Monitoring of the geomagnetic and geoelectric field in two regions of Greece for the detection of earthquake precursors

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Abstract
Two magnetotelluric stations have been installed in the South-Eastern Thessaly basin (Central Greece), which have recorded the geomagnetic and geoelectric fields since 1993. The aim is to detect long lasting abnormal changes of the geoelectric field which may be due to impending earthquakes. The geoelectric recordings were checked against the climatic changes such as temperature changes and precipitation and no correlation was observed. Ten anomalies were observed with characteristics similar to seismoelectric signals which have been reported in the literature and thus we can assume that these changes constitute precursory phenomena. The duration of these signals varies from several days to a few weeks. Some of them keep on developing until the occurrence of an earthquake, and others appear like transient changes several days before. The high seismicity of the area where the stations are located creates difficulties in the correlation of the signals with certain shocks.

Key words *telluric – earthquake precursors*

1. Introduction

In recent decades, long period changes of the geoelectric field have been observed and attributed to forthcoming earthquakes (Fedotov *et al.*, 1969; Sobolev, 1975; Yamazaki, 1977; Raleigh *et al.*, 1977; Di Bello *et al.*, 1994). Changes accepted as signals having short periods have been reported as well (Varotsos *et al.*, 1982, 1983, 1993a,b; Varotsos and Alexopoulos, 1984a,b; Ralchovsky and Komarov, 1988, 1989, 1993; Tate and Daily, 1989).

The form of these signals varies widely (Yamazaki, 1977). Some of them appear as gentle changes followed by steep decay (Raleigh *et al.*, 1977). However, signals showing rapid built up and rather slow recovery have also been reported (Ralchovsky and Komarov, 1988). Sometimes the signal consists in consecutive minima and maxima (Yamazaki, 1977). The wide variety of signal forms may be related to different mechanisms which produce seismotelluric signals as they have been described by several authors (Meyer and Teisseyre, 1989; Dobrovolsky *et al.*, 1989; Scholz, 1990).

During the last three years, monitoring of the triaxial magnetic field and the two perpendicular components of the electric field has

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been carried out by the Geophysical Laboratory of the Aristotle University of Thessaloniki in the south-eastern margins of Thessaly basin, in Central Greece. Another station had been installed in the same area, 11 km east of the first one, by the Geophysical Laboratory of Orleans (CNRS, France). In the present paper an attempt is made to examine the possible correlation of the geoelectric field with seismic events that occurred during the recording period.

The variation of the geoelectric field was first correlated with the climatic changes during this period. Also, magnetotelluric induction effects caused by the variation of the magnetic field were removed, using custom built software. This was done to distinguish the short period changes and study their behavior.

2. Field of study-equipment used

The southern part of Thessaly is seismically one of the most active regions in Greece and the surrounding area (Papazachos and Papazachou, 1989). According to Papazachos *et al.* (1993), a high probability exists for the occurrence of an earthquake of magnitude $M \geq 5.7$ during the current decade. For these reasons, the area of the village «Neraida», near Farsala of Southern Thessaly, and an area next to the village «Mavrolofos» were chosen as sites to install the magnetotelluric stations (fig. 1). The specific sites were selected to be relatively «clean» from undesired noise *i.e.*, care was taken to avoid human activity and in particular any industrial interference.

