A LEWP tornado in Coastal mainland Portugal (Murtosa)

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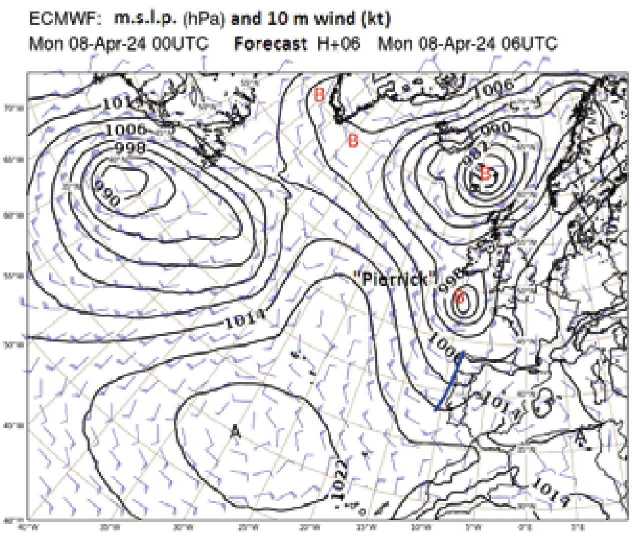
Introduction

According to a systematic data collection and study of tornadoes over Portugal, conducted for the first two decades of the current century in Leitão and Pinto (2020), it was found that these phenomena were more frequent during autumn, winter, and spring and that the most intense ones were spawned by supercells. However, quite a large proportion of weaker, shorter-lived, but still damaging tornadoes were found to be associated with quasi linear convective systems (QLCS). And of these, nearly 70% originated specifically from line echo wave patterns (LEWP). The sorting of tornado types considered in that study has followed the taxonomy proposed by Agee (2014). Weather radar observations of mainland Portugal were accessed to classify the tornado types following such conceptual taxonomy.

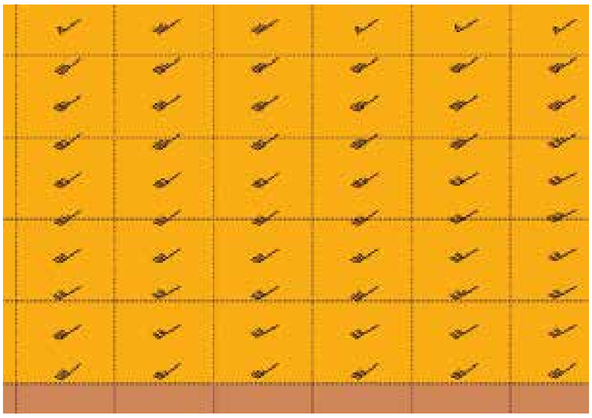
On 8th April 2024, in the Murtosa municipality (40.752 N, 8.648 W), western coastal area of mainland Portugal, strong winds caused a property wall to topple along an extension of more than 30 m. Other locations very close to this one also reported, during the early morning, damaging winds that caused destruction in a farm, uprooted trees and left several other houses roofless. As it was not possible to precisely locate these other occurrences, a trail of destruction could not be identified. However, the photographic evidence showed that all these effects were typical of tornado damage. Observations from a nearby radar have shown rotation over the location in Murtosa between 05:05 and 05:10 UTC (hereby, time is always referred to as UTC).

Synoptic and Atmospheric Environment

The ECMWF m.s.l.p. short-term forecast shows, in the early hours of 8th April 2024, a complex low system with its main core located to the north-northwest of the British Isles, affecting a large part of western Europe. On its southern edge, a secondary low named as storm "Pierrick", was visible to the west of Brittany (France) (Figure 1). A cold frontal surface was associated with this low and, by 06 UTC, was positioned close to the western coast of mainland Portugal (Figure 1). This frontal boundary crossed the Portuguese territory. In the pre-frontal environment, a moderate to strong south-southwesterly flow was advecting a moderate-high pseudo wet-bulb potential temperature airmass (12-16 °C) with moderate precipitable water content (22.5-27.5 mm) and reduced instability (a relative maximum of up to 100-300 J/Kg over the northern part of the west coast, but generally < 50 J/Kg in the environment). The post-frontal environment was characterized by a cool and relatively moist airmass with a pseudo wet–bulb potential temperature below 10 °C. The jet streak, with its right entrance located over the Portuguese coast, was reinforcing lift conditions there and creating a moderate 0-6 km layer shear, of the order of 16-



▲ *Figure 1 – Mean sea level pressure (solid contours, 4hPa intervals) and wind (barbs), 10 m wind, of ECMWF model short term forecast (H+06) at 06 UTC. 08th April 2024. Storm "Pierrick" is referenced and cold front position at surface is depicted by a blue line.*



▲ *Figure 2 – Vertical wind profile of horizontal wind (barbs), VVP algorithm, 04:26-05:26 UTC, 08th April 2024, Arouca radar.*

18 m/s. However, it was a shearing situation with negligible veering in the layer (Figure 2). It is also interesting to note that the wind shear above 3000 m was, indeed, very small. This wind profile was computed from radar data taking an atmospheric volume with 25 km radius from it. Thus, it was considered as representative of the atmosphere in which the phenomenon was generated.

