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Identification and analysis of electromagnetic signals in Greece: the case of the Kozani earthquake VAN prediction

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Abstract. An electric station was installed in July 1993, 4.5 km away from the VAN station of Ioannina, and recorded in the following two years a number of anomalous signals, including those of April 18 and 19, 1995, interpreted by the VAN group as Seismic Electric Signals precursors to the May 13 Kozani earthquake (West-Macedonia). A magnetic station was also installed and clearly recorded the magnetic components of the same events. The amplitude, shape, characteristic pattern and duration, magnetic characteristics and polarisation of the anomalous signals suggest that they are generated by artificial (industrial) sources.

Introduction

A number of authors have studied electric and magnetic signals that might be associated with seismic or volcanic activity (e.g. Nagata, 1944; Sobolev, 1975; Rikitake, 1987; Zlotnicki and Le Mouël, 1990; Park et al., 1993). One of the longest experiments is undoubtedly the one carried out by Greek physicists who have proposed, and currently employ, a method of seismic prediction known as the VAN method (Varotsos and Alexopoulos, 1984 ; Varotsos and Lazaridou, 1991, Varotsos et al., 1993). Signals similar to those reported in Greece have not been unambiguously observed elsewhere (e.g. Maron et al., 1993) and the VAN method remains highly controversial (e.g. Mulargia and Gasperini, 1992; Drakopoulos et al., 1993; Geller, 1996; GRL special issue, 1996). We have installed a field station (JAN E) to monitor telluric electric field variations near Ioannina in Greece (figure 1a) close to a VAN station (IOA) which has been operating continuously for several years and has recorded the largest number of Seismic Electric Signals (SES). According to the VAN interpretation, these signals are related to earthquakes occuring in Western Greece. In this paper, we discuss the April 1995 signals detected at IOA and JAN E stations and two other ones recorded at IOA by the VAN group in 1988. In doing so, we also address the question of the discrimination of natural perturbations from local and regional sources of noise.

Experimental setting and previous work

The telluric station, JAN E, has been installed in the NW-SE Ioannina basin, near the village of Likotrikion, in a location as far as possible from anthropogenic activity, 4.5 km from the VAN station IOA and in a similar geological context (figure 1b).

The electrode configuration we adopted with two orthogonal electric lines C1 and C2 allows us to eliminate very local noise by comparing the polarisation characteristics of signals simultaneoulsly recorded by C1 and C2. In order to discriminate the so-called magnetotelluric (MT) variations, we have installed a high sensivity (0.25 nT) 3-component, observatory-type, fluxgate variometer at the Ioannina airport (JAN M, figure 1b). The different constituents of the electric signal recorded at JAN E between August 93 and May 94 have been described in a previous paper (Gruszow et al., 1995).

New Observations

On April 27 and April 30, 1995, a seismic prediction had been sent by fax to different scientific institutes in Europe and Japan (Varotsos et al., 1996). This prediction was based on anomalous electric signals recorded on April 18, 1995 and April 19, 1995 at the VAN station IOA, with characteristics very similar to those of the electric signals detected at the same station on September 29, 1988, and October 3, 1988, and previously related to the Vartholomio earthquake (figure 1a; October 16, 1988; 37.9°N, 21.0°E, Ms=6.0; Varotsos and Lazaridou, 1991; Varotsos et al., 1993, Varotsos et al., 1996). Subsequent to the analysis of the 1995 signals, two possible epicentral areas were proposed by the VAN group, one near Vartholomio (West-Peloponesus) and the other at a few tens of kilometers NW of Ioannina (Varotsos et al., 1996). Following the Kozani earthquake in Northern Greece (figure 1a; May 13, 1995; 08:47 am GMT; 40.16°N, 21.67°E; Ms=6.6), the VAN group declared that their prediction was to be related to this event (Varotsos et al., 1996). Accordingly, they proposed that this station is also sensitive to events taking place east of the Ioannina basin.

