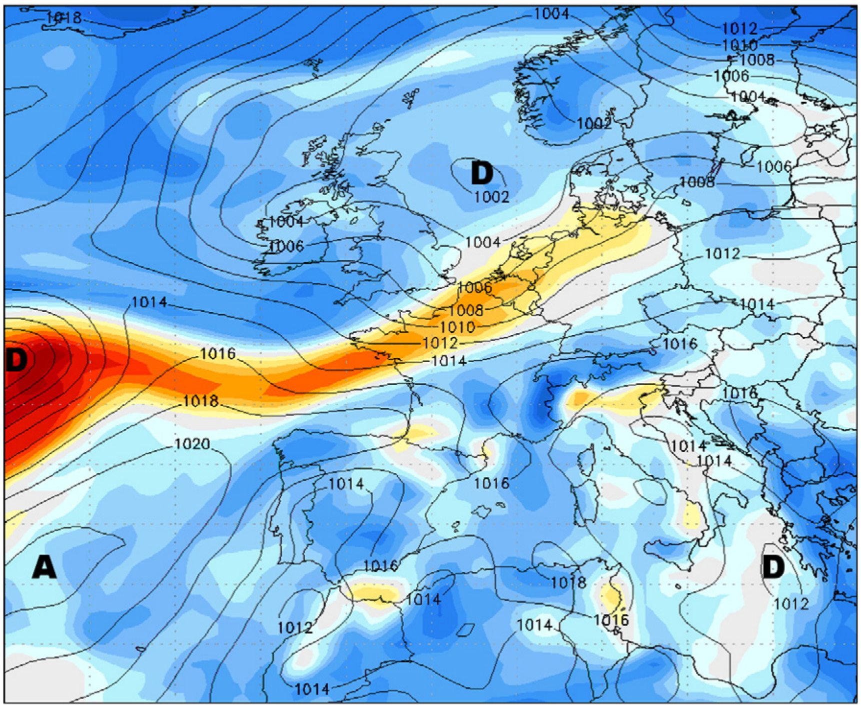

Fig. 5. Mean sea-level pressure and precipitable water on August 3, 2008 at 21:00 UTC (GFS 0.5° initialized at 18:00 UTC).

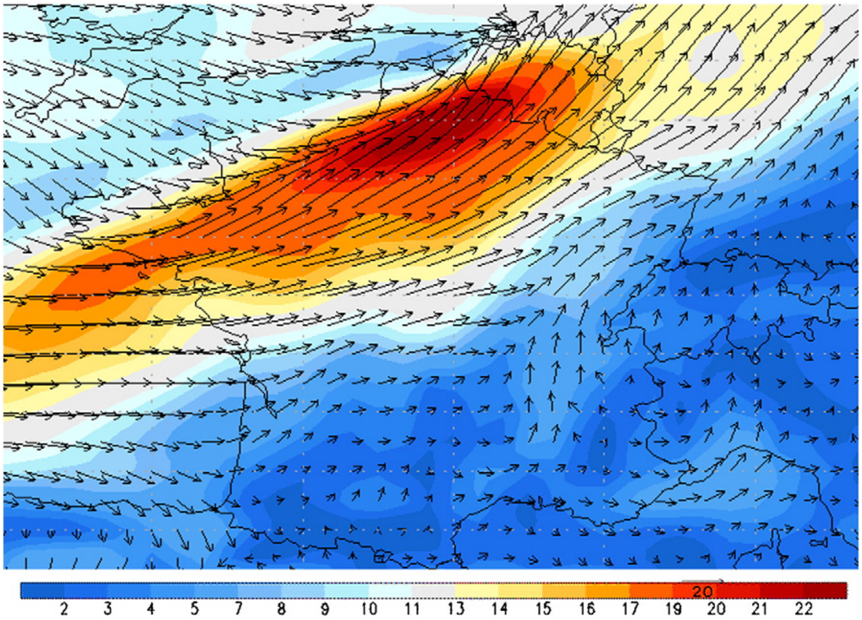

Fig. 6. Strong low-level jet at the 925 hPa level on August 3, 2008 at 21:00 UTC (GFS 0.5° initialized at 18:00 UTC; units in m/s).

tion at around 1500 m AGL, CIN remains relatively low (−26 J/kg) however. Other common instability indicators all display values that support generally mediocre vertical instability: Lifted Index of −1.9°K, Showalter Index of 0.2°K, Total Totals Index of 48.2, K Index of 33.2.

