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DEBRIS FLOWS IN VAL PARMA AND VAL BAGANZA (NORTHERN APENNINES) DURING THE 13 OCTOBER 2014 ALLUVIAL EVENT IN PARMA PROVINCE (ITALY)

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EXTENDED ABSTRACT

Nella giornata del 13 ottobre 2014, durante l'evento alluvionale che ha colpito la provincia di Parma, numerosi *debris flows* si sono verificati in Val Parma e in Val Baganza, in particolare lungo i versanti del Monte Cervellino, tra i comuni di Corniglio, Berceto e Langhirano. Nel versante orientale dell'Appennino settentrionale (cioè la porzione di Appennino incluso nella Regione Emilia-Romagna), i *debris flows* sono fenomeni generalmente considerati molto rari: l'inventario del dissesto della Regione Emilia Romagna indica nello 0.2% la percentuale di frane mappate come depositi riconducibili ai flussi rapidi.

Durante l'evento di pioggia dell'ottobre 2014 circa il 70% dei torrenti è stato interessato da qusto tipo di fenomeni, i quali hanno provocato ingenti danni a strade, briglie ed infrastrutture. La stazione pluviometrica di Marra, la più vicina all'area interessata dall'evento, tra il 12 e il 13 ottobre ha registrato 308,6 mm in 24 ore. L'intensità maggiore è stata registrata tra le 7.00 e le 15.00 del 13 ottobre. Il picco di precipitazione oraria è stato di 81.2 mm: il picco a 15 minuti è stato di 31.2 mm. Questi valori, confrontati con le soglie pluviometriche d'innesco per *debris flows* presentate in letteratura da diversi autori, sono superiori a qualsiasi soglia proposta. Questo evento di pioggia ha un tempo di ritorno superiore ai 100 anni. La mappa delle precipitazioni cumlutate tra le 7.00 e le 15.00, ottenuta attraverso l'interpolazione dei dati pluviometrici, indica che tutti i fenomeni si sono verificati all'interno dell'isoieta 120 mm/8h. Se si considerano i picchi orari delle precipitazioni, i dati mostrano che i *debris flows* si sono verificati nelle zone in cui sono stati superati i 30 mm/h.

La distribuzione spaziale dell'evento di pioggia, ottenuta attraverso l'interpolazione dei dati pluviometrici, non può essere molto precisa in quanto la rete di pluviometri non è abbastanza densa. Il confronto con la mappa delle precipitazioni cumulate realizzata utilizzando i dati radar, permette di ottenenere una distribuzione spaziale dell'evento più accurata.

Indagini sul campo hanno permesso di mappare e documentare diverse zone d'innesco, zone di trasporto e zone di deposito. Nel caso del Rio Vestana, nella zona d'innesco sono stati mobilitati circa 10.000 m^3 di detrito, situazione simile ad altri *debris flows* verificatisi nell'area. L'altezza massima raggiunta dalle colate è stata di circa 3-4 m, come evidenziato dai segni sulle cortecce degli alberi. In molti casi si è osservato che, lungo le zone di trasporto, le colate sono state alimentate dall'erosione laterale che, di conseguenza, ha aumentato la quantità di detrito mobilitato.

Lungo i torrenti interessati da *debris flows*, decine di briglie sono state distrutte, provocando il rilascio di grandi quantità di detriti che precedentemente erano intrappolati dalle briglie stesse. Nella parte inferiore dei torrenti, le briglie sono state anche sepolte dai depositi di *debris flow*. Inoltre, quasi tutte le strade locali che attraversano i torrenti interessati dai fenomeni sono state gravemente danneggiate. In alcuni casi, i torrenti hanno trasportato e depositato lungo strade massi di dimensioni maggiori di 5 m^3.

I *debris flows* nell'Appennino settentrionale sono stati finora considerati come eventi piuttosto rari, sia in termini spaziali che temporali. Le specifiche condizioni meteorologiche, geologiche, geotecniche e idrologiche che possono innescare colate detritiche nell Appennino Emiliano sono state finora poco studiate. Gli eventi che hanno colpito la Val Parma e la Val Baganza nel 2014 e la Val Trebbia e la Val Nure nel 2015 sono da considerarsi un elemento fondamentale nella percezione delle colate detritiche come nuova potenziale causa di danni diffusi in Emilia-Romagna. Pertanto, è importante documentare questo tipo di frana, al fine di attuare politiche di prevenzione dei rischi simili a quelle che sono state adottate nel territorio alpino.

Questo articolo documenta le caratteristiche dei *debris flows* che si sono verificati durante l'evento in Val Parma e Val Baganza del 2014. Esso presenta inoltre un'analisi dei dati delle precipitazioni rispetto alla distribuzione degli eventi, evidenziando come soglie pluviometriche sviluppate in altre zone montane possono essere adottate per questo specifico contesto geologico e geomorfologico. Inoltre, si evidenzia come l'integrazione tra i dati pluviometrici interpolati e i dati radar può essere un buon metodo per analizzare l'evoluzione temporale dell' intensità delle precipitazioni rispetto al verificarsi di *debris flows*.

ABSTRACT

During the 13 October 2014 rainstorm event that affected the Val Parma and Val Baganza area, several debris flows affected the Mt. Cervellino relief (northern Apennines, Italy), causing severe and widespread damages to check-dams, roads and other infrastructures. Such event, together with the Piacenza province event of 2015, has generated the perception of debris flows as a breaking new potential cause of widespread damages in the Emilia-Romagna. The meteorological event of October 2014, reconstructed by means of rain gauges and radar data, reached intensities as high as 80 mm/hour, which is well above any debris flow triggering thresholds presented in literature. However, data show that debris flows have occurred in any location where 30 mm/hour were exceeded. The result was the occurrence of tens of debris flows, which were triggered in zones of failure of slope debris coverage along the streams, and that remobilized and scoured debris along the track and destroyed several check dams and damaged roads that were overflown by debris. This paper is aimed to document the distribution and characteristics of the debris flow events that occurred during such event. By doing so, it also warns against this potentially destructive events that, in a changing meteorological framework, might result much more frequent and widespread than expected also in the northern Apennines.

