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Characteristics of electromagnetic noise in the Ioannina region (Greece); a possible origin for so called "Seismic Electric Signal" (SES)

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Abstract. The study of electromagnetic noise in the Ioannina region (NW Greece) shows the existence of long transient electric signals (duration>10 s) without measurable correlated magnetic signals, as is the case for Seismic Electric Signal (SES) observed in the VAN network of short-term earthquake prediction. Our signals have an artificial origin and are emitted by different kinds of transmitters implanted in the Ioannina region. This origin can be clearly ascertained from simultaneous observation, at stations in direct sight of the transmitters, of four electromagnetic components (two electric and two magnetic) in a broad band of frequencies (10^{-3} - 10^{3} Hz). Relying on these observations, it is proposed that the April 18 and 19, 1995 electric signals, interpreted by the VAN group as SES precursors to the May 13 Kozani earthquake, are due to some transmitter located far to the North of the IOA station of the VAN network. The transmitters of this area would be of digital type, as is increasingly common in radio-telecommunication networks. We believe that careful studies of electromagnetic noise in a broad range of frequencies should precede lengthy discussions of the statistical significance of recorded signals.

Introduction

In a previous paper, based on simultaneous observation at their JAN E station and at the IOA station of the VAN network (Figure 1), Gruszow et al. (1996) proposed that the anomalous electric signals recorded on April 18 and 19, 1995, claimed by the VAN group to be related to the Kozani earthquake in Northern Greece (Varotsos et al., 1996a), were due to artificial (industrial) sources. However Gruszow et al. acknowledged that they were not able to give a definitive proof of this industrial origin. Varotsos et al. (1996b) vigorously objected to this proposal of man-made origin, using, among others, the counterargument : "if these SES were due to nearby industrial source (but not too close, almost in limits of the dipole length), they should have been accompanied mainly by horizontal magnetic field variations". In their first paper on SES, Varotsos and Alexopoulos (1984) had already emphasized that " no significant variation of the magnetic field is produced by the signal" (SES). This absence of magnetic signal has been considered as a firm criterion to select genuine SES. In their discussion of the VAN method Park et al. (1996a) concluded that "the ability to distinguish SES from other electric field variations using objective criteria appears to be established" and that (Park et al., 1996b) "the mechanism generating the SES does not result in observable magnetic fields, regardless of location". In this paper, we will show examples of anomalous electric signals due to artificial nearby sources which are not accompanied by observable variations of the horizontal magnetic field in the long periods range (>10 s), and then propose a plausible origin for the so-called SES observed on April 18 and 19, 1995 simultaneously at the IOA and JAN E stations.

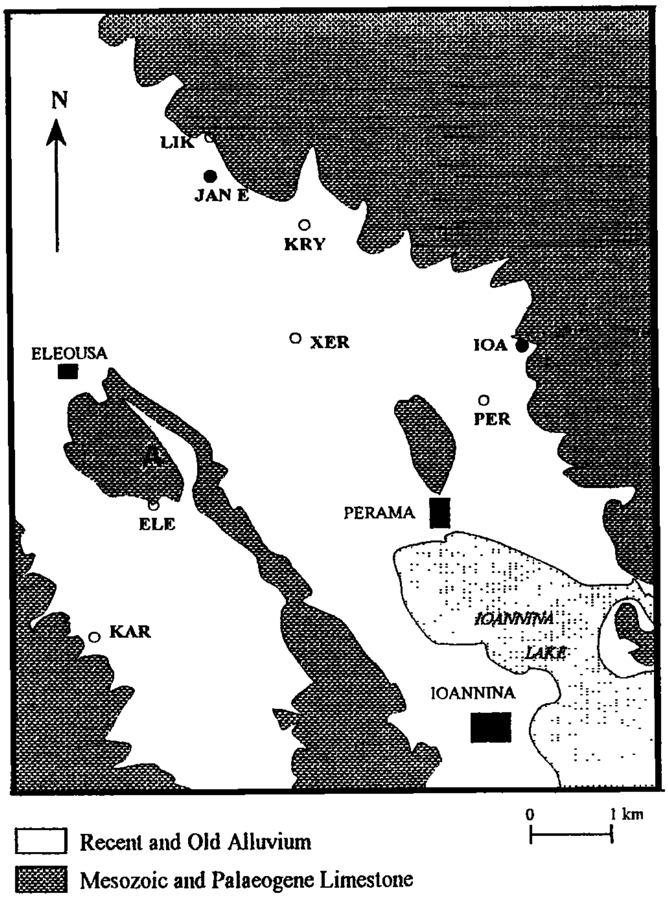

Figure 1. Location of the six occupied sites (white circle) in the Ioannina region on a simplified geological background adapted from the 1/50000 geological map of Greece. Black circles are for monitoring stations of the VAN network (IOA) and the IPGP station (JAN E). "A" symbol represents the location of transmitter antenna near Eleousa village.

