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Real Time Monitoring for Diagnosis and Prevention of Extreme Rainfall Events: An Application to Intense Rainfalls on the Coastal City of Naples, Italy

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Abstract

The rainfall monitoring network of the Naples Department of Hydrographic and Oceanographic Service (NDHOS) was inadequate to measure the alluvial event occurred at Sarno on 5 May 1998, when a low rainfall amount of 101 mm was considered responsible for a dramatic landslide.

To improve the measuring capability of this network, 50 new monitoring stations were later on added and located in such a way to increase significantly the fractal dimension of their areal distribution. The enlargement of the network allowed the correct measurement of the extreme event occurred in Naples on 15 September 2001.

The paper reports also the risk of landslide phenomena (not catastrophic but however not negligible) inside the metropolitan area of Naples, frequently subjected to rock falls and to collapse of underground cavities.

Keywords: Real time network; Intense rainfalls; Extreme events; Fractal dimension

Introduction

The NDHOS began its activity of the collection and the elaboration of data for the editing of the Hydrologic Annals in the year 1918. The real-time rainfall monitoring system started in 1993, when the first 19 stations were installed and connected to the Master Control Center (MCC) in Naples. Since then, other groups of rainfall gauging stations have been installed following several plans carried out after the alluvial events of Sarno (May 1998), Cervinara (December 1999) and Naples (September 2001).

In September 2002 the monitoring network consisted of 136 remote control stations. Real-time rainfall data from these stations are transmitted to the MCC of Naples, within a 10-min delay time, by a radio-communication system based on 10 repeaters in UHF frequencies. A data acquisition system and a set of software packages are implemented in order to evaluate the hydro-meteorological situation.

The occurrence of intense and alluvial phenomena in autumn and winter over the Mediterranean area depends on cyclonic small areas whose dynamics follow the genesis of tropical cyclones (hurricanes) that show a lower energetic level. Such meteorological systems, together with convective systems and orographic rainfall, can be intensified by a big contribution of heat at the surface and, often, determine sudden alluvial events on the coast and the mountains exposed to the winds of sea.

It here shown that the fractal methodology can offer a valid contribution to an enlargement of an existing meteorological network and to an optimal location of additional stations. The areal sparseness of the historical rain-gauge network belonging to the NDHOS has been measured by means of the fractal dimension D that overcomes the limits of the Euclidean geometry [1]. The measurement of meteorological extreme events requires the increase of the capability of a network through its strategic enlargement, resulting in a compromise between the increase of fractal dimension and topographic necessities.

Materials and Methods

Real-time hydrological monitoring network

Until September 2002 the rainfall gauging network [2-4] consisted of 136 stations, 10 repeaters and the MCC in Naples, controlling a total of 259 sensors (50 ultrasonic hydrometers placed on bridges, 112 rain gauges, 54 thermometers and many others meteorological and hydrological sensors) (Figure 1). The repeater systems are in compliance with the EEC regulations; the network frequencies are in the 437-447 MHz range and the transmitting antennas are interference-free; their power supply is provided by generators because of adverse weather conditions for long periods of the year.

The MCC is composed by 3 functional blocks: (1) the DAS (Data Acquisition System) front-end and its peripherals; (2) the MARTE (Meteorological Analysis and Real Time Evaluation) computer (with special software for real-time hydrometeorological applications) and its peripherals, and (3) the communications channels.

The DAS acquires and performs a preliminary analysis of the data from the peripheral stations: it calls the stations periodically (every 10 minutes) and records all the data on magnetic media ascertaining if some alarm threshold, linked to absolute levels or to some tendency in the data, has exceeded. The DAS also allows a real-time visualisation

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and printing of data and reports to be done, as well as selective calls, reconfiguration of the network and all the required other operations necessary for its correct management.

Each of the 136 remote stations is equipped with a data logger system, an automated tipping bucket gauge, a solar panel and a radio device with a transmitting antenna (Figure 2). The peripheral stations have multitasking processors, EPROM and RAM buffered memories. They can control up to 16 sensors. The data are transferred to the Centre by radio, but transmission by modem-phone line is also possible. The power supply is given by batteries charged by solar panels. A battery supplies power for about 30 days, performing the measurements and transmitting the results. Apart for the slightest problems, all the stations worked regularly; only routine half-yearly maintenance has been made, during which sensors were checked and memory buffers were changed. Rarely electromagnetic noise generated spikes on the transmitted signals, mainly in the line from the repeaters to the remote stations. The software of the DAS can easily detect these spikes as anomalies in the signals and then eliminates them.

After the Sarno disaster the NDHOS, in co-operation with the Civil Protection Department and the National Group for Hydrogeological Disaster Prevention of the University of Salerno, organised a hydrometeorological warning system for preventing extreme rainfall events [4,5]. The system has been designed to manage the emergency after the event and to reduce the risk in the territories of five towns: Sarno, Quindici, San Felice a Cancello, Siano and Bracigliano.

For a more detailed monitoring of the damaged zone, four rain-gauge stations and one meteorological station (Torriello) were installed in an area of about 70 km^2 (Figure 3).

The warning system is based on two level threshold schemes for 24, 48, and 72 hours precipitation: the alert warning level and the alarm warning level (Figure 4).