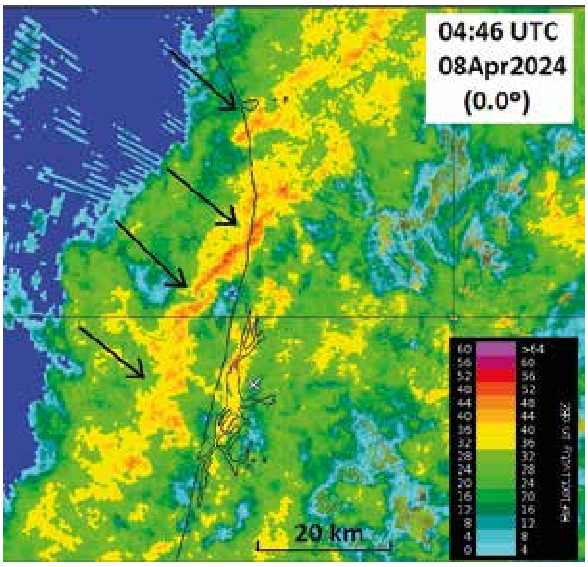
According to these elements, the ingredients of low instability, moderate low-level moisture, considerable vertical wind shear in the deep layer (although weak above 3000 m) and some lift, coincided by 06 UTC in the area where the damaging wind event occurred.

Radar analysis

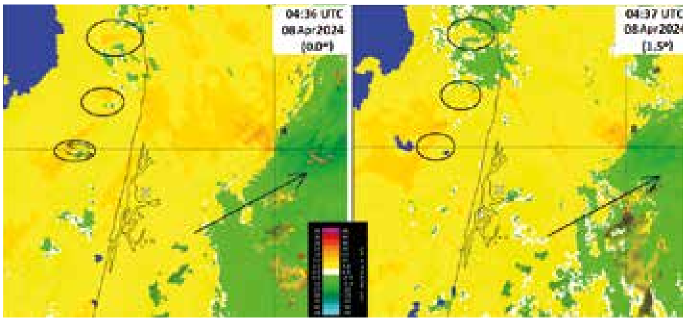
The referred environment and the corresponding synoptic regime were similar to the ones that have been described in Leitão and Pinto (2020), as being typical of the Type IIa tornado types (Agee, 2014) occurrence in Portugal. These types were usually observed along a cold frontal boundary. Even if upper level jet streaks were present, usually they were not overlapping large instability areas and/or deep layer shear. So, the underlying environments were, in fact, not favorable to the formation of supercells, in the sense that deep and persistent rotating updrafts were not observed on radar, during those cases. Instead, multiple short-lived mesovortices (MV) were frequently identified, embedded in the Line Echo Wave Pattern (LWEP) of a Quasi linear convective system (QLCS). There is no universal definition for a QLCS. In Portugal, a quasi-linear pattern of low-level reflectivity above 35 dBZ, with no gaps over at least 40 km, is taken as a QLCS. Radar observations reveal that these QLCS may appear as LEWP on reflectivity patterns. These patterns correspond to a squall line of convective storms that indicate the presence of low pressure areas that are the cause of the formation of characteristic bowing structures.

On 8th April 2024, as the frontal boundary was approaching the coast, low-level radar observations (PPI, Plane Position Indicator) were accessed. Those observations revealed a LEWP, observed in detail during the period 04:36 – 05:06 UTC. An example of the squall line of convection and its reflectivity pattern is presented at 04:46 UTC (Figure 3).

