Additional information for the paper "Attempt to distinguish long range temporal correlations from the statistics of the increments by natural time analysis" after its initial submission

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Abstract

After the submission of this paper on February 25, 2006, a series of strong earthquakes with magnitude up to 5.7-units (according to the United States Geological Survey, or 5.9 according to the Athens Observatory) occurred with epicenters lying at distances 80 to 100 km west of PAT station at which the intense signals –analyzed in the main text- had been recorded on February 13, 2006. This confirms experimentally the classification of these signals as Seismic Electric Signals (SES) activity that was made well in advance. Finally, we present here additional data collected *after* the initial submission of the paper.

I. EARTHQUAKES THAT OCCURRED AFTER THE INITIAL SUBMISSION OF THE PRESENT PAPER

After the submission of the present paper on February 25, 2006, a series of strong earthquakes (EQs) occurred with epicenters lying approximately 80 to 100 km west of the PAT station (Fig. 1). Table I presents all EQs with magnitude (M) larger than 4.5 that occurred within the region (37.5 to 38.7)° N, (20.5 to 22.6)° E during the period from the detection of the SES activity at PAT on February 13, 2006 until April 21, 2006. The strongest EQ of magnitude 5.7 occurred at 16:52 Universal Time (UT) on April 12, 2006 with an epicenter at 37.61° N, 21.01° E (cf. The Institute of Geodynamics, National Observatory of Athens, reported a magnitude Ms(ATH)=5.9 for this EQ).

Note that the amplitude 6 mV/km reported for the SES activity of February 13, 2006 in the caption of Fig. 1 of the main text, is compatible with the aforementioned 5.7 (or 5.9) EQ

magnitude. This can be seen as follows: The electric field amplitude $\Delta V/L$ (i.e., the variation ΔV of the potential difference between two electrodes divided by the length L of the measuring dipole) scales with magnitude M, for a given epicentral distance r, according to:

$$log_{10}(\Delta V/L) \propto \alpha M$$

where the proportionality constant α has a universal value around 0.31 to 0.34 [1-4]. This means that when the EQ magnitude decreases by 1-unit, the amplitude $\Delta V/L$ becomes smaller by a factor of around 2, or so (for r=constant). We now consider that [5] a M=6.6 EQ on May 13, 1995 has been preceded by SES activities of amplitude 12-15 mV/km measured at a distance $r \approx 80$ to 100 km. Hence, the present case of the SES activity at PAT of February 13, 2006, which as mentioned has an amplitude ≈ 6 mV/km, should correspond (since the r is almost the same) to an EQ of smaller magnitude approximately by 1.0-unit (thus being more or less compatible with the 5.7 (or 5.9) magnitude of the EQ of April 12, 2006, if we also take into account a plausible uncertainty of around 0.1-unit in the magnitude determination).

II. SES ACTIVITIES OBSERVED AFTER THE INITIAL SUBMISSION OF THE PRESENT PAPER

In Figs. 2(a), (b) and (c), we depict three SES activities that have been detected on April 13, 19 and 21, 2006 respectively and hence collected *after* the initial submission of the present paper.

The following three facts are worthwhile to be mentioned as far as these three SES activities are concerned: First, they have been recorded *after* the occurrence of the 5.7 (or 5.9) EQ of April 12, 2006. Second, their amplitude (especially of the latter two activities) are somewhat larger than that of the SES activity of February 13, 2006 analyzed in the main text. Third, an inspection of Figs. 2(b) and (c) reveals that these two activities comprise a very small number of pulses, thus not allowing a reliable analysis in the natural time domain [6-10] (in view of the large errors emerged in the calculation of the parameters k_1, S, S_- and S_{shuf}). In such cases (of small number of pulses), the classification of whether a signal is a true SES

activity is made by means of a comparison of its amplitude ΔV/L recorded at a multitude of measuring electric dipoles of different lengths [1-4] (in a fashion similar to that discussed in Section II of Ref. [10]). Such an SES activity had been also recorded at PAT on February 2, 2006, which is given here in Fig. 2(d), for the sake of comparison.

III. ADDITIONAL OBSERVATIONS

Beyond the aforementioned SES activities recorded at PAT, the following facts have been observed at another station located close to Pirgos city, which will be hereafter called PIR. Sixteen electric dipoles are continuously operating at that station, the configuration of which is depicted in Fig. 3.