Precipitation thresholds of duration ***d*** depend mainly on total

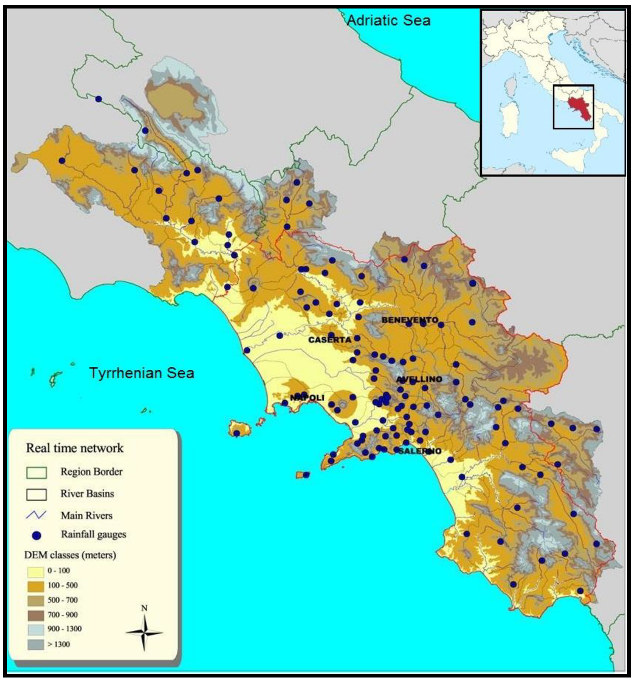

Figure 1: Hydrometeorological network of Naples Department of Hydrographic and Oceanographic Service (NDHOS).

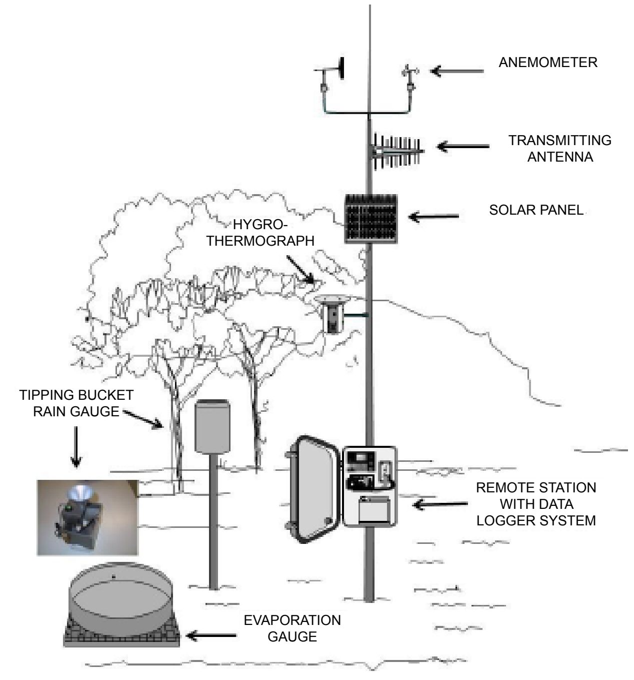

Figure 2: The remote station is equipped by a data logging system, an automated tipping bucket rain gauge, a solar panel and a radio device with a transmitting antenna.

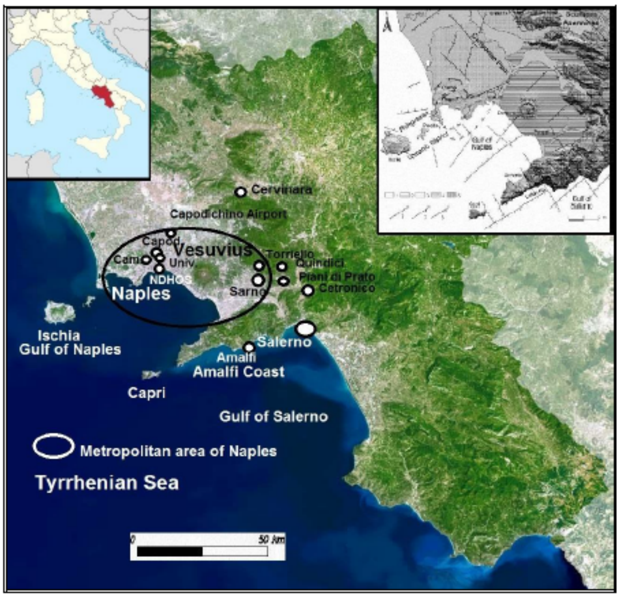

Figure 3: Rain-gauge stations for detailed monitoring of the damaged zone in the Sarno area (the tectonic sketch map of the area is shown at the top left).

precipitation from the first of September (that we assume as the beginning of the wet season) until the last ***d*** hours (precipitation before the event), PA_d, and on total precipitation in the last ***d*** hours (precipitation during the event), PE_d, (Figure 5). Such a threshold scheme was designed to simulate a memory-like mechanism triggering landslide.

The precipitation threshold is referred by each district taking into account the mean value of precipitation measured on a selected group of rain-gauges.

