A new multiparametric geophysical station to detect self-potential and seismometric signals at Tito site (Southern Italy)

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Abstract

In this work we present the main features of a new multiparametric station able to jointly detect self-potential and seismometric signals in a seismic active area of Southern Italy. The new station has been designed and installed at the Tito Laboratories of National Research Council (Italy) that are located in the Southern Apennines, one of the most tectonically active areas of the whole Mediterranean. It combines advanced technologies for data acquisition with robust statistical techniques to pick out extreme events from self-potential recordings. The completely automatic station is equipped with electrical and seismometric sensors (16 channels, A/D 24 bit, sampling rate of 0.25 Hz, range dynamics of 133 dB). After a preliminary filtering procedure, mainly devoted to removing any influence of meteo-climatic conditions and/or cultural electrical noise, we evaluated the performance of the new monitoring station investigating the possible correlation between anomalous patterns of the self-potential signals and local seismic activity. Objective criteria and robust statistical tools have been applied to identify extreme events in electrical measurements and to select the earthquakes that may be responsible for strain effects at the measuring point. The short period of the measuring activity does not allow us to give firm conclusions, however the first results encourage us to continue the monitoring activity by increasing the number of remote stations and improving the use of statistical packages for data processing. We identified a well based monitoring strategy that in the near future could be useful to better understand the possible correlation between anomalous self-potential signals and local seismic activity.

Key words *self-potential signals – earthquakes – extreme events – Southern Apennines*

1. Introduction

The study of spatial and temporal fluctuations of geophysical signals of electrical nature observed in seismic areas during the phase preceding the occurrence of earthquakes is a fascinating problem. The topic is extremely complex, because the relation between incoming earthquakes and geoelectrical anomalies may depend on a wide range of phenomena in addition to the geological setting of the investigated area (Johnston, 1997 and references therein). Many different models have been proposed to describe the physical mechanisms which could generate anomalous Self-Potential (SP) signals near focal areas (*e.g.*, Scholz, 1990; Di Maio and Patella, 1991; Park, 1996; Vallianatos and Tzanis, 1998).

However, a comprehensive theory developed on a physical basis and supported by an ade-

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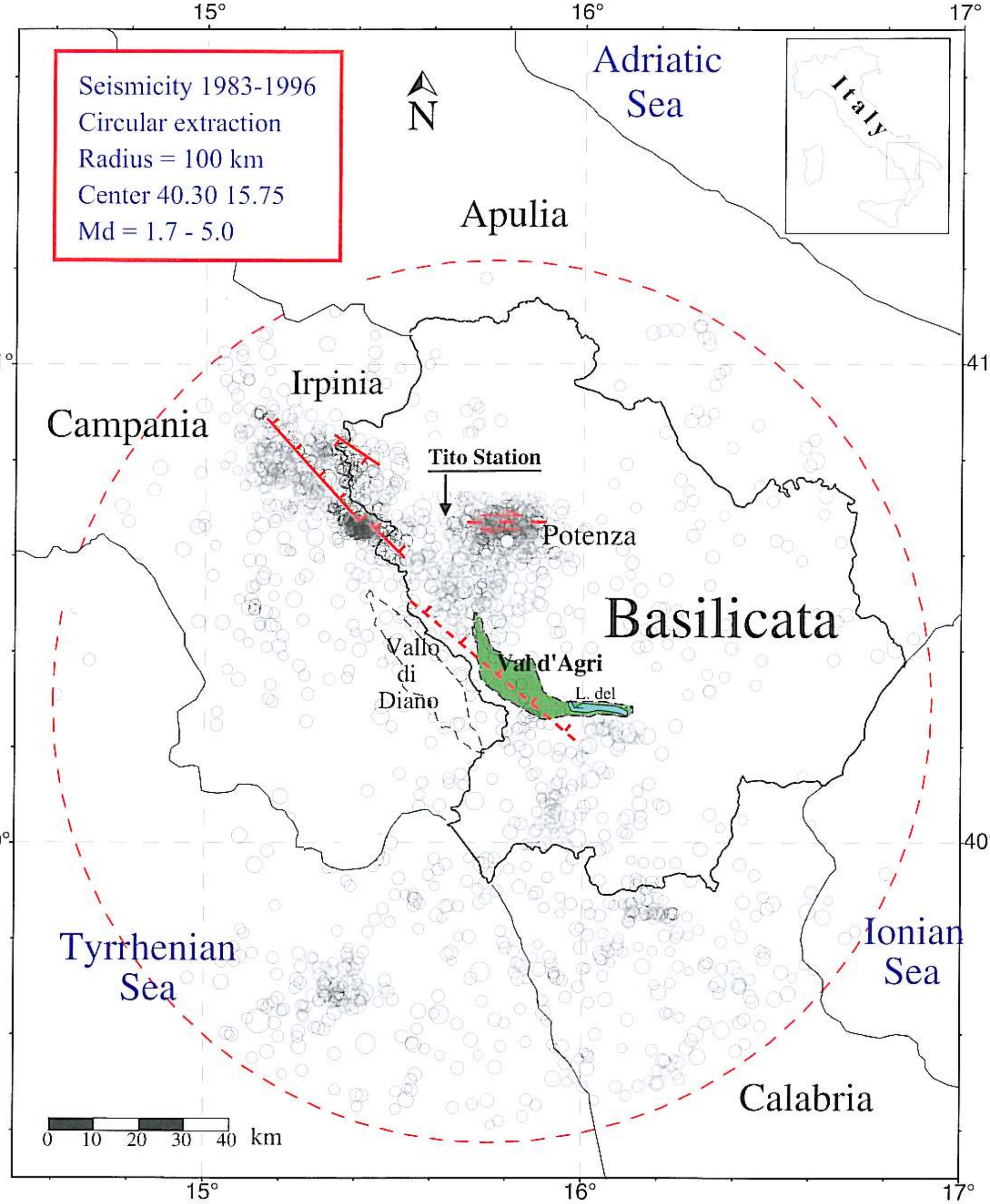

