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Brief communication "A multi-disciplinary approach to a side-flash lightning incident to human beings in the Basque Country"

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Abstract. On 31 August 2011 a lightning incident affecting two human beings was registered in the Basque Country (northern Spain). The two individuals were sightseeing in the Painted Forest of Oma (province of Biscay, Basque Country) when an approaching thunderstorm forced them to look for shelter under the lowest branches of one of the trees. A lightning discharge in that exact place caused serious injuries to the couple, consisting of the loss of consciousness, superficial burns, a tympanic membrane perforation and a broken clavicle. The investigation presented in this paper was carried out in order to find out the causes by which the couple was hit by the lightning discharge and why the injuries were superficial and did not kill them. Using the data available by the lightning detection networks in the Basque Country and the information available by the weather radar, the exact place where the lightning discharge occurred could be found, the mechanism of lightning injury was classified and the episode was reconstructed.

1 Introduction

Lightning discharges to human beings are a well known hazard that cause many accidents all over the world. One of the most important sources of accidents by lightning are trees. The accidents related to the presence of trees may cause injuries and even fatalities. As related by Holle (2012), lightning fatality statistics related to trees have been identified in the last decades, for example by Blumenthal (2012b), Holle et al. (2005), Coates et al. (1993), Cardoso et al. (2011), Pakiam et al. (1981) and Agoris et al. (2002).

Since 2001, according to a regional news agency (El Correo, 2012), there has been only one fatality and eight injured people due to lightning discharges in the Basque Country. The last of these accidents correspond to the episode registered on 31 August 2011, when a thunderstorm crossed over the Painted Forest of Oma (2012), in Biscay (Basque Country, Spain). A couple of tourists that were looking for shelter under the lowest branches of one of the trees were injured by lightning.

The thunderstorm over the forest began at 17:00 UTC. Ten minutes later, the lightning impact that affected the two walkers was detected by the sensor networks. However, notification of the accident did not reach the emergency services until 17:31 UTC, when another walker found the injured tourists, one of them still without having recovered consciousness.

In this paper, the investigation carried out in order to find out the reason why the lightning discharge attached to the human bodies is presented. This work analyses the weather conditions under which the lightning activity appeared over the forest, it locates the lightning discharge that caused the accident using the data provided by two independent lightning detection networks, classifies the mechanism of lightning injury following recent literature by Holle (2012) and Blumenthal (2012b), and presents a reconstruction of the causes that led the lightning discharge to find its way to ground through the bodies.

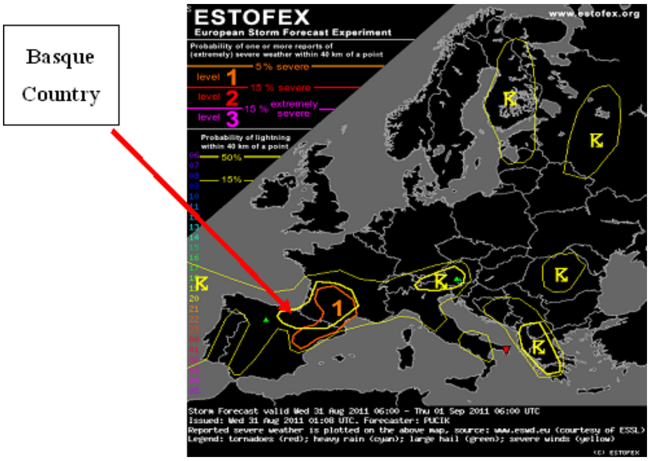

Fig. 1. Location of the Basque Country and meteorological alerts addressed by Estofex on 31 August 2011.

The paper is structured as follows. Section 2 presents the weather conditions under which the thunderstorm developed and the data provided by the lightning detection networks, locating the lightning discharge that affected the two people. Section 3 focuses on the reconstruction of the accident and the injuries that the lightning discharge caused on the bodies. Section 4 presents the conclusions of the study of this episode.

2 Thunderstorm characteristics and lightning detections

On 31 August 2011, the weather report by Euskalmet (the Basque Meteorology Agency) issued the probability of developing storms in the Basque Country territory. The forecast by Estofex (2002) also reported the probability of having storms in northern Spain and lightning in the easternmost part of the Cantabric region.