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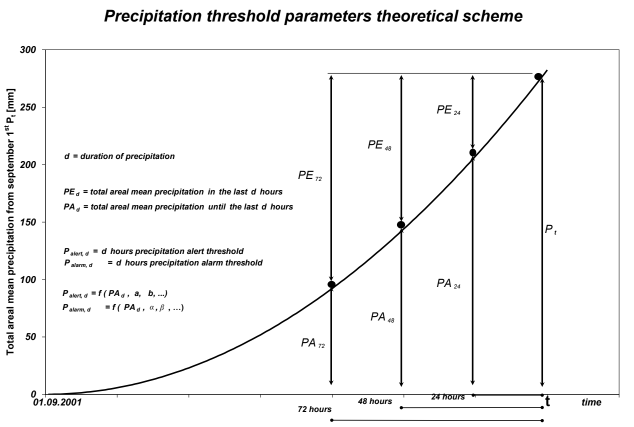

Figure 4: Theoretical scheme of precipitation threshold parameters.

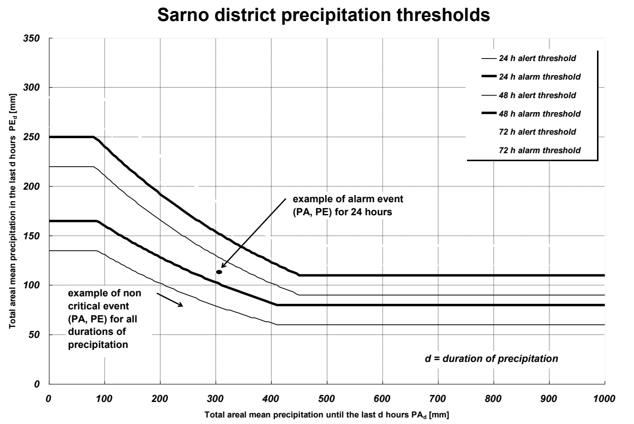

Figure 5: Precipitation thresholds in the Sarno district.

Networks for monitoring extreme rainfall events: a fractal areal distribution

The rainfall physical phenomenon taking place over an area is a termination stage of a number of different processes occurring on different scales and the derivation of its areal-estimates from point observations has been, and probably will remain, one of the most difficult issues within geophysics. Although an ideal network of stations should be spatially homogeneous, in most cases it is almost impossible to realise, perhaps due to practical circumstances which hinder measurements being taken from pre-established points and to a multistage decision process involved in establishing the same network. This inevitably results in interpolation errors in the computation of a regular grid from the observed data. The areal clustering of point sets can be measured by different statistical indices but when the inter-station distances are scale-invariant it can be well characterised by its fractal dimension [1].

The average of a rain field depends on both the scale and the dimension (for example, line, plane, volume or fractal set) over which it is averaged, so that intense and localised spatial phenomena with an extension smaller than the minimum detectable scale and with a dimension smaller than the minimum resolvable dimension will slip through the monitoring network undetected. For more reliable restoring of a physical phenomenon, it is necessary to analyse data recorded by a network with a high spatial and dimensional resolution. The fractal methodology can offer a valid contribution to an enlargement of an existing network and an application to the rain-gauge network of NDHOS is reported by Mazzarella and Tranfaglia [6]. The areal sparseness of the historical rain-gauge network belonging to the NDHOS has been measured by means of the fractal dimension D, that is an index that ranges progressively from 0 (when all the stations are distributed on a single point or on isolated points) through 1 (when all the stations are distributed on a line) up to 2 (when all the stations are distributed homogeneously or randomly on a plane). Particularly, Mazzarella and Tranfaglia [6] found that the value of D of the historical NDHOS network (Figure 6) was equal to 1.84 and not sufficiently high to get correct measurement of the event occurred at Sarno from 4 to 5 May 1998, when a low rainfall amount of 101 mm recorded at Sarno was considered responsible for a dramatic landslide [7]. The extremely high hourly time and space variability observed at the nearest stations with intensity peaks many times above the average was a direct consequence of sparse but intense rainy cells. To understand the problem caused by a network of stations distributed over an area with a fractal dimension less than 2, it has to be said that if the stations were located over a square of side X, the area effectively measured by the stations is not equal to X^2 but to X^D, and that all the rainy phenomena with area $X^{(2-D)}$ would slip through the network undetected [8].

The addition of 50 new rain gauges, located according to the fractal geometry way, allowed the increase of the fractal distribution of the areal distribution of the stations from 1.84 to 1.89 and the achievement of the correct measurement of the rainfall that hit the city of Naples on 15 September 2001 (max recorded value 167 mm) and some of the surrounding towns, and which lasted about 3 hours. The storm was clustered in two very intensive showers (with a mean intensity greater than 50 mm/h). The meteorological event was undoubtedly the most intense event ever recorded, since 1866, on the territory of the Naples district. A comparison with historical events dated since 1821 has been carried out. The recorded monthly precipitation has been correlated with the landslide phenomena frequently occurred in the area of Naples.

It is useful to underline that the fractal dimension of the temporal and spatial structure of the rain depends largely on the threshold intensity [9]. Such a result, known as multifractality of the rainfall, suggests that a large-scale rainy cell is organized in smaller cells and at a later stage in sparser and more intense cells with a fractal dimension so low to make much difficult their identification by a network of stations.