Let us now focus on what was observed at PIR during the period *after* the SES activity of February 13, 2006 recorded at PAT (see Fig. 1 of the main text). All data collected during the (almost) three month period February 13 to April 24, 2006, are presented in Fig. 4. This plot, for the sake of clarity, is made for four electric dipoles only. (cf. The "spikes" having large deviations are due to occasional measurements in order to check the good operation of these dipoles). A careful inspection of this figure, reveals the following two facts:

First, two dipoles, i.e., those labeled 02/02 and 02/03, deviate from the background level around the end of February and more or less return to their initial level after the occurrence of the 5.7 (or 5.9) EQ on April 12, 2006. Such a transient phenomenon (with a typical duration of the order of 1 month), termed Gradual Variation of the Electric Field of the Earth (GVEF), has been reported long ago [1] and appears only for EQs with magnitude larger than 5.5 when the epicenter happens to lie at a small distance (~ a couple of tens of km) from the measuring station (see also Refs. 2-4). In view of the latter property, the detection of a GVEF is of particular importance since it provides an useful information on the epicenter of the impending strong EQ. For example, in the present case immediately after the detection at PAT on February 13, 2006, the epicenter was initially estimated to be [11] within the broad area: (36.2 to 38.7)° N, (21.5 to 23.5)° E, but after the onset of the GVEF at PIR (the last

week of February) it became evident that the epicenter should lie only a couple of tens of kilometers from PIR (in accordance to what finally happened see Fig. 1).

Second, two electric dipoles, i.e., those labeled MP and S_B in Fig. 4, started to gradually deviate around the end of March. This still continues and suggests the initiation of a *new* GVEF.

How the above observations could be interpreted? A preliminary explanation could be the following: The non-common behavior of all PIR electric dipoles may be attributed to the activation of two separate nearby seismic regions. The seismic activation of the one region (associated with the GVEF observed at the former two electric dipoles, i.e., 02/02 and 02/03) has started to diminish after the M=5.7 (or 5.9) EQ on April 12, 2006. On the other hand, the activation of the other region –associated with the new GVEF whose onset appeared at the end of March- has not yet reached its maximum value. The latter seems to be consistent with the detection of the three SES activities in Figs. 2(a), (b) and (c), that have been independently detected at PAT *after* the occurrence of the 5.7 (or 5.9) EQ of April 12, 2006. In other words, *if* the present interpretation is correct, the main seismic activity will probably "migrate" from the previously active region to a new nearby region.

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12. See the United States Geological Survey (USGS) earthquake search web page http://neic.usgs.gov/neis/epic/epic/html

Table I. All earthquakes with magnitude larger than 4.5 that occurred within the region $N_{37.5}^{38.7} E_{20.5}^{22.6}$ after the detection of the SES activity at PAT on February 13, 2006 until April 21, 2006. These data come from the United States Geological Survey catalogue (USGS), see Ref.[12]. In the last column we give the Ms(ATH) magnitude announced by the Institute of Geodynamics of the National Observatory of Athens, Greece.

Year	**Mon.**	**Day**	**Hours**	**Min**	**Sec.**	**Lat.**	**Lon.**	**Depth**	**Mag.**	**(Mag. Sourse)**	**Ms(ATH)**
2006	4	3	0	49	45.66	37.71	21.12	24	4.9	mb GS	5.3
2006	4	4	22	5	4.24	37.73	21.07	7	5.5	MwHRV	5.7
2006	4	11	0	2	44.2	37.71	21.23	23	5.5	MwHRV	5.7
2006	4	11	17	29	28.06	37.65	21.03	10	5.5	MwHRV	5.9
2006	4	12	16	52	3.62	37.61	21.01	29	5.7	MwHRV	5.9
2006	4	12	16	56	29.88	37.66	20.95	47	4.9	MLTHE	5.2
2006	4	15	21	15	15.36	37.77	20.98	35	5	mb GS	5.3
2006	4	17	8	54	44.59	37.64	20.91	35	4.8	mb GS	5.2
2006	4	19	15	16	26.65	37.77	20.92	27	5	mb GS	5.2