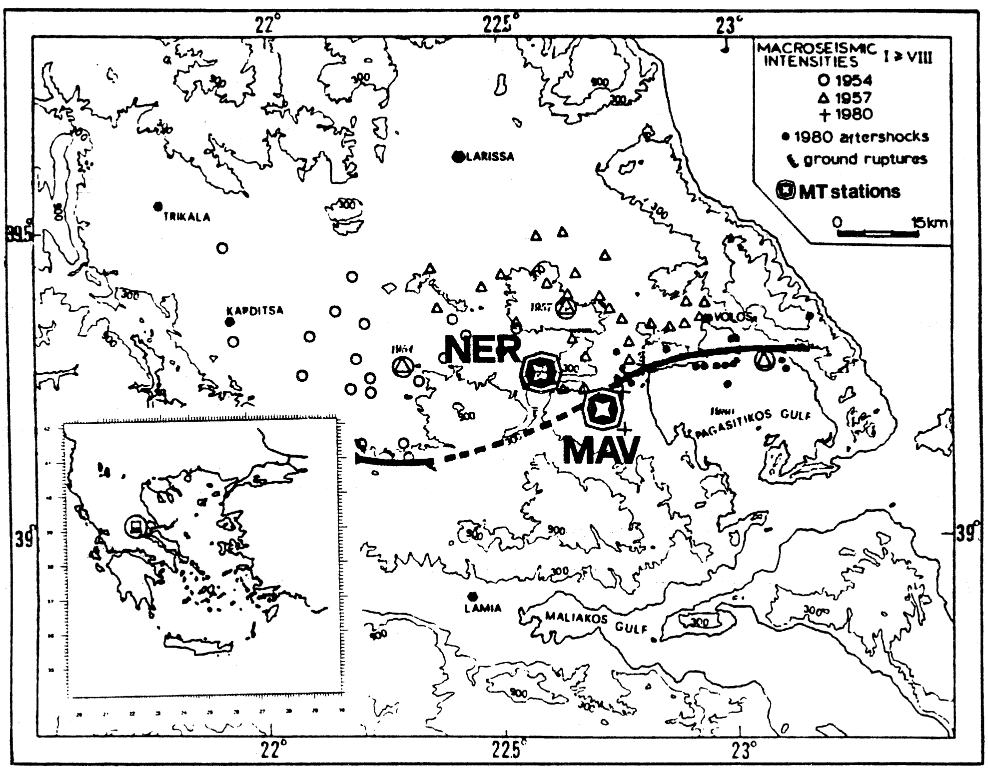

Fig. 1. Location map of the magnetotelluric stations of «Neraida» and «Mavrolofos» in the south margins of the Thessaly basin (after Papazachos *et al.*, 1993). The stations are named as NER and MAV accordingly.

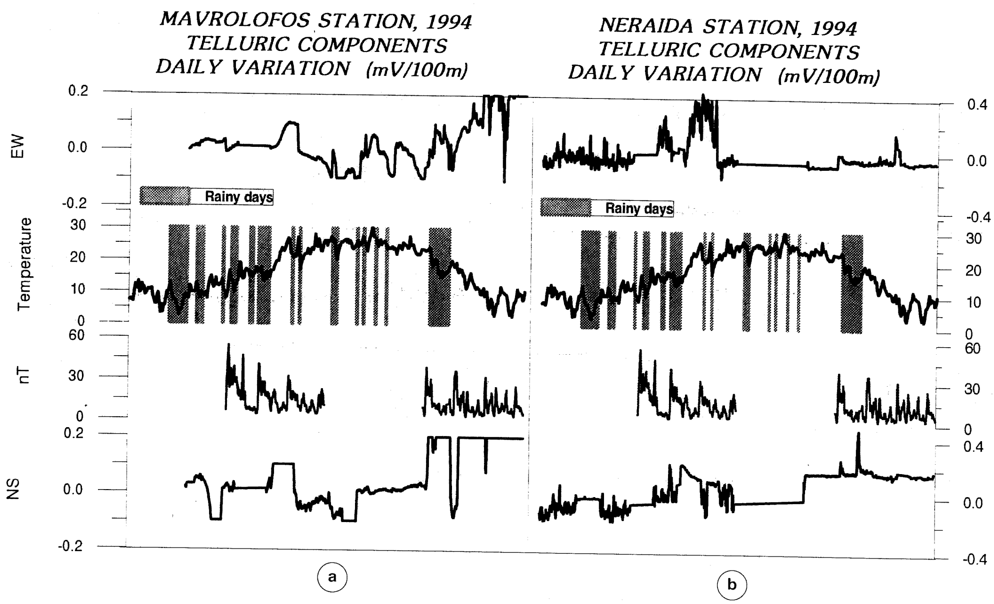

Fig. 2a,b. The variation of the telluric components recorded at Neraida (b) and Mavrolofos (a); the climatic changes and magnetic activity are plotted for the years 1993 and 1994.

The instrumentation at the station of Neraida, consists of a triaxial magnetometer (Bartington), the telluric lines and the recording units.

Two pairs of non-polarised Cu-$CuSO_4$ electrodes were used to measure the horizontal telluric components. One telluric line is set along the N-S direction and the other along the E-W. Each line is 50 m long. The two pairs of electrodes and the magnetic sensor are buried at a distance of 150 m away from the central installation in order to minimise probable influences on the measurements. The fields are sampled with a frequency of 0.03 Hz and the records are stored on the hard disk of a local PC in separate files every 3 h.

