Mediterranean Storms
(Proceedings of the 3rd EGS Plinius Conference held at Baja Sardinia, Italy, October 2001)

PRELIMINARY ANALYSIS OF LANDSLIDES TRIGGERED BY THE 23-24 NOVEMBER 2000 EVENT IN WESTERN LIGURIA, ITALY

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ABSTRACT

From mid-October to 22 November 2000 the Liguria Region experienced prolonged and intense rainfall, with cumulative values locally exceeding 1000 mm in 45 days. The already severe rainfall sequence ended on November 23-24 with a high intensity storm that dumped more than 150 mm of rain in 24 hours. The high intensity event caused flooding and triggered several hundreds soils slips and debris flows, and a few large, complex landslides. Slope failures caused 3 casualties and severe damage to the roads, the private houses, and the agriculture. Large, and very large-scale colour aerial photographs were taken 45 days after the event in the areas most affected by the landslides. Through the interpretation of the 334 photographs covering an area of ~ 500 km^2, we prepared a landslide inventory map showing 1204 landslides, for a total landslide area of 1.6 km^2. For the Ceriana Municipality, an area where the landslides were numerous, historical information on a severe landslide event occurred on 8-11 December 1910 is available. This historical event triggered several hundreds landslides and produced severe economic damage. We attempt a preliminary comparison of the historical and recent landslide events.

1 INTRODUCTION

The Liguria Region extends for 5418 km^2 in northern Italy, lying mostly to the South of the Alps and Apennines mountain chains. Mean annual precipitation ranges from 700 mm to the West, to 1000 mm in the central and eastern parts of the Region. Due to the geographical location, the horography and the geological setting, landslides and floods are frequent in Liguria. In the 20th Century mass movements and inundations distressed 777 and 849 sites, respectively. Some of the sites were affected more than once (cf. http://sici.gndci.pg.cnr.it).

On 23 November 2000 a high intensity rainfall event hit the coast of the Ligurian Sea (*Unità di Crisi per la Liguria Occidentale*, 2001). Damage was particularly severe in the Imperia Province, where landslides caused three casualties and severe damage to the flower industry, and to private houses and buildings. Landslides were most abundant at Ventimiglia, near San Remo and in the Armea and Argentina valleys. Soil-slips were also reported near Mentone (in France).

In this short paper we present a landslide inventory map prepared after the event by interpreting stereoscopic aerial photographs, we briefly discuss the rainfall conditions that triggered the landslides, and we show preliminary results of an historical investigation on a high-intensity rainfall event occurred in the Armea valley in 1910.

2 Rainfall

From mid-October to 22 November 2000 the western part of the Liguria Region experienced prolonged and intense rainfall, with cumulative values for a 45 days period locally exceeding 1000 mm. Locally, the cumulative rainfall exceeded 70% of the mean annual precipitation. Main events occurred on October 10-16, on November 3-7, on November 12-17, and on November 23-24, 2000.

During the first event (October 10-16) cumulative rainfall exceeding 300 mm, and daily rainfall exceeding 125 mm, were recorded. At Colle di Melogno (W of Savona), on 15 October 2000, 80 mm in 12 hours, and 156 mm in 24 hours were recorded. The second event (November 3-7) was characterised by a cumulative rainfall in excess of 200 mm. During this event, the largest cumulative rainfall was recorded at Nasceto (265 mm, NW of La Spezia) and at Loco Carchelli (264 mm, NE of Genoa). At several rain gauges daily intensity exceeded 160 mm. The third event (November 12-17) was characterised by a cumulative rainfall up to 398 mm (at Loco Carchelli, NE of Genoa). The same rain gauge, on 14 November 2000, measured 115.8 mm in 12 hours, and 137 mm in 24 hours.

2.1 The 23-24 November 2000 event

At the end of this very wet period, on 23-24 November 2000, an intense rainfall event hit the coast of the Ligurian Sea, from West of Mentone (France) to La Spezia. Rainfall data for 3 rain gauges around the area most affected by the landslides and floods in the Imperia Province were available to us. Two stations are located along the coast: at Monte Maure (near Ventimiglia, to the West), and at the Seismic and Meteorological Observatory in Imperia (to the Est). The third station is located at the Alpe Grande Rezzo, at an elevation of 1532 m a.s.l., about 22 km from the coast. Cumulative values for the event were also available to us for the San Remo and the San Romolo rain gauges. These were the only rain gauges in the vicinity of the area where the landslides were most abundant.

