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A NOTE ON THE SPATIAL EXTENT OF THE VOLOS SES SENSITIVE SITE

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Abstract

A very strong disturbance, with a duration of around two hours, was recorded at Volos SES sensitive area on March 17, 2001. It was clearly detected in a zone with spatial dimensions (a few tens km) × (several km); this zone, if the disturbance is actually a SES activity, might reveal the extent of the relevant SES sensitive site.

Key words: seismic electric signals sensitivity, seismic electric signals rise time.

An experiment is carried out around VOL station in order to determine the spatial extent of its Seismic Electric Signals (SES) sensitivity. Beyond the eight electric dipoles (6 short/long dipoles and 2 very long ones) operating since 1994, the data of which are transmitted to Athens through an open telephone line, the following additional installation was made (Fig. 1): (a) 16 dipoles collected at "Pagases" and (b) 32 dipoles collected at "Volos".

On March 17, 2001, a strong disturbance was recorded at VOL, which lasted almost 2 hours. Figure 2 depicts the recordings of the real-time telemetric network, while Figs. 3 and 5 correspond to the aforementioned stations at "Pagases" and "Volos". An *in situ* check – concerning the quality of the operation of each of the afore-

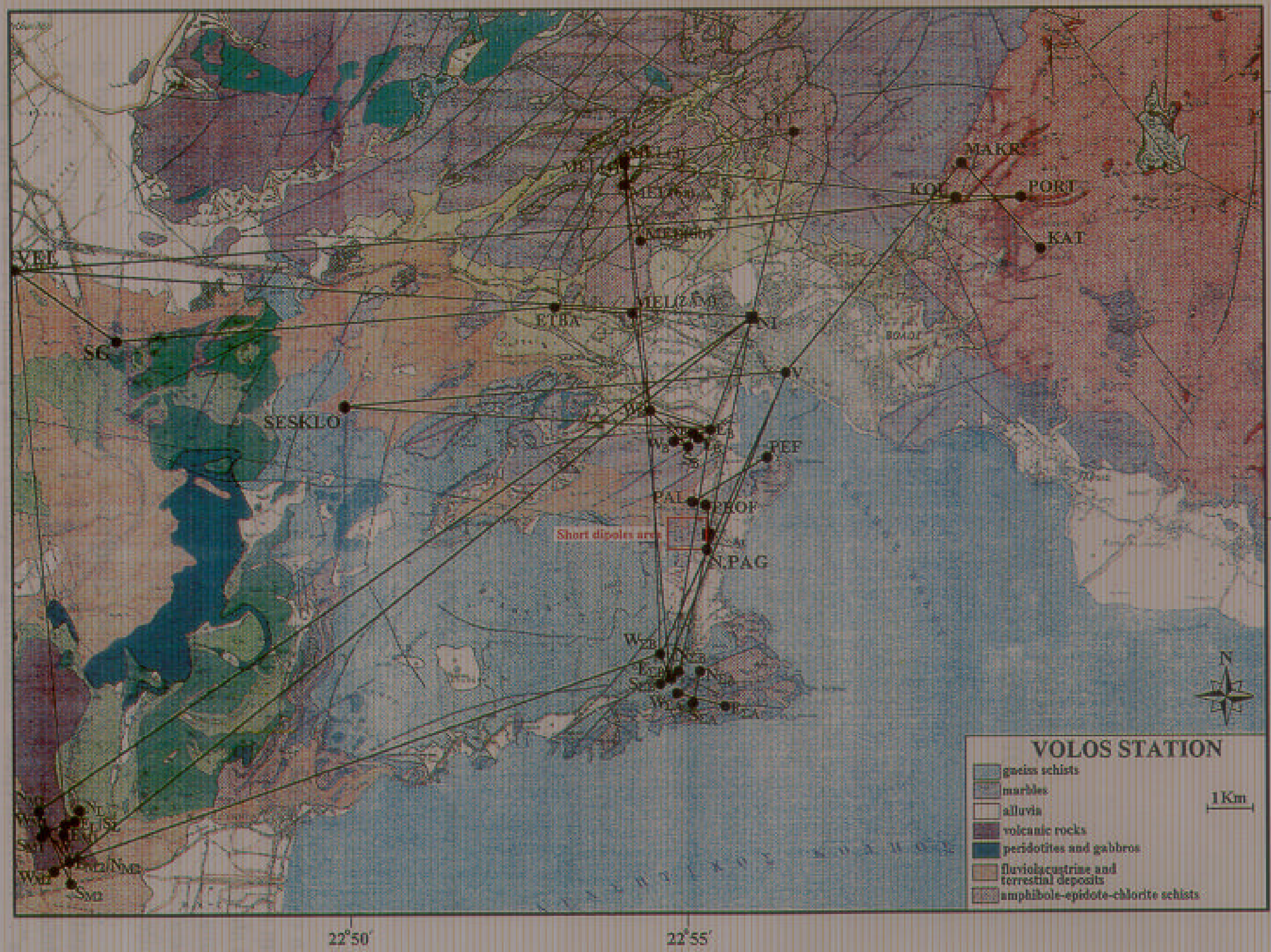

Fig. 1. Configuration of dipoles in Volos area.

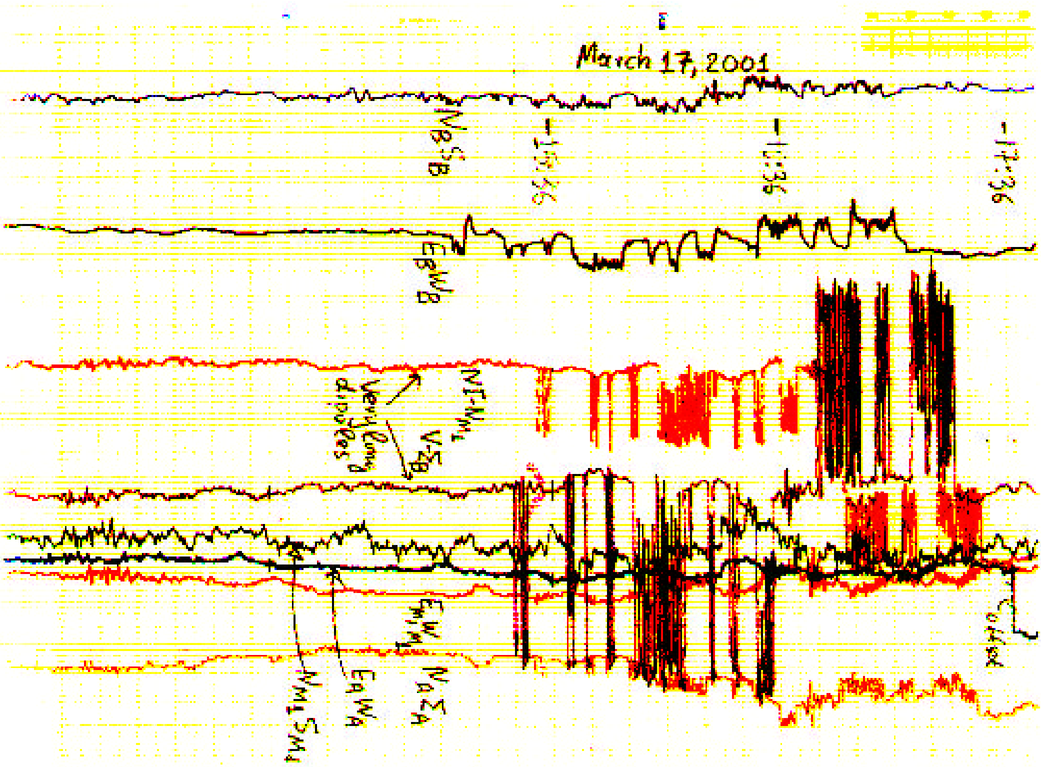

Fig. 2. Photocopy of the real-time records of VOL dipoles at the central station (ATH) of the telemetric network.

mentioned 56 dipoles – started immediately. This lasted until March 24 and revealed that only a few dipoles (marked with a question mark in Fig. 5) had a doubtful operation.