Keywords: debris flows, rainstorm October 2014, Val Parma, Val Baganza, Northern Apennines

INTRODUCTION

Debris flow are a major factor for damages and fatalities worldwide (Dowling & Santi, 2014). In Italy, debris flows are particularly widespread in the Alps (Berti *et alii*, 1999; Pavlova *et alii*, 2014, Nikopolous *et alii*, 2015) in the southern Apennines - especially in pyroclastic deposits (Calcaterra *et alii*, 2000; Fiorillo & Wilson, 2004), in the central Apennines (Guzzetti & Cardinali, 1991) and in the western slope of the northern Apennines (Delmonaco *et alii*, 2003, Mondini *et alii*, 2014). On the other hand, in the eastern slope of the northern Apennines (i.e. the portion of Apennines included in Emilia-Romagna Region) they are generally considered quite rare: the official landslide inventory of Emilia Romagna Region indicates in 0.2% the percentage of mapped landslide deposits ascribable to rapid flows (Regione Emilia-Romagna, 2013) and this figure includes, also, rapid mudflows.

The fact that debris flow have been, in the last decades, quite unusual phenomena in this part of the Apennines, is also reflected on the extremely limited number of historic records, reports and publications dealing with this type of phenomena. For instance, to the Authors best knowledge, the only scientific reports providing an explicit documentation of several debris flow occurring in the same area are these documenting the consequences of the September 1972 and 1973 alluvial events in Modena, Reggio Emilia and Parma provinces (Moratti & Pellegrini, 1977; Papani & Sgavetti, 1977; Rossetti & Tagliavini, 1977). Other widespread debris flows events can indirectly be identified by reading chronicles of the alluvial events of September 1953 in Val Trebbia, in Piacenza province (Pasquali, 2003). For the rest, available historic records report of isolated and single debris flows.

However, in the last couple of years, the occurrence of debris flows in this territory has been significant, both in terms of number of debris flows and in terms of induced damages. Specifically, tens of sub-basins released debris flows during the 13 October 2014 rainstorm event that affected the Val Parma and Val Baganza area (Parma province, which also caused the city of Parma to be partially flooded). On 14th September 2015, another similar event has occurred in the Val Trebbia, Val Nure and Val d'Aveto basins (Piacenza province), causing an even larger number of debris flows. This paper is aimed to document the distribution and characteristics of the debris flow events that occurred in 2014 in the upper Val Parma and Val Baganza (northern Apennines, Italy) and the consequent damages to check-dams, roads and other infrastructures.

RAINFALL AND DEBRIS FLOW DISTRIBUTION

Large part of the debris flows occurred in the Monte Cervellino relief, in the municipalities of Corniglio, Berceto and Langhirano. Rainfall data for this area are available at 15 minutes interval by several meteorological stations of the ARPA

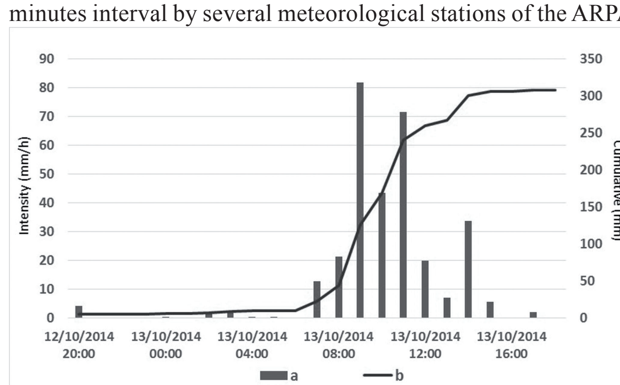

Fig. 1 - Rainfall data recorded by ARPA meteorological station of Marra (PR) between 12 and 13 October - time plot of the event. Legend: a) hourly rainfall intensity (mm/h); b) cumulative rainfall (mm)

Meteorological Station	Height (m)	Tot. Precipitation (24h)	Tot. Precipitation (8h)	Max Intensity (mm/h)	Max Intensity (mm/15min)
Berceto	755	73.2	62.6	37.2	24.4
Bosco di Corniglio	908	261	248.2	72.6	30.2
Calestano	384	139.8	132.6	34.4	11.6
Casaselvatica	830	132.4	106.4	26.6	7
Lagdei	1247	237	224.4	61.6	29.8
Marra	626	308.6	296.6	81.8	31.2

Tab. 1 - Rainfall data of Arpa meteorological stations: the station of Marra has recorded the higher values both as total precipitation and maximum intensity. The rainfall record from the station of Berceto shows lower values of cumulative rainfall, but the rainfall peak in 15 minutes is comparable to those of other stations

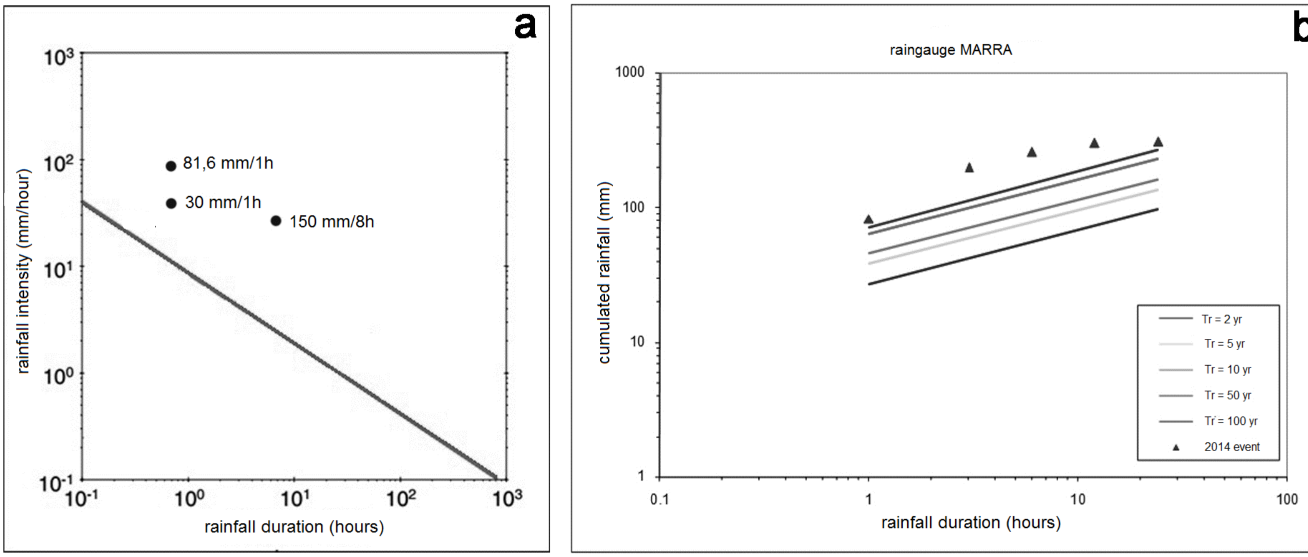

Fig. 2 - a) The event in Val Parma compared to rainfall thresholds triggering debris-flow collected by Guzzetti *et alii (2007); b) Intensity – duration plot for the event of 13th October 2014 compared to return period lines*