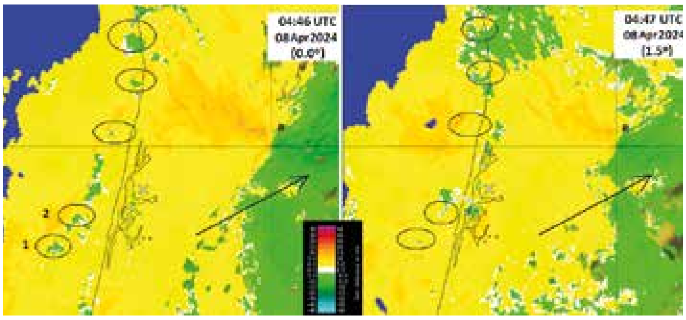
The QLCS was followed on Doppler radar imagery during the referred period (figures 4–7), in order to detail several aspects of the animation of the system. At 04:36 UTC (figure 4, left), there were noted 3 rotation signatures at approximately 1200 m a.m.s.l., as seen by the lowest tilt. At almost the same time (figure 4, right), the rotation signatures were noted at around 2300 m a.m.s.l., as seen by a higher tilt. These rotation patterns, defined as couplets (inbound-outbound) in Doppler velocity, were easier to identify at the lower altitude, as they were better defined there. These signatures corresponded to vortices that developed along the bowing parts of this QLCS. The mesovortices (MV) have distinctive characteristics as compared to supercells. Their small-scale rotation is, typically, firstly identified at very low-levels (as in this case, below 2500 m a.m.s.l.) and tends to build



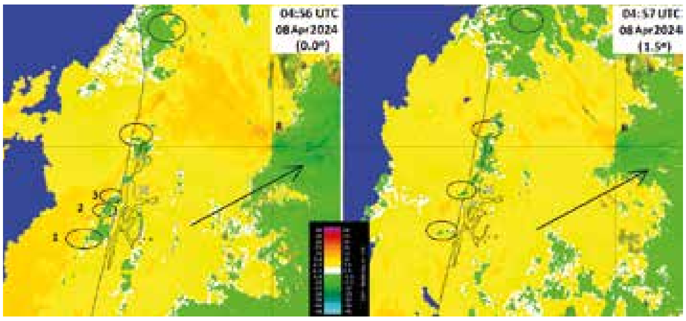
▲ *Figure 3 – PPI of reflectivity (Z, dBZ), 0.0° tilt, 04:46 UTC, 08th April 2024, Arouca radar. Arrows point to bowing structures that define a squall line, forming a LEWP in the frontal boundary. "X" marks the location that would be affected by damaging winds by 05:06 UTC.*



▲ *Figure 4 – Left: PPI of storm-relative velocity (m/s), 0.0° tilt, 04:36 UTC. Right: PPI of storm-relative velocity (m/s), 1.5° tilt, 04:37 UTC. 08th April 2024, Arouca radar ("R"). Mesovortices (MV) locations are depicted by circles. Curved arrows define a cyclonic rotation signature, as an example. Large arrow represents average advection of the MV. "X" marks the location that would be affected by damaging winds at 05:06 UTC.*



▲ *Figure 5 - Left: PPI of storm relative velocity (m/s), 0.0° tilt, 04:46 UTC. Right: PPI of storm relative velocity (m/s), 1.5° tilt, 04:47 UTC. 08th April 2024, Arouca radar ("R"). Mesovortices (MV) locations are depicted by circles. "1", "2" represent MV followed over time. Large arrow represents average advection of the MV. "X" marks the location that would be affected by damaging winds at 05:06 UTC.*



▲ *Figure 6 - Left: PPI of storm relative velocity (m/s), 0.0° tilt, 04:56 UTC. Right: PPI of storm relative velocity (m/s), 1.5° tilt, 04:57 UTC. 08th April 2024, Arouca radar ("R"). Mesovortices (MV) locations are depicted by circles. "1", "2", "3" represent MV followed over time. Large arrow represents average advection of the MV. "X" marks the location that would be affected by damaging winds at 05:06 UTC.*

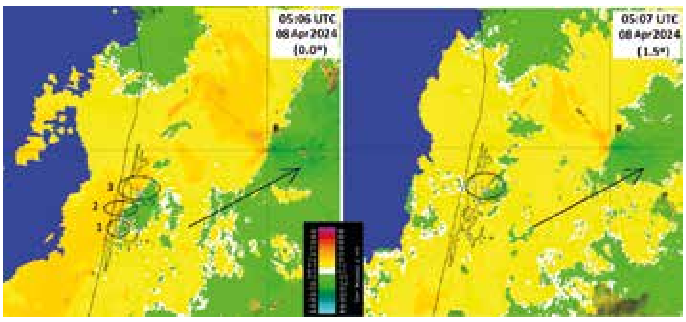
upwards in time, although this is not always easy to confirm in observations. This rotation is co-located with the bowing structures on reflectivity and is, in fact, the primary cause for the bowing. This can be confirmed by comparing low-level reflectivity at 04:46 UTC (figure 3) with low-level Doppler velocity at the same time (figure 5, left). It is clear that each bowing structure identified on reflectivity to the north of the radar site, over the coast, is collocated with each rotation center.