In the Mavrolofos station two pairs of solid solution electrodes Pb-$PbCl_2$ were used. The distance between the probes is 100 m. The sampling frequency is 8.333×10^{-2} Hz and the records are stored in a flash card of 10 or 20 Mb.

The data used in this paper refer to the time period of 1993 and 1994.

3. Influence of meteorological factors and of the Earth's magnetic field activity

In order to observe any relation between the annual variation of the geoelectric field with climatic changes, the temperature changes and the days when rainfalls occurred for the year 1994 were recorded as well. No significant influence of temperature changes on the potential difference between the probes was expected because of the low values of the temperature coefficients of the electrodes used (Petiau and Dupis, 1980).

The information used in this study comes from the meteorological station of Almyros that is located 5 km east of the «Mavrolofos» station and belongs to the National Meteorological Service of Greece.

Records of the magnetic activity for two periods (three months each) were also used. These data were recorded in the Magnetic Observatory of Athens during the year 1994.

Figure 2a,b presents the variation of the parameters referred to, simultaneously with the telluric recordings at the stations of Neraida and Mavrolofos.

It can be seen that these parameters vary independently from the telluric data in the long period sense.

4. Earthquakes occurring during the monitoring interval

Earthquakes of various magnitudes occurred in Greece (34°N-42°N, 19°E-27°E) during the monitoring at the stations of Neraida and Mavrolofos. Some of these earthquakes had very small magnitude or were located at a relatively large distance from Neraida. In both cases, therefore, the shocks could not have caused detectable signal. The earthquakes considered in the present study were those having the following properties:

A: events with $M_s \geq 3.5$ and $\Delta < 160$ km,
B: events with $M_s \geq 4.0$ and $\Delta < 330$ km,
C: events with $M_s \geq 4.7$ in the Greek territory and adjacent areas,

where M_s is the surface wave magnitude and Δ the distance from Neraida.

Of course the length of the zone of the preparatory process of an impending earthquake with $M_s \approx 3.5$, for example, is much less than 160 km. However, the zones were assessed arbitrarily large enough to account for possible transmitted signals and not only for anomalies caused on the preparatory volume directly. Indeed, this is an issue to be resolved in the future.

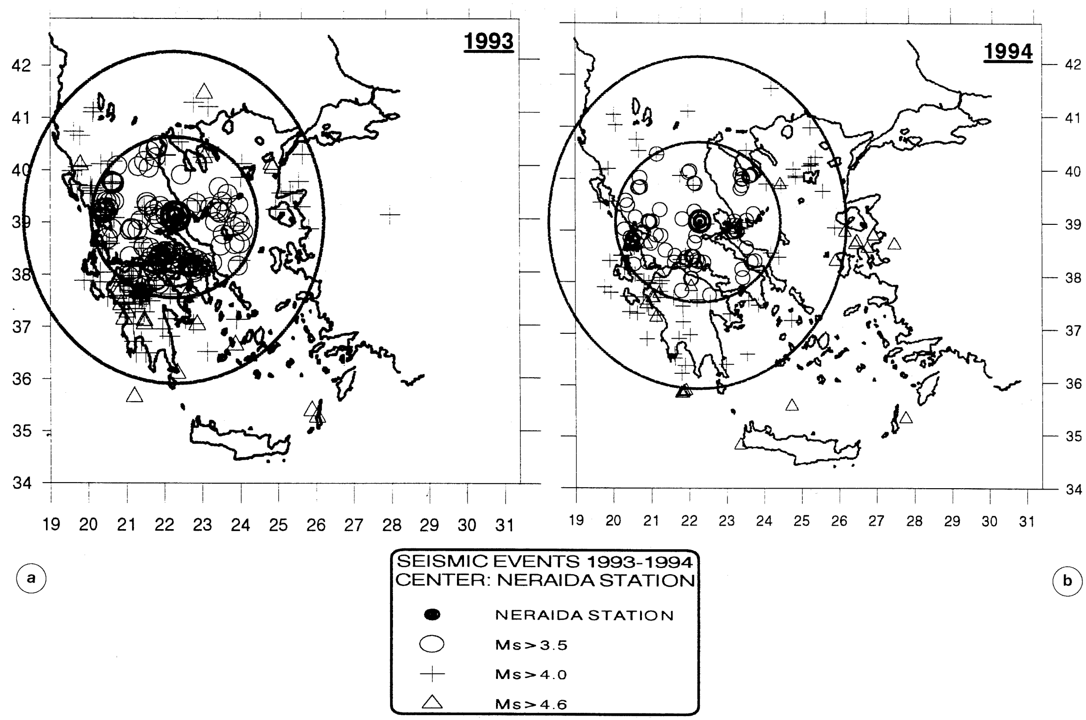

Fig. 3a,b. Location of the epicenters of the earthquakes which occurred in the recording time period. The inner circle has a radius of 160 km while the outer one 330 km. Both circles are centered on Neraida. Different symbols are used to denote the events considered. The shocks which occurred in 1993 are shown in (a) while those for 1994 are in (b).