During the afternoon, convective thunderclouds developed over the Painted Forest of Oma. According to the data provided by the weather radar in the Basque Country (Aranda and Morais, 2006) (see Fig. 2), the core of the convective cell that caused the accident had already crossed over the site where the lightning struck the two people. The picture series in Fig. 3 shows the evolution of the thunderstorm as detected by the weather radar in the Basque Country, the last picture corresponding to the minutes nearest the lightning strike.

2.1 Weather radar data

As it is depicted by the images provided by the Doppler-polarimetric weather radar operated by the Basque Meteorology Agency, the core of the convective cell had already crossed over the forest when the lightning struck. Therefore, the lightning discharge that caused injuries to the two people can be associated with the stratiform part in the back side of the thunderstorm.

The vertical cuts provided by the weather radar show the same situation. The lightning discharge is represented as a red cross in Fig. 2. The picture before the accident shows a much higher vertical development of the thunderstorm over the forest, whereas the picture at the moment of the accident shows the stratiform region over the forest once the convective region has moved forward. The instant of the lightning discharge corresponds to the second vertical cut, and therefore, it can be associated with the stratiform region of the thunderstorm. The data obtained from the weather radar matches the testimony of the injured people, who related how they were already wet when the lightning struck.

2.2 Lightning detections

The cloud-to-ground lightning events detected and located by two independent detection networks (López et al., 2011) do not show an intense electrical activity, with only a few lightning discharges located in the proximity of the forest.

The cloud-to-ground lightning discharge associated with the accident as it was detected by the Linet Network (VLF/LF) (green) and the Basque Country Lightning Detection Network (LF) (red) networks are represented in Fig. 3, showing a good correlation with the exact place of the accident. According to this figure, the two networks located a negative cloud-to-ground discharge with an intensity higher than -10 kA. None of them are exactly located over the affected trees, but, especially in the case of the LF network, the accuracy is very good, with a deviation of only 160 m.

3 Reconstruction of the accident and classification of the lightning discharge

In this section, a reconstruction of the accident based on the testimony of one of the injured people and the data available by the weather radar and the lightning detection networks is presented. Moreover, several visits to the place where the accident happened let us establish the hypotheses presented.

As it has been related before, two people suffered several injuries in the Painted Forest of Oma during a thunderstorm on 31 August 2011. One of the people explained that they became wet due to a heavy rainfall while they were inside the forest. The rainfall has been associated with the previously analyzed thunderstorm together with the strong thunder heard by the two people some minutes before they suffered the lightning impact. That indicates that lightning activity was taking place very close to their position.

Looking at the products provided by the weather radar, it can be seen that the strongest precipitation nucleus of the thunderstorm, which can be associated with the mentioned rainfall, had already passed over the place of the accident before the lightning discharge occurred. The conclusion is that

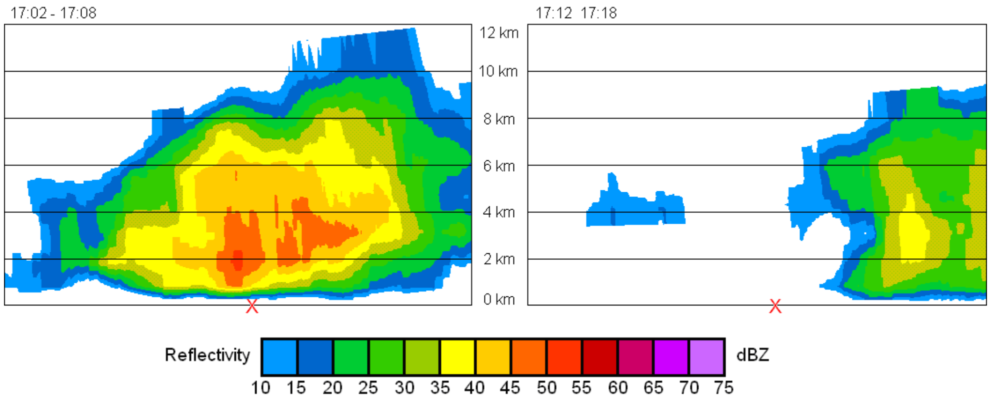

Fig. 2. Vertical cuts of the thunderstorm over the forest (red cross).