Abnormal electrical activity was also recorded at the same dates (April 18 and 19, 1995) at the JAN E station. This activity was accompanied by magnetic variations recorded at the JAN M station.

Let us now analyse and compare the electric signals recorded simultaneously at stations JAN E and IOA on April 18 and 19, 1995. They are shown in figure 2a and 2b. At JAN E for C1 and C2, and at IOA for the different sets of short dipoles (NaSa,EaWa), (NbSb,EbWb) and (NcSc,EcWc) (see Varotsos et al., 1996), we have computed the polarisation and amplitude of the April 18, 1995, signal. We have chosen the well defined square pulses (n°1 and n°2 in figure 2a) composing this signal.

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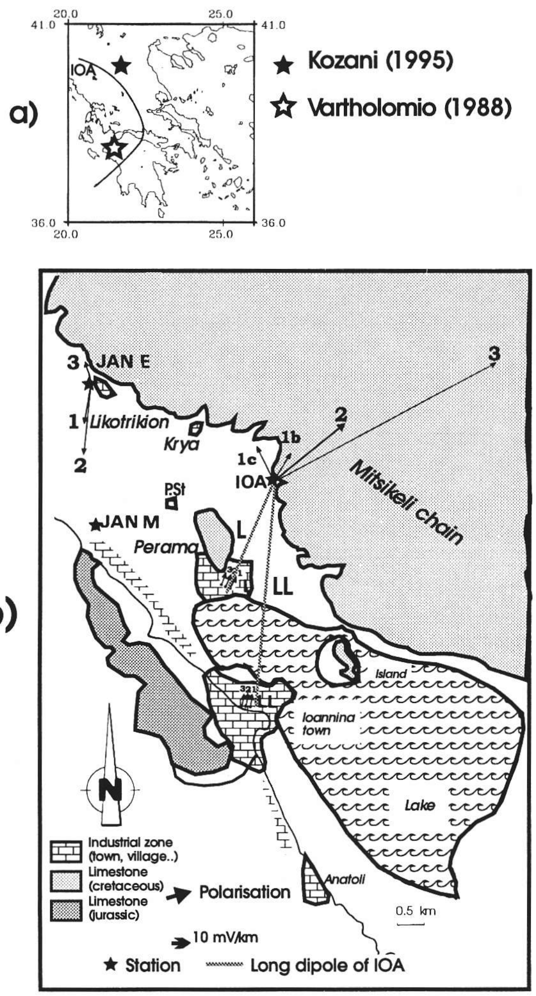

Figure 1. (a) Map showing the location of the Ioannina stations, the Kozani and Vartholomio earthquakes. The black curve is the boundary of the zone of sensitivity associated with the VAN Ioannina station as defined by Varotsos et al. (1993). (b) Simplified map of Ioannina basin, location of stations JAN E (electric), JAN M (magnetic), IOA (short and long dipoles). The arrows are the polarisations of one MT and two anomalous telluric signals recorded on April 18, 1995 at JAN E and IOA (see also figure 2a). Also shown are the locations of the main industrial areas and outcrops of limestones surrounding the basin. At JAN E, the polarisations are displayed for C1-short dipoles; Arrow (1): square pulse recorded at 10:26 a.m (GMT)..At IOA, arrow 1b is for (NbSb,EbWb) dipoles while arrow 1c is for (NcSc,EcWc) dipoles. Arrow (2) : square pulse recorded at 11:45 a.m (GMT). at IOA, arrow 2 is for (NbSb,EbWb) dipoles. Arrow (3) : magnetotelluric variation (MT) recorded between 01:35 and 01:38 p.m (GMT).

