Warning procedures for extreme events in the Emilia-Romagna Region

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1 Introduction

Recently the Emilia-Romagna Region has been hit by several extreme events, among which severe thunderstorms and flash floods, that caused damages and fatalities. This highlighted the need to predispose guidelines for operational procedures to support forecasters in monitoring and nowcasting activities, also according to the National Civil Protection requirements.

The aim of this work is to define procedures for convective events making use of radar and satellite products and data from ground stations. The first task deals with the identification of the products playing a key role for any relevant meteorological situation. For hail events, warning thresholds are evaluated by means of statistical analysis and literature research.

The procedure partially refers to the 2 years-experiments (2010 and 2011) of thunderstorm detection and monitoring carried on by ARPA Emilia-Romagna. In that pilot project some radar indicators, such as thresholds over 1h-accumulated precipitation, had been already identified. In the new scheme, additional products, including velocity-azimuth display (VAD), 45 dBZ-echo top, vertical integrated liquid (VIL), hydrometeor classification and probability of hail (POH) are taken into account. Moreover some satellite information are considered (i.e. HRV-enhanced IR) and the RDT (Rapid Development Thunderstorm) of the SAFNWC is implemented and tested.

To assess the features and the reliability of the presented warning procedures, a summer case study is analyzed.

2 Satellite products

The key role of the satellite information is to detect potentially dangerous cells in their early stage, 5-30 minutes before the storms reach the ground or they are observed by ground stations or radars. For this purpose several satellite products have been implemented to support the forecast activities in the warning emission procedure.

These products are the single channel images (including the Enhanced Infrared image with the addition of a colour palette to highlight the coldest areas), the HRV-Enhanced Infrared image (available only during the daytime) and the RGB products, obtained by the combination of different channels, such as the Convective Storms and the Day Microphysics. Finally some EUMETSAT SAFNWC products (http://www.nwcsaf.org) are also visualized (i.e. Cloud Type and Cloud Top Temperature). All these products are generated by means of the Meteosatlib open source software, that is a suite of libraries, tools and GDAL plugins to manage and visualize real time HRIT data (Zini et al., 2013).

Other crucial information for the identification of the convective cores and the severity of the storms are the lightning data (provided by the Italian Air Force Meteorological Service and the National Civil Protection). In Figure 1 (left panel) the lightning data are superimposed on the Infrared channel image and in the right panel of Figure 1 the HRV Enhanced infrared image is visualized during a convective episode occurred in Emilia-Romagna Region on the 2nd of July, 2014.

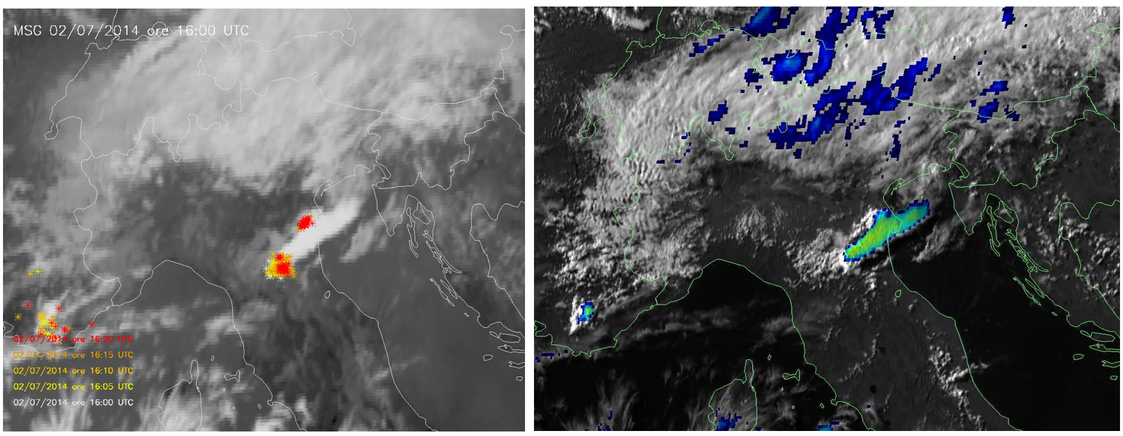

Figure 1. 02/07/2014 16:00 UTC. Lightning -IR information (on the left) and HRV Enhanced IR image (on the right).

