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Investigating the time dynamics of geoelectrical signals measured in two seismotectonic environments in the Mediterranean region: the Southern Apennine chain (Southern Italy) and the Hellenic arc (Crete Island, Greece)

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Abstract
In this paper we explore the time dynamics of geoelectrical signals measured in two seismic active areas in the Mediterranean region: the Southern Apennine chain (Italy) and the Hellenic arc (Crete Island, Greece). After a preliminary filtering procedure carried out to remove man-made and climatic noises, the geoelectrical time series measured in both the seismological environments show features that are typical fingerprints of stochastic processes. In particular the time fluctuations follow a dynamics well described by an autoregressive model of a first order (red noise). The model has been tested in the frequency and time domains applying advanced statistical methodologies. Taking into account these results, we propose an objective methodology to pick out from geoelectrical time series anomalous patterns from background noise and we study the possible correlation between the appearance of extreme events in the electrical signals and the local seismic activity. Finally an in-depth analysis of results obtained in the two investigated areas has been performed.

Key words *geoelectrical signals – time dynamics – extreme events – earthquake prediction*

1. Introduction

In past and recent years field measurements in seismic areas have documented anomalous patterns in geoelectrical parameters (resistivity, self-potential) attributed to stress and strain changes which were followed by earthquakes (*e.g.*, Rikitake, 1988; Chu *et al*, 1996; Park, 1996). However, the use of electrical precursors in earthquake prediction is to a large extent still empirical, due to the many difficulties that still exist in understanding the physics underlying the source mechanisms of geophysical precursory phenomena (Scholtz, 1990; Patella *et al*, 1997), and to well define objective criteria to evaluate the reliability of the short-term predictions based on this type of precursory signals (*e.g.*, Evans, 1997; Geller *et al.*, 1997). A typical example is the VAN experiment (Varotsos

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et al., 1993) in which a significant statistical analysis of claimed geoelectrical anomalies and a discrimination of the cultural noisy sources are completely omitted (*e.g.*, Mulargia and Gasperini, 1992; Kagan, 1997; Pham *et al.*, 1998).

In this topical and highly controversial scientific problem there is a weak point: none of the studies (including both favourable and critical papers) carried out in recent years consider the dynamical nature of the geoelectrical signals. We cannot obtain information on the reliability of geoelectrical precursors without the knowledge of the deterministic or statistical laws describing the time fluctuations of these signals (Cuomo *et al.*, 1996). The identification of extreme events in geoelectrical records must be preceded by a deeper analysis of the time dynamics of this kind of geophysical precursor. Furthermore, it is necessary to take into account the possible influence of local geological and seismological setting of the investigated area.

In this framework, our contribution concerns the comparison of the time dynamics of geoelectrical signals measured in two different seismotectonic environments of the Mediterranean area: the Southern Apennine chain and the Hellenic arc. In this work we use a stochastic model that was introduced by Cuomo *et al.* (1996) to describe the time dynamics of geoelectrical time series recorded in a seismic active area of Southern Apennine chain. The knowledge of a model allows us to identify robust statistical methodologies to discriminate extreme events from background noise (Cuomo *et al.*, 1996). In particular, we analyse self-potential time series recorded during the period 1996-1997 at Giuliano site and during the period 1993-1994 at Heraklion site.

An analysis of possible correlations between extreme events in electrical signals and local seismicity has been carried out and the results obtained in two different test sites are outlined and discussed. The main goal of this work is to define a well based statistical procedure able to pick out extreme events from background noise in electrical signals recorded in different geological and seismological environments. The analysis and comparison of our findings could improve the current strategy of geophysical monitoring strategy in seismic areas.

The paper is so organised: Section 2 briefly outlines the geological and seismological settings of the two investigated areas; Section 3 briefly describes the monitoring stations and the observational data; the mathematical background of stochastic models are briefly resumed in Section 4 and the possible correlation between extreme events in geoelectrical signals and local seismic activity is analysed and discussed in Section 5. Concluding remarks and some general comments are summarised in the last section.

2. Seismological setting

In this paper we analyse the geoelectrical time series instrumentally recorded in two seismic areas of the Mediterranean region: the Southern Apennine chain and the Hellenic arc (fig. 1a,b). In particular, the remote stations able to detect time fluctuation of electrical earth surface field were located in Giuliano village on the northern side of Potenza town (Southern Italy) and close to the Heraklion city (Crete, Greece). In this section we briefly describe the main seismological features of the two investigated areas.

2.1. *Southern Apennine chain*

The measuring station is located on the Southern Apennine chain whose framework consists of a pile of thrust sheet forming a complex system orogenically transported over the flexured South-Western margin of the Apulia foreland. It is the result of a complex sequence of tectonic events associated with the collision between Africa and Europe (Doglioni *et al.*, 1996).

The Southern Apennine chain is one of the most active area of the Mediterranean region. In this area a large normal-faulting earthquake occurred on November 23, 1980 ($M_s = 6.9$), (Pantosti and Valensise, 1990). One of the most historically relevant events, the December 16, 1857 normal-faulting earthquake occurred in

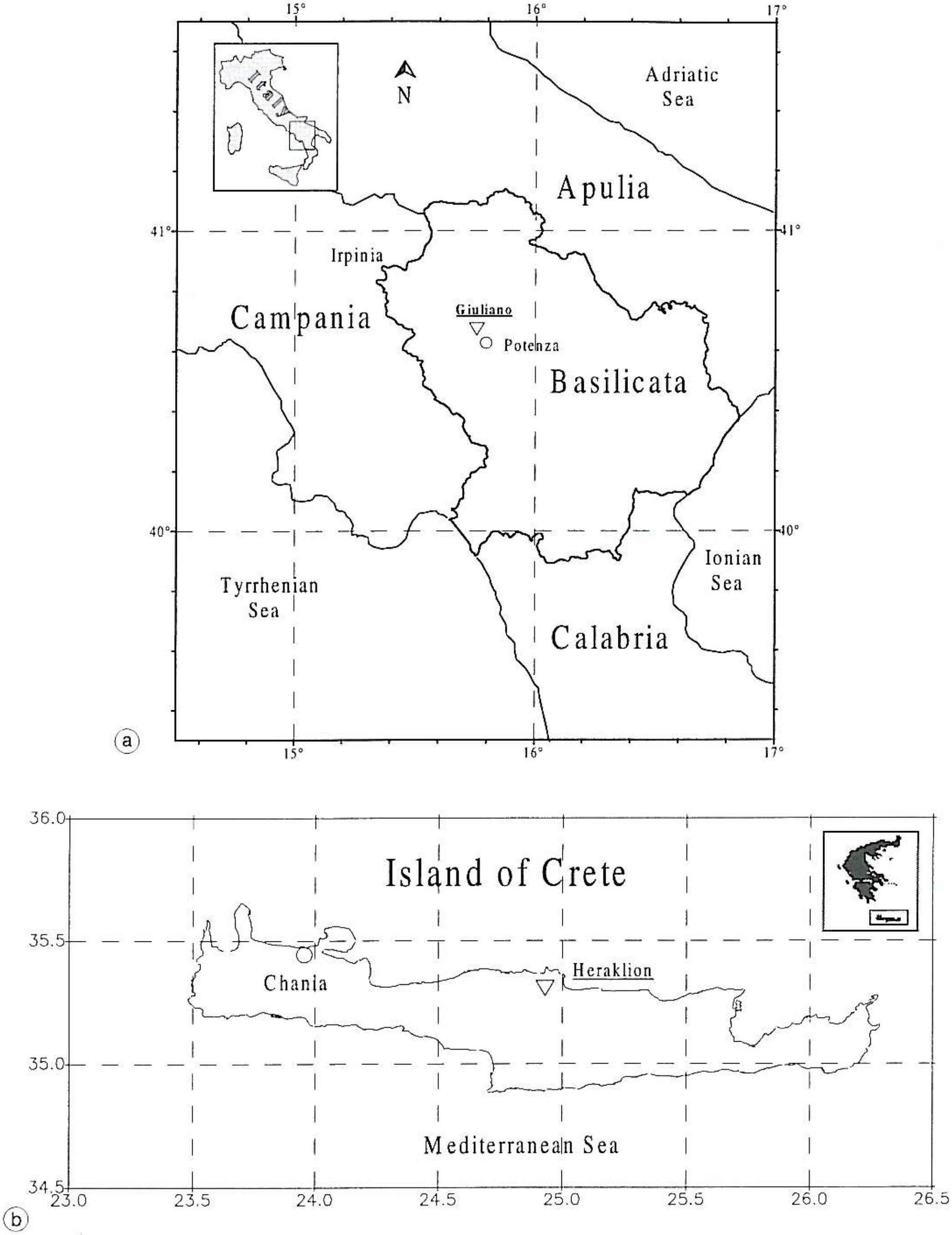


Fig. 1a,b. Map of the two investigated areas: the Southern Apennine chain (a) and Crete Island (b).The locations of the monitoring stations are indicated with triangles.