Fig. 1. The multiparametric station has been installed at Tito site, located on the Southern Apennines that is one of the most tectonically active areas of the whole Mediterranean. The figure reports the seismicity pattern of earthquakes observed in this area during the period 1983-1996.

quate number of experimental data is still not available (Geller *et al.*, 1997). Criticism of the so-called electrical earthquake precursors includes: the absence of high quality data, the absence of statistical tools to evaluate extreme events, the lack of well based physical models to describe the generation mechanism of electrical signals in different tectonic and geological environments (Evans, 1997; Wyss, 1997). The present level of knowledge on this matter is completely inadequate to solve these ambiguities. It is therefore necessary to develop advanced methodologies for the statistical analysis of the measured signals and to create new models to study the inner dynamics of electrical phenomena related to earthquakes (Hayakawa and Itoh, 2000; Nagao *et al.*, 2000).

To achieve this goal it is necessary to improve the technology of geophysical monitoring networks. In the past, the absence of advanced technologies in the design and development of geophysical networks was the real weak point of this research topic. As a consequence, the poor quality of electrical observations does not allow physical models to be adequately used to describe the spatial and temporal dynamics of self-potential signals in seismically active areas.

The complex nature of this problem suggests the development of monitoring networks based on remote stations that may measure anomalous geoelectrical signals during long time spans and with a high spatial resolution. Furthermore, these networks must be flexible and should allow us to make real time data analysis and to modify the monitoring strategy, if needed.

Building adequate physical models describing complex phenomena related to geoelectrical earthquake precursors requires a large database of experimental data collected by a monitoring station built with innovative technological features.

To this aim, in the framework of a project supported by MURST, we have designed a new multiparametric station equipped with sensors able to detect SP and seismometric parameters in active seismic areas. This new station has been designed for geophysical monitoring activity in a seismically active area of the Southern Apennines (fig. 1), and has been installed at the laboratories of the National Research Council located at Tito (Italy). It combines advanced technologies for data acquisition with robust statistical techniques to pick out extreme events from self-potential recordings. Thanks to this station, we can now measure SP signals with great accuracy and detect even very small local earthquakes.

Finally, we investigate the possible correlation between SP anomalies and seismic sequences. Of course the limited period of the measuring activity does not allow us to obtain firm conclusions on this very controversial problem, but these preliminary results suggest a monitoring strategy that in the near future will help to improve current knowledge on the time dynamics of the self-potential signals in active seismic areas.

The paper is organised as follows: Section 2 describes briefly the main features of the prototype here presented and the seismological setting of the investigated area; Section 3 discusses the statistical criteria for selecting the anomalous SP signals measured by the station; finally, Sections 4 and 5 present and discuss the results of this work.