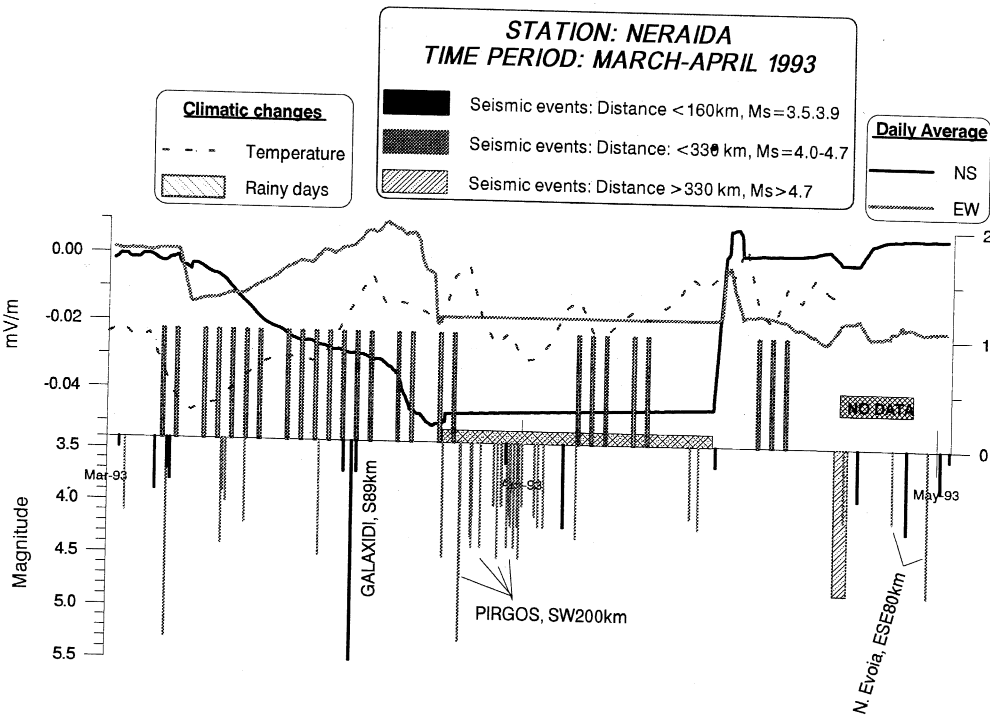

Fig. 4. Telluric field variation on N-S and E-W direction plotted against the seismicity for the period March-April 1993. The days when rain occurred are annotated with dashed bars. Also, the temperature daily mean values are shown by a dashed line.

A total number of 510 such earthquakes were observed in the period 1993-1994. This information is based on the monthly bulletins of the Geophysical Laboratory of the Aristotle University of Thessaloniki and on the preliminary listings of the Seismological Institute of the National Observatory of Athens. Figure 3a,b shows the location of the epicenters of the 510 earthquakes. Symbols of three types are used to denote three magnitude sizes (3.5-3.9, 4.0-4.6, 4.7-5.5).

5. Geoelectric changes observed

Several variations of the geoelectric field were observed during the monitoring interval. Some of those are shown in figs. 4 to 8. The same figures also present the seismicity, according to the referred criteria.

During 1993, only the station in Neraida was partially in operation and several technical problems had to be solved. The only interesting change of the geoelectric field was observed during the time period of March and April. The telluric variation of these months for both the N-S and E-W components are shown in fig. 4. The daily mean values were used and thus, only the long period variations are shown.

Short period transient changes (from 14 min to 5 h) during the same period were observed. These are shown in fig. 5 along with the seismicity of the same period.