During the event, rainfall was clustered along the coast, and occurred in bursts, some of which were particularly intense. The Imperia rain gauge measured 4.2 mm in 5 minutes, 18.8 mm in 30 minutes, and 26.8 mm in one hour (Figure 1).

Rainfall occurred at different times in different places. At Monte Maure (Ventimiglia) at least 6 downpours of rain occurred during the night and in the morning of November 23; the event ended with a heavy shower at about 23:00. The cumulative (total) precipitation at the Monte Maure rain gauge was 98 mm (Figure 1).

At Imperia the event started in the late evening of November 22, with a light rain. Less than 15 mm of rain were recorded during the night (12:00 pm - 6:00 am), and up to 50 mm in the morning (until 12:00 am). Rainfall intensity increased in the early afternoon and remained high until midnight; the rain gauge measured 150 mm of rain in 12 hours (12:00 am – 12:00 pm). At the Imperia rain gauge the cumulative precipitation exceeded 192 mm in 24 hours (Figure 1). Information available for the San Remo and San Romolo rain gauges indicates that cumulative rainfall was about 170 mm at San Remo (comparable to the rain measured along the coast at Imperia) and about 240 mm at San Romolo. At San Remo rainfall was particularly severe in the night and early morning of November 23.

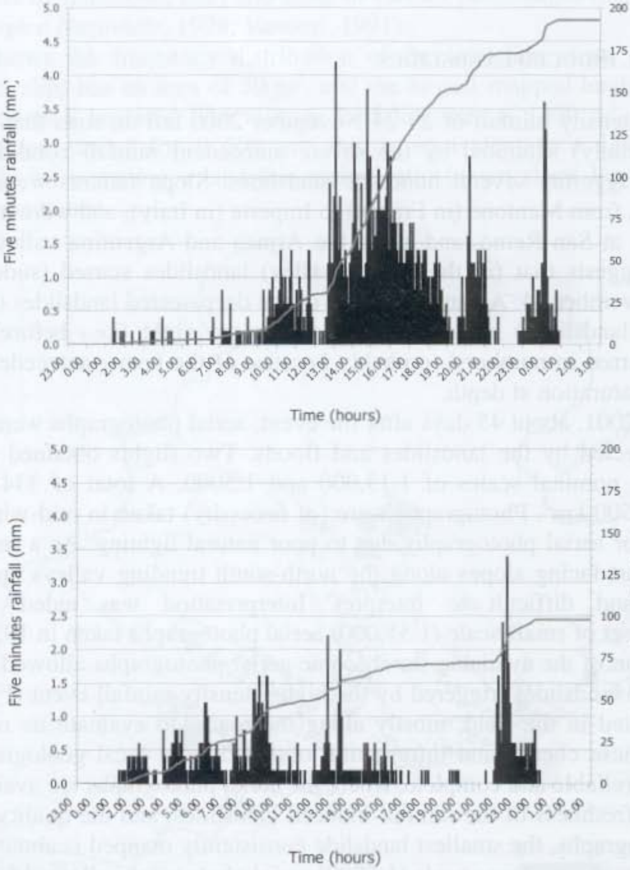

Figure 1. High-intensity rainfall event in western Liguria on 23-24 November 2000. Upper graph: rainfall measured at the Seismic and Meteorological Observatory (Imperia) rain gauge. Lower graph: rainfall measured at the Monte Maure (Ventimiglia) rain gauge.

No rain gauge was operating at the time of the event in the Armea and Argentina valleys. Anecdotal information collected at Ceriana (in the Armea valley) suggests that both the cumulative rainfall and the rainfall intensity were high, and most probably similar to the values recorded at San Romolo.