The results are shown in figure 1b (arrows 1 and 2). On the same figure we have plotted the polarisation of electromagnetic variations and their amplitude for a MT event of April 18, 1995 (arrow 3 in figure 1b). These MT signals are always strongly linearly polarised, both at IOA, on the different sets of dipoles, and at JAN E. Signals 1 and 2 of April 18 have different amplitudes on the two close NS parallel dipoles of JAN E while the MT signal has not. The polarisation and amplitude of signals 1 and 2 change rapidly from one set of dipoles to the other at IOA (central station), although these sets of dipoles are only few hundreds of meters apart. The distribution of the MT event (arrow 3) is also complicated, with in particular a huge amplification at IOA (central station) in the direction N62°E ($\pm 2°$). The distribution of the "abnormal" signals is quite different from that of the MT one which corresponds to a remote source (figure 1b).

Magnetic field variations at JAN M on April 18 and 19 accompany the abnormal electric signals discussed above; the magnetic signal is stronger on Z (the vertical component) (figure 3), with an amplitude of 1 nT, but also visible on the Y component. These magnetic variations can also be seen on the IOA horizontal magnetic recordings, with a stronger NS component, but they have been considered to be insignificant (see legend of figure 5 in Varotsos et al., 1996). This observation that magnetic variations are associated and highly correlated with the anomalous electric signals (JAN M being 3

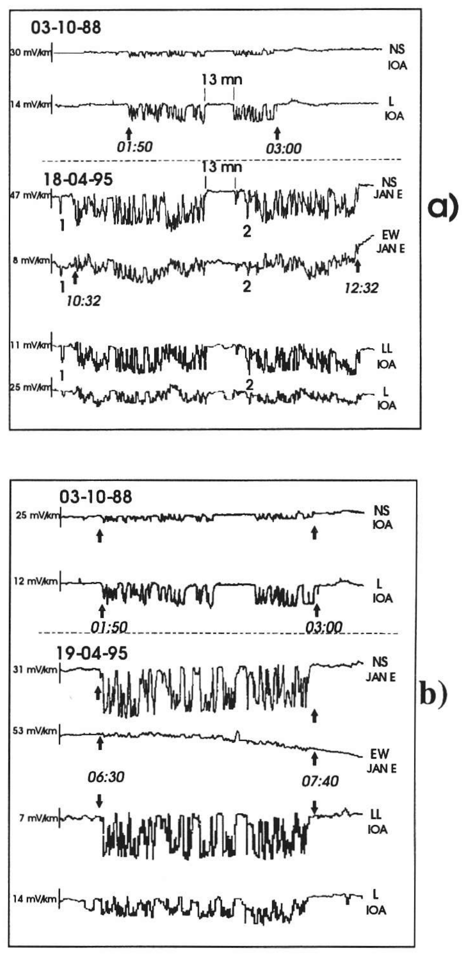

Figure 2 (a). Top: anomalous telluric signal recorded at IOA on long dipole L and one short NS dipole on October 3, 1988. This electric activity was claimed to be a precursor signal of the Vartholomio earthquake (after Varotsos et al. 1993); bottom: anomalous telluric signal recorded at JAN E (on C1) and IOA (long dipoles L and LL) on April 18, 1995. Polarisations of square pulses n°1 and n°2 are given in figure 1b. For the 1995 signals at IOA, data are from Varotsos et al., 1996. (b). Top : same as 2(a) top; bottom: anomalous telluric signal recorded at JAN E (on C1) and IOA (long dipoles L and LL) on April 19, 1995.

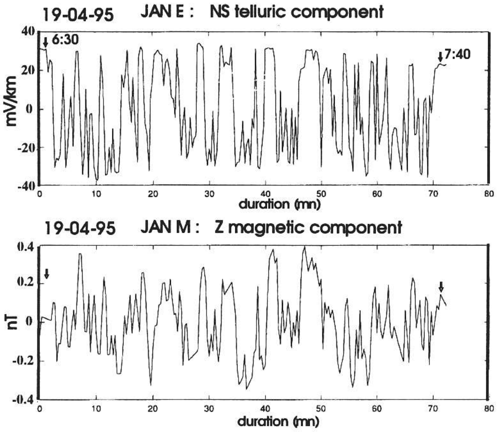

Figure 3. Telluric signal recorded at JAN E and magnetic signal recorded at JAN M on April 19, 1995 between 6:30 a.m and 7:40 a.m (GMT).

km away from JAN E and 3.5 km away from IOA) is of some consequence. The VAN group has apparently never mentioned magnetic variations correlated with SES.