2. Main features of the multiparametric station and seismological setting of the investigated area

The multiparametric station (fig. 2a) was installed at the Geophysical Laboratory of Institute of Advanced Methodology of Environmental Analysis (IMAAA-CNR), located at Tito (Potenza) close an active fault system of the Southern Apennine chain.

2.1. *Design of the Tito station*

The array for the SP measures is formed by four copper electrodes, 1.5 m long, buried at a depth of about 2 m for their entire length and located around the perimeter of the gardens surrounding the laboratories (fig. 2b); their distance is 100 m for the two couples of electrodes in the NS direction and 120 m for the electrodes in the EW direction (Balasco *et al.*, 1999).

(a)

(b)

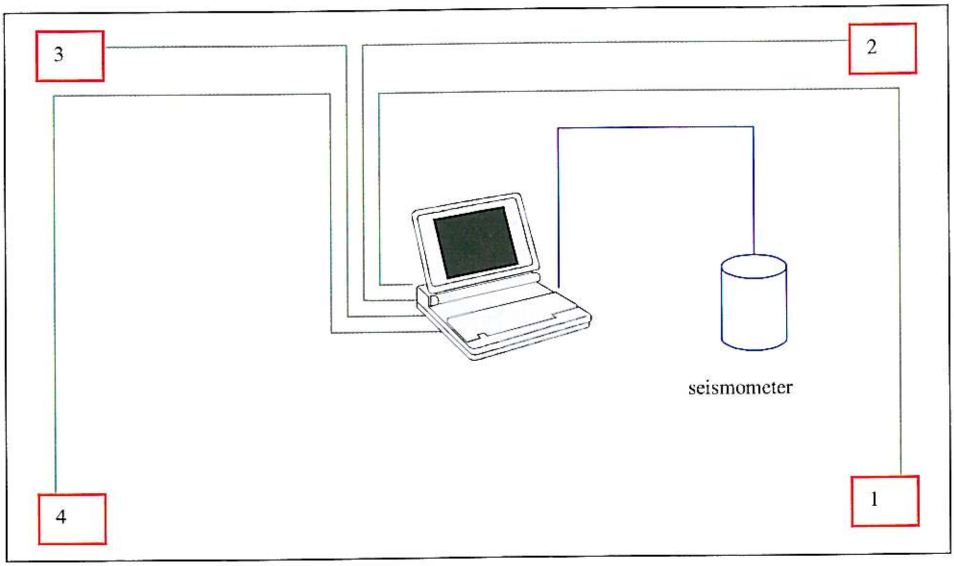

Fig. 2a,b. a) Acquisition and data storage system of Tito station; b) simplified scheme of array configuration: four unpolarizable electrodes distributed along a rectangular perimeter and a 3 components seismometer are connected with an acquisition system.

The SP acquisition system is made up of a high resolution multimeter connected to a PC with an NI4350 interface. The NI4350 instruments contain a 24-bit sigma-delta analog-to-digital converter (ADC) with differential analog inputs. The low leakage construction, along with analog and digital filtering, and the screened cables provide excellent resolution, accuracy, and noise rejection. As shown in fig. 2b, there are four channels qualified for recording.

The SP measures generally concern only two orthogonal dipoles, in this work we considered four dipoles forming a closed circuit. Because the electric field is a conservative one and its circulation must be zero, the algebraic sum of the voltage readings from the four channels in the corresponding instants must be zero. This physical property is very useful in the SP measures. In fact, thanks to the electrodic array installed on the closed circuit in the Area of Research of the CNR, we can identify transient electrical behaviour due to cultural noise. Figure 3 shows typical SP signals recorded at Tito station. In this work we analyse hourly SP mean values recorded during the period March-December 1999; each mean value was calculated from 3600 samples, and the total number of processed data is about 20000000 per channel.

The seismic station became operational on March 3, 1999. It is located in a reinforced concrete well at the co-ordinates: 40°35′-15°44′. The station includes a triaxial seismometer MARK L4-C-3D, an acquisition unit with 24 bit per channel, a GPS receiver (Trimble acutime RS422), and a PC for field test and data recovery.

The seismometric sensor allows us to detect low magnitude earthquakes that are generally not recorded by the national seismometric network of the National Institute of Geophysics (ING), which for the region around Tito has a minimum threshold around magnitude 3. Thus, the ING seismic catalog was integrated with data obtained from the IMAAA station (table I).