Moreover, also for summer convective storms, the RDT (Rapid Development Thunderstorm) has been implemented and

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tested. This product has been developed by Meteo-France in the framework of the EUMETSAT SAFNWC to support the identification of severe convective systems, from meso-alpha scale down to smaller scales. The RDT algorithm includes three steps: the detection of cloud, the tracking of the systems and finally the discrimination of convective cloud objects. This product allows to add information to the satellite image taking into account of several parameters, such as the motion vector, the cooling and expansion rate, the cloud top height and the temporal evolution. The RDT data input are the satellite HRIT files (VIS 0.6, IR 8.7, IR 12.0, WV 6.2,WV 7.3 and IR 10.8 channels), some SAFNWC products (i.e. Cloud Type and Cloud top temperature), the lightning data and the ECMWF model information to assess the instability indices. The output is a BUFR file, that can be converted in a hdf5 file and then it needs a graphic elaboration to be visualized. For this purpose Arpa uses the IDL programming language.

In our implementation the life cycle phase (characterized by the type of the line of the detected cell), the top cloud temperature (indicated by the color of the line: yellow for TB min greater than -25°C, orange for TB min between -25°C and -40° C and red for TB less then -40°C) and the motion vector (shown by a green arrow providing speed and direction) are visualized. The RDT is then overlaid to the IR channel map. An example of the RDT visualization is displayed in Figure 8.

3 Radar products

3.1 VIL analysis

The first index considered in this work to evaluate the intensity of an event is the VIL (Vertically Integrated Liquid), which represents the water content of a column above a cell. In the formulation of Amburn and Wolf (1997) it is calculated as:

$$\mathrm{VIL} = \sum 3.4 * 10^{-6} \left[\frac{(\mathrm{Z_i} + \mathrm{Z_{i+1}})}{2}\right]^{\frac{4}{7}} * \Delta\mathrm{h}$$

where Z_i and Z_{i+1} are consecutive reflectivity values in the vertical column and Δh is the vertical distance between the i-th cell and the i+1-th cell.

In order to identify a VIL threshold to distinguish hail from no hail cases, a statistical analysis was carried out on 150 instants, 131 without hail and 49 with hail. The hail cases were identified using hail reports provided by the 'Consortia for Conservation of Agricultural Production', and maps of hydrometeors classification obtained by means of a fuzzy-logic scheme (Zrnic et al., 2001), which uses polarimetric quantities Zh and Zdr in association with the temperature analysis.

The histograms in Figure 2 show the frequency of maximum VIL value in the map in hail and no hail cases and the percentage of hail cases for each maximum VIL class. Above 40 kg/m^2, always an hail event occurs, between 30 and 40 kg/m^2 50% of cases reports hail and below 30 kg/m^2 less than 10 % of cases shows hail.

In Figure 3 are represented the 99.99° percentile instead of the maxima; the histograms show that at least 3-4 cells with VIL higher than 35 kg/m^2 are present in hail events, while less than 3-4 points showing a VIL higher than 10 kg/m^2 are present in cases of no hail.