Val d'Agri. Seismic activity occurring after the 1980 event consisted of medium intensity events ($M < 5.5$) located close to the border between Campania and Basilicata regions (Alessio *et al.*, 1995). 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 1980 earthquake which occurred in this area (fig. 2). These events have been followed by aftershocks sequences that identify a fault structure located near Potenza town (Lapenna *et al.*, 1998). The seismological analysis of the above mentioned remarkable events demonstrated that such earthquakes were generated by a strike-slip fault in WE direction, perpendicularly oriented toward the Apennine chain (Ekström, 1994). This fault lies north of Potenza town and is located in such a way to limit toward north and south two great seismogenetic faults that caused the 1857 Val d'Agri and 1980 Irpinia earthquakes, respectively. The fault area outlined by the aftershocks extends approximately 20 km in length and 10 km in depth, making it significantly larger than expected for a $M_L = 5.2$ earthquake. The aftershocks were concentrated between 15 and 25 km depth, which is deeper than over well determined focal depth in the Central and Southern Apennines (Ekström, 1994).

2.2. *Crete Island*

Crete is located on the Southern Aegean area that is limited on the north by the continental blocks of the European plate, on the south by oceanic material of the African plate, on the east to Central Turkey and on the west by the Adriatic Sea (Baker *et al*, 1997). The African plate is subducted under the Aegean lithosphere, along the Hellenic arc. Seismic activity is very intense and extends up to a depth of 180 km in this region. The relative motion across the Hellenic trench, as inferred by seismology (*e.g.*, Jackson, 1994) or geodesy (*e.g.*, Noomen *et al*, 1994), is NE-SW and greater than 5 cm yr^{-1}.

The upper surface of Hellenic arc has an amphitheatrical shape, strikes parallel to the sedimentary arc and dips at a low angle from the outer (convex) side to the inner (concave) side of the Hellenic arc, that is, from the Eastern Mediterranean Sea to the Eagean Sea (Papazachos, 1990; Kiratzi and Papazachos, 1995).

Shallow seismicity (fig. 3) is highest along the convex side of Hellenic arc but close to the coast (Ionian Islands, South Peloponnesus, south of Crete, south of Karpathos and Rhodos), in Central Greece (Patraikos-Corinthiakos-Evoikos gulfs, Thessalia) and along a seismic belt which includes the Northwestern Anatolian fault zone, the northern most part of the Aegean Sea and Serbomacedonia zone (Karakostas, 1988). The intermediate depth seismic activity is distributed in two parts of the Benioff zone, which dips from the convex side (Eastern Mediterranean) to the concave side (Aegean sea) of the Hellenic arc.

This location of Crete is the main reason for its complicated geological structure, the high tectonic rates, which become apparent by large active faults, and the significant seismicity of the broader area of the island. The geologic studies which examine the recent tectonic movements of the island conclude with a rising of Western Crete and subsidence of Eastern Crete. Generally the island shows a rotation around a line defined by Tymbaki and Heraklion. The prevailing stresses in this area are extensional for shallow earthquakes and compressive for earthquakes of intermediate focal depth.

3. Data

Technically a geoelectric or self-potential time series is a sequence of voltage differences measured with a fixed sampling interval using a receiving electrode array. The field procedures and the equipment involved in these measurements are well known, being currently used in geoelectrical prospecting. During a geoelectrical sounding, where a current is injected into the ground, the SP signal represents the noise. On the other hand, when we are using a passive measurement technique (*i.e.* without energising system), it represents the signal. In this paper we analyse data recorded at two stations: Giuliano station (Southern Italy) and Heraklion station (Crete).

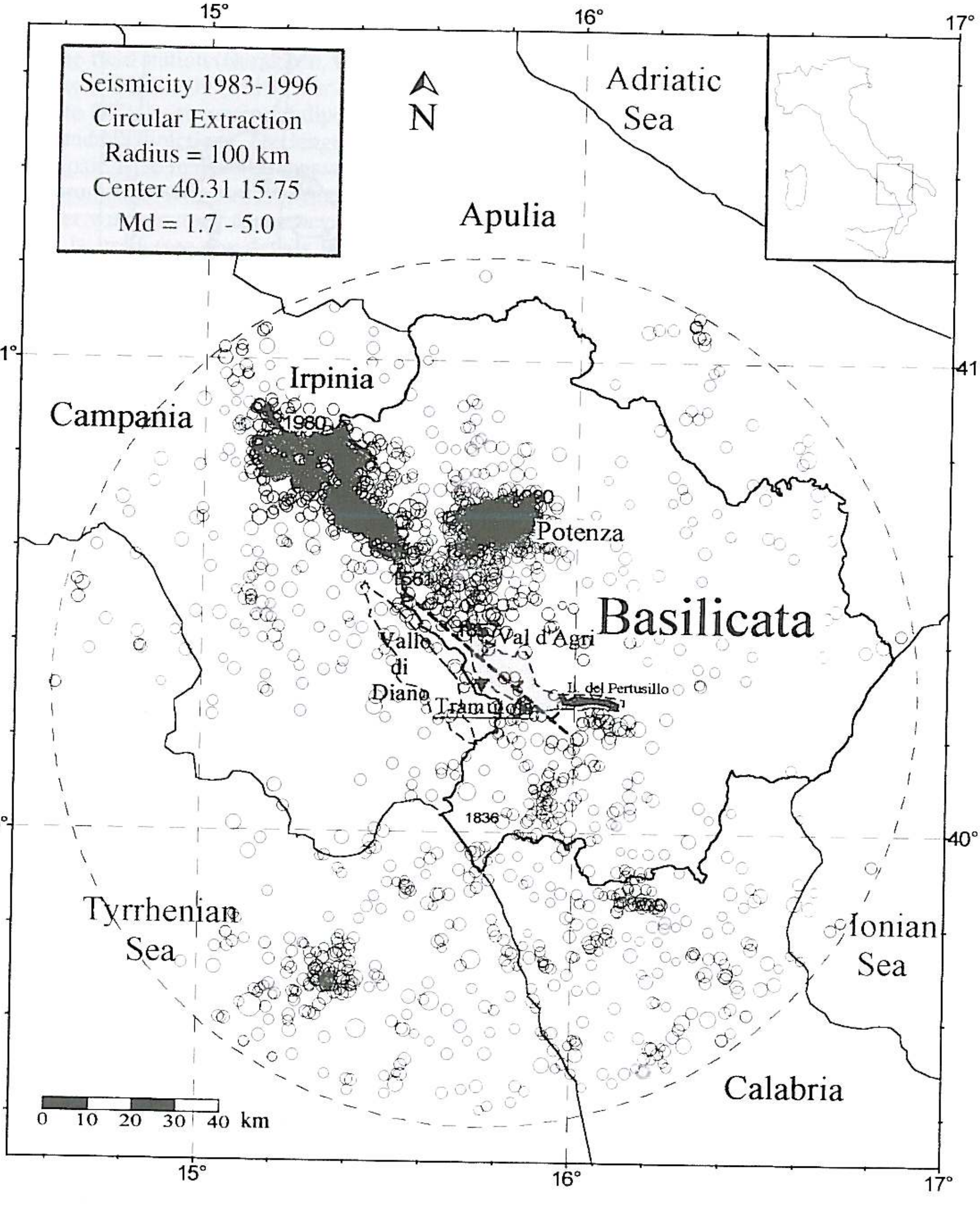


Fig. 2. Spatial distribution of seismic events which occurred in the Irpinia-Basilicata region during the period 1983-1996. The radius of circles is related to the earthquake magnitude.

