Radar identification of intense thunderstorm cores

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Abstract

The thunderstorm occurred in the late afternoon of September 16th, 2021 over the Malpensa airport caused a quite important disruption and infrastructural damages. However, the retrospective analysis of radar reflectivity images of the thunderstorm can't clearly reveal its core structure. This work evaluates the application of some rarely used radar products to distinctly identify the thunderstorm position, duration, extension and intensity. The radar products used in this work are the height difference between the radar echo at 45 dBZ and the zero degree level, Vertical Integrated Liquid water (VIL), and VIL density; the data have been supplied by MeteoSwiss. Although these parameters have been introduced as estimators of the hail probability, their use guarantees to clearly detect the peak that occurred over Malpensa and the analysis of its evolution along time. Those parameters have been also applied to another storm cell occurred the same afternoon between Pavia and Milan, confirming the capability of those parameters to identify the thunderstorm's peak intensity, even without any specific report of damages.

Keywords: weather radar, thunderstorm identification, probability of hail, VIL, VIL density

1 Introduction

During the late afternoon of September 16th, 2021, the area near the city of Varese was affected by heavy rain which caused disruption and damages to some infrastructure; Milan-Malpensa airport was one of the most affected structure. An heavy downpour hit the airport around 18:00 local time (16:00 UTC) producing leaks in terminal T1 and stopping all airport activities for about two hours. As reported by local media, this event caused heading changes to the nearest still-working airports of Turin-Caselle and Bergamo-Orio al Serio. Troubles were so serious to require the intervention of river rescue specialists of Fire Department to extract about twenty people stuck in their cars. Such an event could not be detected through satellite images and radar reflectivity (Z) only, the latter is the most used radar product by forecasters. Different studies have been conducted during past decades to look for suitable indicators able at recognizing convective events such as the one studied in this work. One of the first radar quantities, introduced in Greene and Clark (1972), is the Vertical Integrated Liquid water (VIL): this is the liquid water content in the storm cell. Another quantity, introduced in Amburn and Wolf (1996) to correct VIL values, is the VIL density (VILD). VILD is defined as the value of VIL normalized with the height of the cumulus. Both quantities will be discussed below. Besides the estimate of liquid water content, there are several algorithms used by meteorological services to identify hail cells; hail can indeed have a heavy impact on the population and at the same time is one of the best proxies for an intense thunderstorm. These algorithms (Witt et al., 1998) are based on the computation of the probability of hail (POH). One of the most effective and easy to implement is the one found in Waldvogel. et al. (1979). The authors provided a new criterion to establish the presence of hail within a cloud: this new criterion is based on the

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difference between the height of the echo-top of the 45 dBZ signal and the 0 °C levels. This quantity will be later described. Even if there were no report of hail during the event at Malpensa, it is thought that a high POH can be effective to identify an intense thunderstorm. Of course, high levels of POH does not necessarily imply any hail precipitation because favorable thermodynamic and fluid dynamic conditions must concurrently take place. The present study is structured as follows: section §2 provides a brief discussion about the synoptic configuration on Europe on September 16th, 2021 and about mesoscale configuration on the region of Lombardy; in section §3, quantities used to identify a cell storm are introduced; a description of the data used in this work is given in section §4; section §5 provides a discussion on the results.

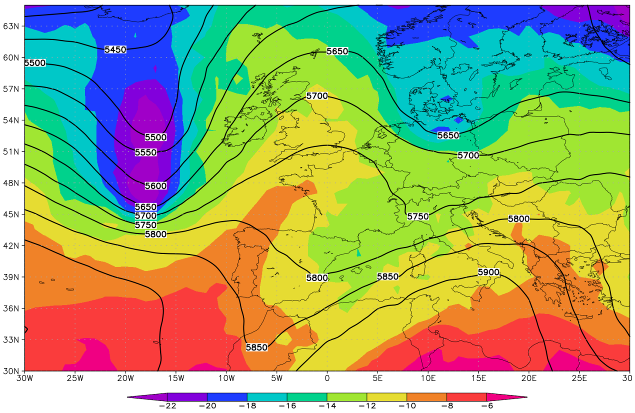

Fig. 1 Synoptic chart from the GFS run at 12:00 UTC of September 16th. Colours are temperatures expressed as °C; black lines are the geopotential heights at 500 hPa

2 Synoptic and mesoscale analysis

On September 16th, 2021, an anticyclone formerly originated in Africa reached the Mediterranean extending itself from Tunisia to Southern Europe; westward from this anticyclone, a trough on the Atlantic Ocean was extended from Morocco to the North Sea. During the day, the ridge axis moved eastward triggering instability on Northern Italy, first, and on Central Italy, later. These conditions resulted from the interaction between the moist flux coming from the Atlantic region in the lower troposphere and the dry, cold air in the upper troposphere over middle-Eastern Europe (fig.1). Over the Lombardy region, the weather was very cloudy with rain in the afternoon on Varese, Mantova, Bergamo, and Brescia. Lately, intense thunderstorms, with gusts up to 17 m/s in the western regions, moved eastward. Rainfall up to 80 mm in the Alpine region and up to 40-50 mm on the plain occurred, with the exception notably of Pieve Emanuele gauge, which reported 144.8 mm at the end of the day. Fig.2 shows the rainfall recorded until 23:55 p.m. (local time) on September 16th, 2021. Temperatures also decreased during the thunderstorm reaching values between 21 and 28 °C near Pavia.