The above disturbance has an average amplitude comparable to that recorded at VOL on April 30, 1995, which preceded the M~6.5 EQ at Egion-Eratini that occurred on June 15, 1995 (cf., the frequency characteristics, as well as the ratios of the combination of various components, are different in these two cases). No such amplitude disturbance has been observed during this six-year period. We emphasize, however, the following peculiarity of the current case: The polarity of the disturbance changes during the last 40 min (after a "cessation" of almost 10-min). On the other hand, the SES activities verified to date had systematically the same polarity (i.e., one-sided anomalies) when they were emitted from the same epicentral region.

Since VOL selectivity map has not yet been determined, the epicenter of the impending seismic activity (if the disturbance is actually an SES) could be estimated as follows: Each of the other operating stations (e.g., IOA, ASS, etc., depicted in Fig. 4)

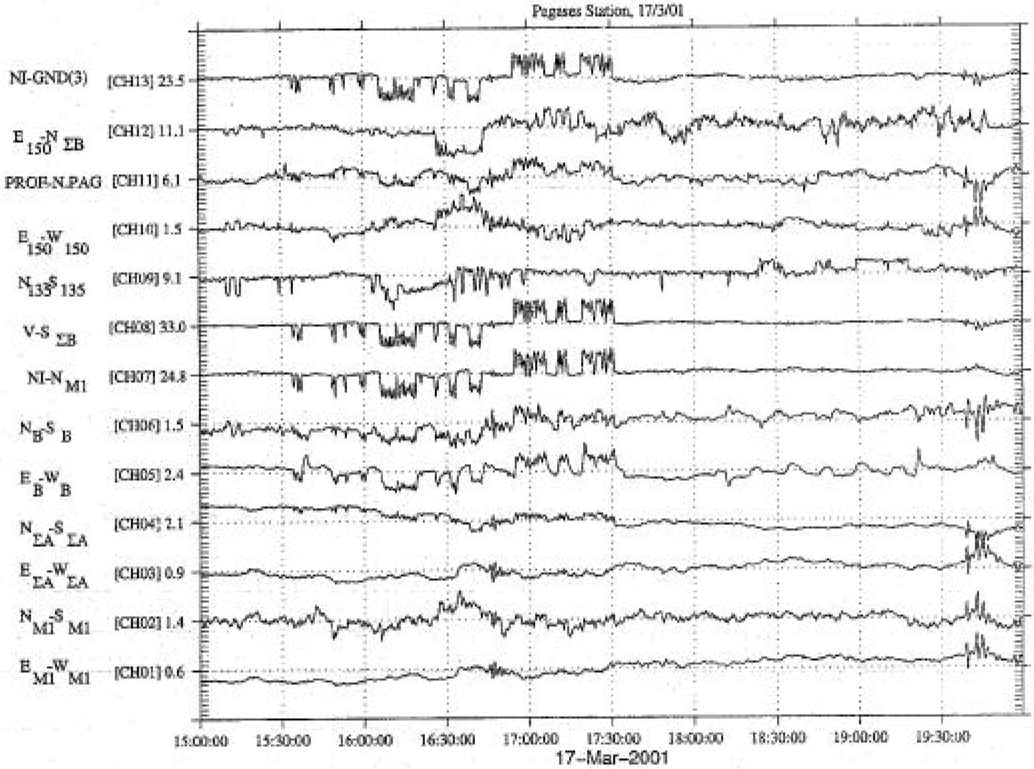

Fig. 3. Recordings of March 17, 2001, at the dipoles operating at Pagases station (cf., the first eight channels are the same as those depicted in Fig. 2).