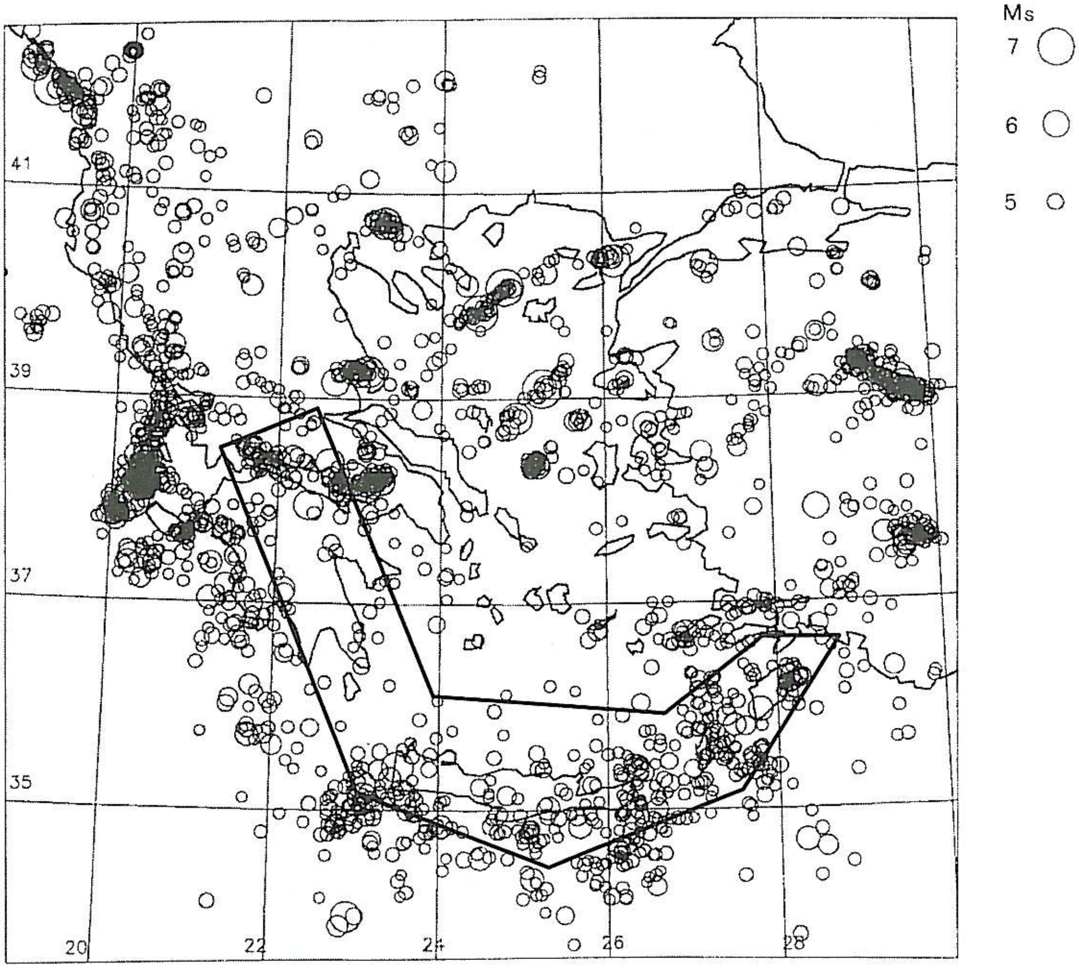


Fig. 3. Spatial distribution of shallow seismicity ($h < 60$ km) in Aegean areas during the time period 1970-1984 (from Karakostas, 1988).

3.1. *Giuliano station*

In this case the station is equipped with a high resolution multimeter connected with a GPIB interface to a computer. The sensors are two electrodes of a dipole aligned with the fault direction. The distance between the probes is 100 m and they are built with copper bars and put into the ground at 1 m depth to avoid the influence of temperature excursions. The electrodes are connected with screened trailing cables to the multimeter. The sampling interval is $\Delta t = 1$ s and after a preliminary screening of the experimental values a mean value every 60 samples is stored. At the Giuliano station there are only two electrodes to measure only a component of the electric field that is parallel oriented towards the fault. This constraint was necessary to jointly measure the electrical and seismoacoustic parameters; in any case there are other stations with the classical couples of electrodes in the investigated area (Di Bello *et al.*, 1996).

3.2. *Heraklion station*

At the field station (Heraklion, Crete Island) we measured the telluric field variations (from 0.1 Hz to DC), by two pairs of dipoles oriented in EW and NS directions. The length of dipoles, in each pair, is 50 m and 100 m, respectively. In our instrumentation a Butterworth low-pass active filter with a cut-off frequency of 0.1 Hz at – 3 dB, is used (see for details Nomicos and Chatzidiakos, 1993). The station is installed 20 km from the coast and is far enough from any industrial noise source, as it was selected after extensive investigation. The field system is based on a datalogger (model 21X, Campbell Scientific), installed at the field station, which digitises the information and stores it. The sampling rate was set to one sample per second and the measurements were automatically stored in a mass memory. A central station uses a commer-

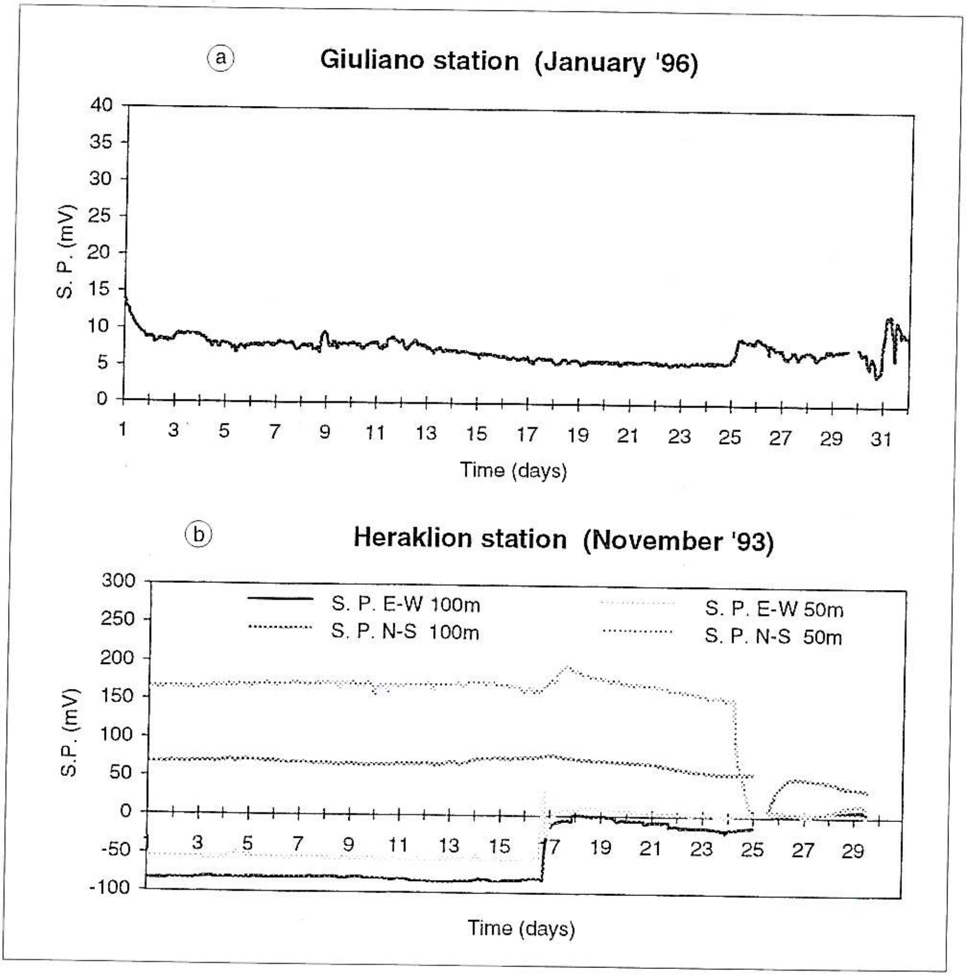


Fig. 4a,b. Typical geoelectrical time series recorded at Giuliano station (a) and Heraklion station (b). The data are hourly mean values; for the Heraklion station we have four different time series related to two different dipole orientations (N-S and E-W) and two different electrode array distances (50 m and 100 m).