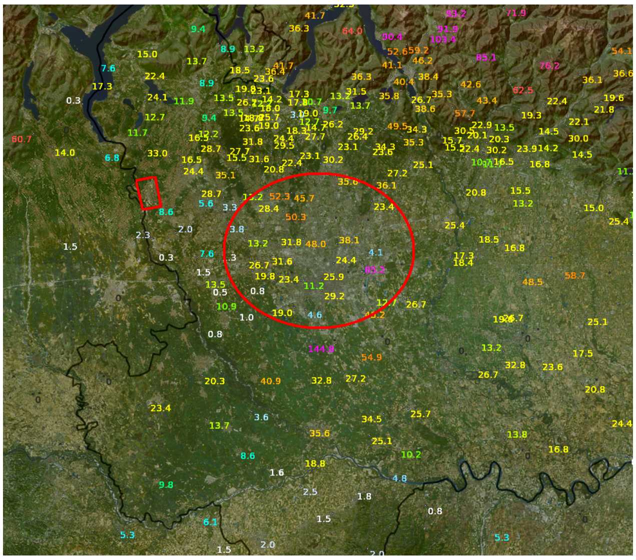

Fig. 2 Cumulative rainfalls over the middle-western region of Lombardy, as recorded by rain gauge, on September 16th, 2021. Image refers to 23:55 local time. The central red circle stands for the urban area of the city of Milan; the eastern red rectangle represents the Malpensa airport. The weather station of Pieve Emanuele shows 144.8 mm of rain, just beneath the red circle (source: `http://www.centrometeolombardo.com/`

3 Radar identification of a storm cell

In this section, the quantities used in the following analysis are introduced. Forecasters generally use these quantities, derived from radar data, to evaluate POH. Hail can be the most dangerous consequence of an heavy thunderstorm, because it can harm people and damage infrastructure. Therefore, most of the studies have been focusing on the identification of convective events able to bring hail at the ground. Although during the considered event of Malpensa, no hail was reported, it may be assumed that indices used to evaluate the POH can be also applied to identify intense thunderstorm cores. This assumption is based on the awareness that hail is formed when favorable thermodynamic and fluid dynamic conditions are met; the lack of these requirements might bring to intense events even without hail at the ground. In the next paragraphs, the parameters used in this work are presented.

3.1 Waldvogel's criterion

The weather radar is one of the most important instrument to detect thunderstorms and to nowcast its evolution. Double polarization radars allow to distinguish hail by comparing the intensities of the horizontal and vertical echoes: signals with similar intensities denote hail. However, single polarization radar used in this work, however, must rely on specific algorithms; a concise survey is provided in Salek et al. (2004). One of these algorithms is the one provided in Waldvogel. et al. (1979). In their work, the authors examined 195 strong convective cells using Z data and information of a dense network of hailpads: through a statistical survey, they derived a new simple criterion to estimate POH. According to the suggested criterion, a non-zero POH is met when the height difference between the echo-top of the 45 dBZ signal and the 0 °C levels is equal to or greater than 1.4 km, i.e.:

$$\Delta H = H_{45} - H_0 \geqslant 1.4 \qquad (1)$$

The cumulative probability distribution found by the authors is given in Holleman (2001) (fig.3). Values of ΔH greater than 6 km are associated with a 100% POH. Different formulas are provided in the literature (Witt et al., 1998) due to different climatological conditions of the areas where they were applied (Salek et al., 2004).

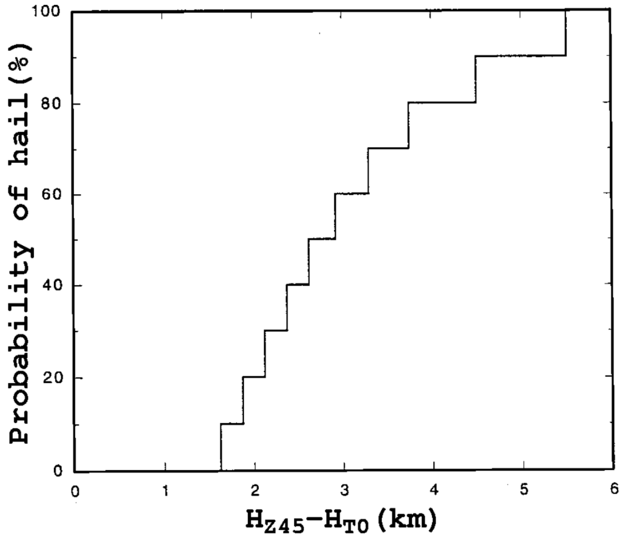

Fig. 3 Probability of hail (POH) as computed by Waldvogel. et al. (1979). POH is expressed as a function of the height difference between the echo-top-45 (H_{45}) and the melting level (H_{T0}). This plot is obtained by Holleman (2001)

3.2 VIL and VIL density

A relevant parameter used to estimate the intensity of a thunderstorm is the water content in a cumulus, known as VIL; this was first introduced in Greene and Clark (1972). The relation between the volumetric density of water and the radar reflectivity Z is found by exploiting the distribution of raindrops as a function of their own diameters (Marshall and Palmer, 1948), i.e.:

$$n(D) = N_0 e^{-\Lambda D} \qquad (2)$$

where n is the volumetric density of raindrops, D is the diameter, N_0 and Λare parameters chosen by the authors. The relation 2, integrated over the height of the storm cell, defines the VIL (measured in kg/m^2) according to the following equation:

$$VIL = 3.44 \times 10^{-6} \int_0^{H_{top}} Z^{4/7} dz \qquad (3)$$

where z is the vertical coordinate and Z is the radar reflectivity measured in mm^6/m^3. The first issue concerning the VIL is the semi-empirical relation used to determine the constant in the integral. Secondly, Z and, hence, VIL depends on the 6th power of the raindrops diameter under the radar beam; therefore, a few big raindrops give the same contribution as many small ones making it difficult to understand the real liquid water content in the cumulus (Marshall and Palmer (1948); Amburn and Wolf (1996); Holleman (2001); Salek et al. (2004)). The third problem is related to the kind of cloud considered: indeed, the same VIL value can be found in a relatively limited-height cloud with a well-developed hail core, comparable to a deep cumulus with a relatively small hail core. The former, however, has a higher probability of developing hail or intense rainfall than the latter. Due to these issues, there isn't a well-established threshold of VIL suitable for distinguishing between an intense cell storm and a weak one. Some reference values can be considered on the basis of the similarity between precipitable water and VIL: the former variable accounts for the liquid water as well as water vapor, while the latter one accounts just for the liquid water. Conversely, it is important to note the difference in how they are measured: the precipitable water is measured through the atmospheric sounding; VIL is computed using radar data. However, as a rule of thumb, it is reasonable to consider VIL values with a magnitude of $O(10)$ kg/m^2 as representative of heavy rainfalls. This is confirmed in Holleman (2001) wherein it is noted that in stratiform cloud VIL rarely exceeds a value of $10\,\mathrm{kg/m^2}$. To handle this lack of threshold, forecasters in the United States often use a "VIL of the Day", a semi-empirical correction of the VIL using temperatures at 500 and 400 hPa (Holleman, 2001). However, a major problem can be related to this practice. Since all the cells within the radar range are not equal and VIL is valued using radar data, its values depend on the distance between the cell and the radar and computations can't consider the cell thickness. A better liquid water content estimate is the so-called VIL density (VILD), first introduced in Amburn and Wolf (1996). VILD is simply the VIL normalized using the height of the cloud core; indeed, VILD (measured in g/m^3) is defined as $VILD = VIL/H_{45}$, where H_{45} (expressed in km) is the echo-top-45. Contrary to VIL which depends on cloud height, and hence on the air mass (deep cumuli are typically associated to the warm season while depthless clouds to the cold season), an increase in the VILD values implies an increase in target diameter; a high VILD is indicative of a well-developed cell core. However, there are some issues with the calculation of VILD. The most important problem is that VILD can be underestimated in the case of tilted and fast-moving cells (e.g. 48 km/h as underlined in the aforementioned article). Typical thresholds used to identify intense thunderstorms can be found at `https://www.weather.gov/lmk/vil_density`: values between 3.0 and 4.0 g/m^3 correspond to intense storms.