A preliminary analysis of the historical rainfall records available for Ceriana revealed that high intensity rainfall is not uncommon in the area. Between 1934 and 1950, 7 events with daily rainfall exceeding 120 mm, 6 events with more than 150 mm in 2 days, and 6 events with more than 200 mm in 5 days were recorded. High intensity events occurred on 2 January 1949 (when 158 mm in 24 hours and 197 mm in 48 hours were recorded) and on 25-29 December 1935 (when 141 mm in 1 day, 221 mm in 2 days, 351 mm in 3 days, and 427 mm in 5 days were recorded) (*Servizio Idrografico*, 1957; 1960).

3 RAINFALL INDUCED LANDSLIDES

The high-intensity rainfall of 23-24 November 2000 fell on soils that were already (totally or partially) saturated by the severe antecedent rainfall conditions, causing flooding and triggering several hundreds landslides. Slope failures were reported all along the coast, from Mentone (in France) to Imperia (in Italy), and were most abundant at Ventimiglia, at San Remo, and along the Armea and Argentina valleys. Anecdotal information suggests that (in the Armea valley) landslides started (suddenly) in the morning of November 24. Apparently some of the deep-seated landslides (the Bestagno and Soldagno landslides) started moving during the night (i.e., before the shallow landslides occurred in numbers), probably because of the heavy antecedent conditions that produced saturation at depth.

In January 2001, about 45 days after the event, aerial photographs were taken in the areas most affected by the landslides and floods. Two flights obtained colour aerial photographs at nominal scales of 1:13,000 and 1:5000. A total of 334 photographs covered about 500 km^2. Photographs were (of necessity) taken in mid-winter, a period unfavourable for aerial photography due to poor natural lighting. As a result, some of the steepest, east-facing slopes along the north-south trending valleys are dark in the photographs, and difficult to interpret. Interpretation was aided by using a supplementary set of small-scale (1:55,000) aerial photographs taken in 1954–1955.

Interpretation of the available stereoscopic aerial photographs allowed preparing an inventory of all landslides triggered by the high-intensity rainfall event (Figure 2). The map was checked in the field, mostly along the roads, to evaluate its reliability and consistency. These checks and information obtained from local geologists confirmed that the map is reliable and complete, where the aerial photographs are available.

Due to the freshness of the rainfall-induced landslides, and the quality and scale of the aerial photographs, the smallest landslide consistently mapped is about 150 m^2. The local availability of very large-scale (1:5000) aerial photographs allowed for particularly precise mapping of the landslides in those areas, and recognition of many of the smallest slope failures.

The landslide inventory map covers an area of about 500 km^2 and contains 1024 rainfall-induced landslides, for a total landslide area of 1.6 km^2 (0.3% of the study area). This is equivalent to an average density of 2.1-landslides/km^2. Locally, landslide density was much higher, exceeding 50 landslides/km^2 (e.g. in the Armea valley, near Ceriana). By far, the most abundant landslides (95% of the total number) were shallow soil-slips and debris flows. The latter were locally very large, involving considerable volumes of material, and travelling long distances (up to 1.5 km in the Armea valley). A few deep-seated landslides, comprising slump earth-flows, complex or compound movements, were also observed. These failures accounted for the largest percentage of the economic damage caused by the mass-movements.

Rainfall-induced landslides were not homogeneously distributed throughout the region. Although sufficiently detailed geologic information is not available to us, it is clear that slope failures occurred with similar frequency on marine deposits comprised of clay, sand and gravel (Plio-Pleistocene in age), and on fysch deposits made up of alternating layers of sandstone, marl and shale in various percentages (Miocene in age) (*Servizio Geologico Nazionale*, 1928; *Vanossi*, 1991).

Figure 3 shows the frequency distribution of the landslide areas. The smallest landslide (a soil slip) has an area of 50 m^2, and the largest mapped landslide (a deep-seated slide) covers 7 hectares. The average landslide area is 1300 m^2, but the most frequent landslides extend for ~ 500 m^2; this is equivalent to a (average) linear dimension of 22 m, assuming a landslide aspect ratio (down slope length vs. across slope width) close to one.

