Supplementary information for the paper 'Entropy of seismic electric signals: Analysis in natural time under time-reversal'

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Abstract

Here we provide additional information concerning the sites as well as the configuration of the measuring dipoles at which the SES activities presented in the main text have been recorded. Furthermore, we give some clarifications on intermittent criticality, and briefly explain how the one sided segments of fractional Brownian motion are read and analyzed in natural time.

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The sites of the telemetric stations that are currently operating in Greece (and are telemetrically connected to Athens) are depicted in Fig. 1.

The SES activities, labelled M_1 to M_4 in the main text, have been recorded at the station MYT which lies in North-Eastern Aegean sea (close to the border between Greece and Turkey). As for the SES activity labelled V_1, it has been recorded at station VOL, located at Central Greece.

The configuration of the multitude of the measuring dipoles at the aforementioned two stations are shown in Fig.2 (MYT) and Fig.3 (VOL). The two channels, the recordings of which are shown in Fig. 1 of the main text, are the following: (1) For MYT, the dipole $N_{300} - S_{300}$ (the lower channel), which is a dipole of length 300 m (oriented in the NS direction) lying in the region labelled "short dipole area", and the dipole $GA - AL$ (the upper); (2) For VOL, the dipole $NI - N_{M1}$ (the lower channel) and the dipole $V - S_{SB}$ (the upper).

Comparing the amplitudes $\Delta V/L$ (i.e., the variation of the potential difference between two electrodes divided by the length of the measuring dipole) of the SES activities presented in this paper to those described in Ref.[1] we note that M_1 to M_4 are now significantly larger, while V_1 is considerably smaller. The amplitude $\Delta V/L$ scales with the magnitude of the EQ according to

$$\log_{10}(\Delta V/L) = \alpha M + constant \tag{1}$$

where α has a value between 0.3 and 0.4.

Concerning the presentation of our computation results on an on-off intermittency model, we emphasize that there is still an ongoing discussion on which dynamic model is appropriate for earthquakes (EQs). In short, we refer to two points on which considerable uncertainty still remains. First, as far as the question on whether EQs are phenomena that are consistent with the self-organized criticality (SOC) aspect originated by Bak et al.[2] (see also Ref.[3]): Yang et al.[4] recently argued that EQs are unlikely phenomena of SOC because their analysis of the Southern California Catalog shows that the first-return-time probability $P_M(T)$ for EQs with magnitude equal to or larger than some prescribed threshold M, is apparently changed after the time series is rearranged. To contrary, Woodard et al.[5] expressed the view that these results of Yang et al., far from discarding SOC for modeling earthquake dynamics, provide further evidence in favor of such a description, but Yang et al.[6] subsequently insisted on the correctness of their initial conclusion[4]. Second, instead of SOC the *intermittent criticality* model has been proposed[7] as being more appropriate (see also Refs.[8, 9]). In order to proceed to a distinction between these two competing models, it has been stated[10] that a more precise definition of the two paradigms is needed, but more recent studies[11] suggest that the EQ data support the intermittent criticality aspect. Hence, we restricted ourselves, in the main text, to the presentation of a simple on-off intermittency model, thus leaving aside the diversity of views on which model is more appropriate for EQs.

In order to visualize that S may be either larger or smaller than S_- (but both of them are smaller than S_u), we depict in Fig.4 two characteristic examples: in the first example (a) we see that $S > S_-$, while in (b) $S < S_-$ (see the corresponding values at $\chi = 1$).

Finally, Fig.5 provides an example showing how the one sided segments of a fractional Brownian motion are read in natural time.