4 Data

Parameters discussed in the previous section have been computed using radar data supplied by MeteoSwiss. The Swiss radar network relies on three C-band (3.75-7.5 cm wavelength) Doppler radars located in Albis, La Dole, Monte Lema, Point the la Plaine Morte (Valais) and Weissfluhgipfel (Grisons). This work uses only the single-polarization radar products. The radar network domain is depicted in fig.4; the Swiss georeferencing system (known as CH1903+ LV95) is also shown. Radar data were supplied as RGB images associated to parameters data by conversion tables to quantify the values reflectivity, rain rate, etc. on every point of the images. In this work Z, H_{45} and VIL data are used: these were provided every 5 minutes starting from 00:00 to 23:55 UTC on September 16th, 2021. From now on, reference times are intended in UTC, except where otherwise indicated. An example of the images used is shown in fig.5: this figure shows the composite Z at 00:00 on the 16th of September 2021 overlaid to the image of the radar network domain. Yellow areas stand for higher values of Z while light blue areas correspond to lower values; black parts represent areas outside the domain range; grey regions correspond to a null signal (-31.5 dBZ); white pixels in the lower corner are clutter. Images were processed in Python and software codes were written to transform these images to data through conversion tables; in particular, the IDE Jupyter was used (`https://jupyter.org/`). As a first step, the domain image (fig.4) was adjusted to obtain the same resolution of the data product, i.e. 710×640 pixel. Then, a simple linear relation was implemented to convert pixel positions to CH1903+ LV95 coordinates. However, the Swiss reference frame is valid only for Switzerland and Liechtenstein (boundaries are shown in fig.4); so, it was necessary to convert these coordinates to a global reference frame, the so-called WGS84. These conversions allowed to define the location of the Malpensa airport (45°37′48″ N, 8°43′23″ E), Milan (45°28′01″ N, 9°11′24″ E), and Pavia (45°11′07″ N, 9°09′18″ E), as reference points used in this study. The conversion from CH1903+ LV95 to WGS84 (Snay and Soler, 2000) was performed by a web converter (`https://epsg.io/2056`). The zero degree level was necessary to compute the

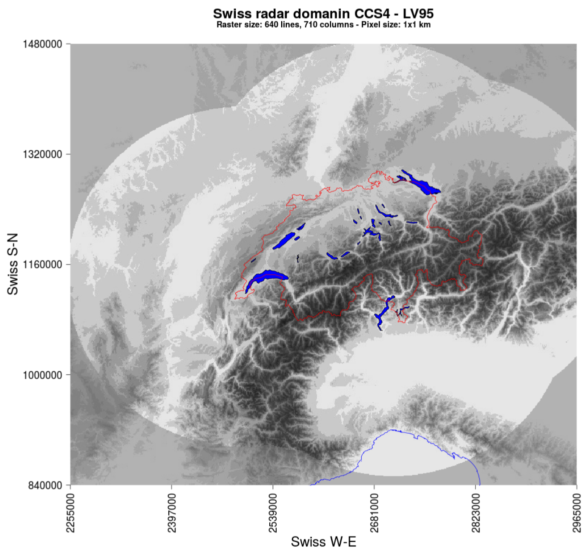

Fig. 4 The domain of the radar network of MeteoSwiss. Coordinates along boundaries are expressed according to the Swiss positional system CH1903+ LV95

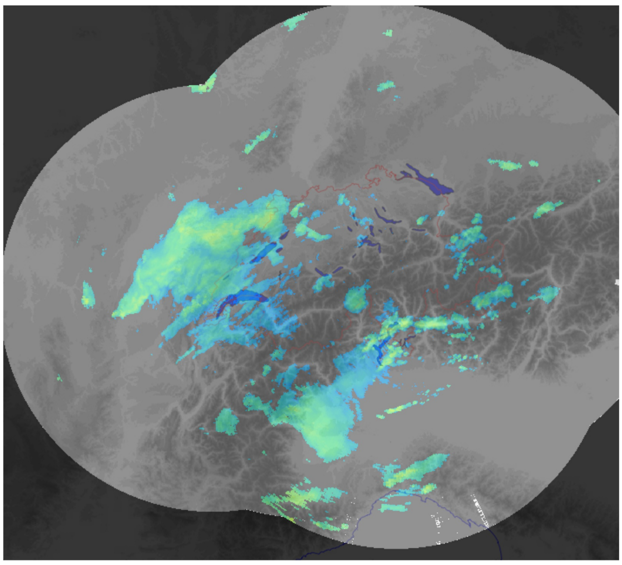

Fig. 5 Example of RGB images that have been supplied by MeteoSwiss. The image shows the composite reflectivity at 00:00 UTC of September 16th, 2021; the composite reflectivity Z is overlaid to the georeferenced image. Yellow regions represent high values of Z and light blue corresponds to lower values. Black areas are outside the radars domain; grey regions correspond to null signals; white spots are clutter

ΔH: this data field was supplied for each hour by Meteo Expert. The zero degree level is the output of a WRF model at 4 km of horizontal resolution using 0.25° GFS data as boundary conditions. The 0 °C-levels is kept constant in time and in space within regions of 40×40 km^2, since a very low variability has been seen inside these regions.