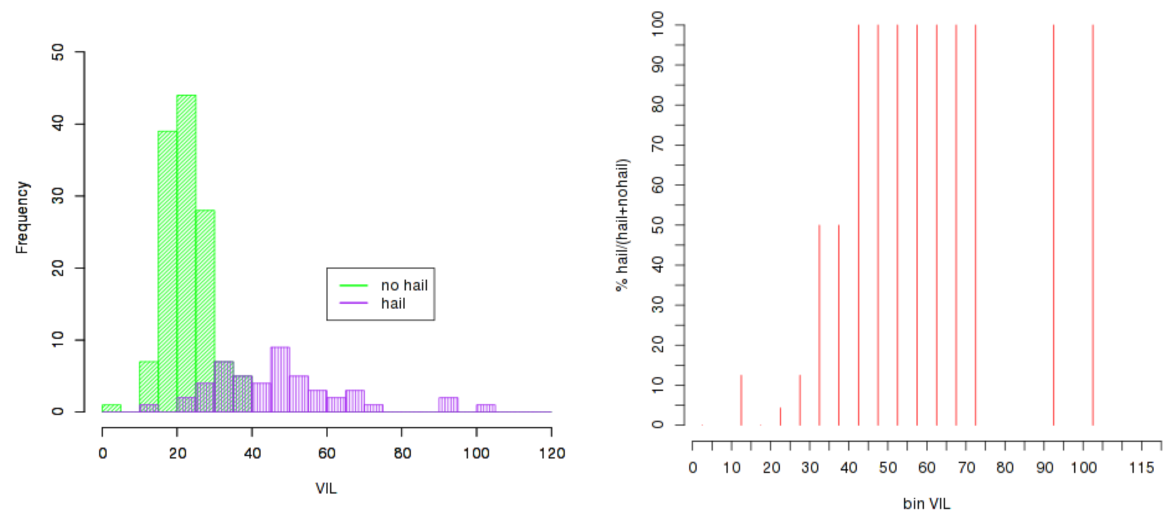

Figure 2. On the left: frequency of VIL maxima in cases of hail (violet) and no hail (green). On the right : percentage of hail cases for each maximum VIL class.

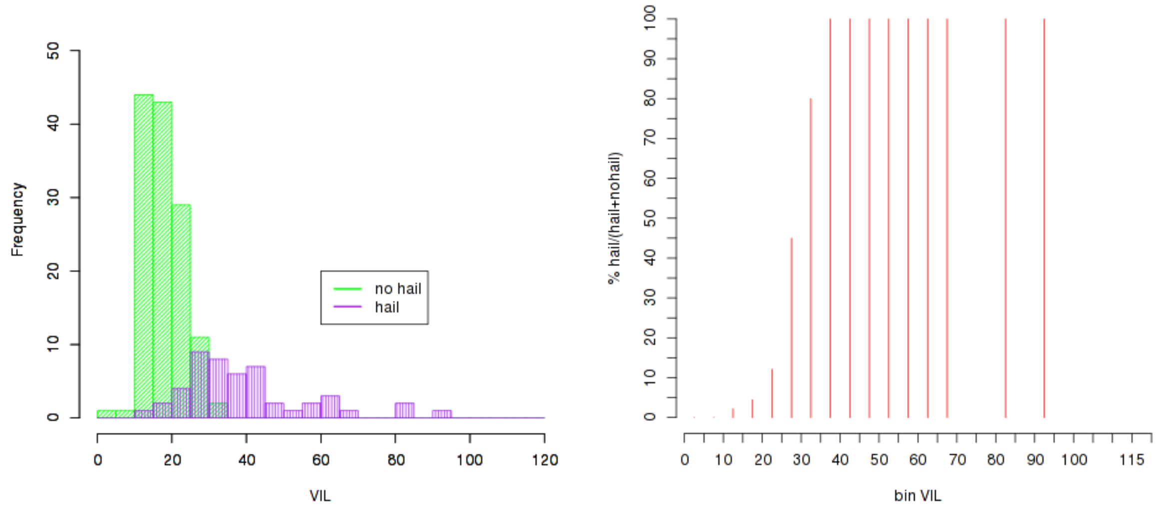

Figure 3 99.99 percentile of VIL in cases of hail (violet) and no hail (green). On the right : percentage of hail cases for each 99.99 percentile of VIL class.

3.2 POH analysis

A further index of severity taken into consideration is the POH (probability of hail), which is defined, in the formulation of Delobbe et al. (2005), as

$$POH = 0.319 + 0.133 * \Delta h$$

where Δh is the difference between the 45 dBZ echotop and the 0° level obtained from the most recent radiosounding.

Figure 4 shows hydrometeor classification map and POH in a hail case. In the black circle are the hail areas characterized by the green color followed by attenuation.