An attempt to correlate the Mediterranean climate scale with the frequency of the extreme events has been carried out by [10]. The

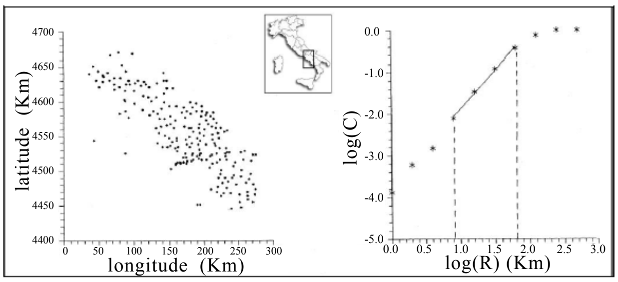

Figure 6: Left panel: sketch map showing the locations of the 215 historical rain gauges belonging to the NDHOS (the longitude is measured starting from Monte Mario meridian: 12°27'8" E); right panel: the log of numbers of pairs C of historical rain gauge network with mutual distance smaller than R, as a function of log(R) (km). The vertical dashed line represent the lower (8 km) and upper (64 km) limits of R, inside which the linear slope provides the best fitting to the investigated coordinates.

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analysis of historical series of rainfall recorded inside the catchments of four large Italian rivers shows that more than 50% of their interannual variance is significantly explained by the 22-year harmonic. It is proposed that the solar magnetic activity of 22 years is able to modulate in cascade the zonal circulation over the Mediterranean basin and the relative rainfall.

The 15 September 2001 intense rainfall event

Landslide phenomena represent a significant aspect of geological hazard in Campania region, including the city of Naples. The storm of September 2001 (declared flood disaster), that hit the Neapolitan districts, has dramatically brought back to the attention the problem of the extreme embrittlement of the territory.

In the early hours of 15 September 2001 the city of Naples and some of the surrounding towns were hit by a violent storm which lasted about 3 hours [11,12]. The storm which had originated in England, swiftly passed over France and Northern Italy finally reached Southern Italy at about 02:00 UTC. In Figure 7, the infrared image taken by the Meteosat satellite at 03:30 UTC on 15 September clearly shows the impact of the perturbation from the North with the hot and humid air sustained by a second perturbation coming from Southwest, originating in North Africa. The thunderstorm cell lingered over the Gulf of Naples from 02:00 to 05:00 UTC, and gave way to 170 mm of rain in a three hour time frame as a consequence of the condensation caused by the impact.

An analysis of this exceptional precipitation event was carried out on the basis of data collected from real time network and recordings. The rain gauge digital stations of Naples Capodimonte (Figure 8), Naples Camaldoli and Pozzuoli Solfatara recorded rainfall starting at 2.00 on 15 September and ending at 5.30 a.m. On the other hand, the Ischia Monte Epomeo stations recorded rainfall onset times about an hour earlier while those of Ottaviano and Torre del Greco, west of Naples, with a delay of about an hour. The event basically developed into two showers of about an hour each, separated by an interval of lighter rainfall. During the two showers very intense rainfall levels were reached: 24 mm in 10 minutes (144 mm/h) recorded at Naples-Capodimonte; 23.6 mm in 10 minutes (141.6 mm/h) at the Naples Camaldoli; 23.4 mm in 10 minutes (140.4 mm/h) at Pozzuoli and Ischia. Table 1 lists the maximum values recorded at the stations of the flooded areas.

The isohyetal map (Figure 9), drawn up on the basis of the recorded values, shows that the event was rather restricted. The flooded area comprised in the 80 mm isohyet (equal to the maximum rainfall ever recorded in a 3 hour time frame in more than 150 years in Naples) extends up to the northern slopes of the Vesuvius.

The hourly precipitation values recorded by the rain gage stations are so uncommon, that routine statistical analysis procedures are inapt. More than 350 million of Euro in damage was done, three men drowned and some others were injured, three buildings were completely destroyed, 23 buildings and dozens of roads were heavily damaged. Power lines, drain and trunk lines were impacted and disrupted. Also the major soccer stadium was heavily damaged.

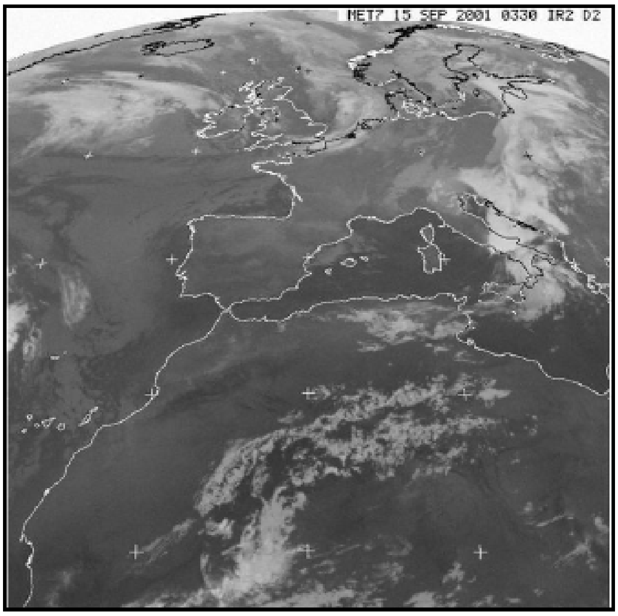

Figure 7: Meteosat satellite infrared image on 15 September 2001 at 03.30 UTC.