Parameters of Interpolation								
Method	**Model**	**Semivariogram Type**	**Lag Size**	**Major Range**	**Partial Sill**	**Nugget**	**Search Radius**	**N° of points**
KRIGING	*ORDINARY*	*SPHERICAL*	*0,00075*	*10.000*	*50*	*0*	*VARIABLE*	*12*

Tab. 2 - Parameters used for the interpolation of rainfall data, through the Geostatistical Analyst tool of ArcGis 10

network. The rain gauge of Marra (Parma province) is the closest to the slopes affected by debris flows (approximately 5 km away). The Marra record between 12th and 13th October 2014 indicates a rainfall of 308.6 mm in 24 hours (Fig. 1). Rainfall intensity peaked between 7.00 and 15.00 of 13th October 2014. In particular, around 9.00 o'clock, the intensity was of 81,8 mm/h, while around 10.00 o'clock it was 43,4 mm/h. The peak intensity at 15 minutes was 31.2 mm. These values are similar to these obtained from other ARPA meteorological stations located near Marra (Tab. 1). If compared to the debris-flow triggering thresholds presented in scientific literature (Caine, 1980; Cancelli & Nova, 1985; Ceriani *et alii*, 1994; Guzzetti *et alii*, 2008), the values are above almost any of the threshold values proposed (Fig. 2a). The intensity-duration plot shows that peaks of such an intensity can be associated to return periods exceeding 100 years (Fig. 2b).

Cumulative rainfall maps have been derived by the kriging method (Laslett, 1994) adopting the parameters in Tab. 2. Such approach is generally used in literature to interpolate extreme rainfall data (Attorre *et alii*, 2007 and Fiorenzo *et alii*, 2008). The 24 hours cumulative rainfall map shows that about 50% of debris flows have occurred in areas where rainfall exceeded values between 200 and 300 mm/24h (Fig. 3). More specifically,

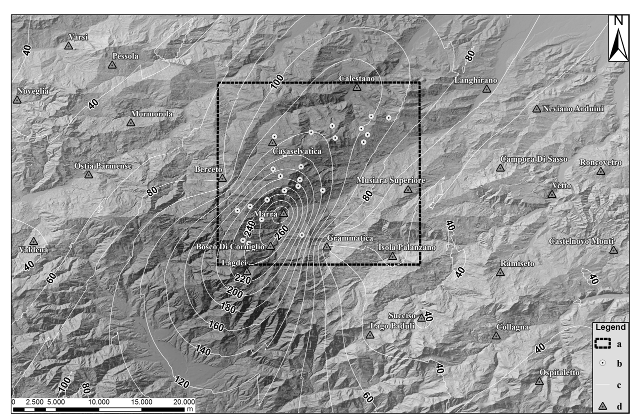

Fig. 3 - Cumulative rainfall map obtained by interpolation of rainfall data recorded in 24 hours. The triggering zones are located in the areas where the isohyets produced shows higher values of cumulative rainfall. Legend: a) area affected by debris flow; b) debris flow triggering zones; c) cumulative rainfall isohyets (24h); d) Arpa meteorological station

the cumulative rainfall maps which considers the "peak" 8 hours between 7.00 and 15.00 o'clock of 13th October 2015 indicates that practically all phenomena have occurred inside the 120 mm/8h isohyet. However, the spatial distribution of rainfall obtained by interpolation is probably not as accurate, as the raingauge network is not enough dense to resolve the fine spatial distribution. This can be appreciated by comparing it with the 8 hours cumulative rainfall map obtained with weather radar data by ARPA (Fig. 4b). Radar data, collected with 5 minutes temporal resolution, were preprocessed in order extract significant meteorological information, interpolated over a 1 km^2 grid in order to produce hourly cumulative rainfall maps. The latter probably underestimates maximum cumulative rainfall values, due to the attenuation of the front of the rainstorm (which propagated from west to east while the radar see the area pointing toward west from the east). Nevertheless, the spatial distribution of debris flows with respect to rainfall derived from the radar maps, shows a very good correspondence at values exceeding the 150 mm/8h isohyet. If the hourly rainfall peaks are considered,