cial PC to communicate twice per day with a data-logger and collects the information via switched telephone line, using a standard CCITT smart modem V21/V22 (Nomicos and Vallianatos, 1996; Nomicos *et al.*, 1997). Data are saved on the hard disk of the central station, for further processing.

For both test sites the geological and seismological settings, combined with a very low level of cultural noise, allow us to consider the investigated areas ideal outdoor laboratories to study the possible correlation between tectonic activity and anomalous patterns in the geoelectrical signals. Typical records of the geoelectrical time series observed at the two different test sites are shown in fig. 4a,b.

In the following section we explore the time dynamics of hourly means geoelectrical time series coming from the two different test sites (Southern Italy and Crete Island) and spanning the period 1996-1997 and 1993-1994, respectively.

4. Time dynamics of geoelectrical signals and probability occurrence of extreme events

In this section the time dynamics of geoelectrical time series measured in the two test sites are compared. We demonstrate that the same stochastic model is able to describe the time fluctuations of data coming from different seismological environments.

The knowledge of a model to describe the time dynamics of electrical precursors allows us to obtain an objective criterion to identify anomalous patterns (*i.e.* extreme events) from background noise that is a critical point in all studies regarding short-term earthquake prediction. Generally one or more consecutive values above/below are considered extreme events only when their occurrence probability is very low. But the estimate of occurrence probability can be estimated only when we have a large enough number of observations to permit a good estimate of the empirical curves of probabilities of abnormal events. Unfortunately, in many applications the size of the records is large enough to assess the structure of the empirical time series of interest, but not to have good statistics about extreme events. Generally, in the study of geoelectrical signals, we have always a limited number of data, as a consequence the statistics on the extreme events is a hard task.

The knowledge of a model able to generate surrogate time series having the same statistical features as observed data allows us to overcome this drawback. The length of experimental time series is large enough to estimate the model parameter, but it is not sufficient to give information about extreme events. In the next two sections, the proposed model is well tested in time and frequency domains and the statistics on the occurrence probability of extreme events are obtained.

4.1. *The model*

To compute the occurrence probability of extreme values in the time series a model to describe the data is necessary. We demonstrated in previous papers (Cuomo *et al.*, 1996, 2000) that the geoelectrical time series can be considered a realisation of a dynamic-stochastic model build of two different components

$$x(t) = s(t) + z(t) \tag{4.1}$$

where $s(t)$ is a deterministic component related to meteo-climatic effects and $z(t)$ a stochastic component well described by an autoregressive process. The first component is generally removed using well known filtering procedures, a complete analysis of these techniques can be found in some previous papers (Di Bello *et al.*, 1996; Cuomo *et al.*, 1996)

We briefly summarize the main theoretical aspects of autoregressive processes. A p-th order autoregressive process (Box and Jenkins, 1976), AR(p), can be considered as

$$y(n) = \sum_{j=1}^{p} \phi_j y(n-1) + w(n) \tag{4.2}$$

where the $\varphi_1 ...... \varphi_p$ are the parameters of the model, p is the order of the process and $w(n)$ a purely white noise. The parameters can be estimated solving the Yule-Walker equations.

In particular, in our analysis we identified an AR(1) process able to well describe the time fluctuations of hourly mean self-potential time series recorded at Giuliano site. The model has been tested in time domain and the frequency domain estimating the autocorrelation coefficients and the power spectra of residuals. The residuals, that are the differences between experimental data and values predicted by the autoregressive process, allow us to check the validity of the model

$$r(n) = z(n) - \hat{z}(n). \tag{4.3}$$

If the model is well fitted to the data, the residuals $r(n)$ must be a realisation of a purely random noise.

Then, we check the model validity testing the randomness of residuals. All data collected are divided into sub-samples (hourly mean values for a period of 1 month) and for each of them we estimated the parameter of the model. In a subsequent step the residuals are calculated applying the eq. (4.3). For each residual sample the correlation function and the power spectra have been estimated. We always find that residuals are a purely random noise: the correlation coefficients are close to zero and inside the tolerance band $\left(\pm\frac{2}{\sqrt{N}}\right)$ and the power spectra are almost flat. The parameter of the AR(1) varyies inside the interval 0.8-0.9.

A typical result obtained from the analysis of hourly geoelectrical time series measured at Giuliano station during January 1996 is reported in fig. 5a,b. Using the same approach we investigated the time dynamics of geoelectrical time series measured at Heraklion station, in this case too we find that a AR(1) model is well fitted to the data. The results of residuals analysis are reported in fig. 6a,b.

The geoelectrical time series, independently from the geological environments in which they are measured, follow a time dynamics that is well described by an autoregressive process. They have an internal correlation and are not purely random signals. Having the model we can reproduce a very large amount of surrogate data and we can apply statistical methods to study extreme events.

4.2. *Identification of extreme events*

At this point a time series model is identified and an estimate of the probability of extreme events can be obtained on the basis of the model fitted to the data using the crossing theory. A sequence of successive values above or below a given threshold is defined as an *extreme event*. Various different statistics are associated with extreme events in many geophysical fields (Kendall and Stuart, 1976; LeBoutillier and Waylen, 1988). In this work we deal with the statistics related to the length of extreme events. It represents the number of values, m, that the variable under study is above or below the selected truncation level z_0. The probability distribution $P(m \geq j; z_0)$, for an arbitrary level z_0, gives the probability that m is greater than a j-values period. The function $P(m \geq j; z_0)$ is normalised so that $P(m \geq 1; z_0) = 1$. In this work we use a variable with unit variance and zero mean, from which the deterministic component is removed and the truncation level is not related with time.

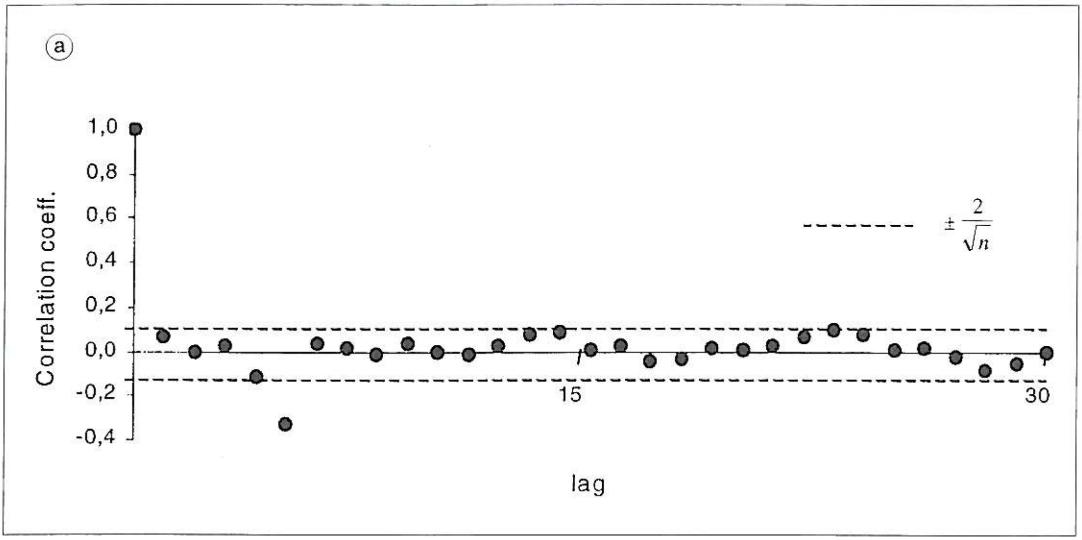
Having a model that describes the empirical time series, the extreme event analysis proceeds straightforwardly. Analytical relations of distributions of extreme event lengths of the AR model are available, even if they are difficult to handle in practical computation. It is easier to estimate $P(m \geq j; z_0)$ by simulating a residual time series made of a very large amount of data using the parameters of the selected AR process.