FIGURES

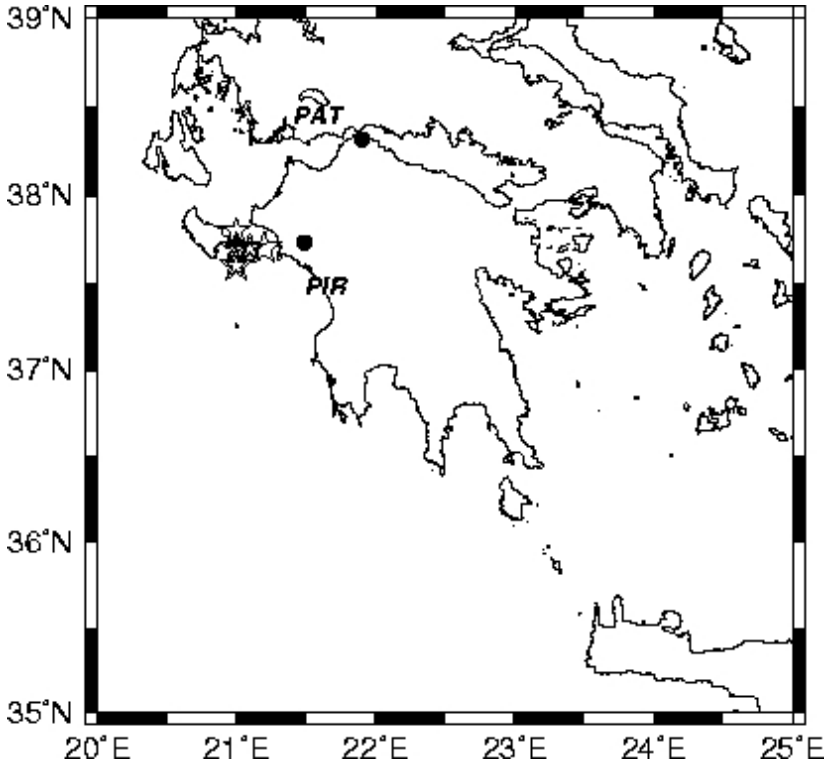

Fig. 1. Map showing the sites of the measuring stations (solid dots). The SES activities and the GVEF under discussion have been recorded at PAT and PIR, respectively (see the text). The epicenters of the earthquakes with magnitude larger than 4.5 that occurred during the period February 13, 2006 – April 21, 2006, are marked by stars (see Table I).