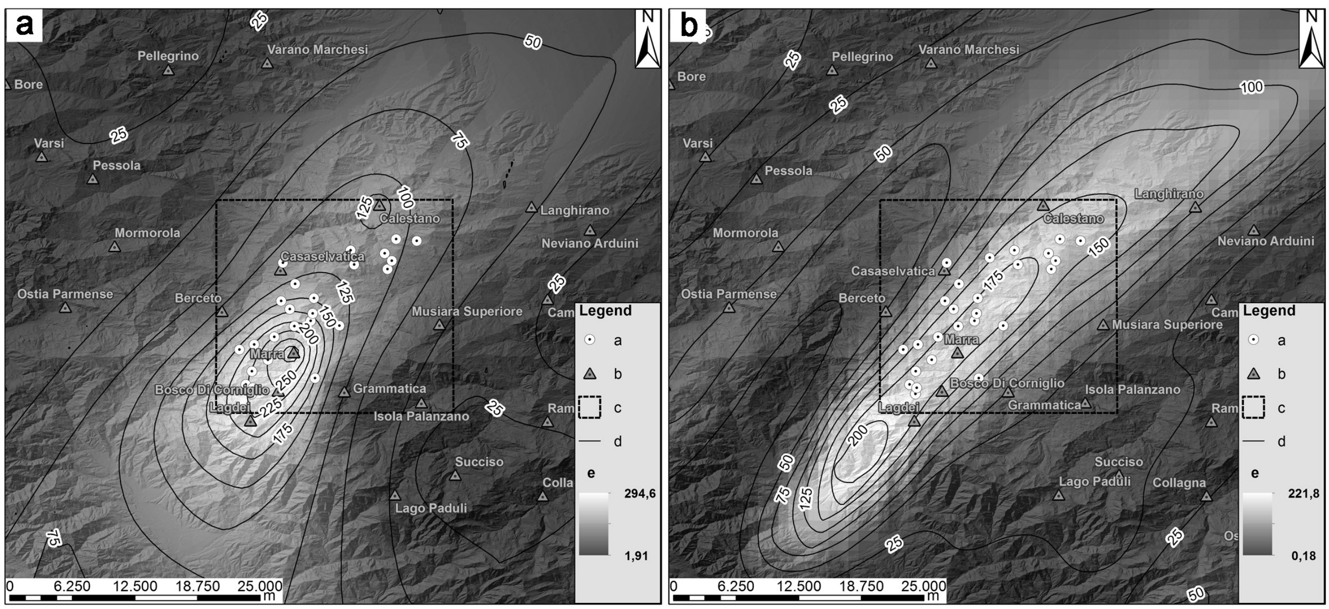

Fig. 4 - a) Cumulative rainfall map, interpolation of rainfall data (8h); b) Radar cumulative rainfall map (8h) by Arpa. Legend: a) debris flow triggering zones; b) ARPA meteorological station; c) area affected by debris flow; d) cumulative rainfall isohyets (8h); e) cumulative rainfall values in 8 hours (mm/h)

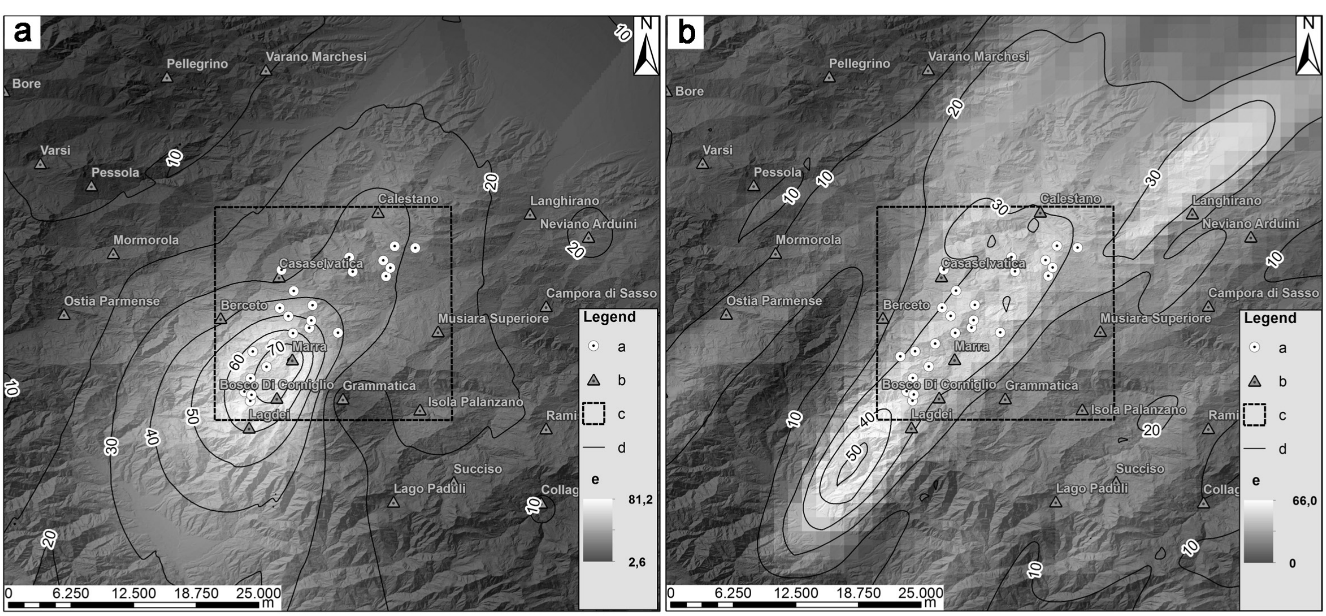

Fig. 5 - a) Cumulative rainfall map, interpolation of hourly rainfall peaks; b) Radar cumulative rainfall map, hourly rainfall peaks. Legend: a) debris flow triggering zones; b) ARPA meteorological station; c) area affected by debris flow; d) hourly rainfall peaks isohyets (1h); e) hourly rainfall peaks values (mm/1h)

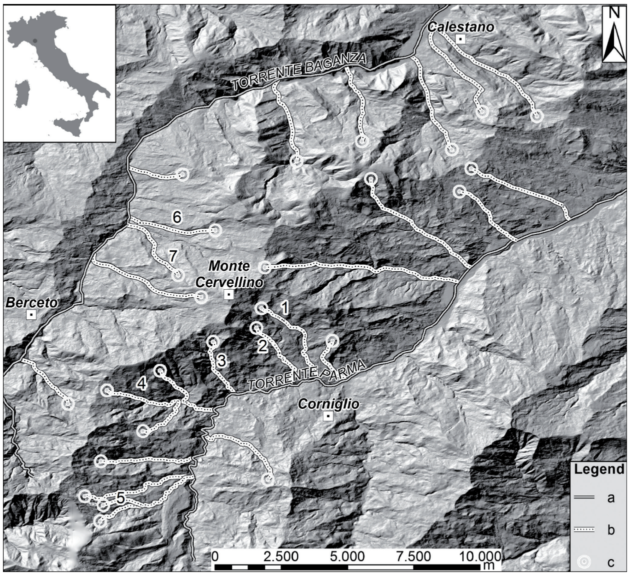

Fig. 6 - Distribution of torrents affected by debris flow in the Mt. Cervellino area (Val Parma and Val Baganza). Legend: a) Main streams; b) Torrent affected by debris flow; c) Debris flow triggering zones; 1) Rio Vestana; 2) Rio Graiana; 3) Rio Lombasina;4) Rio Roccaferrara; 5) Rio Cirone; 6) Rio di Confine; 7) Rio delle Tane

data show that debris flows have occurred in any location where 30 mm/hour was exceeded (Fig. 5). To obtain the peaks isohyets, the hourly rainfall peaks, recorded by each meteorological station between the 7.00 and 15.00 o'clock, have been interpolated. Moreover, to obtain the map of hourly rainfall peaks measured by Arpa Radar, the maximum values of each cell measured in hourly radar images between 7.00 and 15.00 o'clock have been used.