5 Results

5.1 The Malpensa airport

In this section, the analysis of the thunderstorm that impacted the Malpensa airport between 16:00 and 18:00 is provided. An area of 40×40 km^2 centered on Malpensa is depicted in figures 6, 7, 8, and 9. In fig.6, the reflectivity Z is shown at 15:30, 16:00, and 16:35. The Malpensa airport is the little triangle at the center of the images while the city of Milan is the bigger triangle to the right of Malpensa; cities of Novara and Varese are the triangles respectively at the south-east and the north-west of Malpensa. As shown here, Z reaches considerable values over a wide area in the north-western region of Lombardy; in particular, values of 41.5, 52.0, and 58.5 dBZ are found respectively at 15:30, 16:00, and 16:35 within 2 km from the airport. The widespread area of high Z does not allow to clearly identify neither the position nor the extension and nor the evolution in time of the storm cell which caused several damages. For this reason, values of ΔH are computed to estimate the POH, following Waldvogel. et al. (1979). The ΔH is shown in fig.7 at 15:30, 16:00, and 16:35 according to fig.6. Black lines denote the height of 1.4 km and 5 km: the former is the lowest level of ΔH which corresponds to a POH of 0% while the latter reflects 90% (fig.3). In contrast to fig.6, the ΔH points out in a better way the cell core and its evolution over time: as one can see in fig.7, the cell core develops and then intensifies during the following hour. ΔH reaches its maximum of 5.8 km at 16:35, 3 km south-east from the airport. Such a high value approximately corresponds to a POH of 100%. A similar result can also be obtained using the formula in Delobbe and Holleman (2006):

$$POH = 0.319 + 0.133\Delta H \quad (4)$$

This equation is used by the Royal Netherlands Meteorological Institute and it gives a POH of about 109%. At 16:35, over the Malpensa airport, VIL reached the greatest value of 31.0 kg/m^2 which is representative of intense convective rain-

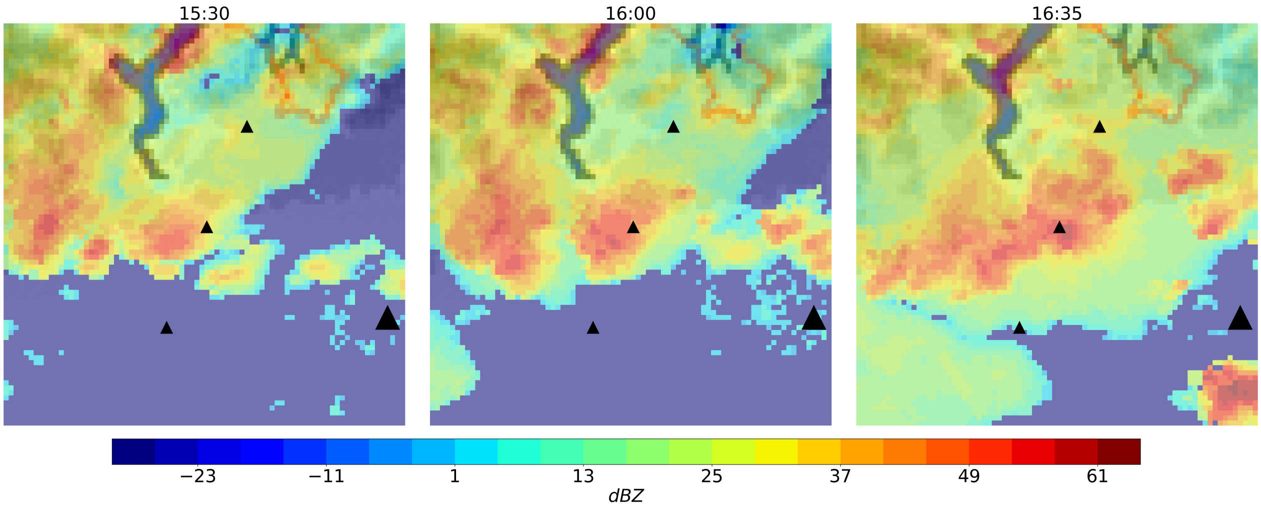

Fig. 6 Images depict reflectivity Z near the Malpensa airport at 15:30 (left), 16:00 (centre), and 16:35 (right). Each image covers a surface of 40×40 km^2 wherein the airport is the centre (central triangle) and the city of Milan is on the right (triangle southeast of Malpensa). Smaller triangles south-east and north-west to Malpensa represent respectively the cities of Novara and Varese. Within 2 km from the airport, the greatest values of Z are 41.5 dBZ (15:30), 52.0 dBZ (16:00), and 52.8 dBZ (16:35)