2.2. *Seismological setting of the investigated area*

The investigated area is one of the most active seismic areas of the whole Mediterranean region, the geological and structural setting of the Lucanian Apennines reflects the complex history of the Southern Apennines, whose framework consists of a pile of trust sheets. The historical seismicity pattern confirms intense regional seismic activity and related complexity in crustal faulting. The November 23, 1980 earthquake (M = 6.9), one of the most destructive events in Southern Italy, occurred in this area (Pantosti and Valensise, 1990). The seismic activity that occurred after the 1980 event consisted of medium intensity events (M < 5.5) located close to the border between the Campania and Basilicata regions (fig. 1). The May 5, 1990 (M_d = 5.0, ING-National Institute of Geophysics) and the May 26, 1991 (M_d = 4.5) earthquakes may be considered the strongest events after the Irpinia earthquake in this area. These events were followed by aftershock sequences

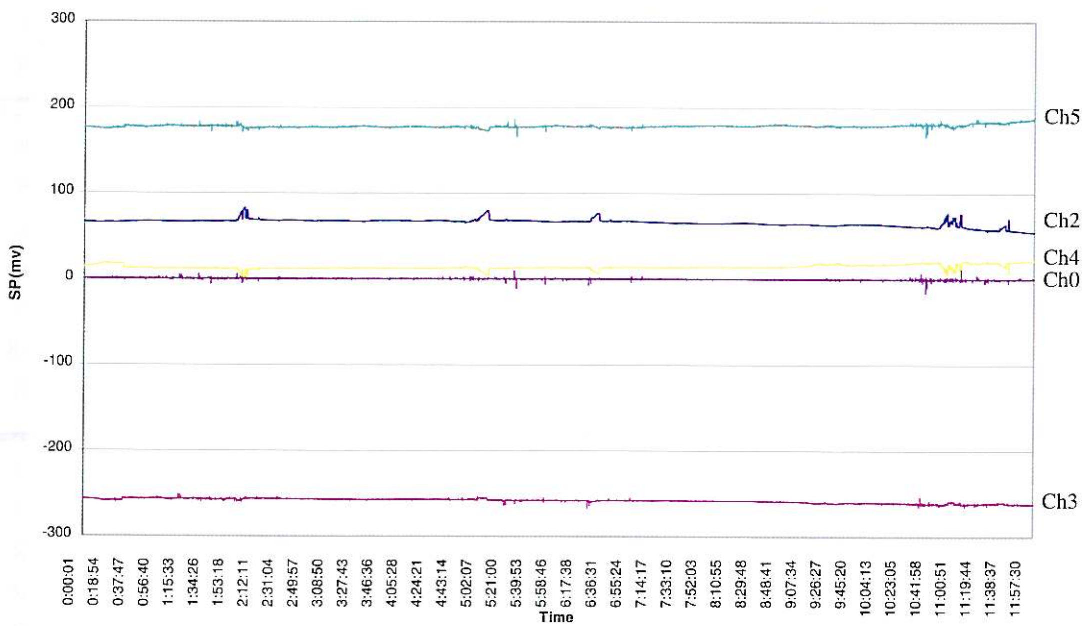

Fig. 3. Example of self-potential data recorded at Tito site; the sampling interval is 1 s. The colours identify the signals measured by the different channels.

Table I. The table shows the seismic events recorded at Tito station. The recorded earthquakes integrate the database of National Seismometric Network (National Institute of Geophysics) introducing in the catalog the local seismic events characterised by a very low magnitude ($M < 3$). With NR ING we labelled the earthquakes recorded only at Tito station and with NR we identify those recorded only by the National Seismometric Network.