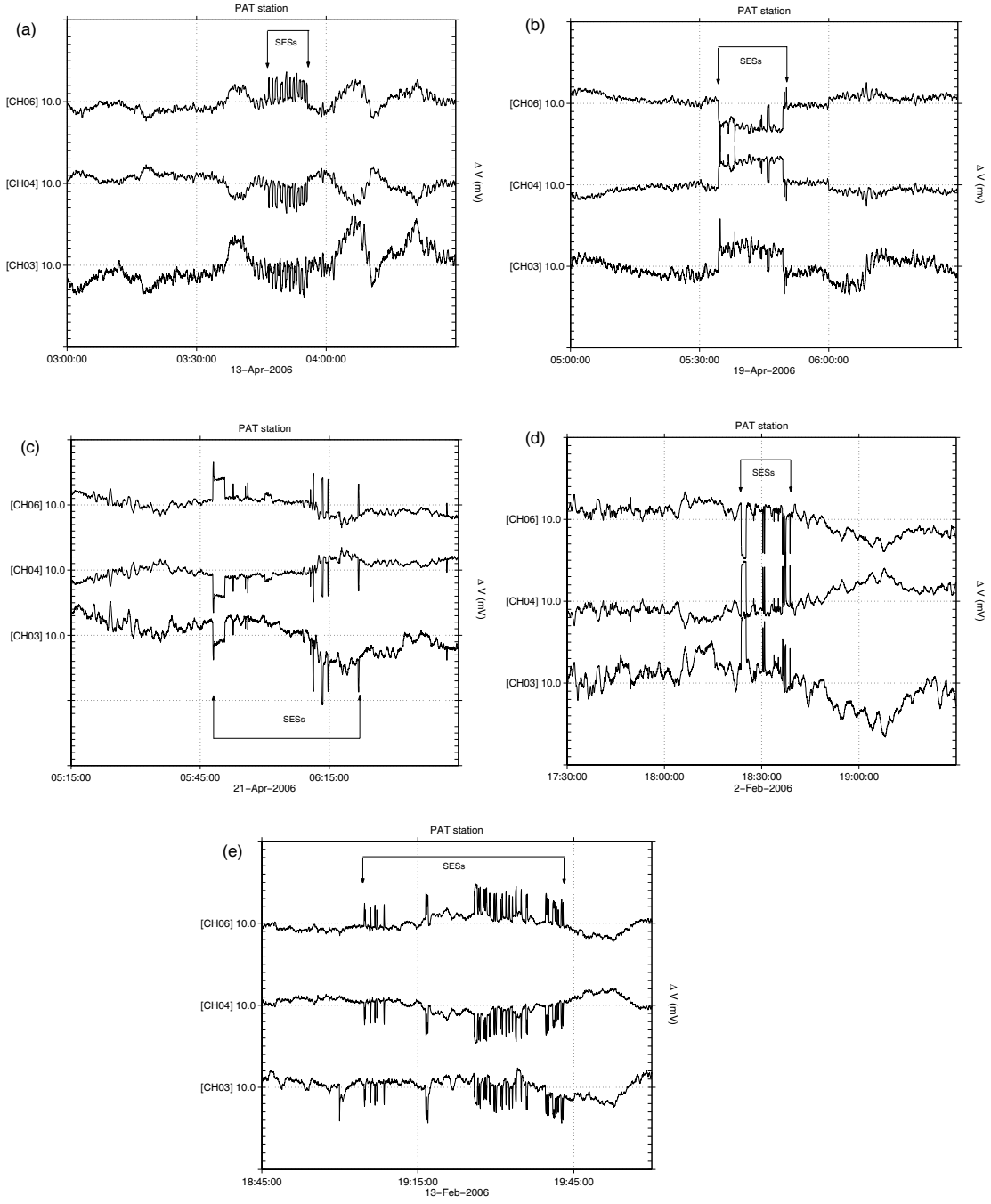

Fig. 2. Additional SES activities recorded at PAT. (a), (b), (c) refer to SES activities that appeared on April 13, 19 and 21, 2006, respectively, i.e., *after* the initial submission of the present paper. For the sake of comparison, (d) presents an SES activity which was recorded [11] on February 2, 2006 (i.e., that preceded the one recorded on February 13, 2006, depicted in Fig. 1 of the main text, which is also reproduced here in (e) for the sake of readers' convenience). Due to the small number of pulses, the SES activities in (b), (c) and (d) could not be accurately treated by natural time domain analysis, but

have been classified as SES activities by means of a different procedure explained in the text.

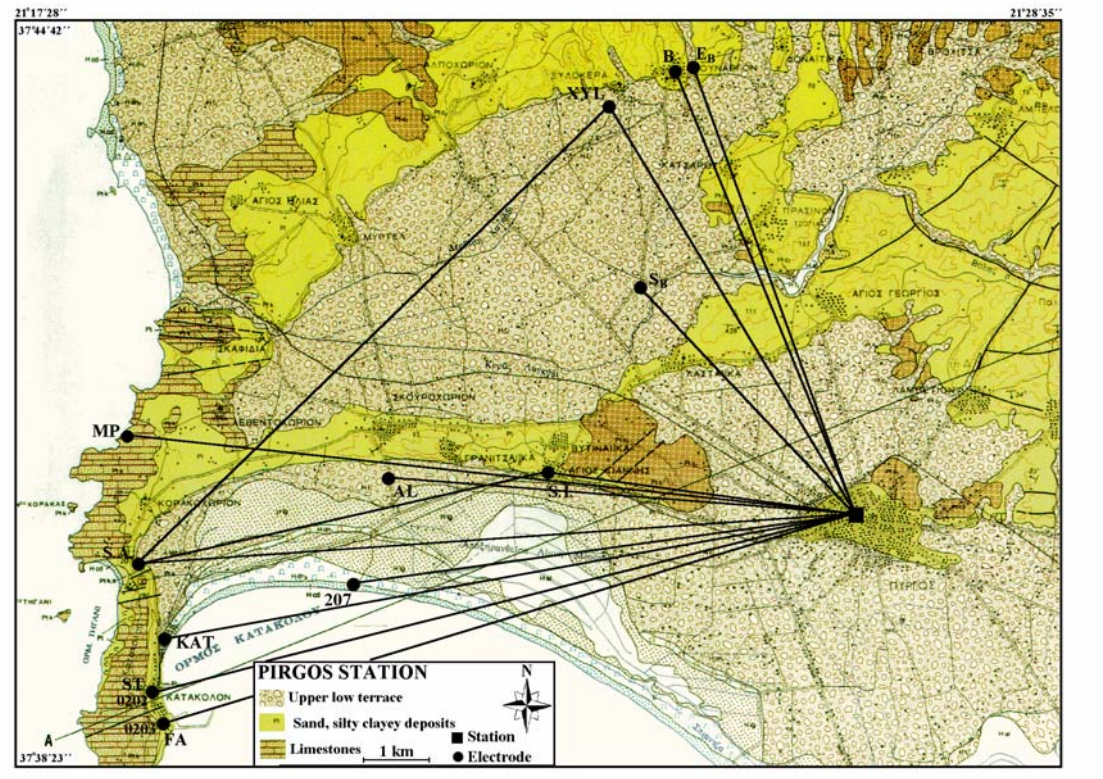

Fig. 3. Configuration of the measuring electric dipoles (solid lines) operating at PIR. The square shows the site of the data collection, where a common electrode of all dipoles is located. The other electrode of each dipole is shown with a solid dot.