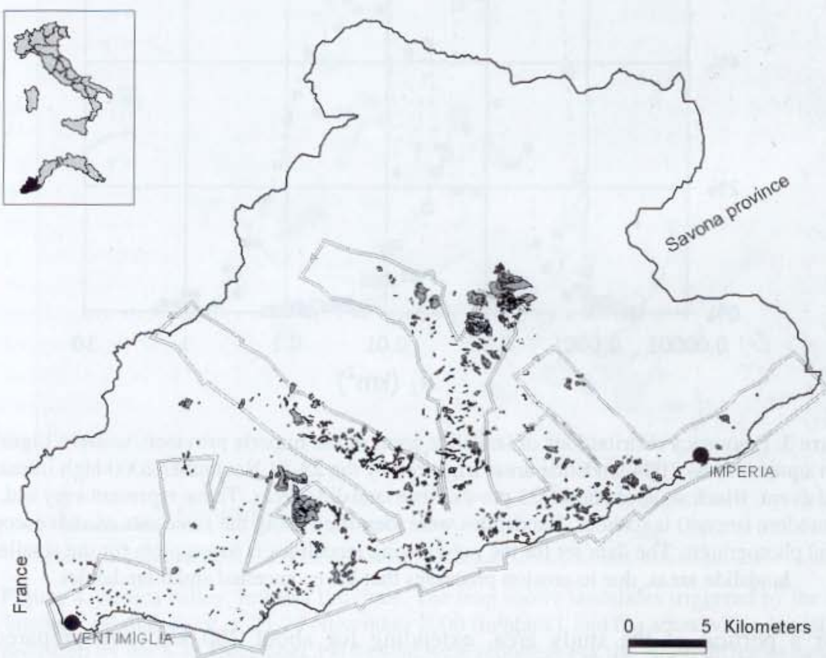

Figure 2. Imperia Province, western Liguria. Inventory map showing landslides triggered by the high intensity rainfall event of 23-24 November 2000. The map shows the location of 1024 landslides triggered by the event (black areas), and 723 pre-existing landslide areas (in grey). A double line shows the extent of the area for which stereoscopic aerial photographs were available. Thick black line is the outline of the Imperia Province.

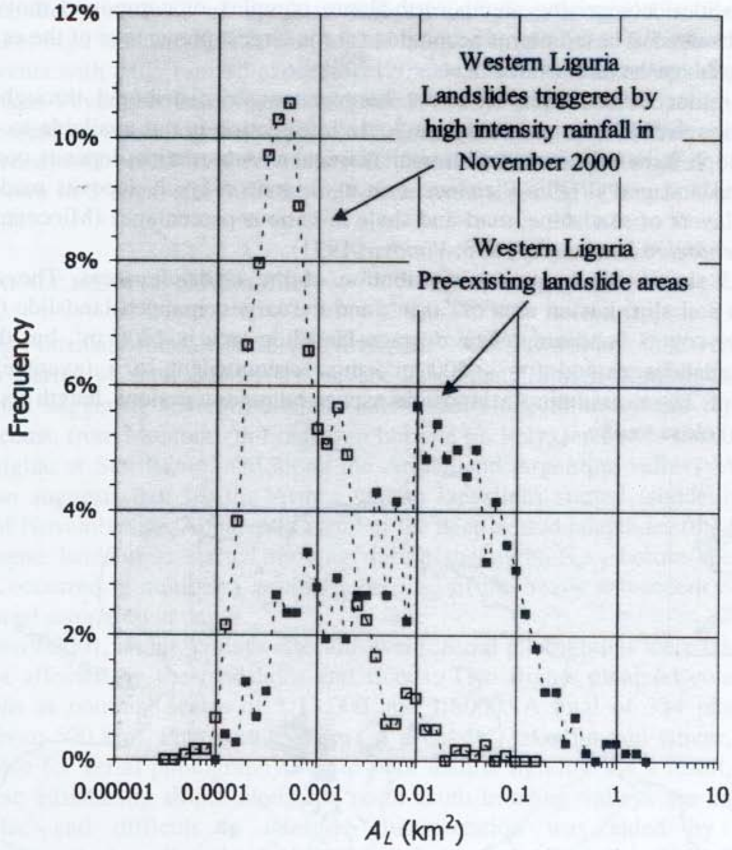

Figure 3. Frequency distributions of landslide areas in the Imperia province, western Liguria. Open squares show 1024 landslide areas triggered by the 23-24 November 2000 high intensity rainfall event. Black squares show 723 pre-existing landslide areas. These represent very old, old, and modern (recent) landslides. Landslides were identified using the same sets of stereoscopic aerial photographs. The data set for the pre-existing landslides is incomplete for the smallest landslide areas, due to erosion processes that have cancelled small landslides.