Date	Time	Magn.	Epicentral area	Tito station
Mar-15-99	23:01	$M = 3.2$	Lucania	R
Mar-20-99	12:04	$M = 2.4$	Lucania	R
Mar-27-99	15:35	$M = 2.8$	Lucania	R
Mar-28-99	19:50	$M = 3.1$	Lucania	R
Mar-31-99	08:14	$M = 3.0$	Lucanian Apenn.	NR
Apr-05-99	05:16	$M = 3.5$	Latronico	R
Apr-05-99	08:51	$M = 3.7$	Laviano (SA)	R
Apr-07-99	15:43	$M = 3.6$	Lucanian Apenn.	R
Apr-07-99	16:00	$M = 3.0$	Lucanian Apenn.	R
Apr-10-99	17:17	$M = 3.1$	Lucanian Apenn.	R
Apr-10-99	00:05	NR ING	Lucanian Apenn.	R
Apr-11-99	10:49	$M = 3.7$	Lucanian Apenn.	R
Apr-11-99	18:45	$M = 2.7$	Lucanian Apenn.	R
Apr-11-99	22:33	$M = 3.0$	Lucanian Apenn.	R
Apr-13-99	06:29	$M = 3.4$	Lucanian Apenn.	R
Apr-15-99	17:47	$M = 3.1$	Lucanian Apenn.	R
Apr-15-99	18:32	$M = 3.0$	Lucanian Apenn.	NR
May-02-99	06:53	$M = 3.7$	Lucanian Apenn.	R
May-05-99	09:52	$M = 3.7$	Laviano	NR
May-06-99	10:47	NR ING	Lucanian Apenn.	R
May-18-99	09:17	NR ING	Muro Lucano	R
May-26-99	18:35	$M = 3.5$	Lucanian Apenn.	R
Jun-15-99	13:52	$M = 3.4$	Lucanian Apenn.	R
Jun-16-99	01:34	NR ING	Potenza	R
Jun-16-99	01:44	NR ING	Potenza	R
Jun-16-99	02:12	NR ING	Potenza	R
Jun-16-99	02:20	NR ING	Potenza	R
Jun-16-99	03:02	$M = 2.9$	Potenza	R
Jun-16-99	03:08	NR ING	Potenza	R
Jun-16-99	03:22	NR ING	Potenza	R
Jul-20-99	10:54	$M = 2.9$	Vallo di Diano	R
Jul-21-99	15:56	$M = 3.3$	Buccino	R
Aug-17-99	00:04	$M_s = 7.5$	Turkey	R
Aug-30-99	22:31	$M = 3.9$	Naples Gulf	R
Aug-30-99	22:54	$M = 3.7$	Naples Gulf	R
Sep-04-99	00:43	$M = 3.2$	Gargano	R
Sep-05-99	22:03	$M = 3.1$	Lucanian Apenn.	R
Sep-07-99	13:58	$M_w = 6.0$	Athens (Greece)	R
Sep-14-99	07:09	$M = 3.3$	Castelluccio	R
Sep-14-99	17:47	$M = 3.7$	South Tyrrhenian Sea	R
Sep-17-99	23:27	$M = 3.0$	Beneventano	R
Sep-20-99	10:49	$M = 3.3$	Pietragalla	R
Sep-29-99	10:01	$M = 3.0$	Potentino	R
Oct-08-99	14:30	$M = 3.0$	Lucanian Apenn.	NR
Oct-09-99	07:41	$M = 3.4$	Vesuvius	R
Oct-18-99	07:04	$M = 2.9$	Vaglio	R
Oct-28-99	15:48	$M = 2.9$	Potentino	R
Nov-12-99	17:57	$M = 7.1$	Turkey	R
Nov-22-99	23:10	$M_b = 3.2$	Balcani	R
Nov-24-99	03:38	$M_l = 4.7$	Greece	R
Nov-24-99	21:10	$M_l = 4.5$	Greece	R
Nov-28-99	00:59	$M = 5.0$	Greece	R
Dec-08-99	18:10	$M = 2.7$	Lucanian Apenn.	NR
Dec-22-99	09:06	$M_w = 5.2$	Albania	R
Dec-22-99	09:07	$M_w = 5.2$	Albania	R
Dec-23-99	23:11	$M_l = 4.7$	Southern Greece	R
Dec-24-99	20:10	$M = 2.4$	Potenza	R
Dec-24-99	20:20	$M = 2.2$	Potenza	R
Dec-24-99	20:27	$M = 2.4$	Potenza	R
Dec-24-99	22:04	$M = 2.2$	Potenza	R
Dec-26-99	04:39	$M = 3.0$	Potenza	R

that identify a fault structure located near Potenza town. This fault lies north of Potenza and is located in such a way to limit toward north and south the great seismogenetic faults that caused the earthquakes of 1857 in Val d'Agri and of 1980 in Irpinia, respectively (Boschi *et al.*, 1994; Alessio *et al.*, 1995).

The Tito station is located close to this fault and the seismometric sensor allows us to detect earthquakes with low magnitude ($M < 3$) and epicenters close to the measuring point (table I).

3. Methodologies to identify extreme events in SP time series

In this section we briefly describe the statistical methodologies we applied to study the possible correlation between the earthquakes observed in the investigated area and the anomalous SP data recorded at Tito station. When we approach this problem the crucial point is to select objective criteria to pick out anomalous patterns from background fluctuations in self-potential signals (Geller *et al.*, 1997; Cuomo *et al.*, 2000).