The four signals (18/04 and 19/04 1995; 29/09 and 03/10 1988) have the form of a train of square pulses. They are all one-sided. Some patterns are reproduced several times along the recordings. There are also strong similarities between the beginning and the end of these signals (after reversing time). We find that:

1) On October 3, 1988 as well as on April 18, 1995 (figure 2a), the signals are interrupted by a similar short break of 13 mn duration.

2) In the four cases (signals of September 29 and October 3, 1988, April 18 and 19, 1995) durations are close to multiples of 10 mn.

3) On October 3, 1988 and April 19, 1995 (figure 2b), the electric activities have exactly the same duration: 70 mn. Another signal with a duration of 70 mn has also been mentionned as SES at IOA station on April 18, 1992 (Varotsos et al, 1993).

4) the durations of the elementary square pulses cluster around 1 and 3 mn.

Discussion

All interpretations of SES calling for an electric source located in the epicentral area (e.g.Varotsos et al, 1993, Lazarus, 1993; Slifkin, 1993) encounter a severe difficulty in providing a correct order of magnitude for electric signals measured hundreds of kilometers away. Puzzling high dielectric paths between the epicenter and the detectors have been invoked or strata with very different electrical conductivity, in order to explain the observations (Lazarus, 1990, 1993). But this is not sufficient ; in addition, strong local amplification effects of the electric signal near the electrodes need to be assumed (Bernard, 1992; Varotsos et al, 1993; Bernard and Le Mouël, 1996). In the case of the April 18 and 19 telluric signals, assuming that they are tectonoelectric in origin and generated in the far field, one has to account for their detectability over an area with decakilometric linear dimensions and also for a companion magnetic signal recorded at two stations, JAN M and IOA, located 3 km away, with an amplitude of the order of 1 nT at JAN M, which requires sufficient flow of electrical currents. This invalidates the explanation of the signal amplitude by a local amplification factor at IOA site near the electrodes as proposed by Varotsos et al., 1993. Energy considerations make the hypothesis even less plausible.

An other observation contributes to preclude the hypothesis of a far away source (we mean at a distance of about 100 km, which is the distance between Ioannina and the Kozani focal zone, that is more than 20 times the distance between JAN E and IOA): the distribution of polarisations of the anomalous electrical field, as described above, is completely different from that of the MT field whose primary source can be considered to be at infinite distance. The sharpness of the square pulses is also to be noted.

We are therefore left with two hypotheses. The anomalous electric signals could be natural tectonoelectric effects generated by changes in the local stress field (we leave aside the question of a connection between such changes and processes associated with an imminent earthquake, hundreds of kilometers away); in this case the natural source capable of generating such signals should be a powerful one (if electrokinetic, a varying pore pressure difference of a few hundred bars over a distance of one kilometer is needed (e.g, Bernard, 1992)). In fact, the characteristics of the signals render a local natural origin highly improbable.The observed regularities in the signals, such as the repetition of a break of 13 mn and the observation that durations are multiple of 10 mn, suggest on the contrary an industrial origin. Furthermore, the similarities in shapes and durations of the 1988 and 1995 signals seem too remarkable for the hypothesis of primary sources located in two distinct tectonic areas, hundreds of kilometers apart (west Peloponesus and west Macedonia), to be plausible.

Electric signals with characteristics such as those discussed above and associated with magnetic signals are commonly generated by industrial activity. For exemple, electric stray currents recorded at Nozay-En Dunois (Eure et Loire, France) on a NS dipole are known to have been generated by the Paris-Orléans DC electric railway, 30 km to the Est of Nozay (Fournier and Rossignol, 1974). These electric variations were accompanied by magnetic ones recorded at Chambon-La-Forêt, the French magnetic observatory located 30 km to the Est of the DC railway. There is no such public railway in Epirus, but similar linked electric and magnetic variations can still be generated by a number of other industrial activities (e.g., Kishinovye, 1951).