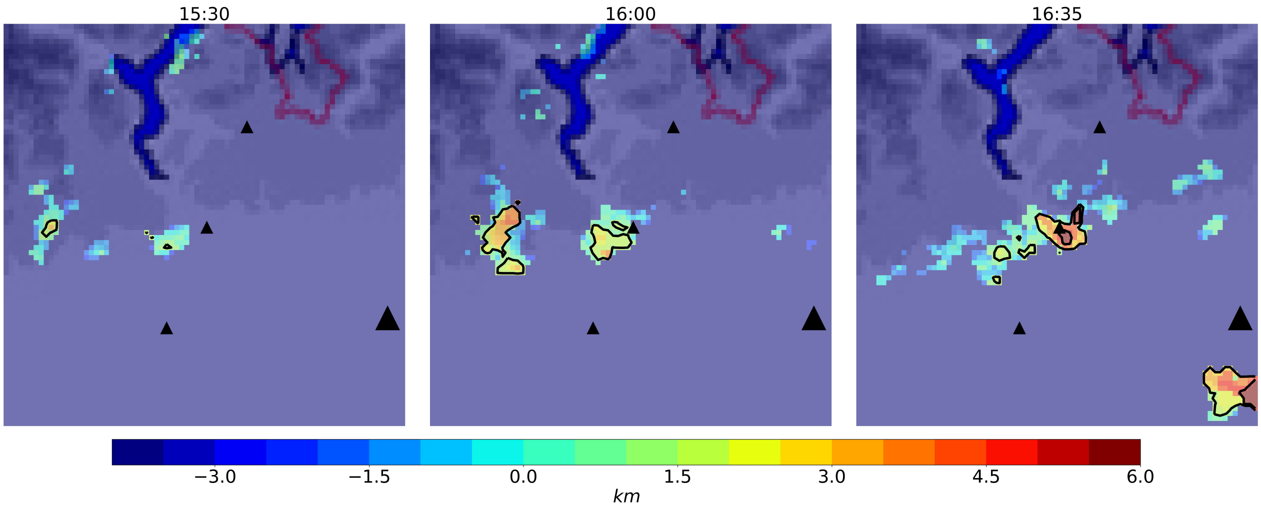

Fig. 7 Images depict ΔH near the Malpensa airport at 15:30 (left), 16:00 (centre), and 16:35 (right). Each image covers a surface of 40×40 km^2 wherein the airport is the centre (central triangle) and the city of Milan is on the right (triangle southeast of Malpensa). Smaller triangles south-east and north-west to Malpensa represent respectively the cities of Novara and Varese. Black lines represent 1.4 and 5.0 km; values greater than 1.4 km are associated with non-null POH, and values greater than 5.0 km are representative of 90% POH. ΔH allows to better identify the cell core. Maximum of ΔH is achieved within 3 km south-east the airport; it reaches 5.8 km at 16:35

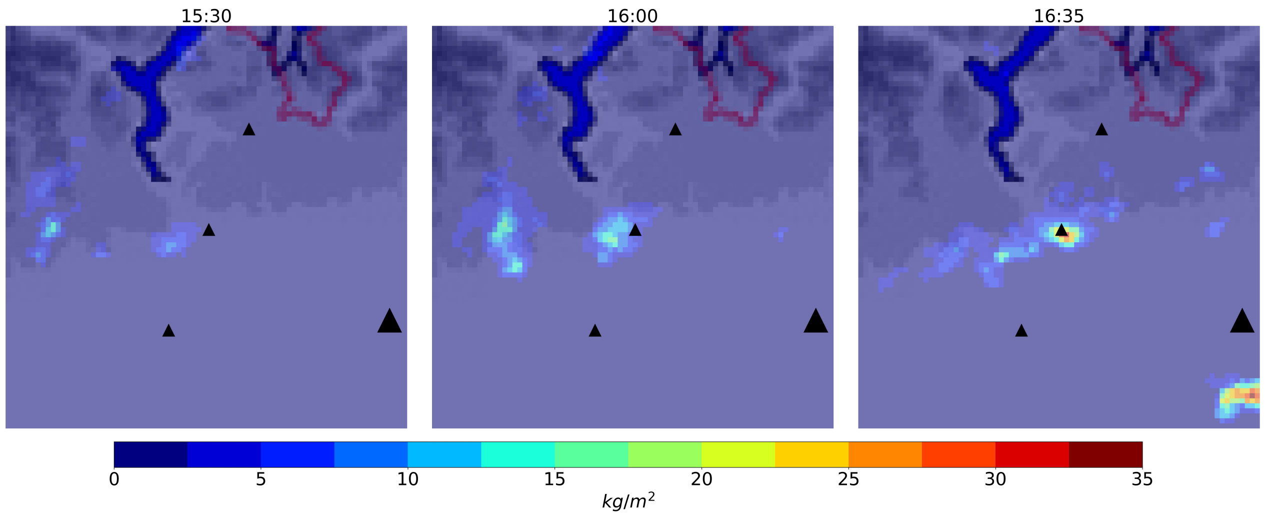

Fig. 8 Images depict VIL near the Malpensa airport at 15:30 (left), 16:00 (centre), and 16:35 (right). Each image covers a surface of 40×40 km^2 wherein the airport is the centre (central triangle) and the city of Milan is on the right (triangle southeast of Malpensa). Smaller triangles south-east and north-west to Malpensa represent respectively the cities of Novara and Varese. Like ΔH, VIL allows to better visualize the cell core. VIL peaks up to $31.0\,\mathrm{kg/m^2}$ at 16:35 like Z and ΔH

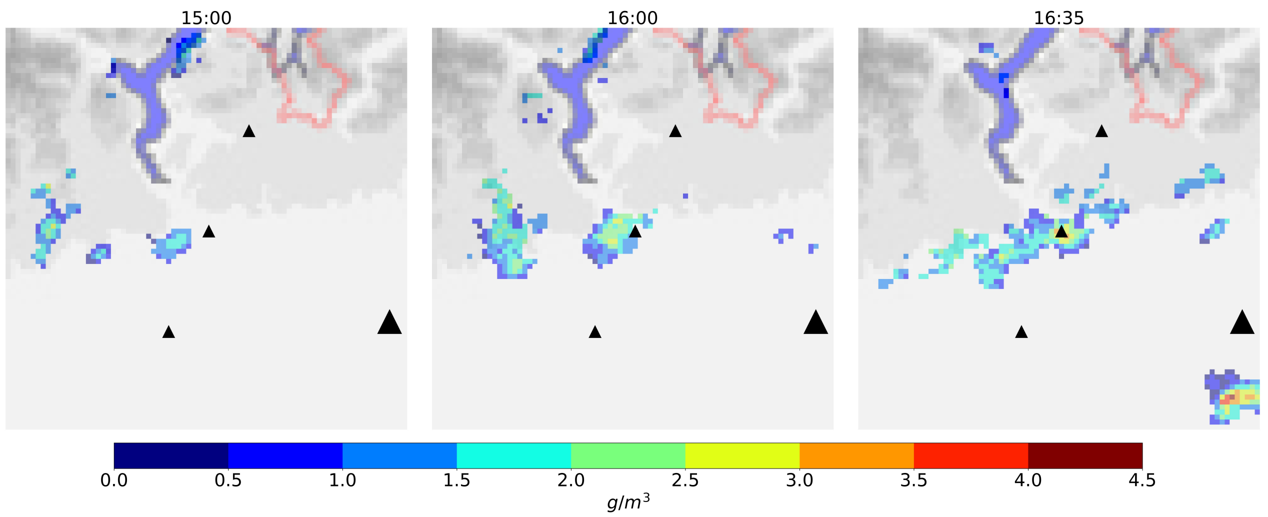

Fig. 9 Images depict VILD near the Malpensa airport at 15:30 (left), 16:00 (centre), and 16:35 (right). Each image covers a surface of 40×40 km^2 wherein the airport is the centre (central triangle) and the city of Milan is on the right (triangle southeast of Malpensa). Smaller triangles south-east and north-west to Malpensa represent respectively the cities of Novara and Varese. The maximum value of $3.45\,\mathrm{g/m^3}$ is achieved at 16:25. The image on the right however shows the 16:35 situation: at that moment VILD is about $3.26\,\mathrm{g/m^3}$