On an hydrographic perspective, the 26 torrents along which debris flows have occurred represent roughly the 70%

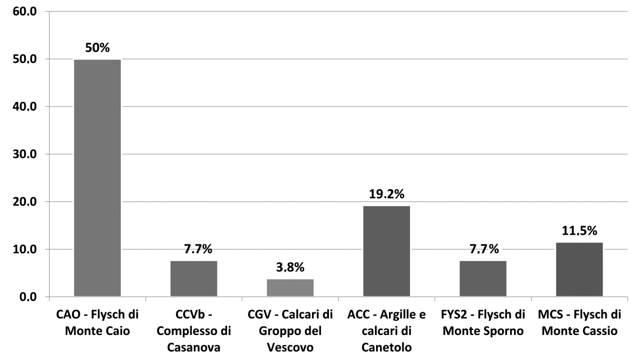

Fig. 7 - Bedrock lithology in debris flow triggering zones: in 13 torrents out of a total of 26, the outcropping lithology is Flysch di Monte Caio

of all the torrents in the Monte Cervellino relief (Fig. 6). The length of the torrent tracks affected by debris flows ranges from approximately 1000 m of Rio Cirone to 3000 m of Rio Vestana. In some cases (Rio Lombasina, Rio Vestana e Rio Roccaferrara) the elevation difference between the triggering zone and the final accumulation zone is up to 600 m, while in other cases (Rio Cirone) is of only 150 m (Tab. 3). Bedrock lithology in the Monte Cervellino relief is flysch and mono-polygenic breccia (Flysch di Monte Caio and Complesso di Casanova) and Argille e Calcari di Canetolo in the SE slope, while it is flysch (Flysch di Monte Cassio) in the NW slope. Bedrock lithology in the debris flows triggering zone is in 50% of the cases the Flysch di Monte Caio (Fig. 7) over which periglacial processes in the Late Pleistocene and slope processes in the Holocene have deposited widespread slope debris and landslide deposits. In most cases, the triggering zones correspond to areas of slope failure affecting coarse debris deposits in correspondence of marked changes in slope gradient (Fig. 8).

	Rio Vestana	***Rio Graiana***	***Rio Lombasina***	***Rio Cirone***	***Rio Roccaferrara***
Basin area (km^2)	**4.1**	**2.8**	**2,4**	**0.3**	**7,5**
Main stream length (km)	**3,7**	**2,7**	**2,3**	**1,1**	**3,3**
Maximum elevation (m a.s.l.)	**1164**	**969**	**1105**	**1143**	**1170**
Minimum elevation (m a.s.l.)	**564**	**573**	**603**	**904**	**622**
Drainage density (km/km^2)	**3.6**	**4.0**	**2.1**	**4.8**	**3.4**
Average slope gradient (°)	**18.6**	**22.5**	**25.1**	**19.4**	**22.2**
Bedrock in triggering zone	**CAO**	**CAO**	**CAO**	**ACC**	**CCVb**

Tab. 3 - Main characteristics of some catchments and torrents affected by debris flow

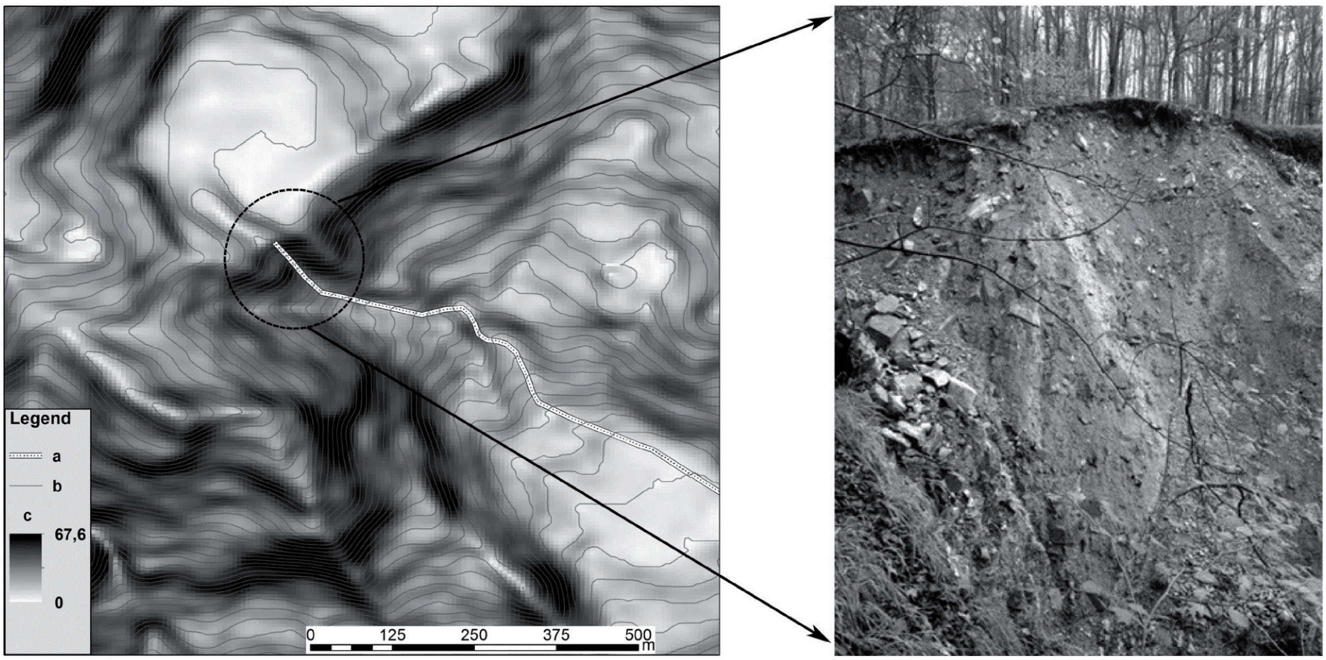

Fig. 8 - Triggering zone of Rio Vestana: Map of slope angles, derived from Digital Elevation Map; triggering of debris flow in correspondence of slope angle changes. Legend: a) location of triggering zone shows in the photo; b) contour lines; c) values of slope angle