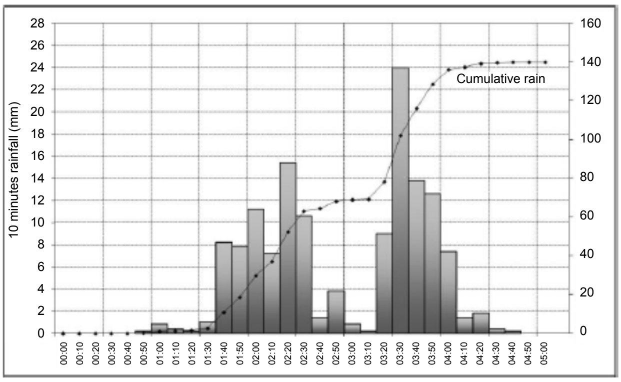

Figure 8: Precipitation (every ten minutes) measured in real time at Naples Capodimonte.

Rain gauge	Type	Altitude	$P_{10',max}$	$P_{30',max}$	$P_{1h,max}$	$P_{2h,max}$	$P_{3h,max}$	P_{total}
NDHOS	Pr	30	-	-	76.8	96.8	166.4	167.4
Naples Posillipo	Pr	170	-	-	59.2	76.2	113.6	116.8
Naples Camaldoli	Pe	385	23.6	53	63.2	102.4	118.2	119.2
Naples Capodimonte	Pe	300	24	50.4	68.2	110	137.6	139.8
Pozzuoli (anfiteatro)	Pr	57	-	-	83	100	160	162.4
Pozzuoli (solfatara)	Pe	110	23.4	59.6	80	121	160.6	161.6
Ischia Mt. Epomeo	Pe	390	23.4	45.4	52.8	54.4	65.8	76.6
Torre del Greco	Pe	332	12.2	33.6	54.2	67.2	82.4	82.6
Ottaviano	Pe	192	23	40	46.6	77	91.2	91.2

Table 1: Maximum precipitation in the area interested by heavy-storm event of 15 September 2001 (Pr=traditional recording rain gauge; Pe=digital recording real time rain gauge).

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In order to verify the exceptional character of the meteorological event of the 15 September 2001 the observed phenomena have been compared with the historical observations available at the stations located in the city: Observatory of Capodimonte (started in 1821), Naples University (Department of Geophysics and Volcanology, started in 1866), and NDHOS (started in 1927). When the Observatory of Capodimonte station did not operate, the data was taken from the nearest station (Capodimonte reservoir); when the station of the Naples University did not operate, the data was taken from the station of Capodichino Airport. Therefore, we constructed a catalogue of 37 catastrophic events (Table 2) that have hit the area of Naples from 1866, simply verifying that a rain greater than 80 mm has fallen in 24 hours, in at least one of the 3 stations taken to reference [11,12].

Historical landslide phenomena in Naples and damage estimation

In the last century, numerous landslide phenomena were induced by heavy rainfall, and caused, at times, severe damages to the economical, social and infrastructural condition of the metropolitan area. We report a striking historical example of such phenomena.

An intensive search for contemporary sources was undertaken in national archives, libraries and private archives of the city. The investigated sources include technical reports, contemporary chronicles, administrative records, national and local newspapers, etc.

Newspapers provided the most useful and reliable source, in fact they provided a detailed description of the phenomena including information on human consequences, such as homeless people, injuries, and deaths and the identification of the damaged areas. Among all the gathered data a temporal window that covers the period ranging from 1821 to 2001 has been selected.

The city of Naples is located in the southern part of the Campanian

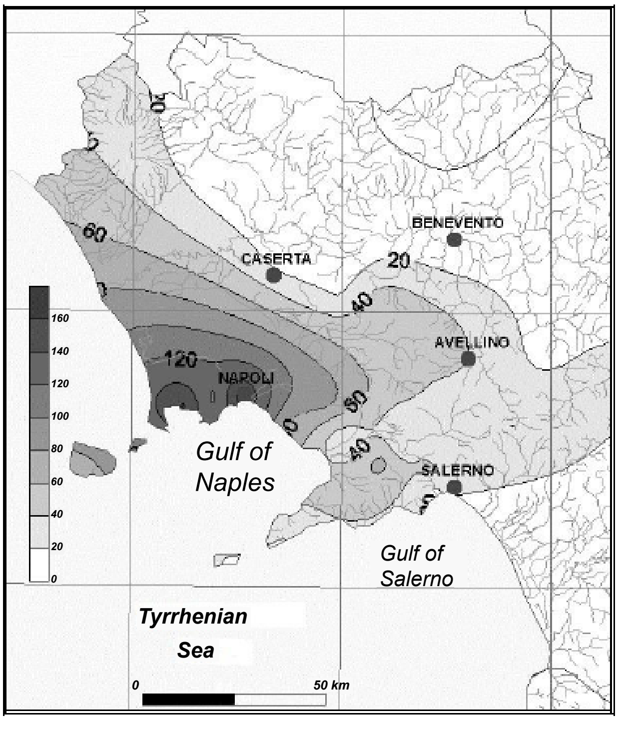

Figure 9: Isohyetal map of the total precipitation on 15 September 2001.