falls (fig.8). Finally, the same analysis was carried out considering VILD. In fig.9, it is showed how an intense thunderstorm core intensified in one hour interval; VILD reached its peak of about $3.45\,\mathrm{g/m^3}$ at 16:25, and then it decreased to $3.26\,\mathrm{g/m^3}$ at 16:35. Fig.9 depicts the situation only at 16:35 when peaks of Z, ΔH and VIL are met. Thresholds of VILD are recorded at `https://www.weather.gov/lmk/vil_density`: values of 3.26 and $3.45\,\mathrm{g/m^3}$ state for intense thunderstorms and a likely hail of small size. Being the cell core quite stationary over Malpensa from 15:30 to 16:35, the values of VILD that are computed can be considered reliable. The results in the previous paragraphs show how the Z cannot be used to distinguish a confined area around the Malpensa airport wherein the most intense rainfalls happened. On the contrary, the usage of ΔH, VIL, and VILD highlights a cell core with a characteristic length of $O(1)$ km (5×5 km^2, approximately). These parameters better reveal that the storm cell was almost static for about two hours, from 15:00 up to 17:00. The estimate of the the magnitude of the sotrm relies on three results: the POH nearly attains 100% (or exactly 100%, depending on the formula which is used); the maximum value of VIL is characteristic of a heavy convective storm; VILD reaches peaks typical of intense thunderstorms characterized by the presence of small hail.

5.2 The cell of Pavia

A confirmation of the reliability of the parameters that have been computed in the previous paragraph, has been found analyzing another thunderstorm occurred near the city of Pavia in the same day, between 16:00 and 17:00. This storm didn't supposedly caused any troubles to local people, but no information has been reported by media about this event: only a few observations provided by local weather enthusiasts. The only official measurement data of the rainstorm has been the weather station in the city of Pieve Emanuele, which recorded a cumulative rainfall of 144.8 mm (fig.2). High values of Z near the city of Pavia are shown by the Swiss radars at 16:00. Even though some relevant values of Z are just found at 15:00, the most intense core starts to develop an hour later. Figures 10, 11, 12, and 13 cover an area of 40×40 km^2 centered in the city of Pavia. Fig.10 depicts images at 16:05, 16.25, and 16:45; the central triangle stands for Pavia, while the city of Milan is represented by the big triangle north to that one. The cities of Voghera, Tortona, and Lodi are also symbolized by three triangles, respectively to the west, south-west, and north-east of Pavia. The reflectivity reaches 65 dBZ at 16:45, south of Milan; values of Z greater than 60 dBZ are generally associated to hail. This storm appears to be quite isolated compared to the one in Malpensa, looking at Z images only. Another important difference is the northward movement; the thunderstorm covered about 20 km in 45 minutes. Fig.11 shows the ΔH in the same hours as fig.10. Looking at the left image in that figure, referred to 16:05, a non-zero POH is recognizable as soon as the cell appears over the city of Pavia. The cell storm intensified until 16:45 (right images) reaching the value of 7.39 km: such a high value refers to a POH of 100% according to both formulas 1 and 4. Fig.12 shows the VIL values. Since VIL allows to better identify the cell core, this appears quite isolated like the cell core over Malpensa. On the contrary, the core over Pavia intensified quite rapidly in just 40 minutes: it reached a value of $39.0\,\mathrm{kg/m^2}$ at 16:45, a value higher than the peak computed over Malpensa. VILD can refine the VIL estimation and fig.13 depicts it at 16:05, 16:25 and 16:45. VILD reached $3.1\,\mathrm{g/m^3}$ in the early stage, at 16:05, exceeding the $3.0\,\mathrm{g/m^3}$ threshold for intense thunderstorms. This quantity peaked to $3.75\,\mathrm{g/m^3}$ at 16:45, a value as high as the one reached over Pavia, generally associated with severe hail storms. However, the calculation of VILD might be inaccurate due to the high speed of the cell (30-40 km/h); nevertheless, this type of error would lead to an underestimated value of VILD and, therefore, an underestimated intensity of the cell storm.

From the data analysis, it is possible to state that the thunderstorm over the city of Pavia had been very intense, with values similar to the storm over Malpensa; the cell over Pavia, however, reached an intensity even greater than the storm over Malpensa, as one can notice by looking at Z, ΔH, VIL, and VILD. Anyway, there are some differences between the two cell storms concerning the temporal evolution: the cell storm over the Malpensa airport appeared almost stationary within one hour, while the cell storm over the area of Pavia moved quite rapidly, starting from Pavia and approaching the southern area of Milan in less than an hour.