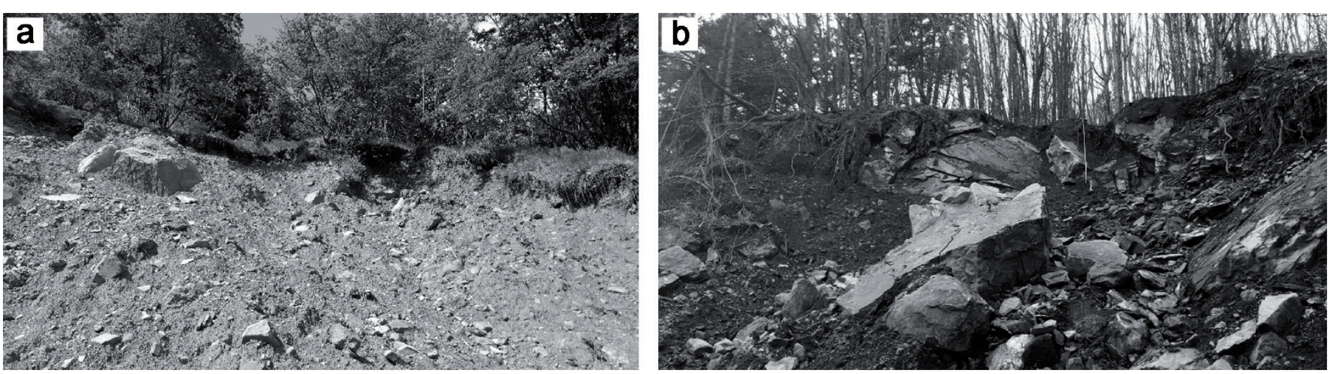

Fig. 9 - a) Triggering zone of debris flow in Rio Roccaferrara; b) Triggering zone of debris flow in Rio Cirone

DEBRIS FLOWS FEATURES AND DAMAGES

Field surveys have allowed to map and document several triggering zones, debris flow track channels and deposition areas. In Rio Vestana, slope failure in the triggering zone has affected approximately 10.000 m^3 of coarse debris (Fig. 8). A similar situation has been surveyed in many other triggering zones (Fig. 9).

Along the debris-flow track channels, evidences of streambed scouring (Fig. 10a), erosion of materials previously trapped above check dams, partial accumulation in wooden zones at the sides of the track and debris levees showing the typical inverse gradation of debris flow deposits can be observed (Fig. 10b). The maximum height reached by debris flows was about 3 to 4 m, as it is evidenced by marks and scars on the bark of trees (Fig. 11a). In many cases it was observed that, along the track channels, the debris flows were fed by lateral erosion that, consequently, increased the amount of mobilized debris (Fig. 11b).

The data collected during field surveys have allowed the erosion and deposition areas to be mapped. For instance, the map of Rio Vestana (Fig. 12) shows dominant erosion in the triggering zone, a partial deposition in the upper part of torrent, and alternated erosion and deposition areas down the track. This pattern is mostly controlled by local topography, i.e. alternation of areas of higher and lower slope gradient.

One of the most relevant and widespread damage type associated to debris flow was the cut-through of tens of check dams along the affected torrents (Fig. 13a). This caused the release of large amounts of debris that was previously trapped upslope check-

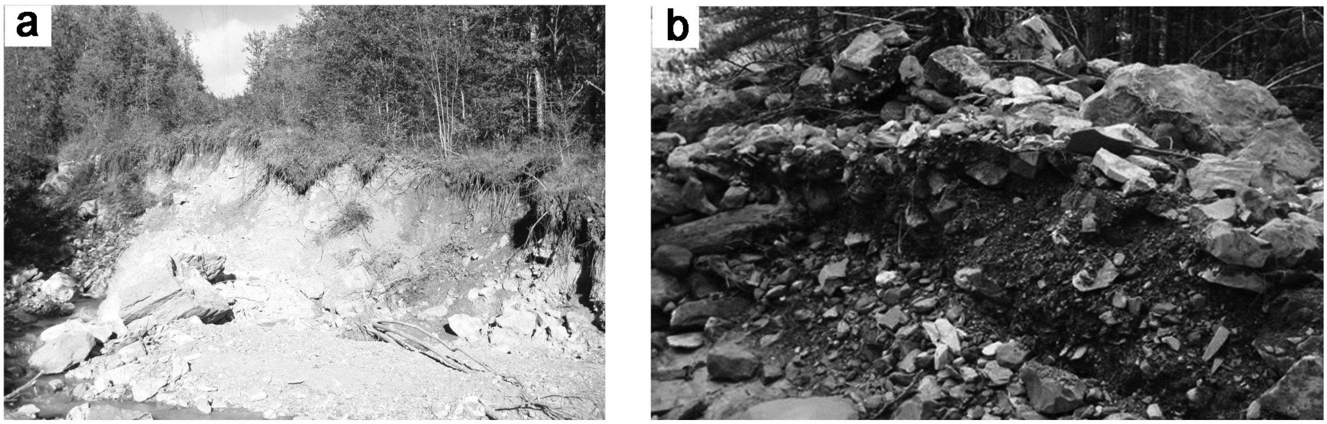

Fig. 10 - a) Track channel of Rio Vestana: evidences of streambed scouring; b) Levees with inverse gradation of debris flow deposits in Rio Vestana

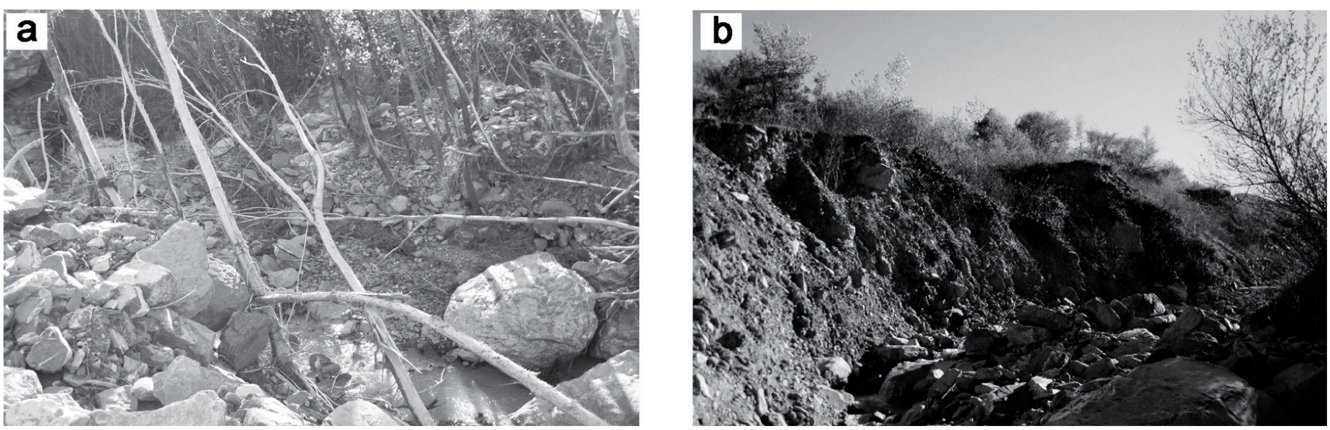

Fig. 11 - a) Track channel of Rio Lombasina: marks on the bark of trees; b) Example of lateral erosion