However, it is worth noting that the lower layers present high dew points, greater than 18 °C at ground level. This presence of mild and very moist air in the lower layers produces a particularly low Lifted Condensation Level (LCL : 154 m AGL). While not generating strong vertical instability, these moist lower layers produce a profile that is known to be favorable to the appearance of tornadoes, if the other elements of the vertical profile are favorable, of course. Indeed, the favorable impact of low LCLs on the production of a tornado has already been documented. Rasmussen and Blanchard (1998), for example, established that half of the US tornado cases studied presented LCLs lower than 800 m AGL. Even though the purpose here is not to discuss the results of this study with regard to a French case, it is nevertheless worth noting that this criterion analyzed in the Rasmussen and Blanchard study is confirmed in the Hautmont case.

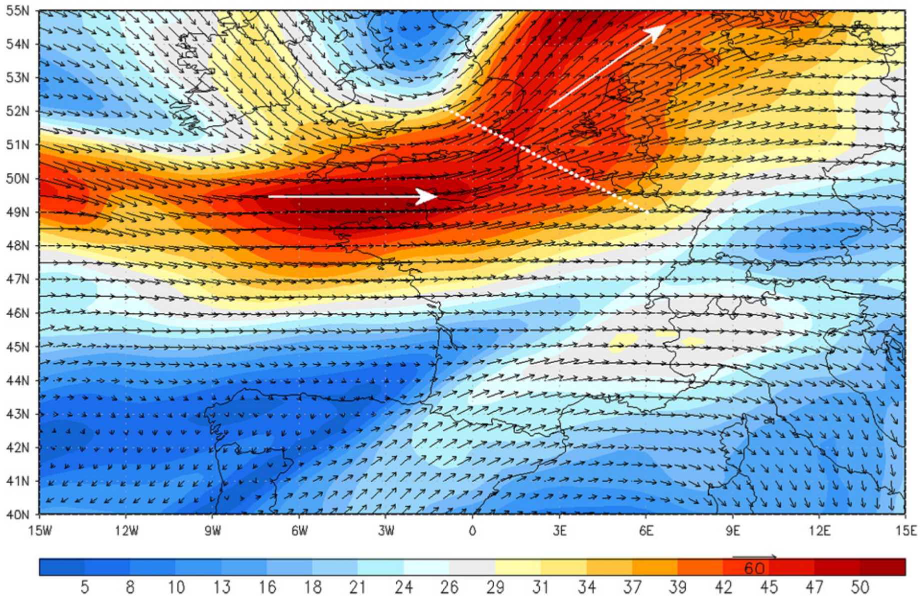

Fig. 7. Simultaneous left-exit and right-entrance jet-stream pattern, insuring strong divergence on northern France. Wind at 300 hPa level on August 3, 2008 at 21:00 UTC (GFS 0.5° initialized at 18:00 UTC; units in m/s).