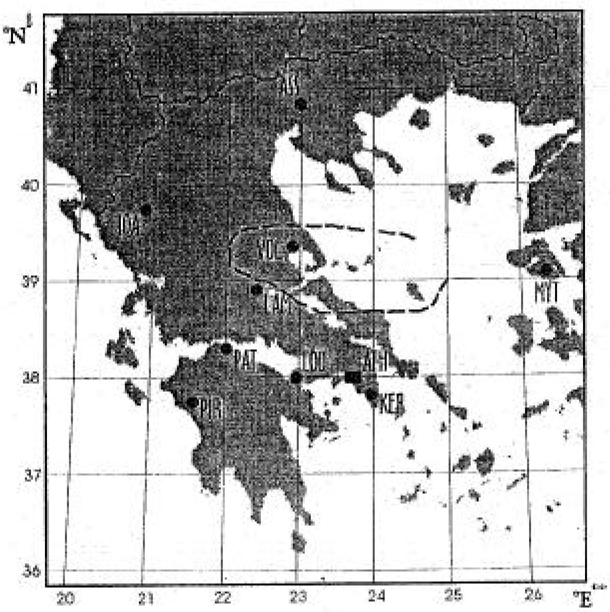

Fig. 4. The thick broken line indicates the candidate area for the epicenter of the impending seismic activity. Field stations are marked with black dots, the main station by a square.