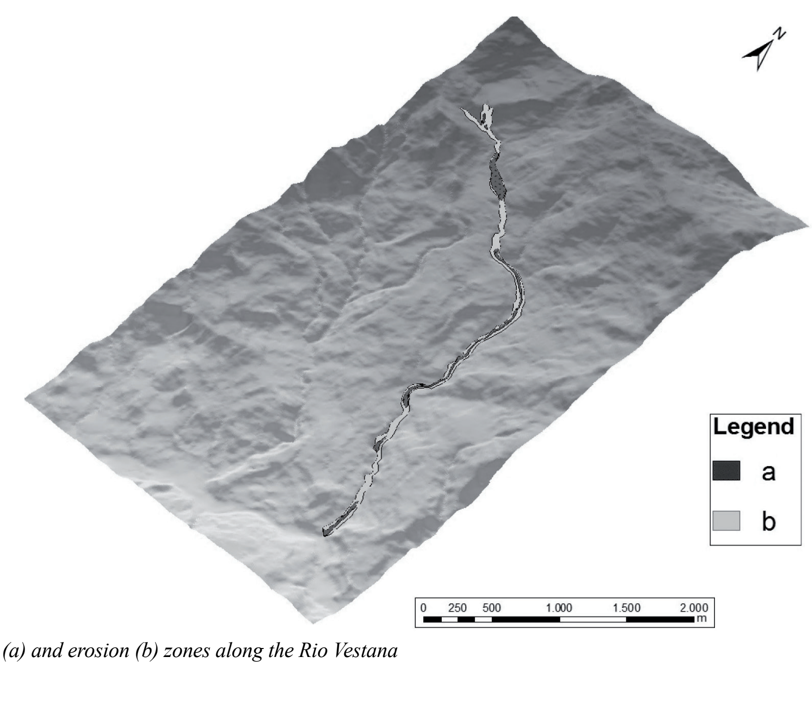

Fig. 12 - Map of deposition (a) and erosion (b) zones along the Rio Vestana

dams. In the lower portion of the torrents, check-dams were also buried by debris flow deposits (Fig. 13b). Also, almost all of the local roads crossing the debris flow tracks were severely damaged. In practice, in many road crossing areas the torrent had been previously reduced to flow into 1 to 2 m diameter pipes in order to avoid the need for bridges. In these conditions, the flow-pipes were rapidly obstructed by the debris flows: this caused the outburst of pipes, the run of the debris flows on top of the roads and, in many cases, the final erosion and cut-through of the road track and of the areas immediately downslope the road crossing point (Fig. 14). At the base the slopes, large amounts of debris filled bridges and outflow pipes and overflowed main provincial roads. This was particularly severe in the fan–shaped accumulation zones at the confluence of the torrents into the Parma river (Fig. 15a). In some cases, the torrents transported and deposited along roads boulders as large as 5 m^3 or more (Fig. 15b).

CONCLUSIONS

Debris flows in the northern Apennines have so far being considered as quite rare events, both in temporal and in spatial terms. However, the Parma-Baganza valleys event in 2014 (presented in this paper) and the Trebbia-Nure-Aveto valleys event in 2015, which occurred at one year time interval one another, are to be considered a cornerstone in the perception of debris flows as a potential cause of widespread damages in the Emilia-Romagna.

The specific meteorological, geological, geotechnical and hydrological conditions that can trigger debris flows in the Emilia Apennines are so far almost unstudied. Therefore, it is important to document and inventory this type of landslide, in order to implement risk prevention policies similar to these that have been adopted in the Alpine area (Arattano & Moia, 1998; Genevois *et alii*, 2000; Marchi & D'Agostino, 2004; Cavalli & Grisotto, 2005).

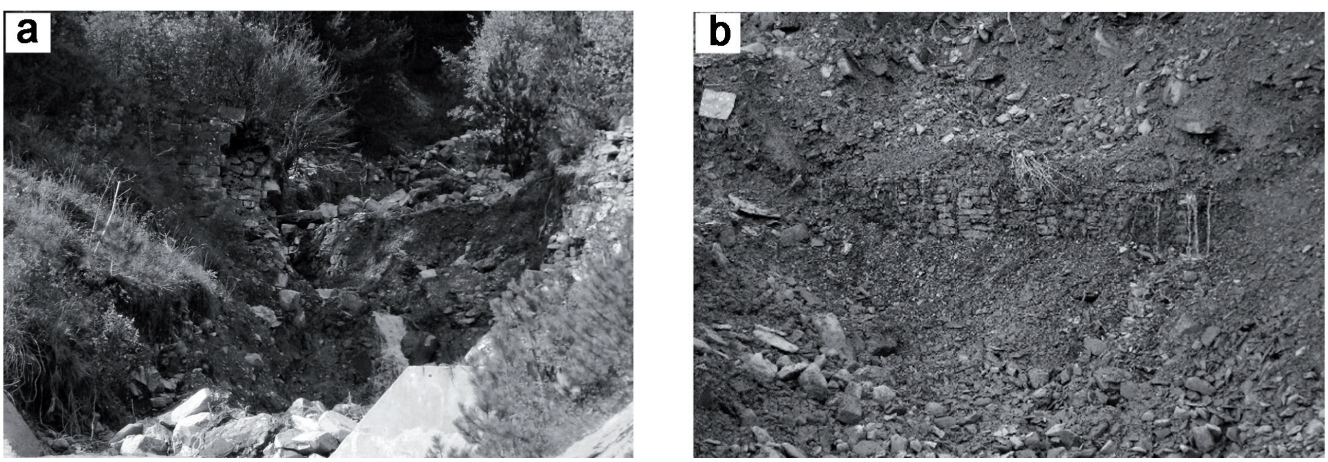

Fig. 13 - Examples of check-dams cut-through by debris flows: a) check-dam in the Rio Vestana destroyed by debris flow; b) check dam in the Rio delle Tane completely submerged by debris