Taking into account these considerations, we define as extreme events or runs those values of the recorded signals that have a low occurrence probability (many consecutive values out of a range with a length of $\pm\sigma$, $\pm 2\sigma$, $\pm 3\sigma$). In the framework of the crossing theory (Le Boutillier and Wylen, 1988) it is well demonstrated that the occurrence probability of extreme events strongly decreases when there are more consecutive values above/below the threshold.

Cuomo *et al.* (1996) proposed a dynamic stochastic model to describe the temporal dynamics of self-potential signals; starting from this model, they generated surrogate data with the same statistical features as experimental data. Applying the crossing theory, they observed that the occurrence probability of five consecutive SP values above/below a threshold of $\pm 2\sigma$ was less than 5%. We do not report all the mathematical details regarding the statistical techniques to discriminate extreme events from SP time series, but this topic is extensively described in many papers (*e.g.*, Box and Jenkins, 1976; Cuomo *et al.*, 1996, 2000 and references there-

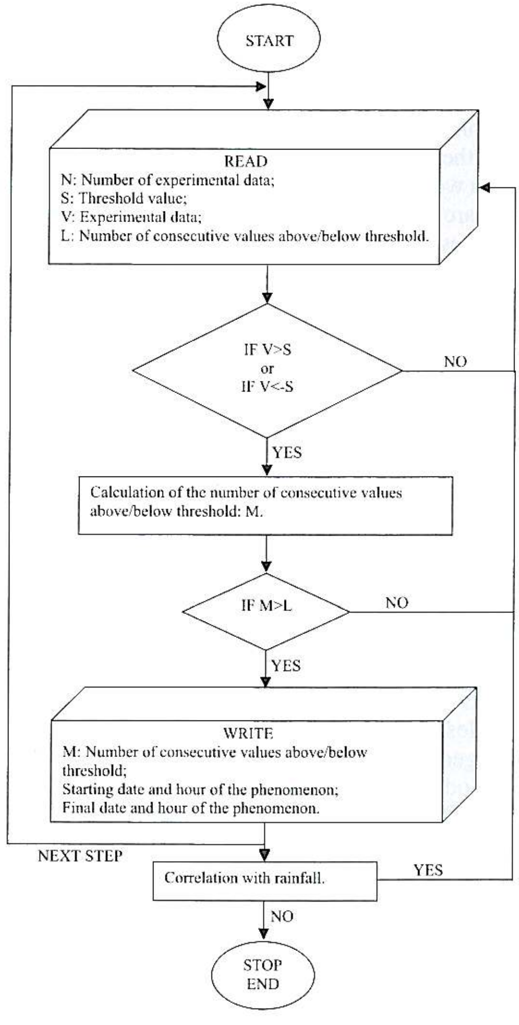

Fig. 4. Flow chart of the software procedure developed to identify extreme events in self-potential time series.

in). Taking into account the previous studies, in the present work we use an algorithm that identifies anomalous pattern having at least five consecutive events above/below $\pm 2\sigma$.

To this aim we have developed a new software package, written using the Visual Basic programming language, that detects the so-called extreme events in the recorded SP sequences. It works in the following way (fig. 4). First, we put the data in the form of potential differences expressed in mV, and we normalise the data subtracting the mean value and dividing all the measured values by the standard deviation. In a second step, we select the thresholds identifying the presence of runs ($\pm n\sigma$; $n = 1, 2, 3$) and then we find, order and count the extreme events we are looking for.

If we input also the date and time of acquisitions, separated from the single values recorded for every channel, we will obtain a summary diagram for the detected runs, with the specification of the hour and the day both of the beginning and of the end of the anomalous activity for every channel. Furthermore, it is possible to make use of different time scales for the identification of the runs, according to the desired accuracy of the problem. In particular, we discuss the results obtained from the analysis of hourly mean values.

Because the SP data can be generally contaminated by climatological parameters, we paid great attention to perform a filtering procedure to remove all the external influences and, in particular, the perturbation due to the rainfall cycles. Before the identification of the runs, we purged the anomalies corresponding to rainy periods that may alter the normal behaviour of the SP signals. By the simultaneous analysis of the SP and rainfall sequences, provided by the National Hydrographic Network, we discriminate all the extreme events possibly due to the rainfall effects and we can thus eliminate them till 24 h after the end of the last rainy event. In such a way, we can be sure that the remainder of the extreme events are not due to the rainfall.