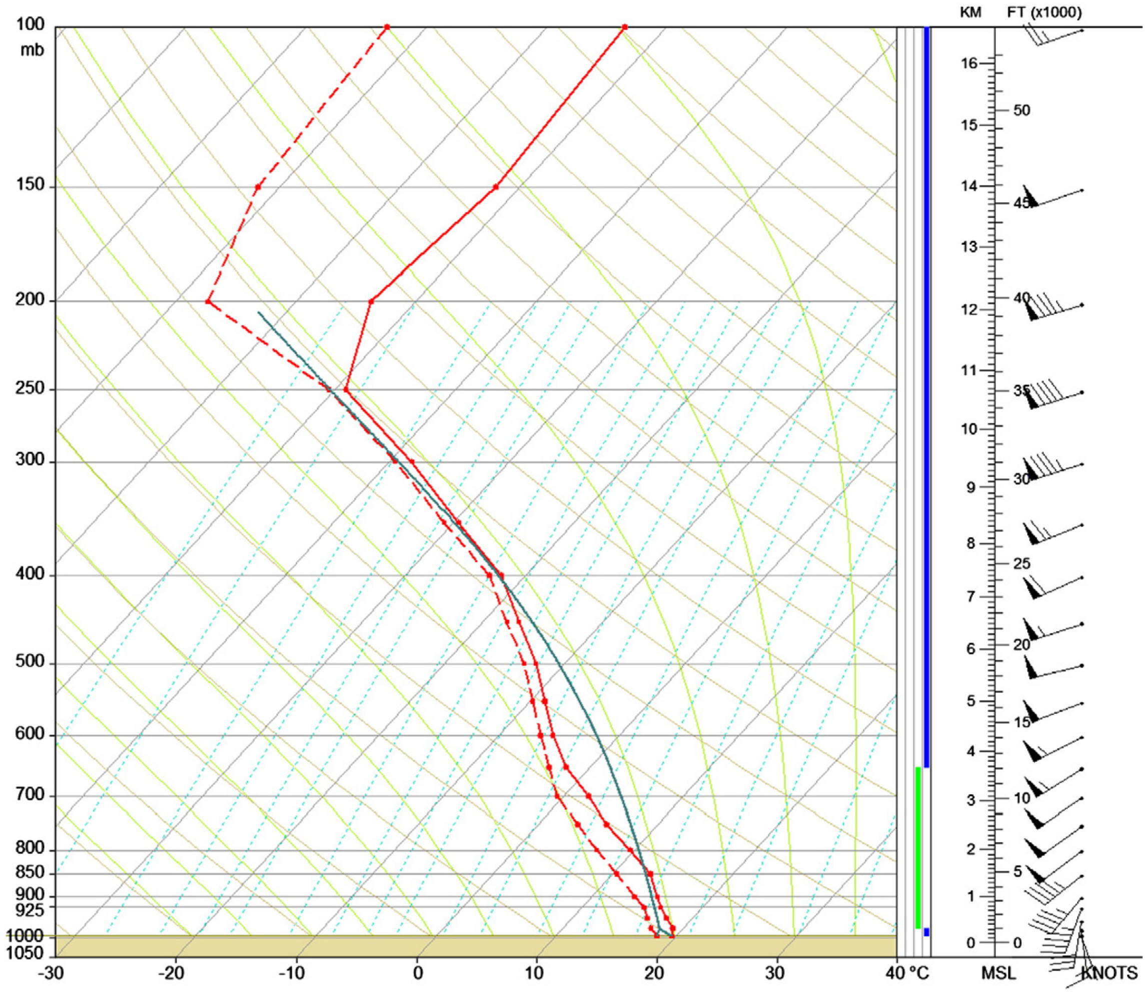

Fig. 8. Reconstructed vertical profile for the town of Hautmont on August 3, 2008 at 20:30 UTC.

Although the vertical instability in this vertical profile is not large, the same is not true of wind shear, which displays markedly more critical values. The circulation of a mesolow over northern France in the evening in fact generated a marked low-level wind rotation in the south/south-east sector, an element that dramatically increased wind shear in the lowest kilometers of the atmosphere, furthermore affected by a vigorous low-level jet. We also note a 0–1 km storm-relative helicity (SRH) of 519 m^2/s^2 and a 0–3 km SRH of 564 m^2/s^2, for a storm motion vector of 255° and 23 m/s. These storm-relative helicity values exceed the thresholds generally recognized as critical to tornado formation. Wind shear in the lowest kilometer of the atmosphere was particularly high, and at a level rarely observed in a convective summer situation. On this subject, Esterheld and Guiliano (2008) were able to show the importance of wind shear between the ground and 500 m or 1000 m aloft in tornado-producing situations. The sample studied presented a significantly higher risk of tornadoes when the 0–1 km SRH exceeded 280 m^2/s^2. In the case of Hautmont, this threshold was fully surpassed, considering that it exceeded 500 m^2/s^2. The same study also presented an interesting analysis of the hodographs associated with strong intensity tornadoes and reports a fairly typical hodograph structure. The authors conclude that a strong straight-line hodograph in approximately the lowest 500 m AGL oriented orthogonal to the storm-relative inflow vector at 10 m favors significant tornadoes. It is worth noting that the reconstituted hodograph for the Hautmont tornado presents this type of structure (see Fig. 9).