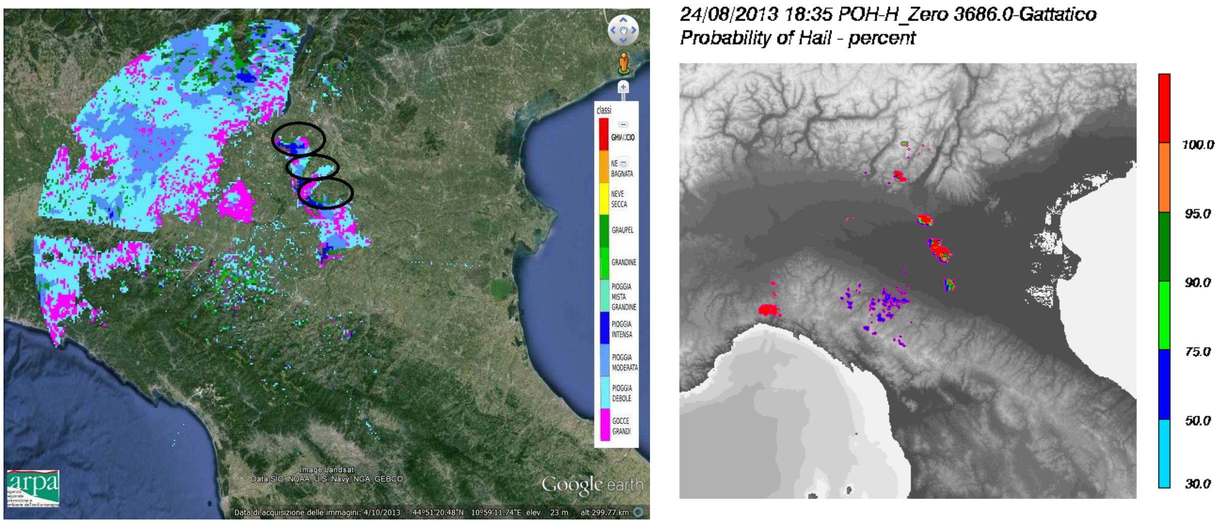

Figure 4 Hydrometeor classification map (on the left panel) and POH (on the right panel) on 24/08/2013 at 18:35 UTC.

The statistical analysis is carried out on the same sample of VIL analysis. In the box and whiskers plot of Figure 5 are represented the POH distributions of each hail time analyzed. The green box represents the interval between 25° and 75° percentile, the black line the 50° percentile, the whiskers are the minimum and maximum values of the distribution except of outliers. The box width is proportional to the number of points of the distribution. For each time is extracted the POH value in the cell showing the maximum VIL and this value is marked with a cross. POH values correspondent to VIL maxima are above the threshold of 80%.

In the box-plot of Figure 6 is represented the POH distribution in no hail cases. In most of the time POH is not calculated since the maximum reflectivity value in the map is below 45 dBZ. In other cases VIL maxima are reached in points where the POH is not calculable. In 5 cases the POH is defined in correspondence to the VIL maximum; in these cases the VIL assumes values in the range 15-40 kg/m^2.