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Experimental field work

In order to get information on the characteristics of the electromagnetic noise in the Ioannina region, the Institut de Physique du Globe de Paris (IPGP), the National Observatory of Athens (NOA) and the Institute of Geodynamics conducted a short campaign of measurements in this area in June 1997.

The data acquisition system was a high sensitivity magnetotelluric (MT) instrument designed for MT survey and covering a broad band of frequencies (10^{-3} - 10^{3} Hz) (Pham et al., 1986; Chouliaras et al., 1997). The electric (or telluric) sensors were low noise and stable unpolarizable electrodes of the lead-lead chloride type. The magnetic sensor was a high sensitivity search-coil magnetometer with a flux-feedback, giving directly the magnetic field with a flat amplitude response in a large range of frequencies. The analog subsystem had five differential input channels, each equipped with an active fourth order notch filter which eliminates the 50 Hz powerline signal and its harmonics. A set of active high-pass and low-pass filters, with selective cut-off frequency every decade, allowed one to choose different ranges of frequencies upon request. The digital acquisition was controlled by a portable micro-computer which directly displayed the signals on a screen to control and store the data.

Six sites were occupied in the Ioannina region in June 1997 (Figure 1). At each site four components of the electromagnetic signal were recorded, two electric and two horizontal magnetic components, along two perpendicular directions: N 130° which corresponds to the general structural direction of the Ioannina basin (Figure 1), and N 40°. The two electric dipoles are 100 m long. For convenience, the dipoles along N 130° and N 40° directions are called hereafter respectively NS and EW, and the horizontal magnetic components along these two same directions respectively H and D. Consequently, the two pairs of components of the electromagnetic field are EW-H and NS-D. The electromagnetic field was recorded in five overlapping ranges of two decades of frequencies: G1(10-10^{3}Hz); G2(1-10^{2}Hz); G3(10^{-1}-10Hz); G5(10^{-2}-1Hz); G7(10^{-3}-10^{-1}Hz).

Experimental results

The first studied site is the station PER located near the station IOA of the VAN network installed inside the military base of Perama (see Figure 1). The base occupies a very large area far from the Perama village and far from the Ioannina industrial zone. Figure 2 shows an example of simultaneous recordings of the four electromagnetic components corresponding to the three long period ranges: G3, G5 and G7. In the two first ranges G1 and G2 (not shown here), despite the high dynamics of the notch filter, the 50 Hz signal and its harmonics, and some other cultural noises, subsist continuously. This site is very noisy, but the high frequency cultural noise is easy to identify. In the third range G3 (Figure 2a) where the high frequencies (>10 Hz) cultural noises are filtered out, natural MT signals are clearly observed on the four electromagnetic components in the two first 128 samples blocks (N^{os} 1 and 2). But, suddenly, from the onset of block N° 3, a set of short (a few seconds time constant) highly directional spikes appear intermittently as a train of spikes, bigger on the NS-D pair than on the EW-H pair. In the G5 range (Figure 2b), a short pulses pattern is observed as in G3 on the two electric components EW and NS, but not on the two magnetic components H and D. Some bigger and wider pulses (a few tens of seconds duration) appear on the electric components (see block N° 9), which correlate with small amplitude (~0.1 nT) pulses on the magnetic components. Finally, in the G7 range (Figure 2c), where short pulses are undistinguishable from the background of the natural electric signal, some isolated strong and long (about one minute