For the year 1994 the Earth's magnetic and telluric field was simultaneously monitored at both stations of Neraida and Mavrolofos

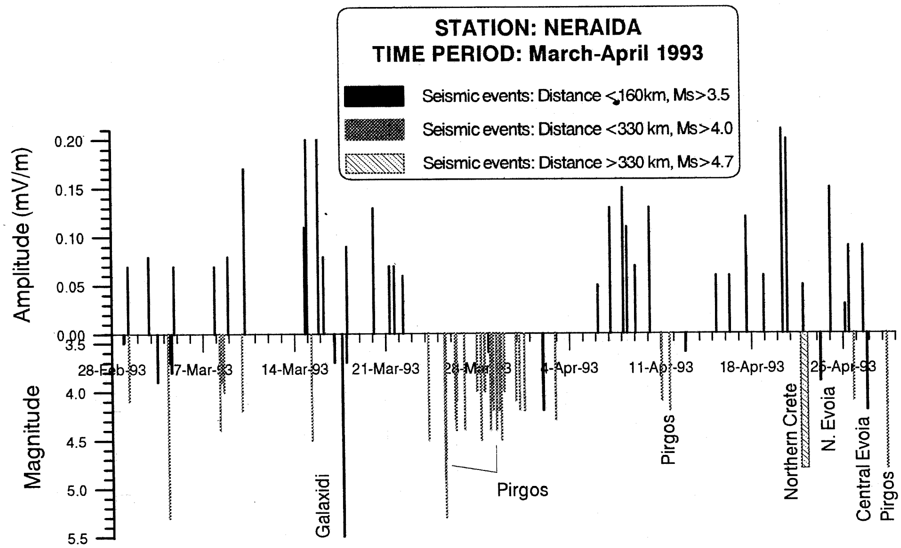

Fig. 5. Transient telluric signals observed in the Neraida station for the period March-April 1993. Only the amplitude of the transients is depicted in the figure.

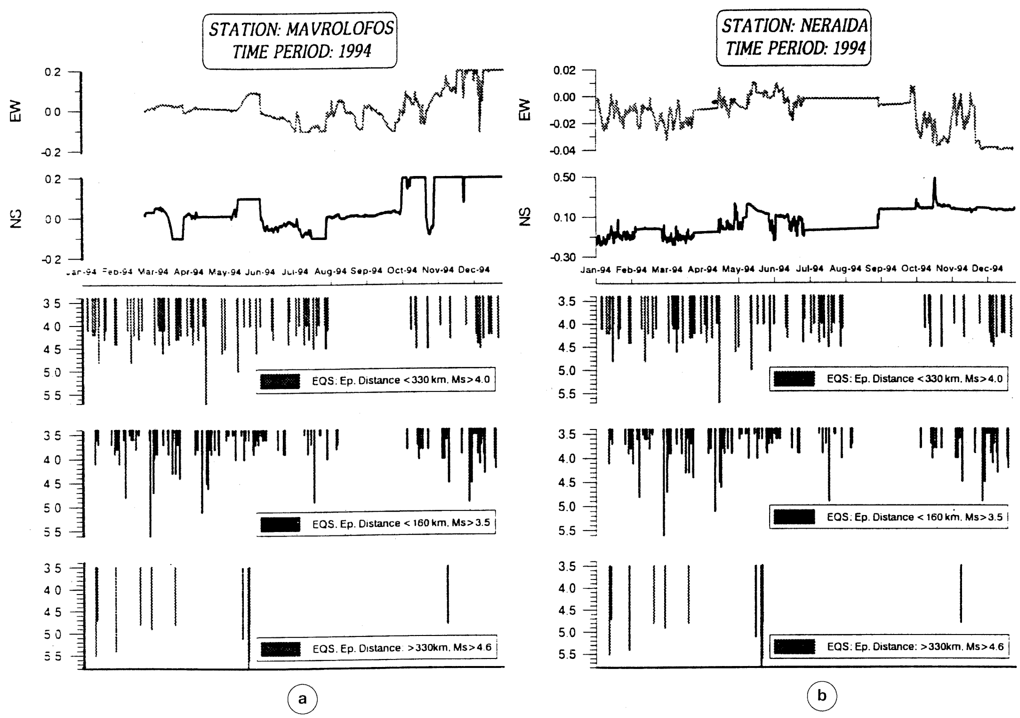

Fig. 6a,b. Variation of the telluric field (daily mean values) and seismicity for the year 1994. The records for the station of Mavrolofos are in (a) and those for Neraida in (b).

(Volos). The annual variations of the telluric field against the observed seismicity are presented in fig. 6.