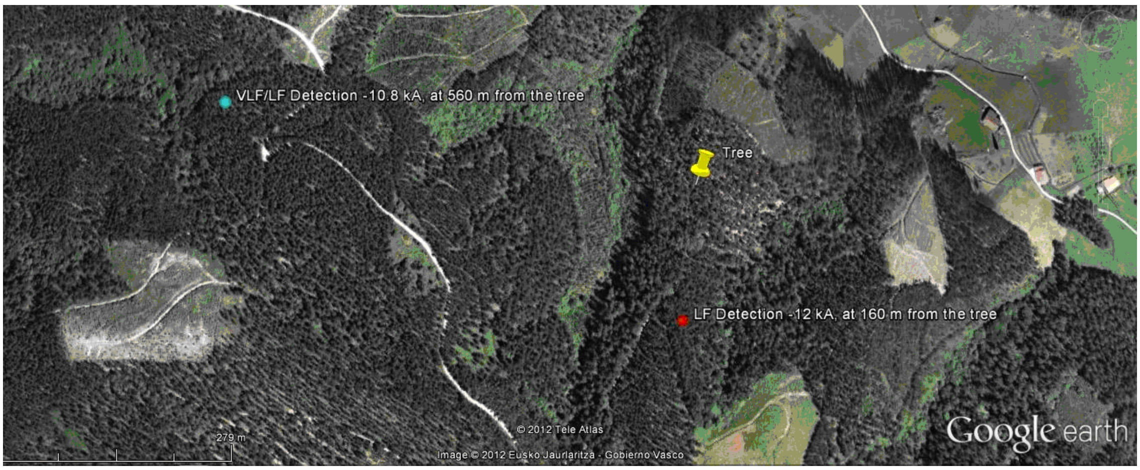

Fig. 3. Location of the lightning discharge that caused the accident as it was located compared to the two networks.

this convective nucleus left most of the rain that wetted the two bodies. When the stratiform part of the thunderstorm was located over them, the cloud-to-ground lightning discharges that usually surround the convective nucleus started getting closer to them. The two people looked for shelter under the lowest branches of one of the closest trees due to the rain and the perceived close proximity of the thunder.

The investigation that was carried out after the accident retrieved the phone call made to the emergency service by the witness that found the bodies. The call was made between twenty and thirty minutes after the lightning discharge impacted the bodies. At first sight, one of the tourists seemed to be dead, and so it was told to the emergency service.

When the medical care arrived at the site, they could confirm that one of the tourists was conscious but injured and that the other one had lost consciousness. They provided the first aid at the site as is recommended in these cases (Browne and Gaasch, 1992), and the two injured people were transferred to the hospital.

Notice of the accident was received by the Basque Meteorology Service (Euskalmet) the following day, 1 September. Through this investigation the lightning discharges over the forest were found (see Fig. 4) and a special search for the one that caused the accident was performed.

In order to find the specific discharge, first communication was established with the people responsible for the forest. Thanks to this communication, one of the trees that had suffered damage by lightning could be found, and then its position was correlated with the data available from the two lightning detection networks, reaching the conclusion that the lightning discharge causing the accident was a negative cloud-to-ground discharge with a peak current of −10 to −12 kA.

A visit to the lightning incident site was performed in order to independently assess the physical evidence and to corroborate it with the witness's testimonial evidence.

The damaged painted tree (*Pinus radiata*) is clearly visible because it is close to one of the paths that crosses the forest. It is a 15 to 20 m *Pinus radiata*, and the wound left

Fig. 4. Wound over the *Pinus radiata* (left) and over the dead trunk (right).

by the discharge covers it from the tip to the bottom, leaving a double strip over the bark. This was a live tree, and the bark was wet due to the rainfall. The pass of the lightning current caused the breaking of the bark and the double strip that remains over the trunk.

However, considering the testimony of the injured man, this could not be the tree where they looked for shelter. It has no low branches that can protect from the rain, and it is too close to the main path; the one they found was a little further away and on a smooth slope. A closer look at the site revealed that there was another wounded tree in another position that looked much more like the one described by the man.

This second tree is located about ten meters away from the painted one, and it presents a unique stripped wound on the bark. It is located over a slope, 2 to 3 m away from the main path, and the lowest part of the trunk presents at first sight a cover made of branches at about two meters over the ground. Actually, these branches do not belong to the tree that suffered the lightning impact but to another close tree. The trunk that suffered the direct lightning impact is not a live tree; it is a dead trunk that has remained standing close to other trees in the forest.