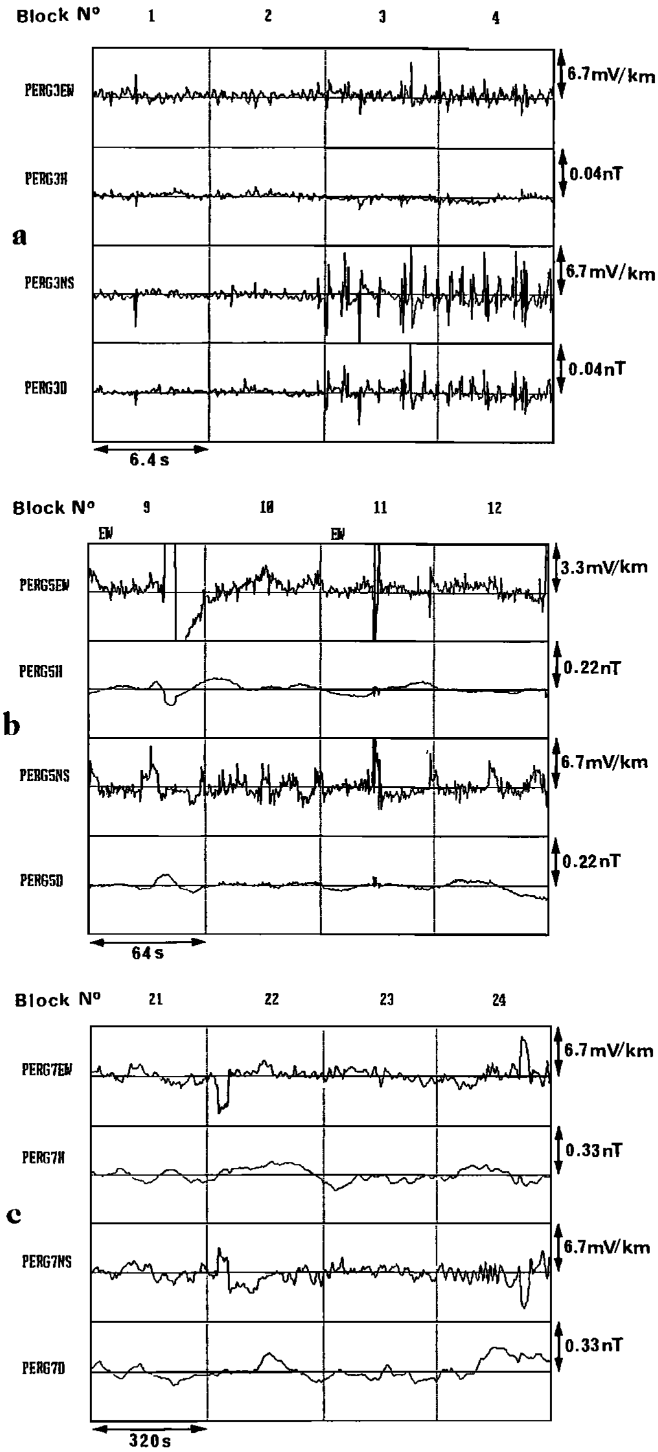

Figure 2. Examples of recordings of four electromagnetic components in three ranges of frequencies at the PER station : (a) range G3; (b) range G5; (c) range G7. The filename of the recording includes the station symbol, the frequency range and the component as indicated in the text (e.g. : PERG3EW). Each recording comprising 512 samples is divided into four blocks of 128 samples. Each block is identified by a number (top of the figure).

duration) electric pulses appear without any observable corresponding magnetic signal. It is interesting to note that the electric pulse in block N°22 is quite similar to some published SES, as the one recorded at IOA on May 14, 1985 (Figure 16 of Varotsos et al., 1993). Moreover, this kind of pulse is observed only in the G7 range whose filter has the same cut-off frequency (0.1 Hz) as the low pass-filter of the acquisition device of the VAN network (Nomicos and Chatzidiakos, 1993).

Longer period pulses (>1 s) have been often observed in MT surveys without the source being identified. Here they are clearly related to the transmitters of the military base surrounding the station (≈ 100 m). In fact, these transmitters are responsible for all the spikes and pulses described above, in all the frequency ranges. For relatively high frequencies (>0.1 Hz), the artificial transient magnetic signals correlated with the transient electric signals can easily be observed. But, in the very low-frequency range (<0.1 Hz), the amplitude of the natural magnetic field (>1 nT) is larger by more than one order of magnitude than the amplitude of the artificial noise (see Figures 2b and 2c). Because of the high signal/noise ratio of the natural magnetic field, the transient magnetic noise is not observable on the corresponding recording. Let us recall that several similar long transient electric events (about 15 during the 1993-1994 time space) have been observed by Gruszow et al. (1995) at JAN E station without any observable correlated transient horizontal magnetic field, again because of the large amplitude (several nT) of the natural magnetic field variations.