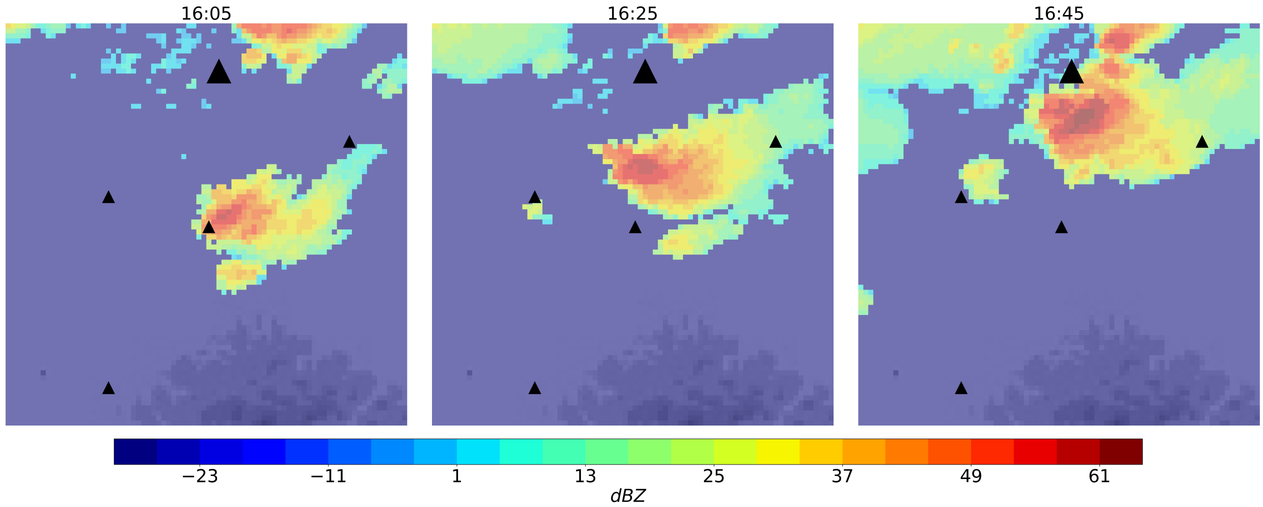

Fig. 10 Images depict Z near the city of Pavia at 16:05 (left), 16:25 (centre), and 16:45 (right). Each image covers a surface of 40×40 km^2 wherein Pavia is the centre (the central triangle) and the city of Milan is on top. Smaller triangles at the west, south-west, and north-east of Pavia represent the cities of Voghera, Tortona, and Lodi, respectively. The storm is quite isolated and moving northward. The greatest value of 64.5 dBZ is shown at 16:45

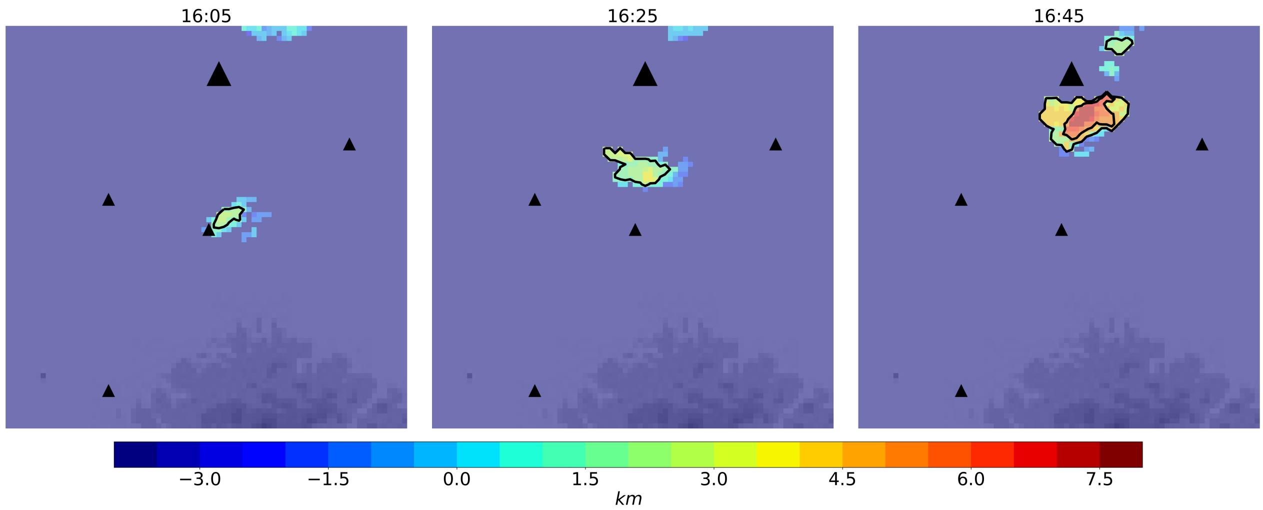

Fig. 11 Images depict ΔH near the city of Pavia at 16:05 (left), 16:25 (centre), and 16:45 (right). Each image covers a surface of 40×40 km^2 wherein Pavia is the centre (the central triangle) and the city of Milan is on top. Smaller triangles at the west, south-west, and north-east of Pavia represent the cities of Voghera, Tortona, and Lodi, respectively. Black lines represent 1.4 and 5.0 km; values greater than 1.4 km are associated with non-null POH, and values greater than 5.0 km are representative of 90% POH. Already at 16:05 (left image), the cell core achieved a non-zero POH; at 16:45 (right image) ΔH is 7.39 km. Such a high value denotes a 100% POH according to 1 and 4