Rasmussen and Blanchard (1998) also demonstrated that indices combining vertical instability (CAPE) and wind shear are the most discriminating ones in predicting tornadoes. It is worth noting that the environment that gave rise to the tornado presented an Energy-Helicity Index (Hart and Korotky, 1991; Davies-Jones, 1993) of 1.6 and a Vorticity Generation Parameter (Rasmussen and Blanchard, 1998) of 0.215. Yet, Rasmussen and Blanchard were able to establish in their study that over half of the tornadoes observed were in environments with an Energy-Helicity Index (EHI) greater than 1.5, while 90% of non-tornado-producing storms were produced in profiles with an EHI less than 0.77. Thus, despite very modest instability, an index such as EHI manages to bring out the potentially tornadic nature of the environment in the case of Hautmont. The Vorticity Generation Parameter

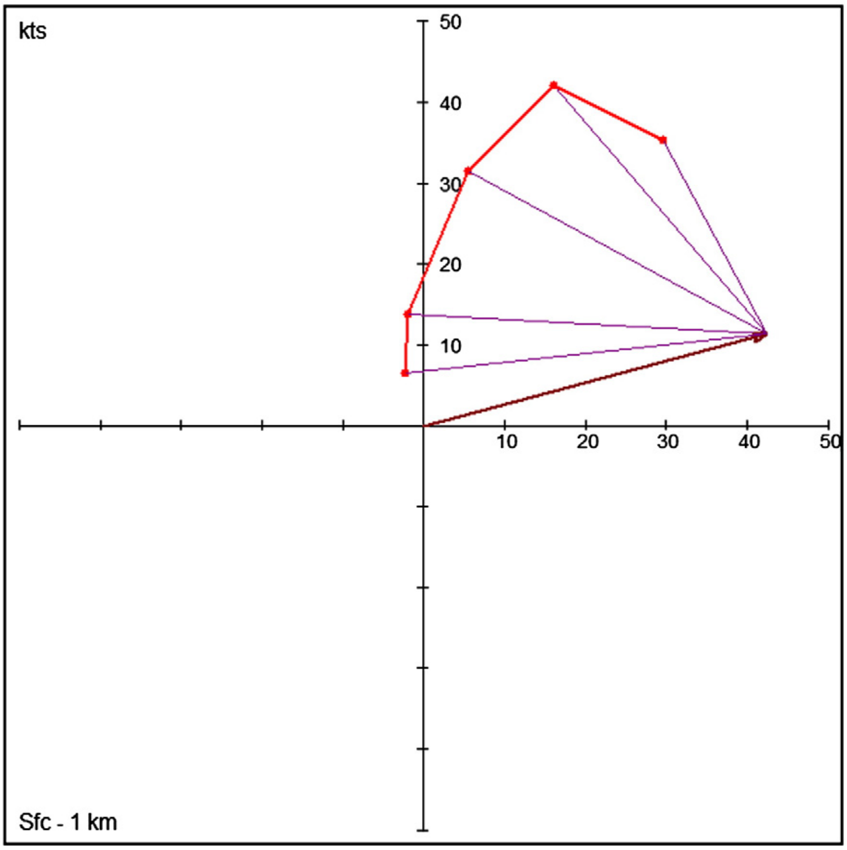

Fig. 9. Reconstructed hodograph for the lowest km AGL, for the town of Hautmont on August 3, 2008 at 20:30 UTC.

value is also within the thresholds presenting a tornado risk, but less markedly so than EHI. Here again, the intention is not to compare the particular Hautmont case with the climatology of US supercells without making a distinction, but to show that the French case meets, despite the low CAPE recorded, a certain number of criteria already established in the US literature. From this viewpoint, the Hautmont case presents, in fact, a certain number of characteristics in common with the profiles already pinpointed as favorable to tornadoes on the North American continent.

6. Conclusions

The tragic events of August 3, 2008, in northern France, are related to a severe tornado, which hit seven cities on a 19 km long and 150 m wide path. Site investigation shows that the vortex reached an F4 intensity and had a translation speed of about 80 km/h.

It appears that this strong intensity tornado formed within a low CAPE environment, which once again demonstrates that violent storms can be observed in weakly unstable contexts. The detailed study of the synoptic situation, the mesoscale situation, and vertical profiles, tends to show that this mild instability was compensated by:

— intense wind shear, especially in the lowest kilometer of the atmosphere,
— a strong convergence of moist air and mild air in the low levels,
— a very dynamic synoptic configuration.

All of these elements therefore combine critical factors to be monitored, notably in the context of forecasting violent storms, even in the presence of limited instability.

Furthermore, from a climatological point of view, this tornado confirms that the Nord–Pas de Calais French area counts among the European areas which are the most frequently hit by severe tornadoes (Dessens and Snow, 1989). Indeed, in this 12,400 km² area, we count no less than 2 F3 (1965, 1998), 2 F4 (1967, 2008) and 1 F5 (1967) tornadoes in the modern period. That means that the tornado risk in this area could be considered as significant.

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