The simulation approach just described can produce artificial time series that reflect any desired run length compatible with the set of observations. Finally the $P(m \geq j; z_0)$ value is estimated as the sample relative frequency of extreme event lengths that are greater than j-values period

$$P(m \geq j; z_0) = \sum_{i=j}^{\infty} F_i \Big/ \sum_{i=1}^{\infty} F_i \tag{4.4}$$

where F_i indicates the number of runs above or below the threshold z_0 that are i samples long. In the previous equation a truncation point must take the place of the theoretical infinity limit appearing in the summation.

Using the parameters of AR(1) models well fitted to hourly geoelectrical time series coming



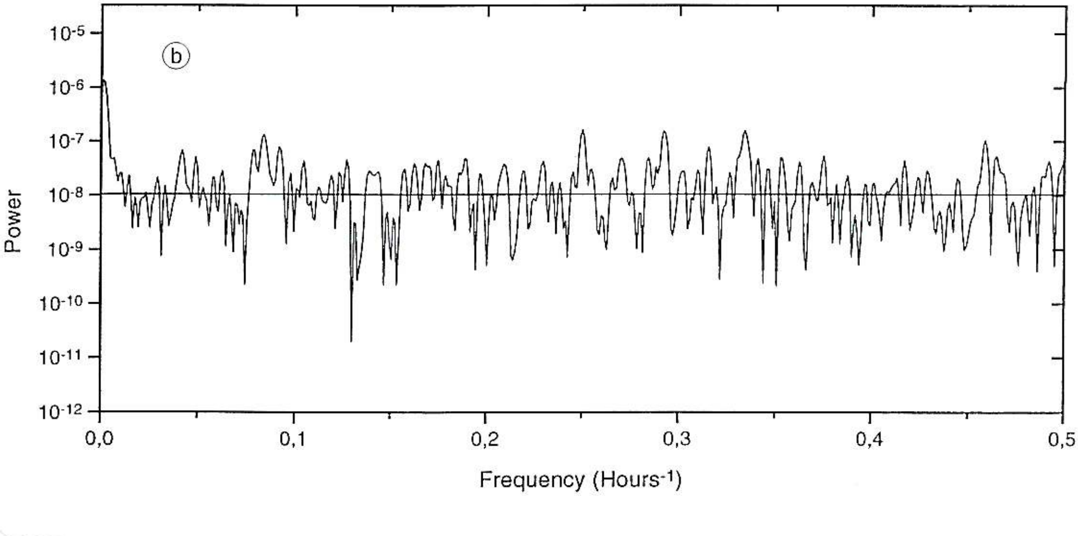
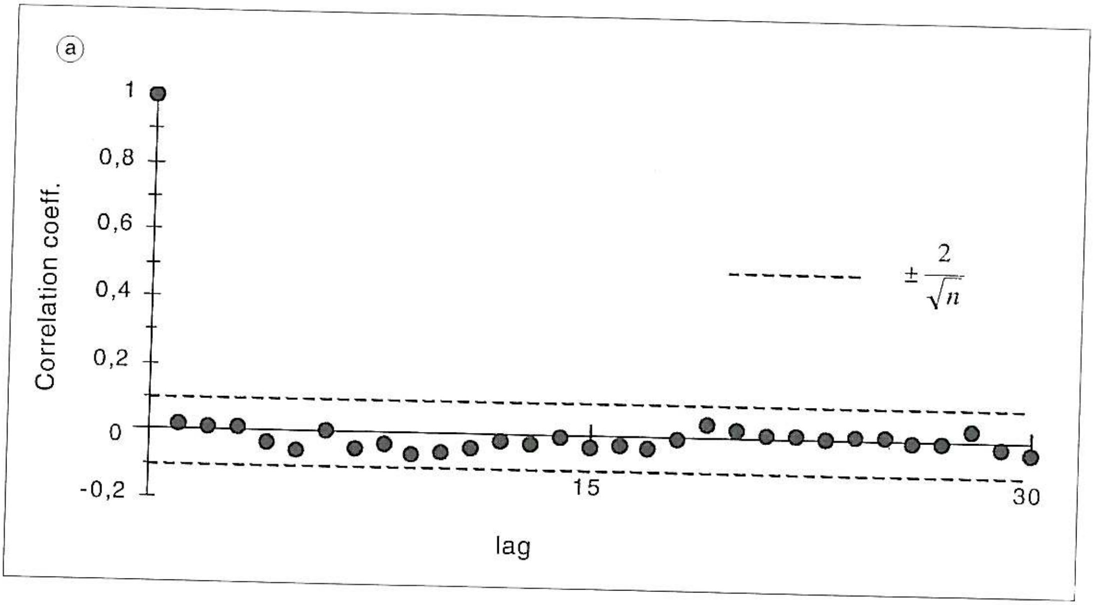


Fig. 5a,b. Autocorrelation function (a) and power spectra (b) of the residuals obtained from the differences between the geoelectrical time series plotted in fig. 4a and the values predicted by the AR(1) model. The behaviour of the autocorrelation and the power spectra are typical signatures of purely random noise.



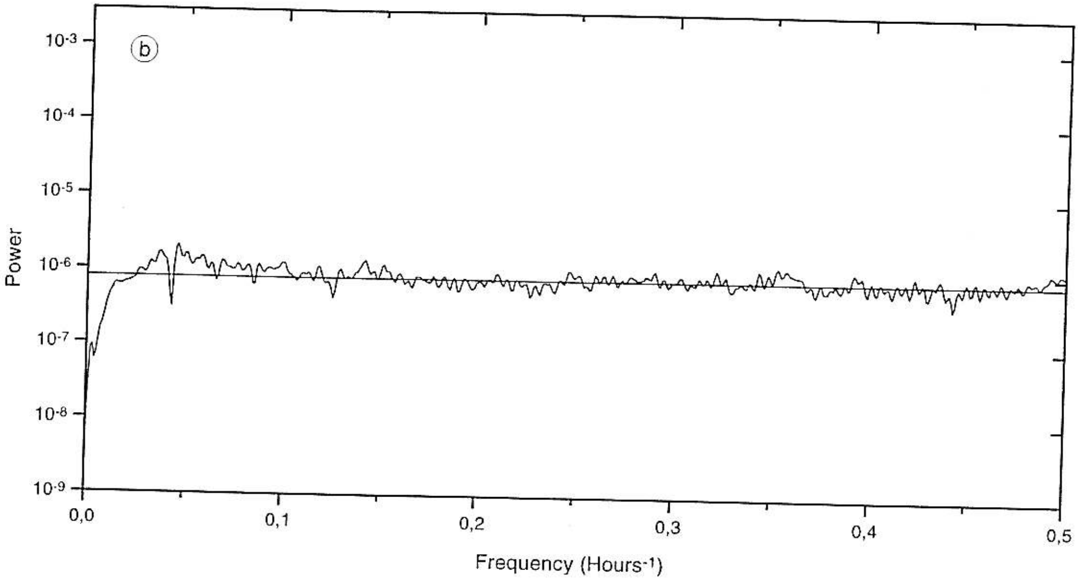


Fig. 6a,b. Autocorrelation function (a) and power spectra (b) of the residuals obtained from the differences between the geoelectrical time series plotted in fig. 4b and the values predicted by the AR(1) model. The behaviour of the autocorrelation and the power spectra are typical signatures of purely random noise.

from the two test sites, we reproduce a very large amount of surrogate data. In a successive step we estimate the occurrence probability curves P counting the events as indicated in the previous formula.