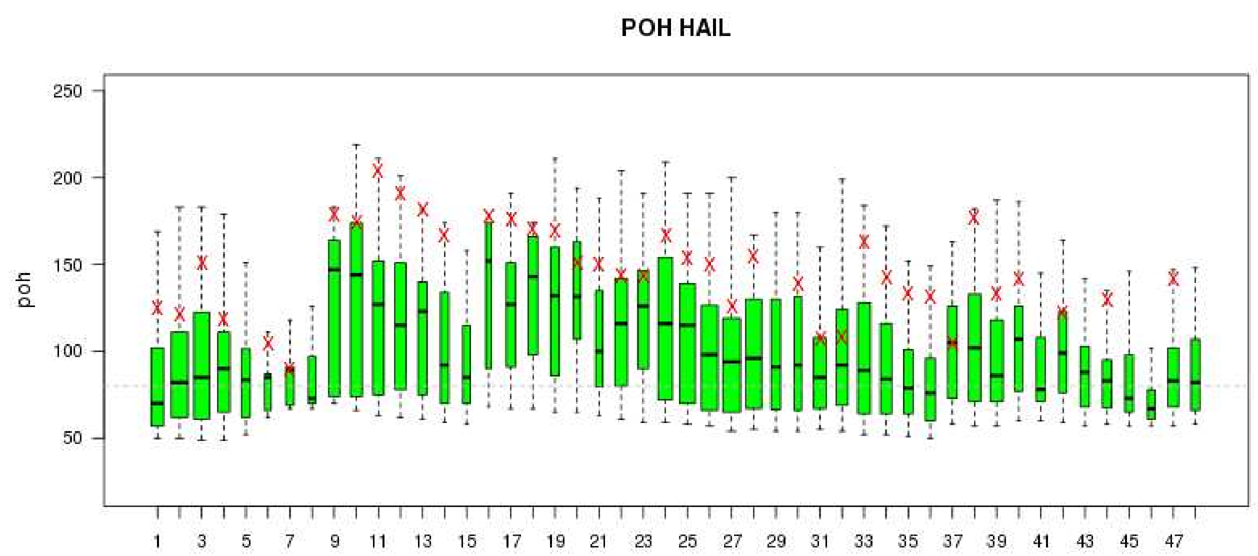

Figure 5 Box-and-whiskers plot representing probability of hail in hail cases enumerated from 1 to 49. The red crosses are POH values corresponding to VIL maxima.

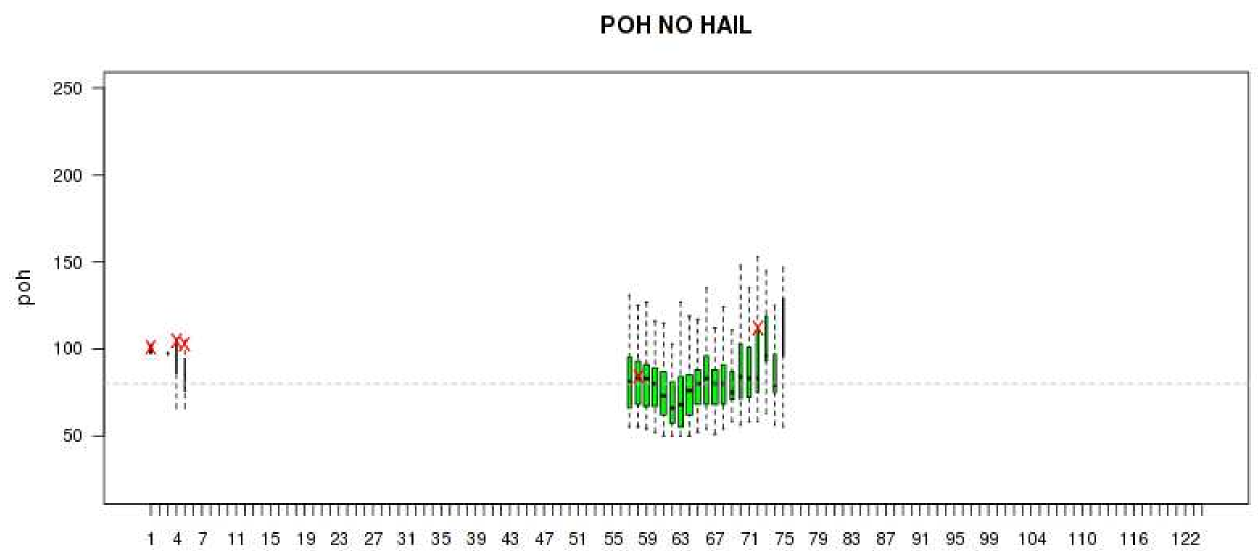

Figure 6 Box-and-whiskers plot representing probability of hail in no hail cases enumerated from 1 to 131. The red crosses are POH values corresponding to VIL maxima.