Finally, our multiparametric station combines new technologies with advanced statistical procedures to detect extreme events in SP time series characterised by a very low occurrence probability and that are not contaminated by climatological variables.

4. Results

The last step of this work is to compare the filtered runs with the seismic sequences recorded in the same period by the seismometric station. We considered only earthquakes that occurred in a circular area centred on the measuring point and having a radius obtained from the Dobrovolsky rule (Dobrovolsky, 1992). From an analysis of the temporal sequences of SP runs and earthquakes we obtained preliminary results on the possible correlation between fluctuations in SP time sequences and local seismic activity. Obviously, the data available are still not enough to give a firm conclusion on this controversial scientific problem.

Figure 5a-c compares the extreme events detected in SP time series with the seismic events occurred in the investigated area. In particular, in fig. 5a we observe three runs above/below the threshold of 2σ in Ch3 and Ch4: the first was observed from 7:00 pm to 11:00 pm of June 11, 1999; the second from 7:00 pm of June 10, 1999 to 1.00 am of June 11, 1999; the third from 4:00 am to 10 am of June 11, 1999. Each run was at least five hours long (five consecutive hourly mean values below/above $\pm 2\sigma$) and not influenced by any climatic or cultural noises: as a consequence, we can consider them rare events characterised by a very low occurrence probability.

On June 16, 1999 a sequence of local earthquakes (more than five events with magnitude $M < 3$ spanning a period of three hours) located near the measuring point was recorded. Furthermore, during this period, we observe other extreme events in channels 2 and 5 lasting more than 15 h, but we should remove them because in the same period a rainfall event occurred, even if it was not strong (0.8 mm). This observational evidence suggested considering the fluctuations in the SP time series possibly related to the increase in local seismic activity.

Figure 5b shows the SP extreme events observed during May 1999. Two sequences of significant runs (with threshold of $\pm 2\sigma$) were observed from May 7 to May 8 in channel 3 lasting over 15 h, and during May 29 in channels 3 and 4 lasting 6 and 7 h, respectively. During this period, no seismic events have occurred close the investigated area. This is a clear example of SP fluctuations not followed by an increase in seismic activity.

Figure 5c shows the SP extreme events and earthquakes detected at the Tito station during September 1999. This is an example which includes two local seismic events (on Septem-