Nr	Year	Month	Day	Capodimonte	University	NDHOS
1	1875	10	15	60	82	
2	1889	12	27	92	89	
3	1890	12	2	81	83	
4	1910	10	24	120	99	
5	1911	9	21	73	89	
6	1915	9	2	110	90	
7	1915	10	1	89	89	
8	1918	6	6	78	91	
9	1918	10	5	125	99	
10	1920	6	20	51	87	
11	1921	10	27	68	92	
12	1922	11	4	77	94	
13	1925	9	28	90	91	
14	1930	10	25	69	83	
15	1933	11	23	86	85	103
16	1947	9	6	126	103	>>
17	1948	9	5	106	68	85
18	1951	9	25	75	63	80
19	1952	10	23	100	87	82
20	1953	12	20	77	81	85
21	1957	10	22	95	64	54
22	1961	10	7	82	68	75
23	1969	9	19	74	83	87
24	1973	1	1	91[2]	114	94
25	1978	9	5	82[1]	77	88
26	1979	10	28	119[1]	138	133
27	1980	11	13	60[1]	61	81
28	1981	10	21	68[1]	72	108
29	1985	11	16	95[1]	114	168
30	1986	11	21	22[1]	86	44
31	1986	11	23	68[1]	96	62
32	1987	11	9	76[1]	98[2]	136
33	1990	4	9	53[1]	59[2]	89
34	1995	4	15	62	114[2]	81
35	1996	9	20	58	57	87
36	2001	9	15	140	P> 100[2]	167
37	2003	9	9	86	73[3]	91

Table 2: Intense rainfalls of more than 80 mm occurred in Naples, measured in a day, at least for one of rain gauge station reported in the table [[1]Capodimonte reservoir; [2]Capodichino Airport; [3]Camaldoli].

Plain, which is prevalently composed of a large variety of pyroclastic deposits (tuff, pozzolane, pumices) related to both, Campi Flegrei and Somma-Vesuvius volcanic activity, whereas alluvial soils and sea shore sand are recognized along the coastline. Naples lies on an alternation of tuff, pozzolane, pyroclastic soil with interbedded pumices, which generally present an overall thickness of over 100 m. In particular, the Neapolitan Yellow Tuff Formation is either outcropping or is located some tens of meters below the surface and is characterised by an intricate network of artificial cavities which have been excavated as far as in Greek and Roman times.

The analysis of the historical data allows us to identify (Figure 10) more than 100 new landslide phenomena in the last century [12]. According to historical descriptions, five main types of effects have been identified: rock fall, earthflow (landslide), collapse, flood and lahar (the latter only occurred after the 1900 volcanic eruptions). Other rock types include those that occurred in quarries. Rock falls of Neapolitan Yellow Tuff were the most frequently observed phenomena

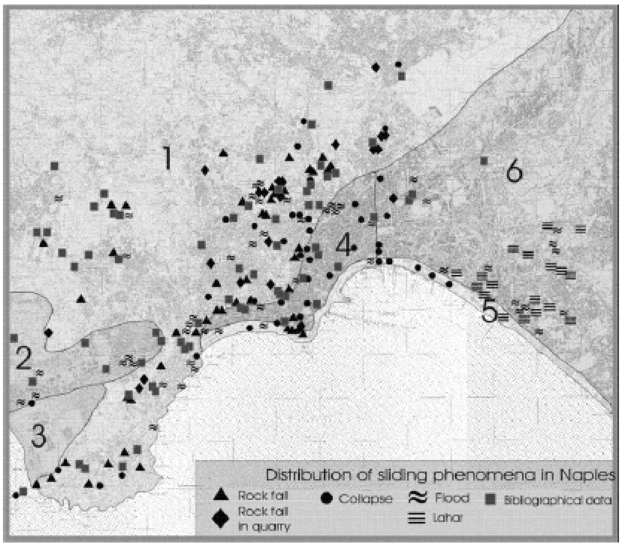

Figure 10: Landslide phenomena of the last century in Naples.

(52% of the registered events), characterized by detachment of small-medium volumes of material (max 200 m^3); these landslides, located along the Capodimonte and Posillipo hill slopes and Neapolitan Yellow Tuff quarries (North-North West sector of the city), caused the death of 33 people between 1821 and 1964.

Only few cases of earthflow of pyroclastic soil have been recognized along the Posillipo hill slopes. This kind of phenomenon involves only the most external part of the slope where the weakest material collapses, reaching some hundreds of cubic meters of material.

The collapses (34%) were prevalently observed in the area of the ancient cavities underneath the historical center of the city. They caused severe damages to historical buildings and infrastructures. Flood events (10%), induced by heavy precipitation, occur about every ten years. These effects were largely diffused in the Southern and Eastern sectors of the city. Eleven lahar events (4%) caused many damages to buildings, railways, mainly due to the slide of thousands of cubic meters of material with thickness between 0.5 and 1.5 m.