For a portion of the study area, extending for about 260 km^2, we prepared an inventory of the pre-existing landslides. The investigation was completed along the coast, and in the San Romolo, Armea and Argentina valleys. We used the same sets of aerial photographs used for mapping the rainfall-induced landslides. The inventory map contains 723 very old, old, and recent (modern) landslides, for a total landslide area of about 29.9 km^2 (11.5% of the study area).

Figure 3 shows the frequency distribution of the pre-existing landslide areas. The smallest landslide (a shallow failure) has an area of 100 m^2, and the largest mapped landslide (a deep-seated, complex and compound slide) extends over 2.6 km^2. The average landslide area is 4 hectares, and the most frequent (abundant) landslides have an area of about 1 hectare. The data set for the pre-existing landslides is somehow incomplete for the smallest landslide areas, because of erosion processes that have cancelled the small landslides.

3.1 Damage assessment

The high-intensity rainfall event of 23-24 November 2000 caused 3 casualties and severe damage to private properties, roads, and to the agriculture. Two casualties were reported at Ceriana, where the Bestagno landslide destroyed a house (killing the two people) and damaged the Provincial Road n. 55 connecting Ceriana to Baiardo. The third casualty was a truck driver, killed by a shallow landslide that hit his vehicle near San Lorenzo al Mare, at the entrance of a tunnel along the Genoa-Ventimiglia freeway.

Information obtained from the Municipality of Ceriana indicates that in that Municipality the total economic damage to public and private structures and infrastructures was estimated at Lire 24 billion (Euro 12 million). This is not considering the costs of fixing the deep-seated landslide that threat the village.

Figure 4. Armea valley, Imperia Province. The map shows landslides triggered by the high intensity rainfall event of 23-24 November 2000 (in black), and the areas where landslides produced by the 8-11 December 1910 event were reported. For the latter, different patterns represent different landslide abundance: light dotted pattern = few (1-2) landslides; oblique pattern = many (3-10) landslides; coarse dotted pattern = very many (> 10) landslides.

4 HISTORICAL INVESTIGATION

The area affected by the November 2000 event is not new to high-intensity or prolonged rainfall that triggers numerous landslides and produces inundations. A preliminary analysis of the available historical information revealed that particularly damaging events occurred on 8-11 December 1910, on 11-13 December 1916, on 11-13 December 1957, and on 18-20 February 1977. The 1910 event caused extensive damage in the Armea valley, and in the Ceriana Municipality. The 1916 event caused several landslides, one of which severely damaged the railway connecting Genoa to Nice. The 1957 event was widespread and particularly severe, producing numerous landslides. The 1977 event was less severe, but landslides near Ceriana damaged the Provincial Road n. 55.

In the following section we describe the preliminary results of an historical investigation on the 8-11 December 1910 event.

4.1 The 8-11 December 1910 event

An historical investigation carried out in the archive of the Ceriana Municipality (by Mr. Massimo Vaccari, *written communication*) revealed that a high intensity rainfall event occurred on 8-11 December 1910. The event caused numerous landslides and flooding, and produced extensive damage. Along the Armea torrent, 3 bridges were destroyed and 3 were damaged. Two bridges were destroyed and one was damaged along the Muanda (at the time called Palarea) stream, where it flows through the town of Ceriana. In the same area 3 houses were damaged or destroyed. Severe damage was reported along a mule-track connecting Ceriana to Taggia, where slope failures, river erosion, and the fall of (small) retaining walls were reported at 17 sites.