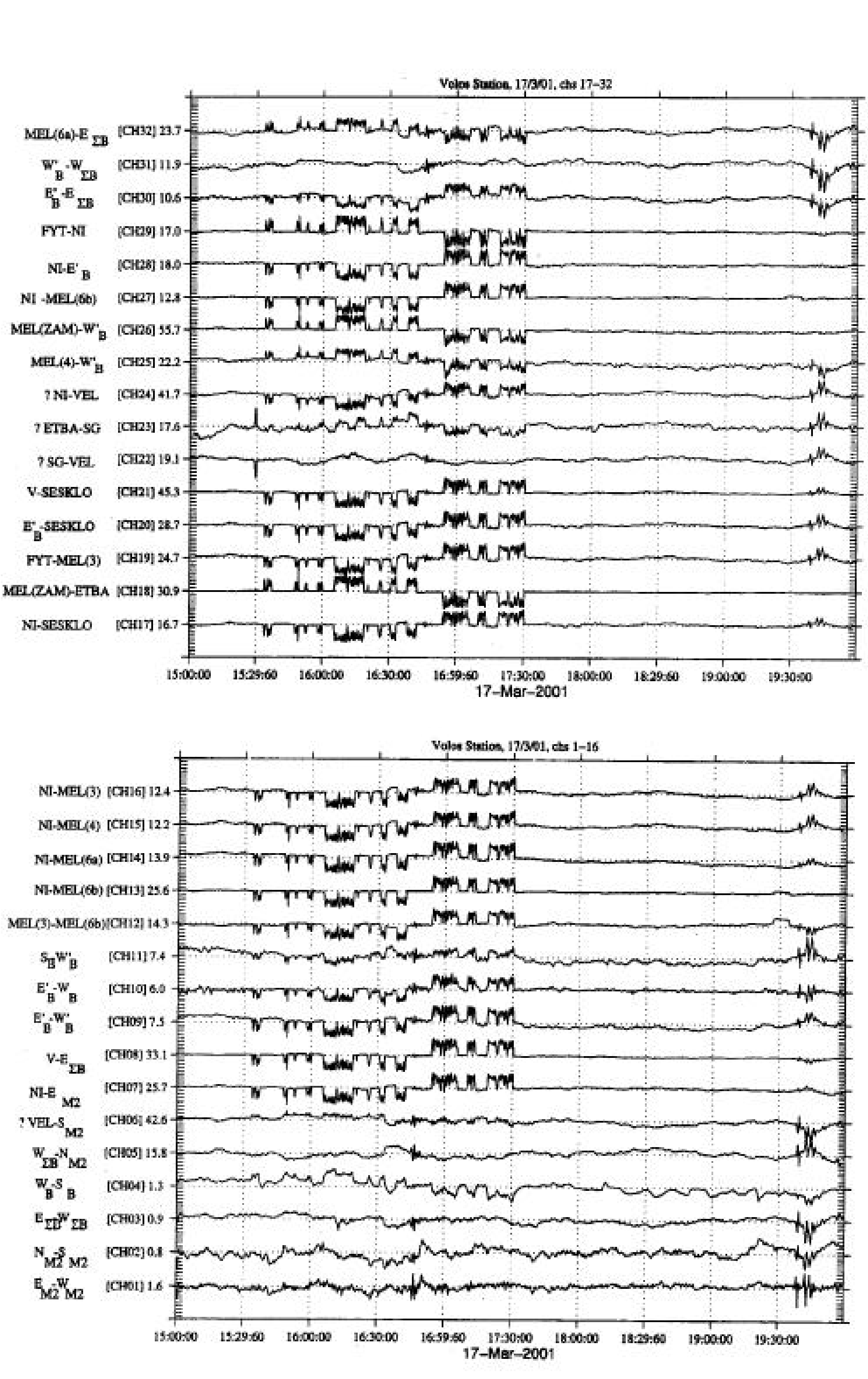

Fig. 5. Recordings of March 17, 2001, at the dipoles operating at the Volos.

has its own selectivity map. Since none of them recorded this disturbance, we exclude the regions belonging to their selectivity maps. We are thus left with the probable candidate area indicated by the thick broken line in Fig. 4.

APPENDIX

The area within the thick broken line in Fig. 4 (hereafter called "broken area") was drawn, as mentioned in the main text, on the basis of the assumption that the SES activities were solely recorded at VOL station. We now summarize the following facts:

(1) *Concerning the electrical activity*: This was continued solely at VOL. As an example, we give in Fig. A1 the SES activity recorded on July 25, 2001.

(2) *Concerning the seismic activity*: Studying the seismicity, within $N_{38.5}^{39.5}$ $E_{21.5}^{25}$, from the Earthquake Catalogue of the Seismological Institute of the National Observatory of Athens (SI-NOA) available on the Web on July 29, 2001, we see the following main feature: This seems to have started on March 26, 2001 with the M_S(ATH) = 4.6 earthquake (EQ) at 39.4°N, 21.7°E, i.e., close to the western edge of the "broken area"; it was then continued on May 19, 2001 with a 4.8 EQ at 39.1°N, 22.5°E, i.e., only a few tens of km SW of VOL. Finally, a m_b (USGS) = 6 strong EQ (cf., Athens Observatory reported $M_L = 5.2$, and hence $M_S = 5.7$) occurred on July 26, 2001, at 39.1°N, 24.3°E, i.e., within the "broken area" (and close to its eastern side).

The epicentral distance affects the SES rise time

We compared the SES activities recorded (on different dates) at the same dipoles of VOL. We first noticed a difference in the ratio of their amplitudes (for a given pair of dipoles). Second, a difference in their "rise time" was found. We now focus on the latter point, in view of the recent theoretical insights concerning the diffusing nature of the SES transmission (see Varotsos *et al.*, 1999a; 2000). The latter reveals that a characteristic time $\tau_0 = \mu d^2/(4\rho_{host})$ governs the shape of the recorded signal; the symbol ρ_{host} denotes the resistivity of the host medium (i.e., that surrounding the highly conductive path along which most of the current travels), d stands for the distance from the emitting source, and μ is the magnetic permeability. Thus, the rise time (for a constant measuring site and several locations of the emitting source) should scale with d^2/ρ_{host}. A typical value of τ_0, for $d \sim 100$ km, is around 1 sec and hence a direct determination of the rise time would require a sampling rate of several Hz, but the sampling rate was only $F_s = 1$ sample/s. This was balanced by taking advantage of the fact that each SES activity consists of a large number of pulses. A Monte Carlo simulation of