Though not totally exhaustive, our present knowledge allows us to underline significant aspects of the vulnerability of the Naples urban territory.

Such phenomena have been compared to rainfall data since 1821. We analyzed all the monthly rainfall data from 1821 to 2003 recorded by the Capodimonte rain-gauge station, until 1986 for Naples University and until 2001 for the NDHOS.

With the aim of verifying that the historical series of pluviometric monthly data of the stations in the city of Naples were homogenous, we resorted to the classic analysis of the double-mass curve.

The values accumulated of the depths of rainfall measured in each station have been connected with the correspondent values of precipitation measured in the other stations.

The analysis between the stations of Naples University and NDHOS and between the stations of Naples Capodimonte and Naples University shows, besides an evident homogeneity of the historical series, a difference between the rainfalls values in the order of 5%. On the other hand, from the same analysis it becomes evident that between the station of Naples Capodimonte and NDHOS (Figure 11) there exists a significant homogeneity (constant slope of the double-mass curve), but also a substantial coincidence between the historical series (the curve of the double-mass overlaps the straight line with 45° slope).

On the basis of such considerations, it has been possible to build for the city of Naples (Figure 12) a historical series of precipitations 182 years long (from 1821 until to 2003), integrating the lacking data into the series of Naples Capodimonte with those of the series of NDHOS. In more than 160 years, the maximum value of rainfall at Capodimonte (391.3 mm/month) was registered in October 1918 (Figure 13 and Table 3); in the same month the maximum value was registered at Naples University (391.0 mm/month). Perhaps due to the infrequent rainfalls in the nine previous months, no landslide phenomena were observed in relation to such values. The maximum rainfall at NDHOS was registered in November 1985 (397.8 mm/month). Values exceeding 300 mm/month occurred at Capodimonte five times between 1821 and 2003 (352.0 mm, November 1851; 302.0 mm, November 1862; 300.9 mm, October 1910; 328.9 mm, November 1980; 301.4 mm, November 1985). But values of 200 mm/month have been recorded 78 times with a concentration in the autumn season, 20 times in October, 18 times in November and 22 times in December.

These studies analyzed a particular period of time to compare groups of landslide phenomena and monthly precipitation. This correlation shows a correspondence between more severe sliding phenomena and periods of precipitation characterized by higher seasonal rain level rather than a maximum monthly precipitation. Geologic configuration and analysis of recurrent landslide phenomena characterizing the area led to refer the main mass movement occurred in conjunction with the storm events to soil slide debris/earth flows mechanisms.

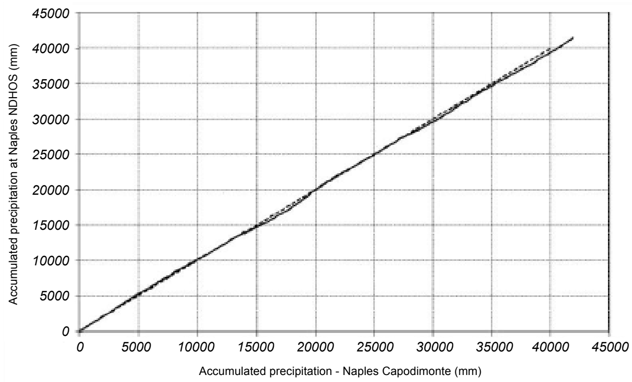

Figure 11: Double-mass curve between the station of Naples Capodimonte and NDHOS.

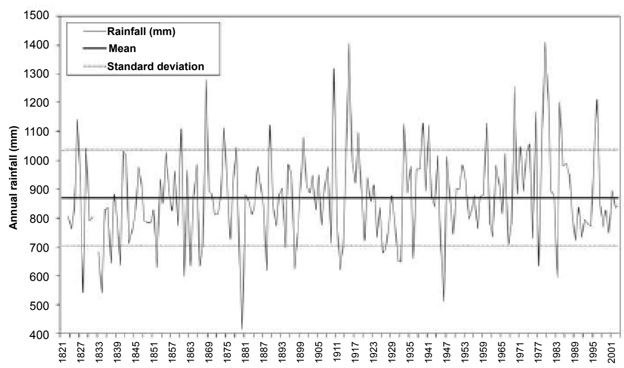

Figure 12: Annual rainfalls at Naples Capodimonte (1821-2003).

Month	NDHOS				Naples University				Naples Capodimonte			
	Y. O.	Aver.	Max.	Min.	Y. O.	Aver.	Max.	Min.	Y. O.	Aver.	Max.	Min.
Jan	71	104.1	269.8	4	117	101.5	280.2	2.8	168	99	276.4	0.1
Feb	71	81.9	236.6	0	118	77.7	228.6	0.2	166	75.2	219.1	0
Mar	71	70.1	254.2	0.8	118	72.7	203.6	1.1	169	71.7	222.2	0
Apr	71	64.5	185.4	3.1	118	64.7	186.8	1.5	168	62.9	217.3	0
May	71	48.1	151.1	0	118	47.3	161.3	1.9	169	48.9	191.2	0
Jun	71	30.4	124	0.2	117	32.2	169	0	169	32.8	170.8	0
Jul	71	16.1	82	0	118	17.3	155	0	168	16.2	147.2	0
Aug	71	30.3	119.6	0	117	26.4	98.4	0	169	28.6	174.1	0
Sep	70	77.3	258.2	0	116	72.4	244.9	0	169	76.2	223.5	0
Oct	70	110.4	243.2	1	117	119.9	391	0	168	115.3	391.3	2.6
Nov	70	136.2	397.8	11.8	117	125.4	319	9.6	168	122.8	352	10.2
Dec	70	116.1	262.4	10.8	117	123.4	284.6	12.8	166	117.6	282.2	0.4
Year	70	887	1374.8	613.8	117	879.9	1385.3	478.5	163	871.1	1410.9	415.4