Damage to the agriculture was extremely severe, and several tens of requests for subsidy were filed after the event. Careful analysis of these requests indicates that damage was reported at 80 different areas in the Ceriana Municipality. The damage was caused by (an estimated number of) 690 landslides, and by inundation and river erosions at 127 sites.

Little information on the type of landslides is available. At several sites multiple landslides were reported (98). The majority of landslides were described as small (616), but a few landslides were described as large (56) or very large (4). For five landslides an estimate of landslide area is available, ranging from 16 to 3000 m^2. No information is available on the area or volume of the larger landslides. A few slope failures were describes as "long landslides" (14); these were most probably debris flows, similar to those occurred in November 2000.

The exact location of only a few landslides is known. Nevertheless, careful reading of the requests for subsidy allowed inferring the approximate location (within some hundreds meters) of several landslides. This information was stored into a GIS and used to prepare a map of the (inferred) location of the landslides and inundations occurred in December 1910 (Figure 4). The map shows the inferred abundance (i.e., few, many, very many) of landslides triggered by the December 1910, compared to the location of landslides triggered by the November 2000 event.

4.2 Damage assessment

The historical investigation allowed collecting abundant information on the estimated economic damage caused by the landslides and floods. The cost for rebuilding or fixing the bridges destroyed or damaged near Ceriana was estimated at Lire 13,881. This corresponds today (2001) to Lire 80 million. The bridges were rebuilt or fixed by 1914. Fixing and repairing the Taggia mule-track cost 2753 Lire. Damage to three houses in Ceriana was estimated at 17,800 Lire. By far the largest economic damage was to the agriculture (e.g., olive and chestnuts trees, orchards, agricultural land and structures); the damage listed in the requests of subsidy amounts to 240,000 lire, equivalent to Lire 1.37 billion (2001). The total economic damage was estimated at Lire 274,434, equivalent to Lire 1.56 billion, or Euro 808,000 (2001).

5 FINAL REMARKS

Not all the information for a complete discussion of the causes of the 23-24 November 2000 event, and for a thorough comparison with the 8-11 December 1910 event, is currently available. Only a preliminary discussion can be made on the rainfall characteristics that have trigegred the numerous landslides, and an initial comparison of the damage caused by the recent and historical events can be attempted.

For the areas where the landslides and floods were most abundant (i.e., the Armea and Argentina Valleys) no rainfall information is available. Analysis of the meteorological conditions that triggered landslides is therefore based on the 5 nearest rain gauges (i.e., Ventimiglia, Imperia, Alpe Grande Rezzo, San Remo and San Romolo), and on anecdotal information collected at Ceriana. The available information indicates that the rainfall pattern was characterized by high-intensity short-duration bursts that occurred at different times in different places. This introduces uncertainty in the definition of rainfall thresholds.

A comparison of the damage caused by the two events can also be attempted. The available information suggests that damage caused in the Ceriana Municipality by the December 1910 event was more diffused (wide spread) and more severe (particularly to the agriculture) than the damage caused by the November 2000 event. About 690 landslides were reported in 1910, whereas 273 landslides were mapped after the November 2000 event, in approximately the same area. Assuming that the number of landslides reported in December 1910 is reasonably correct, and that the inventory of the November 2000 landslides is complete, the 1910 event was about 2.5 times more severe than the 2000 event (690 vs. 273 landslides).

The estimated cost of the November 2000 event (in excess of Lire 24 billion) is much higher than the damage estimated for the December 1910 event (about Lire 1.5 billion). This indicates that the 2000 event was 16 times more costly than the 1910 event (1.5 vs. 24).

Despite the fact that the severity (or intensity) of the December 1910 event was 2.5 times larger than the severity of the November 2000 event, the economic damage was much lower (1:16). More work is needed to clarify this point, but the reason has to do with changes in the land use and in the economy of the area, and with increased repairing and building costs.

Acknowledgments. We thank Franco Siccardi and Giorgio Roth for providing the opportunity to work on the event, and Giorgio Boni and Luca Ferraris for making available the rainfall data. We are grateful to Massimo Vaccari for the historical information, to Guglielmo de Luigi for making available the aerial photographs, and to Sergio Peracchi for rainfall information. The paper is CNR-GNDCI Publication No. 2456.

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