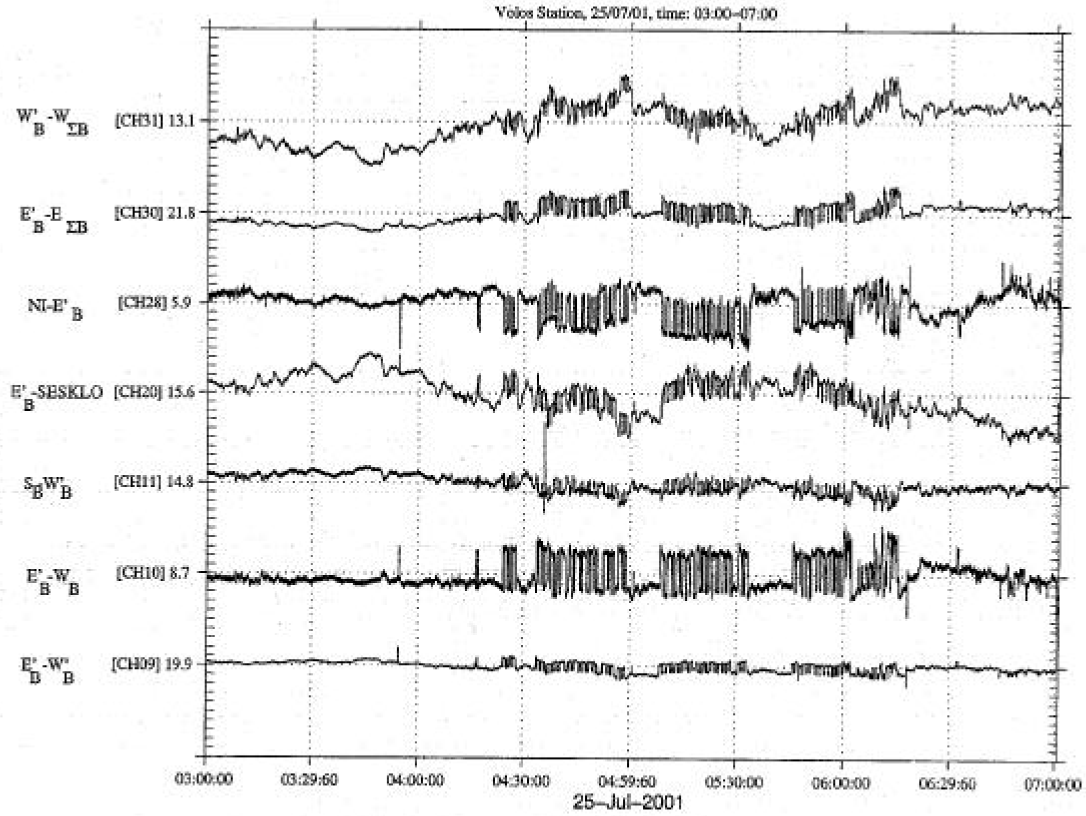

Fig. A1. SES activity (ΔV values) recorded at VOL on July 25, 2001.

the recording system (that uses $f_p = 1$ Hz low pass filters) was employed so that τ_0 could be inferred from the minimum percentage of the recorded pulses that exhibit "transition time" (i.e., the duration of the initiation and/or cessation) more than 1 s. In summary, one hundred synthetic "SES activities", each consisting of 144 boxcar pulses (see the Note added to the proofs of Varotsos, 2001), were simulated and Fig. A2 depicts the results (more details will shortly appear). As an example, from Fig. A2, the τ_0 of the SES activity on July 25, 2001, is found (2.9 ± 0.6) s, while that of March 17, 2001, is (1.1 ± 0.4) s using the 99% margins (in order to balance the influence of the approximations involved, see also below). Notice that such values are incompatible with nearby industrial sources, and their difference is well above the experimental uncertainty. Figure A3 depicts the distance *d versus* ρ_{host} for the two SES activities. Assuming reasonable values of ρ_{host} (i.e., a few thousand Ωm) their τ_0 val-