Considering the histograms of VIL and the POH box-plots the hail warning should be issued if VIL is higher than 40 kg/m^2 or if VIL is higher than 30 kg/m^2 and POH is higher than 80%.

3.3 Wind analysis

For monitoring purposes retrieved wind radar profiles are analyzed. In the operational framework radar wind profiles are generated every 15 minutes through the VAD technique (Lehrmitte and Atlas (1961), Browning and Wexler (1968)) using the highest elevation and then are plotted over a 6 hours framework every 30 minutes (Figure 7). This type of visualization shows the evolution of wind profiles from which information about approaching fronts, detection of sea breeze, rapid direction changes in wind direction and velocity can be inferred.

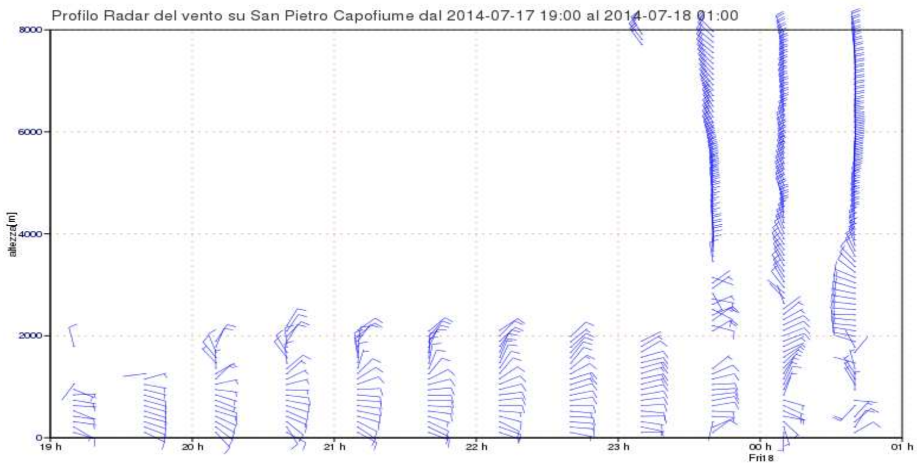

Figure 7 Example of VAD analysis

4 Case study

On 13 July 2013, a severe hail storm hit the city of Boretto and other municipalities, in the mid-western part of the Emilia Romagna region. The supercell, coming from the north, developed in the early morning and caused severe damages in the involved areas.

The RDT product in Figure 8 shows the early stage of the convective event developed in the North-East of Italy during the night, some hours before it reached the Emilia-Romagna region. On the left panel of Figure 8 the growing cells have top temperature greater than -40° and the life stage is identified as “triggering phase” (continuous orange line). About an hour later, the top temperature decreases, highlighting the intensification of the cells and the phase is classified as “mature” (dashed red line).