In order to double check that the sources of the observed transient electromagnetic noise are indeed the radio transmitters, we have performed similar recordings at the station ELE located South of the Eleousa village (Figure 1), where the antenna of two transmitters is in direct sight, 500m Northwards. The recordings in the different frequency ranges show signals with the same characteristics as discussed above for the PER station. Figure 3 shows typical anomalous electric signal in the G7 range generated by the transmitters. The amplitude of the signal in block N°2 is three times larger than any signal recorded at PER (in the same range). These transmitters are presumably more powerful than the transmitters in the military base.

Besides PER and ELE stations, four others sites were occupied in June 1997 : LIK, KRY, XER and KAR (Figure 1). Except for KAR located far away westwards, all the stations are located in the Ioannina basin and present the same noise

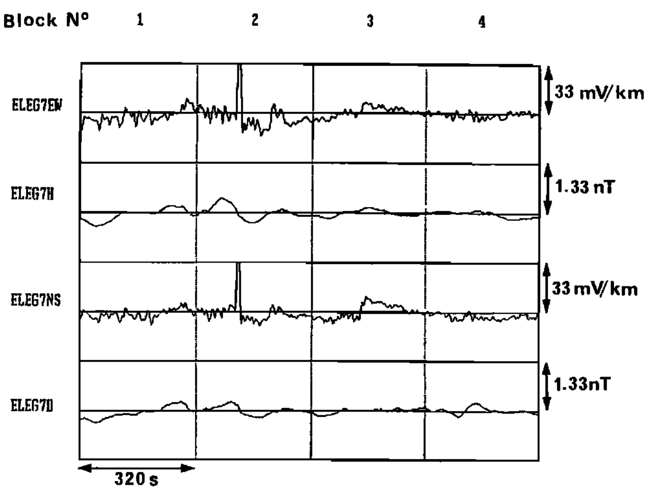

Figure 3. Typical anomalous electric signal in the range G7 at the ELE station.

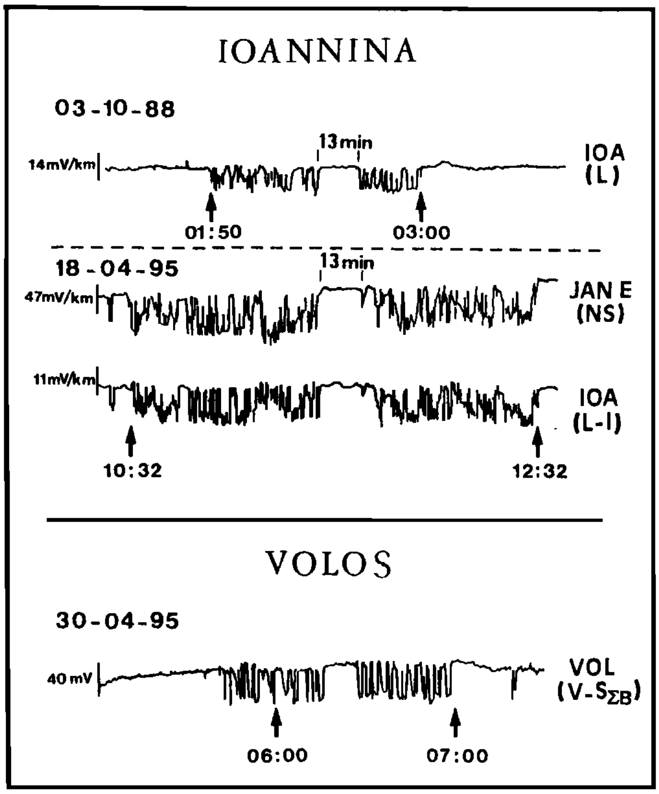

Figure 4. Comparison of four records, three from Ioannina region, one from Volos region. Ioannina data are from Figure 3 of Gruszow et al., (1996), and Volos data from Figure 10 of Varotsos et al., (1996b).

characteristics as PER and ELE. There is some evidence that the electric transient signals recorded at these stations are also emitted by transmitters located along the Ioannina valley and the surrounding hills where the most important agglomerations are concentrated.