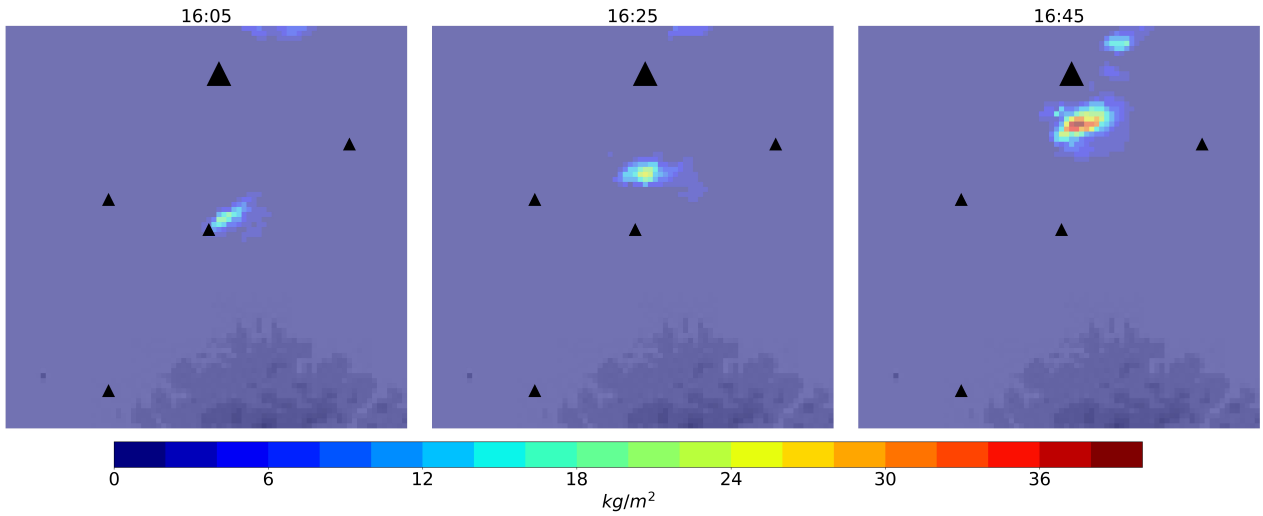

Fig. 12 Images depict VIL near the city of Pavia at 16:05 (left), 16:25 (centre), and 16:45 (right). Each image covers a surface of 40×40 km^2 wherein Pavia is the centre (the central triangle) and the city of Milan is on top. Smaller triangles at the west, south-west, and north-east of Pavia represent the cities of Voghera, Tortona, and Lodi, respectively. The greatest value of VIL is reached at 16:45 with $39.0\,\mathrm{kg/m^2}$ just south Milan

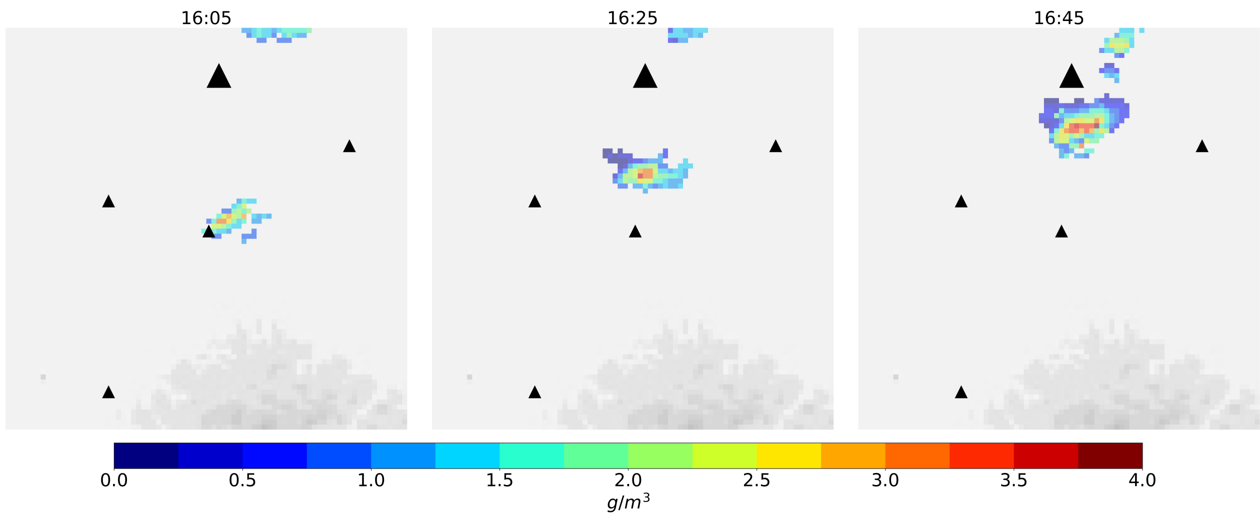

Fig. 13 Images depict VILD near the city of Pavia at 16:05 (left), 16:25 (centre), and 16:45 (right). Each image covers a surface of 40×40 km^2 wherein Pavia is the centre (the central triangle) and the city of Milan is on top. Smaller triangles at the west, south-west, and north-east of Pavia represent the cities of Voghera, Tortona, and Lodi, respectively. The cell core moved rapidly northward, reaching at 16:45 the south of Milan; at that moment, VILD peaks up to $3.75\,\mathrm{g/m^3}$, a value typical of an intense thunderstorm with severe hail

6 Conclusions

During the late afternoon of September 16th, 2021, an intense rainstorm impacted the area near the city of Varese, in particular the Malpensa airport. The main radar product, the reflectivity (Z), has shown high values on a quite wide area around, making it difficult to identify the storm core. This work has investigated the capability of secondary radar products to clearly identify the core of a thunderstorm, such the one occurred over Malpensa. Radar data supplied by MeteoSwiss have been used to compute three parameters: the difference between the height of the echo-top of the 45 dBZ signal and the 0 °C level (ΔH), the Vertical Integrated Liquid water (VIL), and the VIL density (VILD). These parameters are found in literature as estimators of the Probability Of Hail (POH). Even though there were no reports of hail during the event of Malpensa, it has been supposed that these parameters might be useful to estimate the intensity of the thunderstorm. ΔH, VIL, and VILD have clearly shown the cell core over the Malpensa airport and its evolution in time; they have also led to a POH of nearly 100%, suggesting a high concentration of liquid water in the cell storm. To confirm the capability of these parameters as estimator of thunderstorm's intensity, another event occurred in the same day has been analyzed. This other storm interested the area within the city of Pavia and the area just south of Milan. ΔH, VIL, and VILD have reached values as high as the ones over Malpensa; however, the cell over Pavia have shown even higher peaks that have been reached in a quite shorter period. These radar products have led to a better estimation of the intensity and extension of the cell storm, as well as a better identification of their own cores. Moreover, the use of Z alone could not allow understanding effectively the different evolution during time of the two rainstorms. The comprehension of the physical causes that led to the downpour over the Malpensa airport is beyond the scope of this work. However, the radar products used here have represented the intensification and a re-generation over an hour of the storm cell core over Malpensa. These phenomena might be also the result of dynamical effects, such as a local convergence and an intense shear in the lower troposphere, as well as the action of Prealpi Varesine mountains, upstream of the intense mesoscale flux. For the other event, the storm core over the city of Pavia showed a much faster development within 40 minutes and a fast-shifting to the northeast; the movement, along with the soil characteristic of that area, could have determined different damages and disruption. In fact, the areas between the cities of Pavia and Milan are mainly agricultural, flat sites, with a large capability of draining water than built-up areas, where, in front of slopes and an insufficient run-off, floods may occur. These last considerations need to be investigated in future works.

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