Among the observed changes of the telluric field the two most interesting events occurred during May-June and October.

5.1. *May-June 1994*

Figure 7 shows the variation of the geoelectric field along with the seismicity for the interval May-June 1994. It can be seen that the E-W component rises with the same pattern in both stations (the stations are 11 km apart). More or less the same behavior can be observed in the N-S component.

The duration of the common behavior of the telluric field in both stations is approximately 26 days. The recovery takes a shorter time and occurs in a sudden manner in Volos. On the contrary in Neraida the recovery was completed after a few days and a second positive anomaly followed.

5.2. *October-November-December 1994*

Two signals were observed at the station of Neraida during October 1994. As can be seen, the pattern of these signals is markedly different from those described so far (fig. 8). A sharp increase can be observed with a gradual recovery. Ralchovsky and Komarov (1989) had presented signals of the same pattern which were attributed to forthcoming shocks.

Besides the examples presented so far, some other «abnormal» interesting changes were observed. These changes are shown in table I along with the earthquakes assumed to be associated.

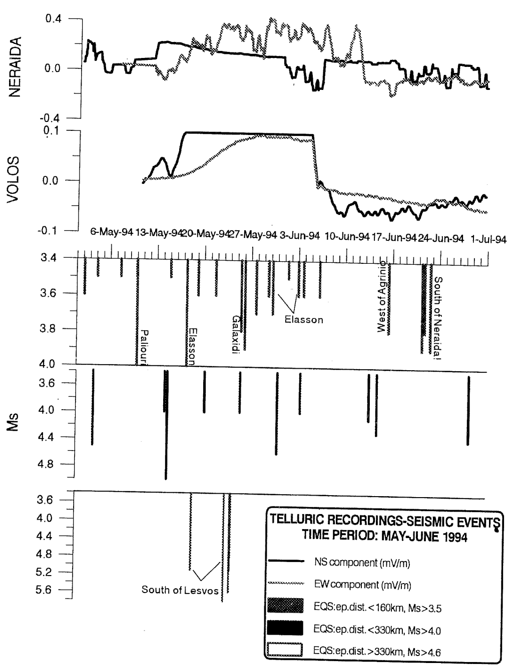

Fig. 7. Telluric variation and seismicity for the period May-June 1994.

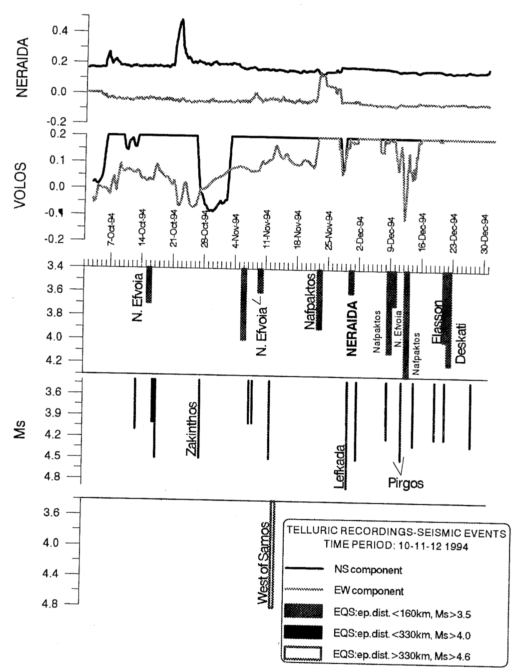

Fig. 8. Telluric variation and seismicity for the period October-November-December 1994.

Table I. Signals along with the earthquakes assumed to be associated. The epicentral distances are measured from the station of Neraida.

Epicenter	M_s	Lag time (days)	Amplitude (mV/m)	Distance (km)
Galaxidi	5.6	12.5	0.03	89
Pirgos	5.4	20.3	0.045	198
Paliouri	4.4	9.0	0.17	119
Salamina	5.0	12.0	0.17	158
Elassona	4.0	7.0	0.1	79
Galaxidi	3.9	18.0	0.1	89
Neraida	3.8	5.0	0.4	20
Amvrakikos Gulf	3.8	7.0	0.1	139
N. Efvoia	4.0	15.0	0.3	79
Lefkas	4.9	7.0	0.2	158