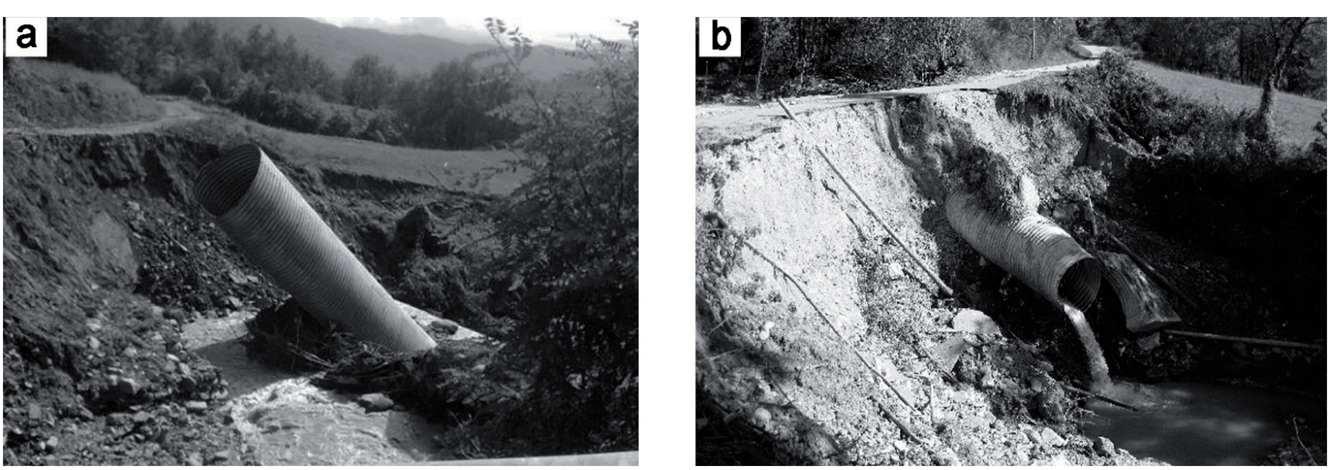

Fig. 14 - Examples of road-crossing area along the track of the torrent: a) Rio Vestana, the pipe for the outflow of the torrent was outburst during the debris flow and significant erosion occurred downslope of the road crossing; b) Rio Roccaferrara, the debris flow overflowed the road and significant erosion occurred downslope of the road crossing zone

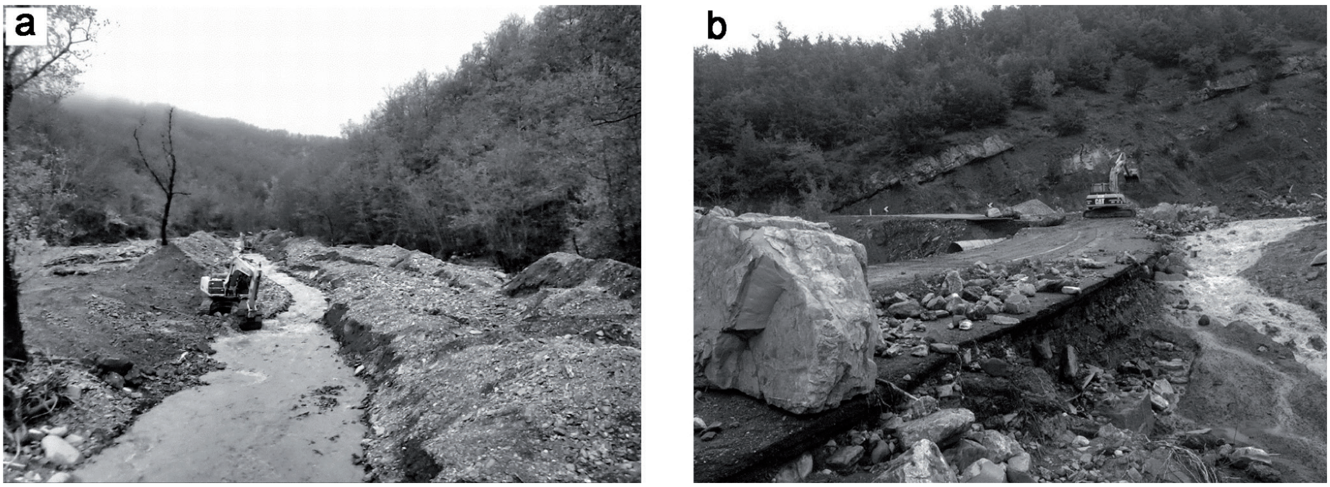

Fig. 15 - a) Parma river, debris transported and deposited by the torrents; b) Rio di Confine, boulders with size of 5 m³ deposited along the provincial road

This paper documents the characteristics of debris flows occurred during the Val Parma-Val Baganza valleys event in 2014. It also presents an analysis of rainfall data with respect to the distribution of events, highlighting how a rainfall thresholds developed in other mountain areas can also be adopted for this specific geologic and geomorphic context. Furthermore, it highlights how the integration between interpolated rain gauge data and weather radar data can be a good way to analyze the temporal evolution of the intensity of a rainfall events with respect to the occurrence of debris flow. In particular, the spatial distribution of debris flows with respect to rainfall derived from the radar maps as well as from rain gauges, shows a very good correspondence at values exceeding the 150 mm/8h isohyet in the "peak" hours between 7.00 and 15.00 o' clock of 13th October 2015. If the hourly rainfall peaks are considered, data show that debris flows have occurred in locations where the 30 mm/hour threshold was exceeded.

The surveys conducted after the event, have also evidenced how check dams did have little or no effect in preventing debris flows and that, on the contrary, they were the source for mobilization of large amounts of debris when cut-through by debris flows. Also, the road network along the slopes is absolutely inadequate to cope with this type of phenomena. Stream crossing points along roads are mostly characterized by the presence of water pipes that were rapidly clogged by debris and that can overbusted under the pressure of the debris flows, causing severe damages to the road and surrounding zones.

Finally, it is worthwhile stressing the fact that the event in the Parma province in 2014, as well as the Piacenza province event of 2015, are clear warnings against this potentially destructive events that, in a changing meteorological framework, might become much more frequent and widespread than so far expected in the orthern Apennines.

ACKNOWLEDGEMENTS

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