Let us make some order of magnitude estimates. The stray currents source is represented by a wire L km long, carrying an electric current I, grounded at both ends A and B. The Earth is represented by a half space with a conductivity $\sigma(z)$ depending only on the vertical coordinate. The vertical B_Z and the horizontal $\vec{B}_H$ components of the magnetic field (induction) generated at point P by this source are:

$$B_Z(P) = \frac{\mu_0 I}{4\pi}\int_A^B \frac{\sin\theta . dl}{r^2} \quad \text{and} \quad \vec{B}_H = \frac{\mu_0 I}{4\pi}\left[\frac{\vec{\varphi}_2}{r_2} - \frac{\vec{\varphi}_1}{r_1}\right]$$

($\vec{\varphi}_1$ (respectively $\vec{\varphi}_2$) is a unit vector orthogonal to $\vec{r}_1 = \overrightarrow{AP}$ (respectively $\vec{r}_2 = \overrightarrow{BP}$)) If M is the current point on line AB, r is the distance from M to P and $\theta = (MP, MB)$)

We do not know the distance R from JAN E and IOA to the source. Reasons discussed above suggest it is not very far. Due to, in particular, the distribution of the intensities and polarisations of the signal , it seems safe to suppose that this distance is of the order of the distance between IOA and JAN E (probably closer to JAN E), i.e 4 km. Supposing L<<4 km (there is no railway in the neighbourhood):

$$B_H \approx B_Z \approx \frac{\mu_0}{4\pi} \cdot \frac{IL}{R^2}$$

(R being the distance from P to the middle of AB)
If B=1 nT, it yields IL=1.6x10^5 A.m, if R=4 km, and IL=4x10^4 A.m, if R=2 km; the required power is of the order of few hundreds of kW. Such sources are not at all improbable in this industrial area.

Let us make one remark on the VAN "polarity criterion". The condition that ΔV/L must be constant for short dipoles when the signal is a SES, as advocated by the VAN group (e.g Varotsos and Lazaridou, 1991; Varotsos et al., 1993, 1996), clearly fails here at JAN E and IOA. The VAN group relied on an other criterion, the polarity criterion, which they considered to be of "decisive importance " (Varotsos and Lazaridou, 1991) in order to help discrimination between a local anthropogenic noise and "true SES" (Varotsos et al., 1993). The April 1995 (and September-October 1988) anomalous electrical activities passed this criterion. However, it must be noticed that signals coming from local sources (grossly speaking inside the array of electrodes) can easily pass over this criterion and be misinterpreted as distant signals (Gruszow et al., in preparation). It may also be remarked that in the close neighbourhood of the distant electrode of dipoles L and LL there are two industrial areas: Perama village 2.5 km to the South-West of IOA, Ioannina town and suburbs 4 km to the South of IOA (figure 1b).

Conclusion

Our preferred interpretation of the signals of April 18 and 19, 1995 and also of the less well documented signals of September 29 and October 3, 1988, interpreted as SES by the VAN group and respectively related with the Kozani and the Vartholomio earthquakes, is that these events were generated by an industrial source located in the neighbourhood of the recording stations. Considerations on the form, durations, geographical distribution and polarisations of the anomalous electric signals recorded at JAN E and IOA support this statement. Observations of highly correlated magnetic data at JAN M provide further support for this inference. It must be acknowledged that we have not yet been able to give a definitive proof of this industrial origin which would require us to identify and locate exactly the source.

Considering the difficulties of assessing the VAN method solely by statistical evaluations of the predictions, we find it necessary, in order to understand the physics of the signals, to study their time and space characteristics in a wide domain surrounding the stations where SES are thought to have been frequently recorded. Since the beginning of 1996, we have started operating a mobile electric station in the Ioannina basin.

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