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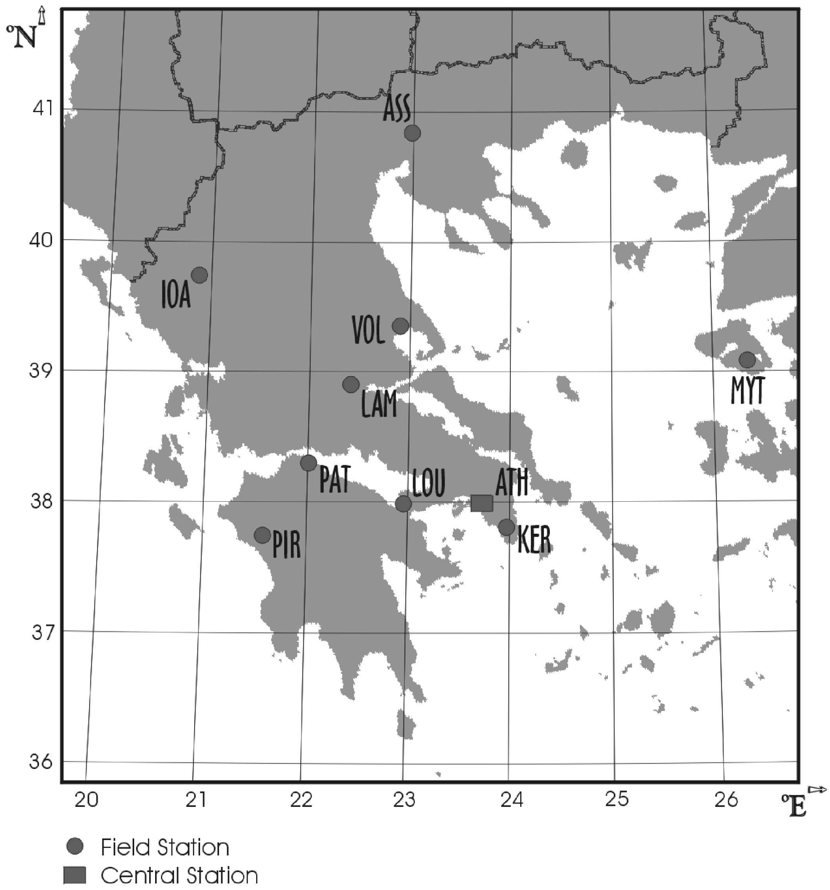

FIG. 1: Map showing the sites of the measuring stations. The SES activities under discussion have been recorded at MYT and VOL (see the text)