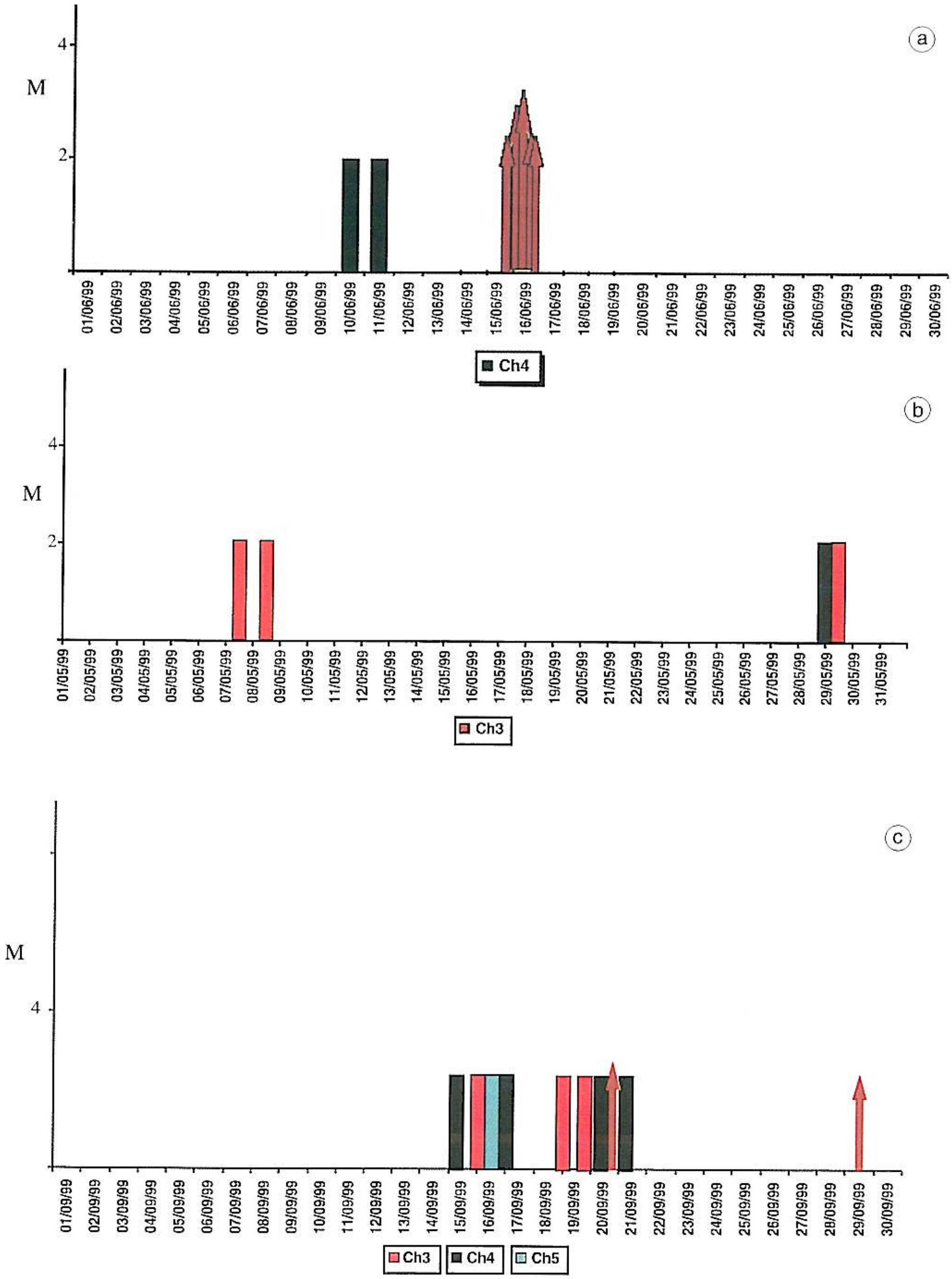

Fig. 5a-c. Correlation between electrical anomalies and observed earthquakes during the period: a) June 1999; b) May 1999; c) September 1999. The arrows label the earthquakes and the bars identify the extreme events related to different channels.

ber 20, with magnitude $M = 3.3$ and on September 29, with magnitude $M = 3$), but significant fluctuations in SP time sequences are seen only before the earthquake that occurred on September 20, 1999. In fact we can observe four sequences of significant runs (with threshold of $\pm 2\sigma$): the first, from September 15 to September 16, in channels 3, 4 and 5 lasting 5, 12 and 25 h respectively; the second, during September 18, in channel 3 lasting 7 h; the third, during September 19, in channels 3 and 4, both lasting 5 h and the last, during September 20, in channel 4 lasting 7 h. Unfortunately, during the period preceding the second earthquake (September 29, 1999) there was a technical failure with the measuring sensors, so we cannot comment on possible correlations between electrical signals and seismic sequences.

By applying statistically well based objective criteria, we noted in some cases an effective correlation between seismic and SP run sequences, but in some other cases we noted extreme events not followed by seismic events or seismic events not preceded by runs sequences. These occurrences stress the need to improve our analysis with more data. In fact, the remote station described earlier was installed at the beginning of 1999, and in the first few months of operation we often had to modify many parameters to optimise it. Thus, we still need to gather more data before obtaining quantitative results that would make the identification of a sequence of extreme events a precursor of a seismic recording.

5. Conclusions

We described the main features of a new prototype of a geophysical multiparametric station that is capable of detecting SP signals and seismometric parameters. The design and the development of this new station are based on advanced technologies and the processing of the observed data has been carried out using robust statistical methodologies.

The use of this new prototype discloses the possibility to measure SP signals and earthquake parameters in the investigated area, with the goal of improving current knowledge on the correlation between anomalous patterns in SP time series and local seismic events, that in some cases are not detected by the National Seismometric Network.

The first results regarding the analysis of extreme events observed during the period March-December 1999 do not allow us to obtain firm conclusions on earthquake electrical precursors, but we have tested the high quality of the data measured by the new station and the goodness of the proposed procedure to identify the extreme events. Continuous application of these procedures on a larger database could give us a statistically significant estimate of the possible correlation between the extreme events and earthquakes sequences.

In the near future we will increase the number of multiparametric stations to build a geophysical monitoring network mainly devoted to the study of electromagnetic phenomena in seismic active areas.

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