A complete discussion of this simulation procedure is reported in a previous paper (Cuomo *et al.*, 2000), for the sake of brevity in this work we summarize the main results. The occurrence probability rapidly decreases when increasing m values. To have an occurrence probability lower than 10%, it is necessary to have at least five consecutive values above/below a threshold of 2σ.

Taking into account these results, we select the following procedure to pick out extreme events in the geoelectrical time series recorded in the two test sites. First of all we analyse hourly mean values moving throughout the data with a time window spanning a period of 1 month. For each sub-sample of time series, after computing the residuals with a first order AR model we normalise the residuals subtracting the mean value and dividing for the standard deviation, in a subsequent step only the extreme events characterised by at least five consecutive values above/below 2σ are considered. Recalling that in Heraklion station we have four measuring channels, in the analysis of geoelectrical time series measured in Crete we use a more restrictive rule: only extreme events appearing in the same period in at least two channels are considered significant.

Now, on the basis of the methods above discussed, seismic sequences and geoelectrical anomalies observed in the two investigated areas were compared.

5. Results

In this section we discuss the main results obtained from the comparison of the temporal map of anomalous patterns extracted from the geoelectrical time series plotted *versus* the local seismic sequences. In particular we report the time sequences of extreme events identified in geoelectrical time series using the crossing theory discussed above.

As concerns the earthquakes, we must include in our analysis only seismic events that in principle can produce geophysical variations at a measuring site. This is another very controversial problem, a deeper analysis of this crucial phase requires more than a section of a scientific paper. In this work we focus our attention on the identification of anomalous patterns in geoelectrical signals and we simply report the temporal map of seismic events applying procedures based on the well known Dobrovolsky algorithm (Dobrovolsky, 1979)

$$r = 10^{0.43M} \qquad (5.1)$$

where r is the radius of the area in which the effects of the earthquake are in principle detectable and M is the magnitude.

This rule has many limits and ambiguities. In any case it represents a trivial, but objective rule to select seismic events able to produce geophysical fluctuations at a measuring site. Other approaches are generally based on an empirical choice of a minimum threshold for the magnitude. In this section we use three different procedures to select the seismic sequences: the Dobrovolsky rule; the minimum magnitude rule (*e.g.*, only seismic events with $M > 4$ are considered); a more restrictive approach based on the combination of the two previous criteria.

Figure 7a-c reports the results obtained from the analysis of data measured at Giuliano site during 1996. We calculated the temporal map of anomalies in electrical signals selecting extreme events with at least five consecutive values above/below a fixed threshold ($\pm 3\sigma$). The seismic events are extracted from the catalog of the National Institute of Geophysics applying the three previous criteria. Before the seismic event which occurred on April 3, 1996, a sequence of abnormal electrical values are clearly identified (fig. 7a). But in the subsequent period we note many seismic events that are not preceded or followed by any extreme events in geoelectrical signals. On the contrary, assuming more restrictive criteria we select only the main earthquake which occurred in the investigated area (fig. 7b,c).

In the analysis of data measured at Heraklion station during 1993, the high rate of earthquake occurrence as obtained from the catalog of National Observatory of Athens, does not yield

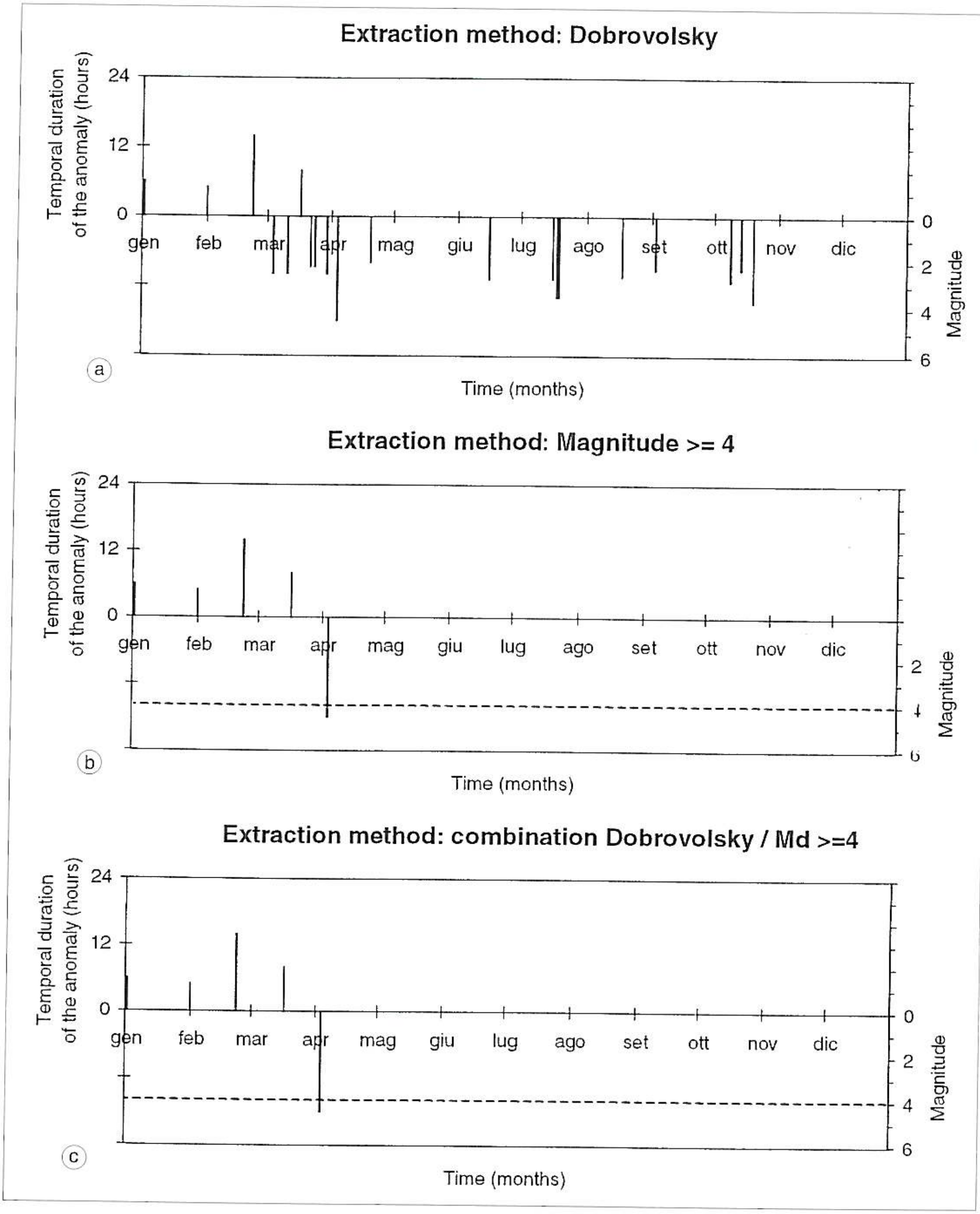


Fig. 7a-c. Temporal map of extreme events in electrical signals measured during 1996 at Giuliano site *versus* the seismic events which occurred in the investigated area. The extreme events are obtained using a threshold of 3σ, the three different graphs are obtained varying the criteria to select the useful seismic events from the catalog.