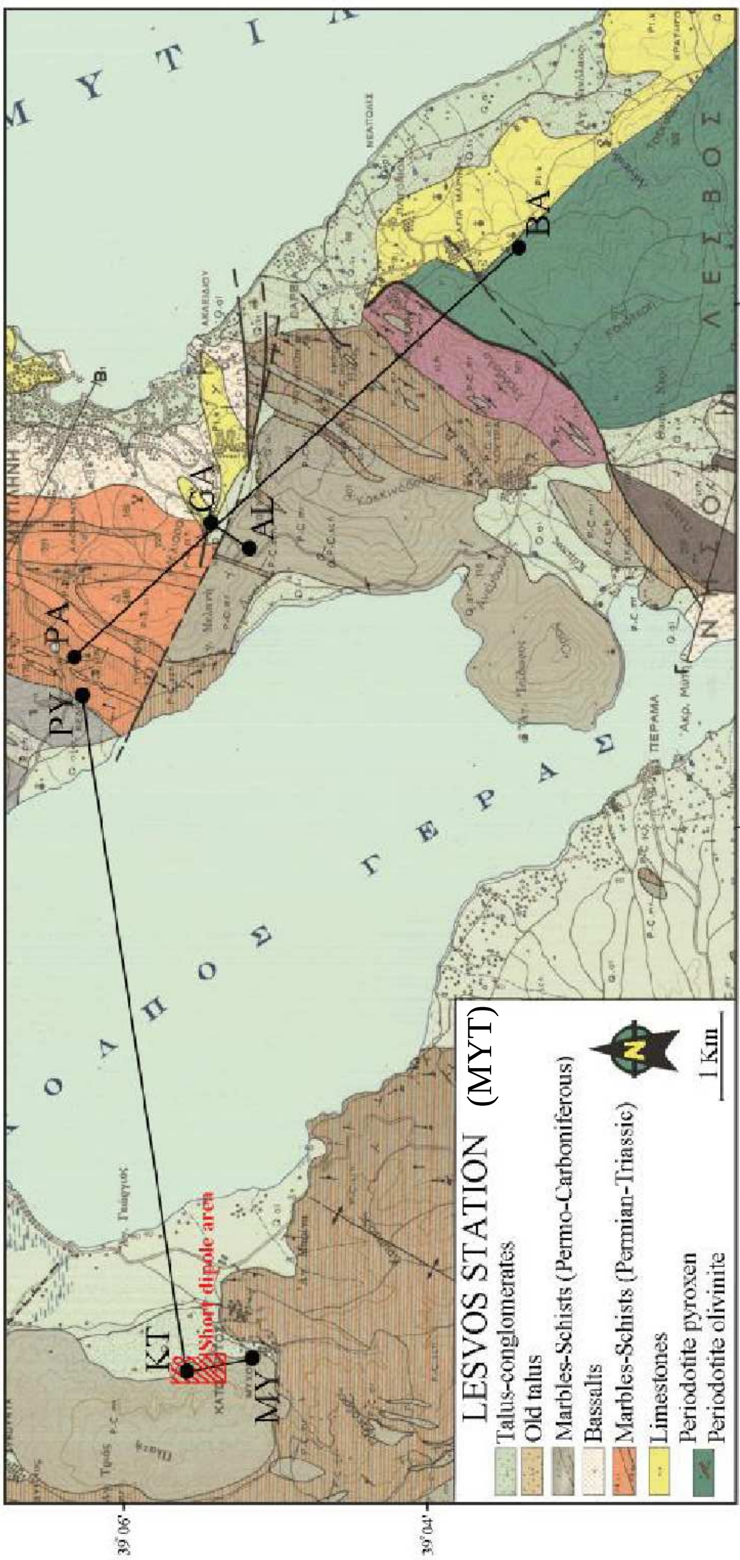

FIG. 2: Configuration of the measuring dipoles at MYT.