A possible origin of April 18 and 19, 1995 SES activity at IOA station

According to the VAN group (Varotsos et al., 1993b), there are three types of SES : single SES, SES activity (SESA), Gradual Variation of Electric Field (GVEF). The April 18 and 19, 1995, electric signals recorded at IOA and JAN E are considered as typical SESA (Uyeda, 1996). Figure 4 presents, with the same time-scale, SESA recorded on October 3, 1988 at IOA (Varotsos et al., 1993a), on April 18, 1995 at JAN E and IOA (Gruszow et al. 1996; Varotsos et al. 1996a), and on April 30,1995 at VOL (Varotsos et al., 1996b). As already pointed out by Gruszow et al. (1996), there are strong similarities between the 03/10/88 and the 18/04/95 signals, both recorded at IOA (see Figure 4). The similarity is still more striking between the 30/04/95 signal recorded at VOL and the 03/10/88 signal at IOA. There is no significant probability that signals emitted by seismic sources in different regions of Greece, recorded at different epochs and at different stations, have the same picture. Only artificial sources can reproduce a pattern in such a way. The form of the train of one-sided square pulses strongly suggests again, as the responsible source, the radio-telecommunication network of digital transmissions. One observes a big difference in the amplitudes of the NS component of the 18/04/95 event at IOA and JAN E, 5 km apart: about 15 mV/km at IOA (L-I) (Varotsos et al., 1996b) and about 65 mV/km at JAN E (NS) (Gruszow et al., 1996) (see Figure 4); the ratio ΔV/L is four times larger at JAN E (short dipole) than at IOA (long dipole). According to the VAN criterion itself (Varotsos et al., 1991), the 18/04/95 signal should be considered as noise of artificial origin. It is rather strange that the VAN group claimed that "Gruszow et al.'s (1996) measurements offer a further confirmation that the signals (18/04/95) reported by VAN are actually SES" (Varotsos et al., 1996b). The 19/04/95 signal presents the same characteristics, and the corresponding ratio ΔV/L is also four times larger at JAN E than at IOA (see Figure 2 of Gruszow et al., 1996). Therefore, the source of these signals is quite probably closer to JAN E station. Moreover, as they are polarized approximately NS (Gruszow et al., 1996), at both stations for short dipoles as well as for long dipoles (Varotsos et al., 1996b), we expect the source to be a transmitter localized North of JAN E station.

Discussion and conclusion

Our study of the electromagnetic noise in Ioannina region has shown that:

* for high-frequency ranges (>1 Hz) the noise is principally of cultural origin and is easily identified.

*for low-frequency (<1 Hz), the noise consists in transient signals (spikes and pulses) of different durations, from a few seconds to a few minutes; for the longest time constants (> 10 s) no associated magnetic variation is observed because of the high signal/noise ratio.

The latter noise is now clearly identified as emitted by the transmitters of the Perama military base at the PER station and by others, near Eleousa village, at the ELE station. Shorter duration (a few seconds) pulses are observed more frequently (Figure 2a) than longer duration (>10 s) pulses (Figure 2b and 2c).

There are two types of radio-telecommunication networks: analog and digital. Digital transmission started replacing analog transmission from 1970 for the "Radio-Relay-Link" (RRL) network, and from 1988 for the mobile telephone network. The new digital mobile telephone network, well known as the GSM (Global System for Mobile communications), is now widely developed in most countries, especially in Greece because of the difficulty to install phone lines in this country. It is interesting to note that the summary of all predictions issued from January 1st, 1987 to June 15th, 1995 by the VAN group (Varotsos et al. 1996a, Table 1), has shown a clear increase of the relative number of SES activities (SESA) since 1988.

The VAN method remains highly controversial as shown in a recent GRL special issue "Debate on VAN" (1996) and in the book "A critical review of VAN" Ed. J. Lighthill (1996). Most debates were focused on the statistical evaluation of VAN prediction and the physical mechanisms for generation and propagation of SES. We think that the discrimination of SES from artificial noises is the first priority in any thorough examination. The criteria adopted by the VAN group are not sufficient to distinguish SES either from the noise due to remote sources or from natural MT disturbances. It is therefore not sure that "the electric signals,recorded only at a restricted number of stations" are SES, as asserted by Varotsos et al. (1984,1996a). The natural MT electric field may also be quite different from one station to the other, depending on the local geological structure. GVEF, recorded principally during the first period of monitoring of the VAN network, cannot be guaranteed to be SES.

We advocate, for the future, that it is necessary to study thoroughly the characteristics of the electromagnetic noise in a large neighbourhood of any planned monitoring station, not only in low-frequency ranges, but in a very broad frequency band, as in the experiment reported here, in order to try to identify the origin of all noises. Special attention will have to be paid to the characteristics of the surrounding transmitters and possibly to powerful remote transmitters. Such studies should precede discussions about the statistical significance of the issued predictions.

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