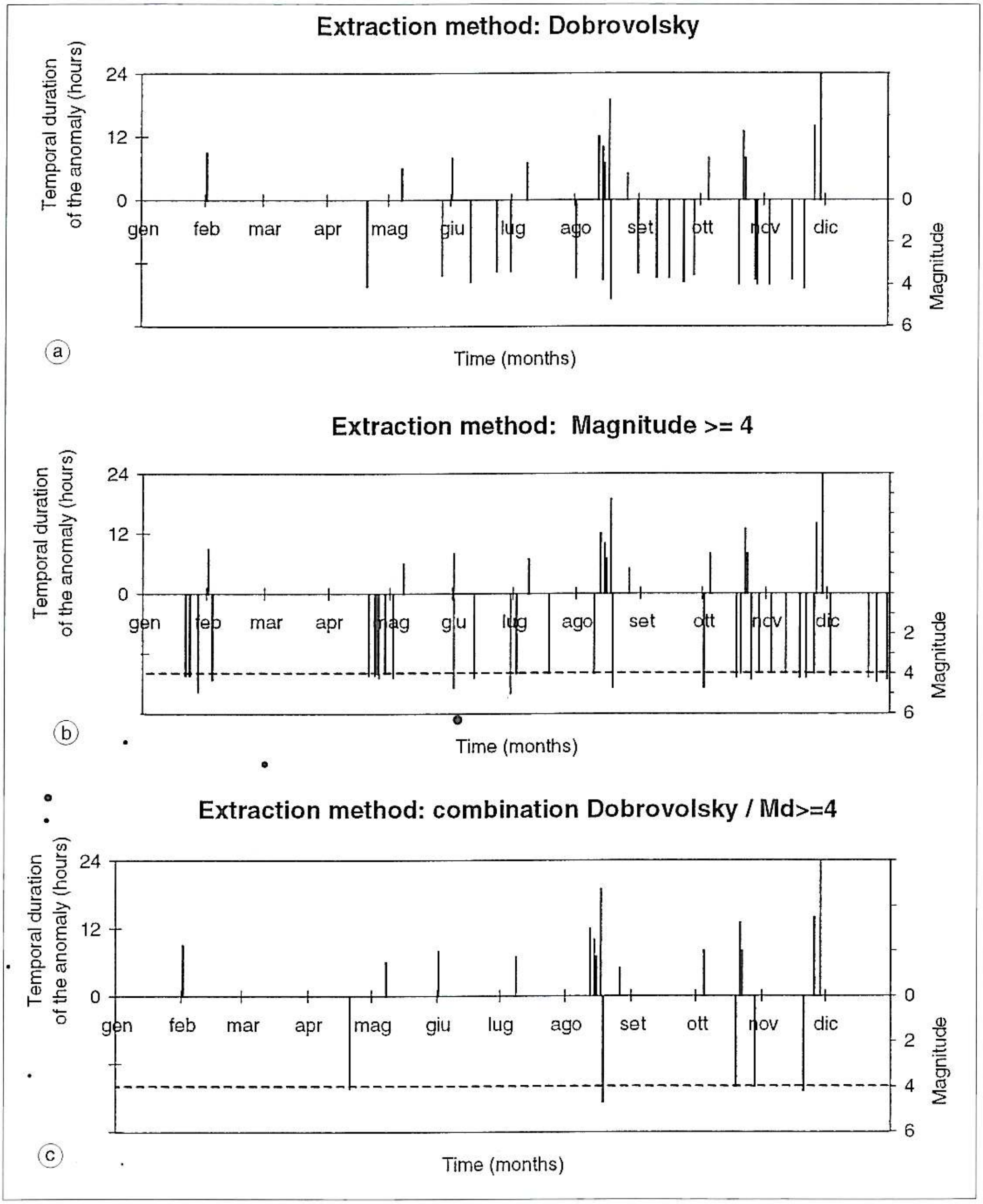
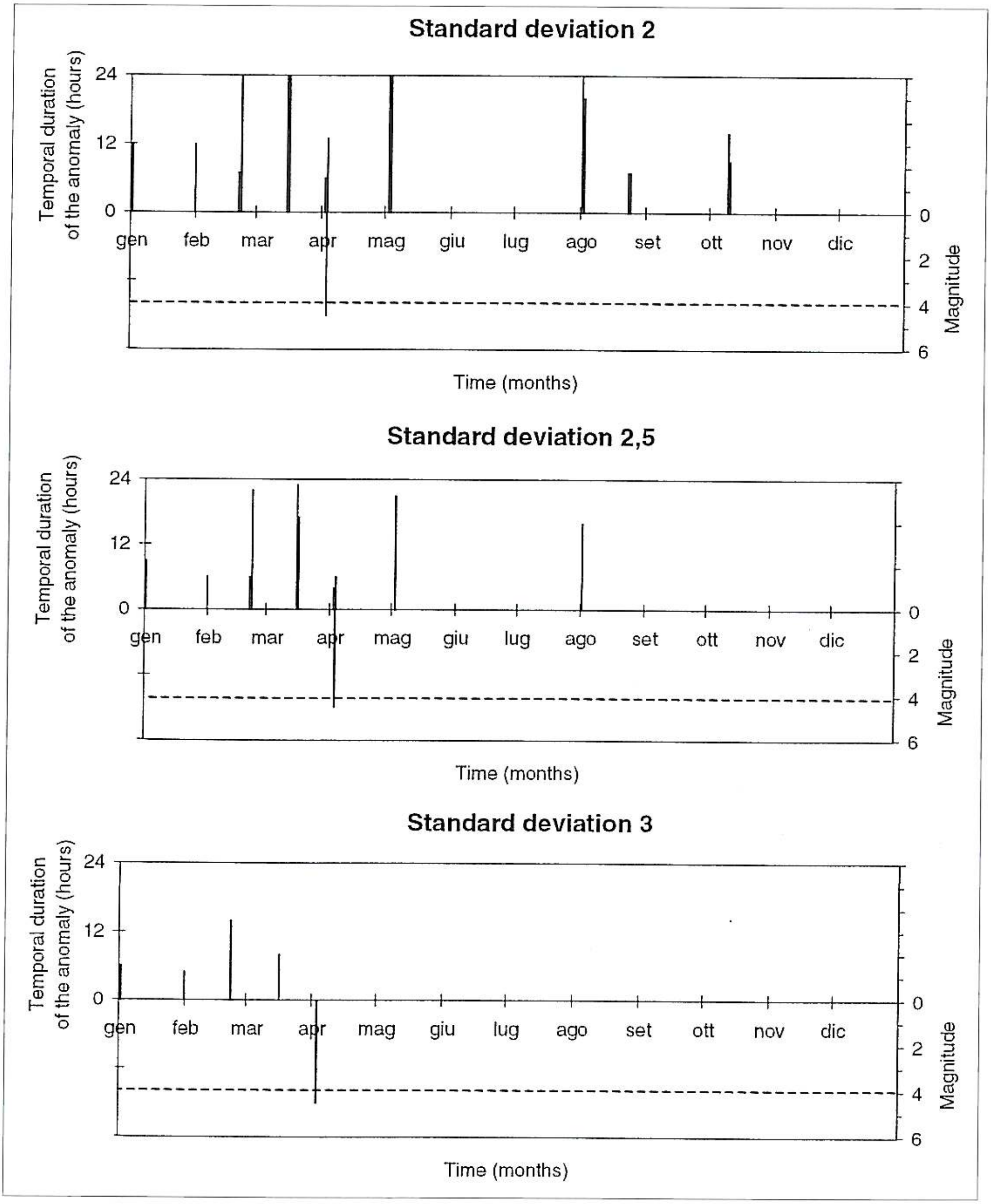


Fig. 8a-c. Temporal map of extreme events in geoelectrical time series measured at Heraklion site during 1993 *versus* seismic events. Using more restrictive criteria we note that many significant extreme events appear before the main seismic events which occurred in this investigated area.