The hypothesis leads us to think that it was not a single stroke. It looks more like two separate strokes, 10 m away from each other, that hit two different trunks, one belonging to a *Pinus radiata* in the forest and the other to a dead tree close to another tree with low branches where the tourists tried to shelter form the rain.

The fact of being a dead trunk is thought to be relevant for this investigation. When the wound over the bark of the dead trunk was studied, it revealed that it does not reach the floor. It stops at a height close to that of the wounded man, coinciding to his testimony, as he related that the lightning discharge impacted directly in his shoulder. Then the lightning current flowed over the surface of the dead tree, because it was the wettest part of it, and then an electric arc was produced between the bark and the man's shoulder. Therefore, we now consider the six different mechanisms by which lightning injures a victim (Blumenthal, 2012a): directly, touch potential, side flash, step potential, upward streamers and the electroblast effect. The mechanism of lightning injury in this case is assumed to be a side flash due to the fact that the lightning discharge stroke first entered the tree and then it jumped to the bodies.

The hypothesis suggests that the accident occurred as follows:

- The two people became wet due to the passing of the convective nucleus of the thunderstorm.
- They started hearing close thunder when they were below the stratiform part of the thunderstorm.
- They looked for protection from the rain below the low branches that belong to the tree close to the dead trunk.
- One lightning stroke hit the dead trunk and covered it from the tip to a height over the ground similar to the man's height.
- Once the lightning current reached that height on its way to the ground across the bark of the tree, an electric

arc was produced between the bark and the more conductive wet body of the man (side flash).

– The current crossed the man's body over its surface, producing burnings and superficial injuries over his skin and his companion's, because they were embracing. The fact that the two bodies were so wet was determinant for the current circulating over the skin and not looking for a more conductive path to the ground through the bodies.

As can be seen in Fig. 4, the wound on the *Pinus radiata* reaches the ground, whereas the wound on the dead trunk stops slightly over a man's height similar to the injured walker's height.

Injuries suffered by the two people

The two injured people were a young man and a woman. In the moment of the accident, and according to the man's testimony, they were embraced, looking for shelter behind the low branches of the tree close to the dead trunk.

When the electric arc jumped from the trunk to the man's body, it connected to the wet clothes of his right shoulder. The current circulated over his skin, from the right shoulder to the left hip, crossing the chest in a diagonal. Then, the current found its way to ground from the left hip to the heel.

As it has been explained before, the mechanism of the lightning injury in this case is the side flash. In these cases, when the lightning strikes first on the tree and the current circulates over the bark, part of the energy of the lightning discharge is dissipated. Therefore, when the discharge jumps to the bodies, the injuries caused are less serious than in the case of a direct impact.

As a result of this side flash, the man presented serious burnings, although superficial, over his body. He also lost consciousness. The woman suffered burnings on her chest, due to the pass of the current over the man's body and the presence of a necklace in contact with her own skin. The effect of the lightning discharge on the woman's body had serious effects because she was displaced a few meters after the impact. She suffered a serious contracture in her shoulder and, as a result of that, a broken clavicle. She also suffered a perforation in the tympanic membrane.

After several months, the two people seemed to be almost recovered. The man relates having pins and needles in his left hand and occasional slight pain also in his hands, which suggests slight damage to the peripheral nervous system (Kleinschmidt-DeMasters, 1995).

4 Conclusions

This paper concerns itself with the multi-disciplinary forensic approach to two lightning strike victims. As it has been explained, the lightning discharge affected two separate trees in the forest. The two people were looking for shelter under some branches close to a dead tree. The lightning current jumped from the dead trunk to one of the bodies, the so-called side flash, causing the serious injuries that have been related.

This investigation found the exact place of the accident and reconstructed the happenings thanks to the data available from the weather radar and the lightning detection networks, and the testimony of the man affected in the accident.

As a general conclusion, the fact must be remarked that the injuries suffered by the two people, although serious, could have been worse if the two bodies would not have been wet. This was determinant for the current to circulate over their skins and not through the bodies. In this last case, the injuries would have been much more serious because they would have affected internal organs. Moreover, the fact of suffering a discharge of the side-flash type suggests that the injuries suffered should be less severe than in the case of a direct strike, because a proportion of the energy has already dissipated in the object first struck, as it is explained by Blumenthal (2012a).

It must also be remarked that looking for shelter close to a dead tree could have been relevant to suffering the accident. The lightning current looked for the most conductive path on its way to ground, and it was found on the wet bodies rather than in the dead trunk.

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