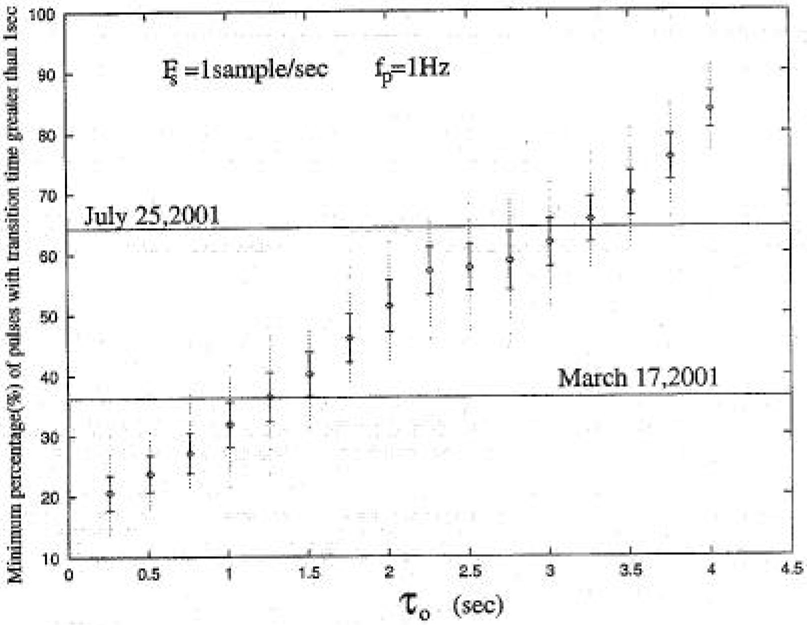

Fig. A2. The minimum percentage of pulses with "transition time" larger than 1 sec as a function of the characteristic time τ_0. The average value together with the standard deviation of the results (dots) have been obtained from Monte Carlo simulation (see the text).

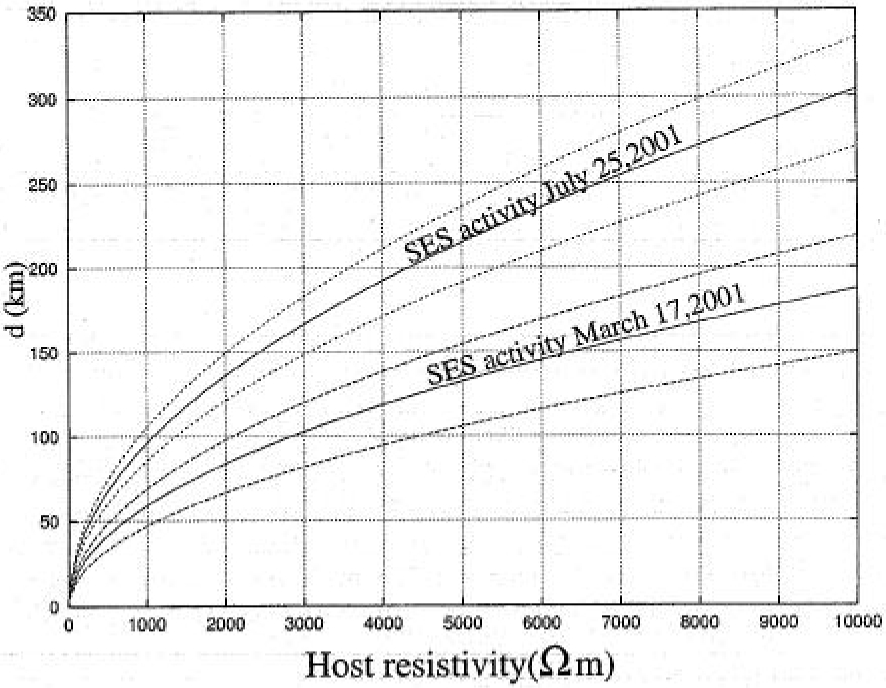

Fig. A3. The epicentral distance d as a function of the host resistivity (solid lines); the marginal curves (broken lines) in each case correspond to the experimental error in the determination of τ_0 values.

ues are compatible with epicentral distances (from VOL) of the order of ~100 km and ~150 km, respectively (cf., the strongest EQ on July 26, 2001 occurred at a distance around 130 km from the measuring dipoles).

The aforementioned concepts reveal how the epicentral distance can be estimated when analyzing the detailed feature of the SES. This estimation, however, should be considered as a rough one in view of the following approximations: the presence of the conductive path close to the emitting dipole source, as well as the presence of the "air-earth's surface" interface, may influence the "rise time" of the signal recorded; on the other hand, the results of Varotsos *et al.* (1999a) – which were used as a basis for the aforementioned simulation – refer to a dipole source located inside a homogeneous conductive medium. Furthermore, the case of synthetic "SES activities" emitted in a non-boxcar shape needs additional study.