Table 3: Summarizing table of statistical data of monthly precipitation at Naples (Y. O. years of observations).

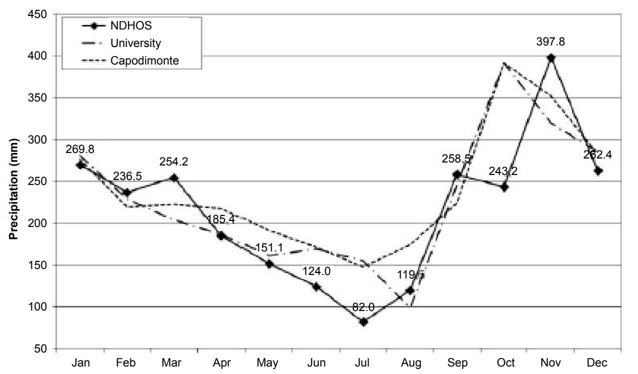

Figure 13: Maximum monthly precipitation at Naples.

Discussion and Conclusions

The meteorological events that hit Campania region highlighted that the ability to obtain accurate estimates of spatial variability in rainfall fields becomes crucial for the identification of locally intense storms that could lead to flash-floods or debris/mud flow.

The accurate estimation of the spatial distribution of rainfall during extreme events requires a very tight network of instruments. The intense phenomena, in fact, have often an extension smaller than the current areal resolution of the network so that they will slip through the network undetected.

The extremely high hourly time and space variability observed at the nearest stations, with intensity peaks many times above the average, was a direct consequence of sparse but intense rainy cells.

All the physical-mathematical efforts to overcome the network weakness were doomed to fail from the start. Inadequate network resolution could never be recovered by mathematical or stochastic procedures of interpolation. Such methods can perform accurate estimations of areal precipitation when the density of network is able to describe spatial variability in rainfall fields. The increase in the measuring capability of a measuring network must always occur through its strategic enlargement resulting in a compromise between the increase of fractal dimension and topographic necessities.

Appreciating the fractal dimension of a network and its limits of validity is the key to understand the limits of reliability of an inhomogeneous distribution of measuring stations. The areal distribution of the stations will be repeated on different scales in the same manner inside the scaling region, the main variable being the fractal dimension D. The areal phenomena, with an extension smaller than the areal resolution of the network or spatially clustered with a fractal dimension smaller than the dimensional deficit of the network, will slip through the network undetected even if the network is infinite. A good way to increase the measuring capability of an existing network is the addition of new stations able to increase both the fractal dimension and the relative scaling region.

Denser rain-gauge coverage of NDHOS network has been designed with the installation of new stations having as primary objective the achievement of hydrological necessities. This type of network enlargement may, however, determine an increase of the areal clustering of stations and so a decrease of the fractal dimension with all the above-mentioned negative consequences. To mitigate such a risk, it has been proposed that, as a preliminary measurement, one third of all additive stations be located in places whose co-ordinates allow also the increase of the historical fractal dimension. Mazzarella and Tranfaglia [6] obtained a network constituted by 300 stations with D=1.89+0.01, confident at a level higher than 99%, a linear resolution of 2 km and a dimensional deficit of 0.11. The enlarged network, which arose as a compromise between fractal and topographic necessities, shows a higher capability of rain-field restoring, with a dimensional deficit and a resolution ranging from 0.16 to 0.11 and from 4 km to 2 km, respectively.

The meteorological event that hit the cities of Naples and Pozzuoli on 15 September 2001 was undoubtedly one of the most intense events ever recorded on the territory of NDHOS.

The isohyetal map, drawn up on the basis of the recorded values, shows that the event was rather restricted. The flooded area comprised in the 80 mm isohyet (equal to the maximum rainfall ever recorded in a 3 hour time frame in more than 150 years in Naples) extends up to the northern slopes of the Vesuvius.

The metropolitan area of Naples is characterized by a widespread risk of landslide phenomena (not catastrophic but however not negligible), which occur with a certain frequency in the whole district. It has been observed that generally rock falls occur in the whole area, while collapse of underground cavities is mainly localised in the historical center. Floods are common in the whole area except in the historical center, where only four cases are reported and lahars only occurred in the eastern part of the city and are closely related to the 1906-1918 eruption cycles of the Somma-Vesuvius.

A correlation between monthly precipitation and type of sliding phenomena has been performed. It shows a relation between more severe sliding phenomena and periods of precipitation characterized by a higher seasonal rain level rather than a maximum monthly precipitation.

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