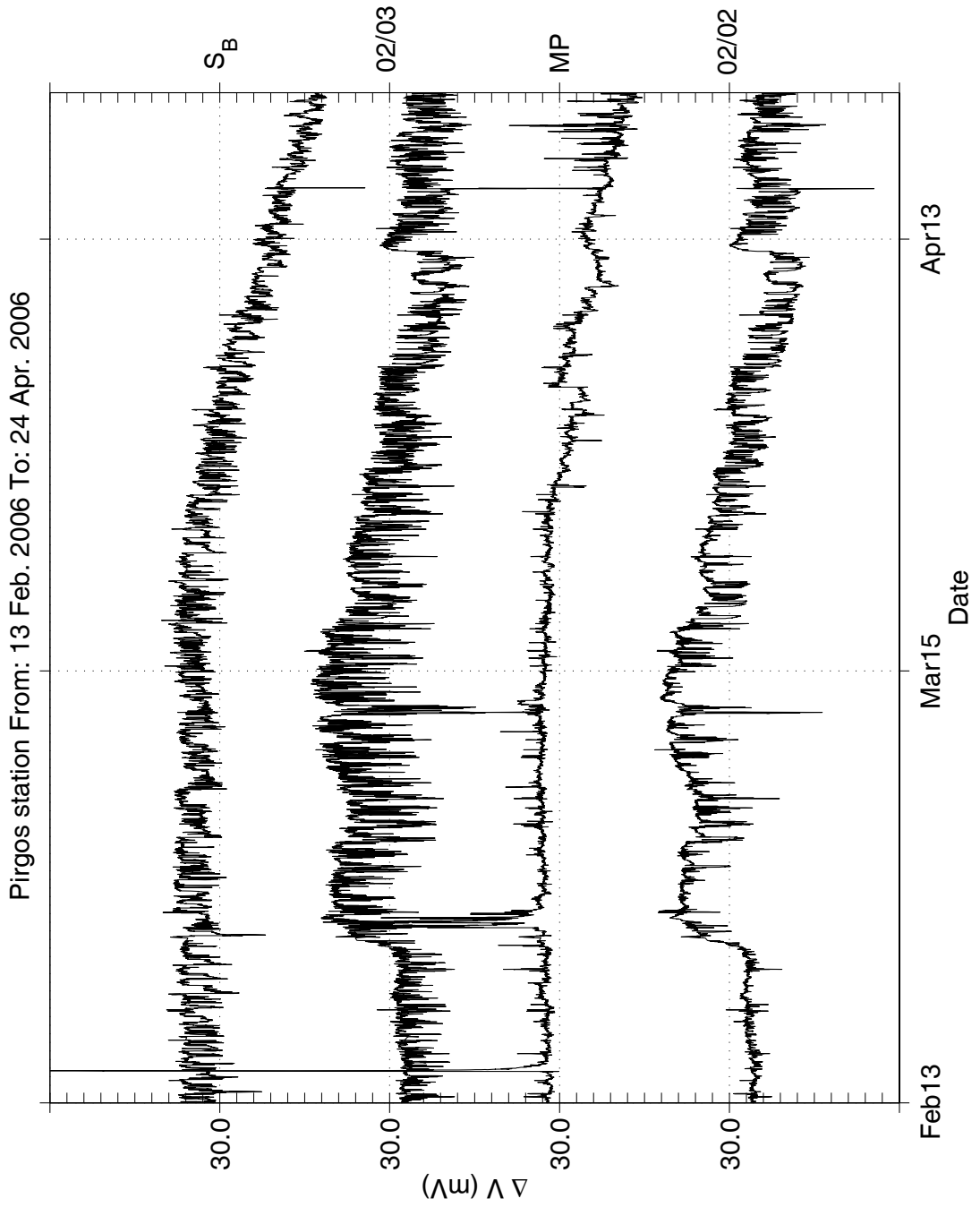

Fig. 4. Plot of almost three months data, i.e., from 13 February to 24 April, 2006, recorded at four electric dipoles operating at PIR. (cf. The sites of the electrodes are shown in Fig. 3).