Standard deviation 2

Standard deviation 2,5

Standard deviation 3

Fig. 9. Temporal map of extreme events in geoelectrical signals *versus* seismic events observed during 1996 in the Irpinia-Basilicata region. The different graphs are related to three different thresholds, in the last graphs a group of extreme events in electrical signals appear before the main seismic event observed in the investigated area.

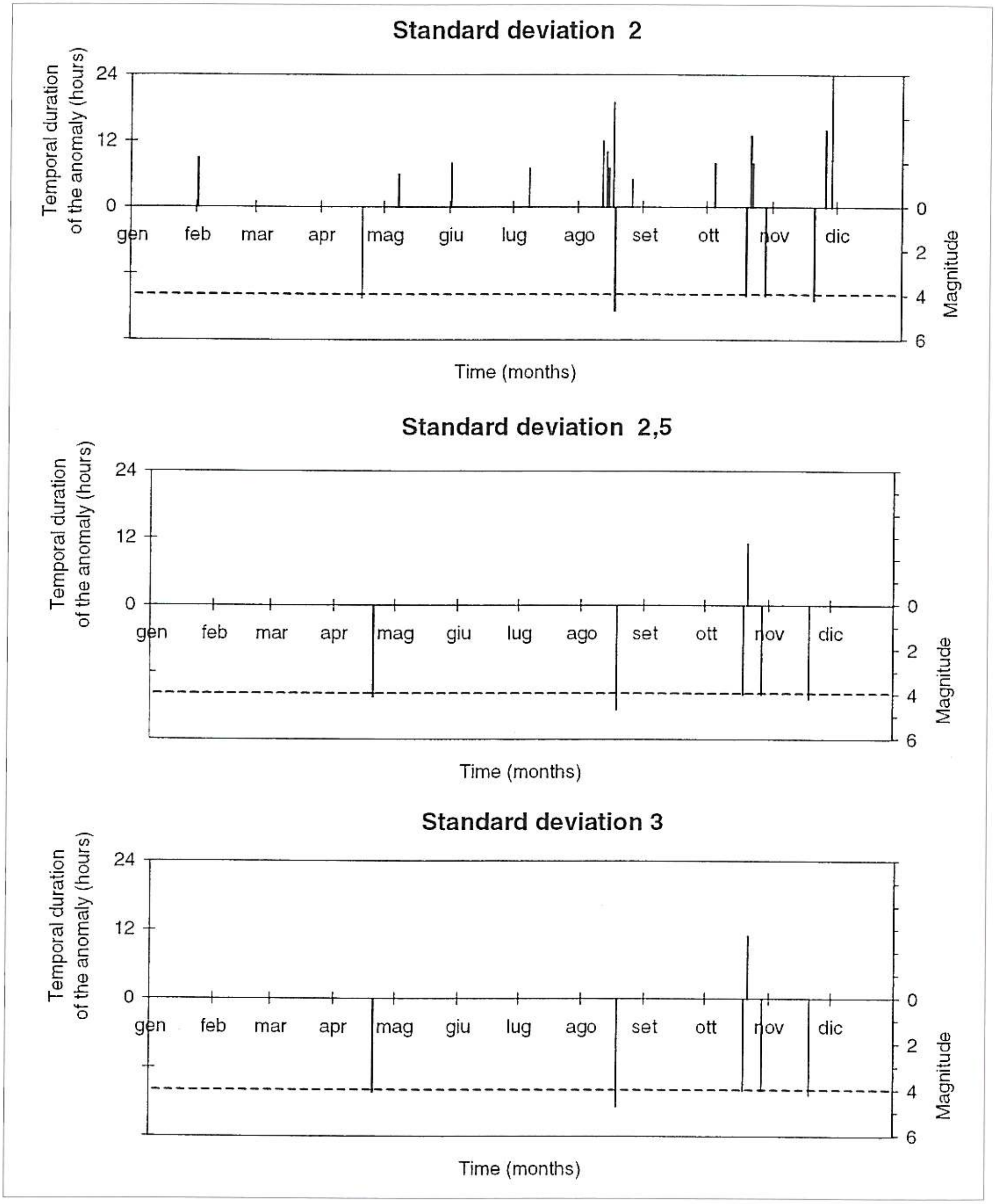


Fig. 10. Temporal map of extreme events in geoelectrical signals *versus* seismic events observed during 1993 in the investigated area (Crete). The high seismicity rate does not allow firm conclusions about the possible correlation between geoelectrical anomalies and earthquakes.

firm conclusions. There is only a weak time clustering effect: the electrical anomalies seem to have a higher temporal density in the period with intense seismic activity (fig. 8a-c). It is quite evident that applying a more restrictive algorithm based on the combination of the Dobrovolsky and the minimum magnitude rules, we would obtain more interesting results. In the third case (fig. 8c) significant extreme events before the main seismic event which occurred in this area were identified. In the period preceding this earthquake, extreme events in geoelectrical time series were detected in all four measuring channels of Heraklion station.

In fig. 9 we observe the results regarding again the geoelectrical data measured during 1996 at Giuliano site, but the procedure was applied changing the threshold ($\pm 2\sigma$, $\pm 2.5\sigma$ and $\pm 3\sigma$) and using only the more restrictive rule (third case) to select the useful seismic events. The temporal anomaly map obtained selecting a threshold of 2σ does not yield firm conclusions on the identification of pre-seismic, co-seismic and/or post-seismic electrical signals. On the contrary, increasing the threshold value, we clearly identify a sequence of electrical extreme events before the main earthquake (April 3, 1996; $M = 4.5$) which occurred in the investigated area during the monitored period.

To better substantiate this hypothesis we remark that in the same period (March-April 1996), other anomalous patterns in electrical, geochemical and acoustic signals recorded by means of other monitoring stations located in the same investigated area were detected (Di Bello *et al.*, 1997).

The same criteria were applied to identify extreme events in geoelectrical time series measured in Crete. Figure 10 reports the temporal map of geoelectrical extreme events *versus* seismic events for 1993. The high rate of seismic activity does not allow us to obtain evidence of pre-seismic, co-seismic and/or post-seismic fluctuations in electrical signals. The analysis needs the study of time clustering effects in both electrical anomalous patterns and seismic events. Unfortunately, the change in the threshold magnitude does not solve the problem.

Our findings cannot give firm conclusions on the reliability of geoelectrical precursors, the complexity of the problem under study needs analyses of a larger amount of successes and failures. In the near future our results could be improved considering other seismological parameters such as the hypocentral depth, focal mechanism and seismic moment.

On the contrary, the results highlight the stochastic nature of geoelectrical time series: the dynamical properties of the experimental time series are not influenced by the local geological and seismological conditions. We demonstrate that a better knowledge of the time dynamics of this kind of geophysical signals contributes to objective procedures to identify extreme events.

6. Conclusions

The geoelectrical time series measured in two different geological and seismological environments are a realisation of a stochastic process, but they are not purely random fluctuations. There is an internal correlation that is a typical fingerprint of the markovian process, the geoelectrical time series after the filtering of the seasonal effects are well described by first-order autoregressive models. Our findings on the time dynamics of geoelectrical time series contribute to better define the objective criteria to discriminate anomalous patterns from background noise in electrical signals measured in seismic active areas. We associate to each possible extreme event an occurrence probability considering significant only the events characterised by a very low occurrence probability ($P < 10\%$). The routine application of this robust statistical methodology in the analysis of geoelectrical signals can contribute to removing many ambiguities in the procedure to identify possible precursory signals. Before studying any possible correlation between anomalous patterns in electrical signals and incoming earthquakes, a better analysis of the time dynamics of experimental (*i.e.*, filtering of the seasonal effects related to meteo-climatic parameters, analysis of deterministic and/or stochastic behaviours, identification of extreme events etc.) signals must be pursued. In conclusion, the only way to remove the ambiguities regarding the geoelectrical precursors is to have large monitoring arrays, observations spanning very long time periods and results extracted by means of advanced statistical methods.

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