At 04:46 UTC, five MV rotation signatures were noted, as two new patterns were identifiable at an altitude of 1200 m (figure 5, left, marked as "1", "2"). Higher, at approximately 2300-2500 m a.m.s.l. (figure 5, right) the signatures were also identified but, once again, it is clear that they are better defined at the lower levels.

At 04:56 UTC, the MVs were identified close to the coastline or even inland, at the low levels (figure 6, left), at around 1200 m altitude. Again, the signatures were also followed above, at 2200 – 2400 m altitude (figure 6, right) but, once more, are less clearly resolved than at the lower levels. The MVs that were marked as "1" and "2" at 04:46 UTC (figure 5, left) have progressed northeastwards by 04:56 UTC and a new MV is, now, identifiable as "3" (figure 6, left).

Finally, by 05:06 UTC, three MVs were identified inland at the lowest level (figure 7, left). Around 1000 m above (figure 7, right) only the signature of MV "3" was identifiable. The azimuthal shear was computed at both levels (not shown) to evaluate the magnitude of rotation associated with each rotation center observed during the entire period. It was found that the strongest rotation was associated with this MV "3" at 05:06 UTC. Furthermore, the rotation was similar at both levels only for this stronger MV, at the time it was over the location where damaging winds were reported.

There is an observational characteristic suggesting that a MV has a genesis quite distinct from that of a supercell (SC). The SC is generated by a mechanism that converts horizontal vorticity that is available at low levels in the environment (through favorable wind shear in the boundary layer), into vertical



◀ *Figure 7 - Left: PPI of storm relative velocity (m/s), 0.0° tilt, 05:06 UTC. Right: PPI of storm relative velocity (m/s), 1.5° tilt, 05:07 UTC. 08th April 2024, Arouca radar ("R"). Mesovortices (MV) locations are depicted by circles. "1", "2", "3" represent MV followed over time. Large arrow represents average advection of the MV. "X" marks the location affected by damaging winds at this time (MV "3").*

▲ *Figure 8 - General view of a property wall (left), in Murtosa. Damaged wall after the strong wind event of the 08th April 2024 (right) (photo in public circulation on the Internet).*

vorticity, through the ascending updraft that forms the mesocyclone. This SC could, then, spawn a tornado originated from its mesocyclone. The SC is the most long-lived mesoscale storm in the atmosphere, due to its prolonged steady state. The MV is thought to be formed as the result of convergence between air masses, perhaps similar to, although with more intense atmospheric circulation than, the case seen in the formation of land/water spouts. In a QLCS the convergence is provided by a squall. If the convergence ensures availability of vertical vorticity and there is enough instability in the environment at low levels to produce a strong ascending current, should the two be collocated, this updraft may acquire rotation. In this case no mesocyclone forms, and by stretching mechanisms a vortex will start from the surface, upwards.

Radar observations of this event seem to support this mechanism. For each rotation center, the signatures detected at lower levels were always more clearly resolved and detected earlier than the ones observed at higher levels. Furthermore, the magnitude of rotation in each center was always greater at lower levels. Only in the case of the vortex that affected the surface with damaging winds, the magnitude of rotation was similar at lower and higher levels. This suggests a larger upward extension of the rotation in the stronger MV that was observed in the area.

Damaging wind event

According to available documentation and reports, it was found that this phenomenon of strong wind caused a property wall to topple along more than 30 m (figure 8). This location corresponds to the one marked in the radar imagery. The level of destruction can be seen by comparing the situation before (figure 8, left) and after (figure 8, right) the event. For places not far from the location, and at the same time, the destruction of an agricultural farm, two houses left roofless, and trees uprooted were also reported, however, the locations could not be confirmed and for this reason, it was not possible to identify a trail of destruction.

The application of technical procedures to the analyzed elements, allowed to assess that the intensity of this event was F1/T2 (F, Fujita scale, 1971; T, Torro scale, 2012).

Nowcasting challenge

These phenomena have a significant impact at the local level but are extremely difficult to forecast due to the very short life span and the reduced spatial scale. First, it is not possible to predict the exact location and time of formation of the vortices. Then, from the available observation, including the always difficult interpretation of radar images, it is not possible to distinguish from all the vortices that are active, which one has the characteristics that allow it to evolve until effects are noticed.

However, the regions of the country that may be affected, the synoptic environments in which they may occur, and the necessary ingredients for their formation have been identified. This allows the reporting of the risk to the Civil Protection authorities and close monitoring.

IPMA has been working on a nowcasting warning dedicated to small-scale convective phenomena, to be made available to the public. However, without a consistent forecast of location, time, and intensity, it is a challenge to raise public awareness of the risk and propose a reliable warning.

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