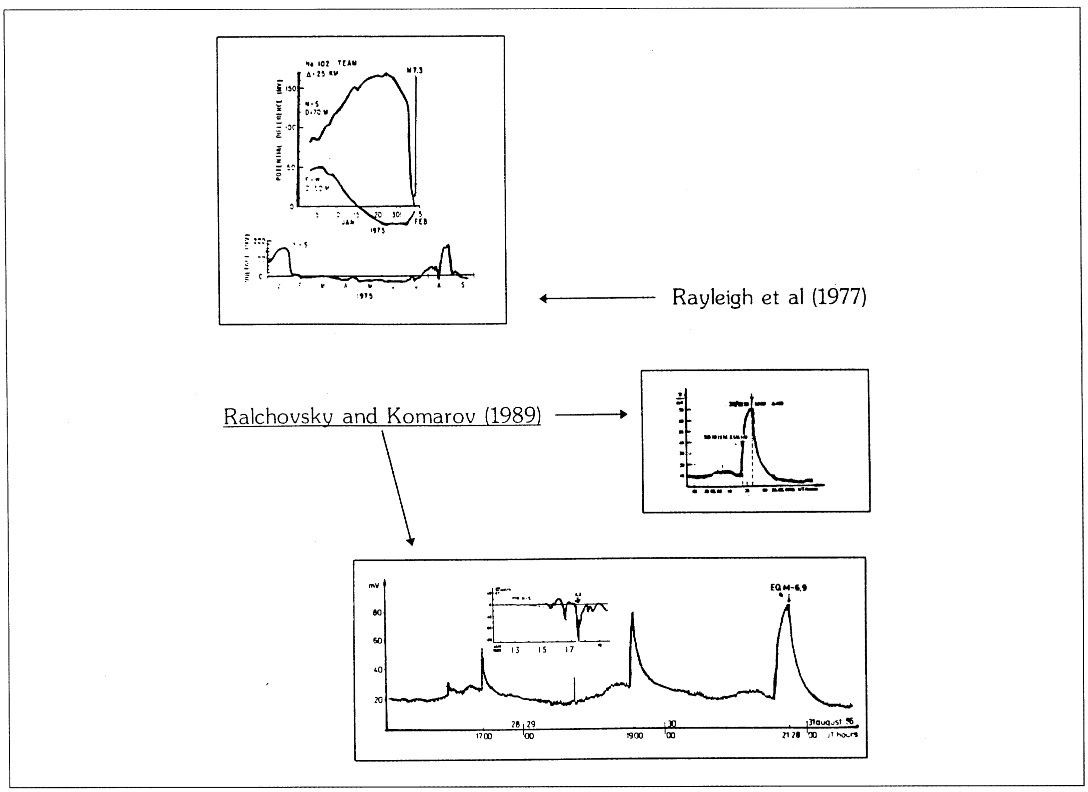

Fig. 9. Examples of signals similar to those shown in this paper which have been recorded elsewhere in the world and reported by Raleigh *et al.* (1977) and Ralchovsky and Komarov (1989).

6. Correlation of telluric field variation and impending earthquakes

The signals observed at the stations of Neraida and Mavrolofos have similar patterns to those reported so far by other researchers (Rayleigh *et al.*, 1977; Ralchovsky and Komarov, 1989). Characteristic examples are shown in fig. 9.

We can therefore assume that our signals are associated with forthcoming earthquakes.

On the basis of this assumption, the characteristics of these signals can be summarized as follows:

– they can be distinguished to variations having long (3 days to 3 weeks) or short periods (14 min to about 5 h);

– the lag time of their appearance before impending earthquakes varies from 5 to 20 days having an average of 11 days;

– two patterns of variations were observed. Those having gradual build up followed by a sharp decay simultaneously with the occurrence of an earthquake and those which show a sudden change followed by a gradual recovery. The first pattern seems to be associated with the long period changes, and the second with the short period changes;

– the assumption for a possible relation between changes of the telluric field with seismicity is more likely to concern earthquakes occurring within the first zone of 160 km. An exception is the case of the earthquakes of Pirgos (fig. 4) which can be correlated with a three week disturbance and the epicentral distances are up to 200 km.

Therefore, signals can sometimes be correlated with a number of forthcoming or preceding shocks. The major problem in relating variations assumed to be «signals» with the seismicity, is that the seismicity in Greece is very high and spread all over the country.

Appropriate statistical processing is necessary to approach the problem. Also, quantitative analysis of the background noise for each station could improve the recognition of patterns attributed to impending earthquakes.

Acknowledgements

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