An independent estimation could be achieved by using the (measurable) time difference between the "arrivals" of the diffusing electric and magnetic fields, as recently reported by Varotsos *et al.* (2001a; b). Unfortunately, in the present case no simultaneous measurements of the two fields were available.

In summary, a sequence of SES activities at VOL, that occurred within a few month period, was followed by a strong EQ activity in the "broken area" initially estimated. We emphasize that no such strong EQ occurred in this area during the last 40 years, or so. However, the following puzzling fact is not yet understood: the strongest SES amplitude was observed in the initial period of the SES activity sequence, leading to a time lag (between the strongest EQ and strongest SES amplitude) which is larger than that in the case of the 6.5 Egion-Eratini EQ by a factor 2 to 3.

Remark 1. An attempt towards understanding the peculiarity of the SES activities on March 17, 2001, mentioned in the main text (i.e., the change of the polarity during the last 40 min), was also made. We proceeded to a detailed analysis of the two parts that have different polarities. The results gave comparable τ_0 values, thus revealing almost equal epicentral distances from VOL. A similar peculiarity was also observed in the SES activities collected at LAM on September 1 and 2, 1999, before the Athens EQ of September 7, 1999, and was initially interpreted as a new impending EQ (Varotsos *et al.*, 1999b). In the latter case, the peculiarity was partially resolved in view of the following. Kikuchi (April 4, 2001, private communication) applied the inversion of complex body waves procedure suggested by Kikuchi and Kanamori (1991) and found that: there was probably a sub event ($M_w = 5.5$) after about 3.5 sec of the main event ($M_w = 5.8$) and the moment ratio of the two was 1:3. The corresponding strike-dip and rake values were different, i.e. (129°, 58°, −74°) and (92°, 23°, −51°) for the events $M_w = 5.8$ and $M_w = 5.5$, respectively. In the present case, however, such an inversion procedure of the EQ of July 26, 2001, is not yet available to us. Thus, the question of interpreting the aforementioned peculiarity still remains open.

Remark 2. After an intriguing suggestion of Prof. H. Kanamori (2001, private communication), we studied the seismicity during the periods before and after the prominent SES activities recorded at VOL on March 17, 2001. We used the aforementioned SI-NOA Catalogue. In Table 1, we give all shallow EQs within $N_{38.5}^{39.5}$ $E_{21.5}^{25}$, with M_L(ATH) ≥ 3.7, during the period October 1, 2000 – July 25, 2001 (i.e., until before the strong EQ on July 26, 2001). Actually, the seismicity in this area has been higher since March, 2001, than in the period before March. For example, no EQ with M_L(ATH) ≥ 4.0 occurred during the period October 1, 2000 – March 17, 2001 (i.e., before the SES activities), while several of them occurred in the period after the SES detection.

Table 1

All shallow EQs within $N_{38.5}^{39.5}$ $E_{21.5}^{25}$, with magnitude M_L(ATH) ≥ 3.7, during the period October 1, 2000 to July 25, 2001.(Taken from http://www.gein.noa.gr/services/monthly-list.html and http://www.gein.noa.gr/services/2000-list.html on July 29, 2001)

Year month day	Time	Lat. N	Long. E	h [km]	M_L(ATH)
2001 2 20	$08^h15^m21^s$	39.08	24.39	20	3.8
2001 3 26	08 28 02.2	39.35	21.73	5	4.1
2001 4 06	18 10 39.7	38.62	23.76	5	3.9
2001 5 14	08 33 06.1	38.79	23.68	4	3.7
2001 5 19	03 11 16.1	39.16	22.57	5	4.3
2001 6 12	03 04 22.2	38.69	24.96	30	3.7
2001 7 21	12 45 59.8	39.10	24.35	21	4.1
2001 7 21	12 47 38.7	39.06	24.35	18	4.6
2001 7 25	15 43 13.4	39.06	24.32	19	4.2

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