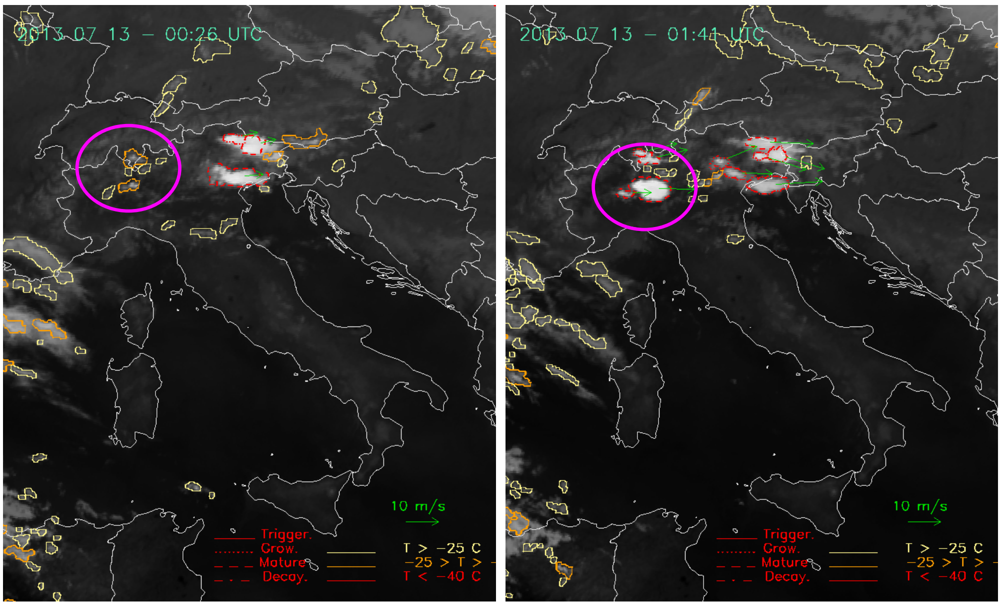

Figure 8. 13/07/2013. RDT images at 00:26 UTC (left) and at 01:41 UTC (right).

In the mature stage of the event (Figure 9.left), the Enhance IR image shows the overshooting top and the U-shape cold areas (yellow areas) linked to the more active area of the event. In the right panel the lighting data (indicated by red stars) and the HRV information confirm the strong convective activity and the location of the core of the storm.

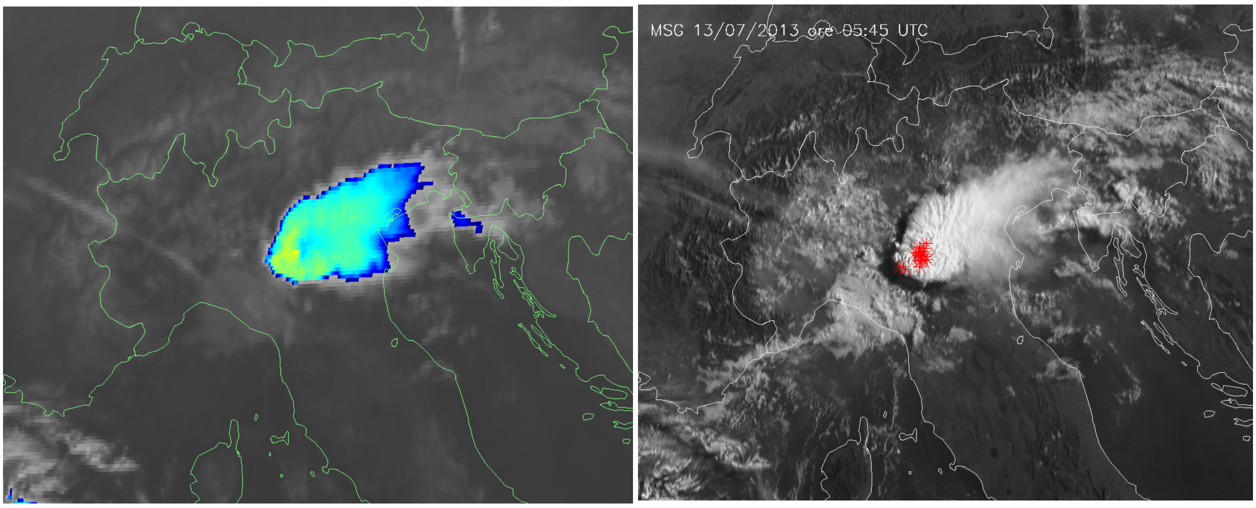

Figure 9. 13/07/2013. Enhanced Infrared image (left) and lightning data and HRV channel (right) at 05:45 UTC

In Figure 10 are represented the VIL, the POH and the 45 dBZ echotop at 05:48 UTC and the municipalities hit by the hailstorm. The VIL values in the core of the cell are higher than 60 kg/m^2, the POH reaches 100% and echotop reaches 14 km. As specified in the previous section, in this condition a hail warning should be issued.

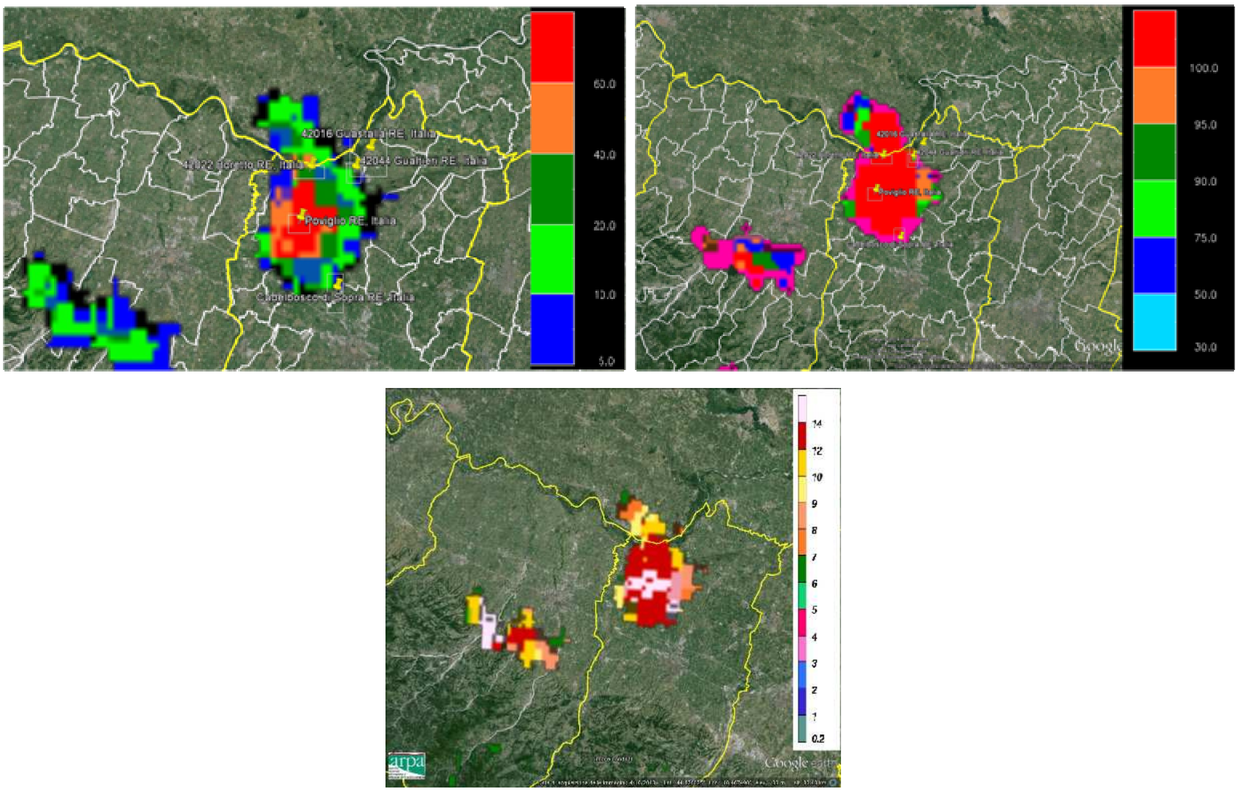

Figure 10 VIL (above on the left), POH (above on the right) and 45 dBZ echotop (below) on 13/07/2013 at 05:48 UTC. Zoom on the area hit by the storm. Yellow markers show the municipalities hit by the hailstorm.

5 Conclusions

In this work a set of instruments to identify severe storms is presented, as first step for the definition of summer warning procedures. In particular radar and satellite products are taken into account.

Satellite products (i. e. RDT, enhanced infrared and RGB maps) provide the first insight on the developing storm, anticipating the radar and ground station observation, and they are able to identify most active areas of the cells. Lightning adds information on the severity of the storms.

When the storm reaches the mature phase and starts to produce precipitation, radar becomes the main instrument to describe the event. In particular in addition to the precipitation products (accumulated rain), other quantities are evaluated to assess the severity of the convection.

Among others, VIL and POH are considered and a statistical analysis is carried out to define thresholds to issue a hail warning. The investigation shows that if VIL is higher than 40 kg/m^2 or if VIL is higher than 30 kg/m^2 and POH is higher than 80% a severe hailstorm is expected.

6 References

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