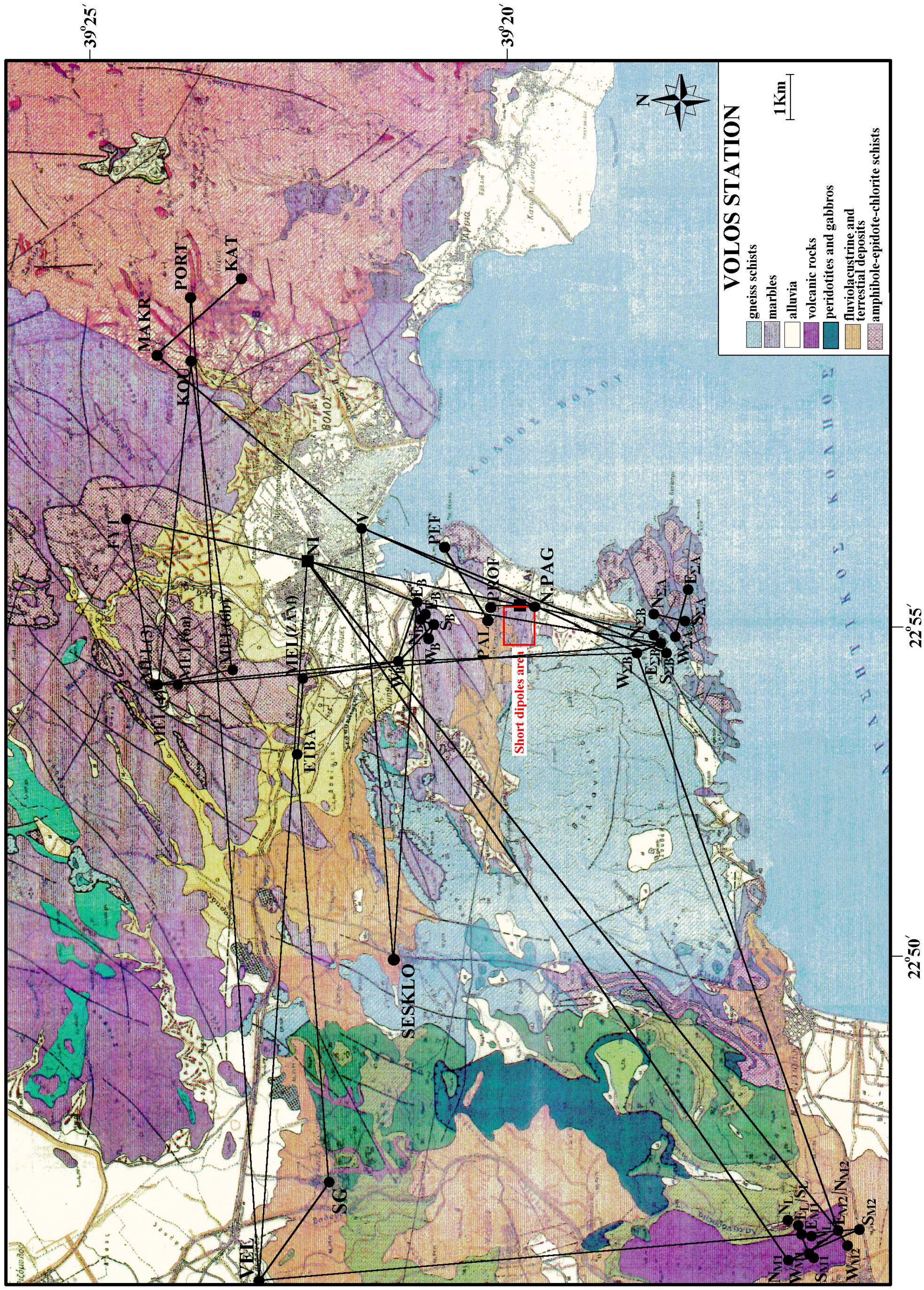

FIG. 3: Configuration of the measuring dipoles at VOL.

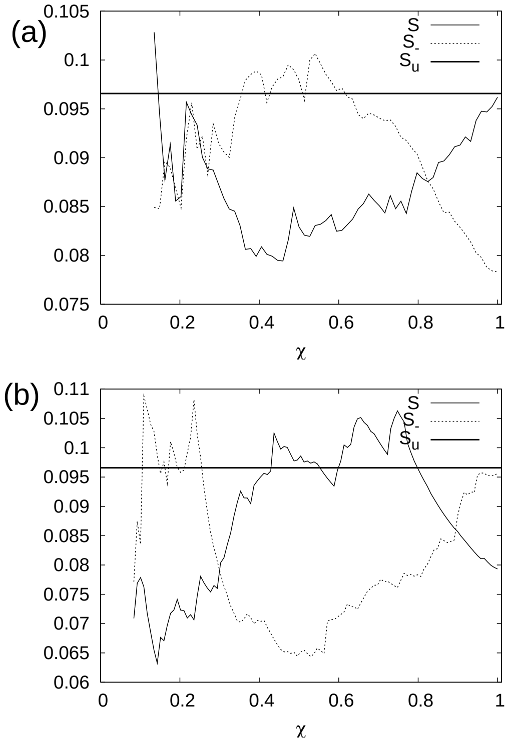

FIG. 4: Two examples showing how the values of S and S_- evolve versus the natural time. (a) and (b) correspond to the SES activities labelled M_1 and M_4, respectively in Fig. 1 of the main text. Note that, at $\chi = 1$, we find $S > S_-$ in (a), while $S < S_-$ in (b); in both cases, however, the values of S and S_- are smaller than S_u. The thick horizontal line corresponds to $S_u (= 1/2 \ln 2 - 1/4 \approx 0.0966)$.

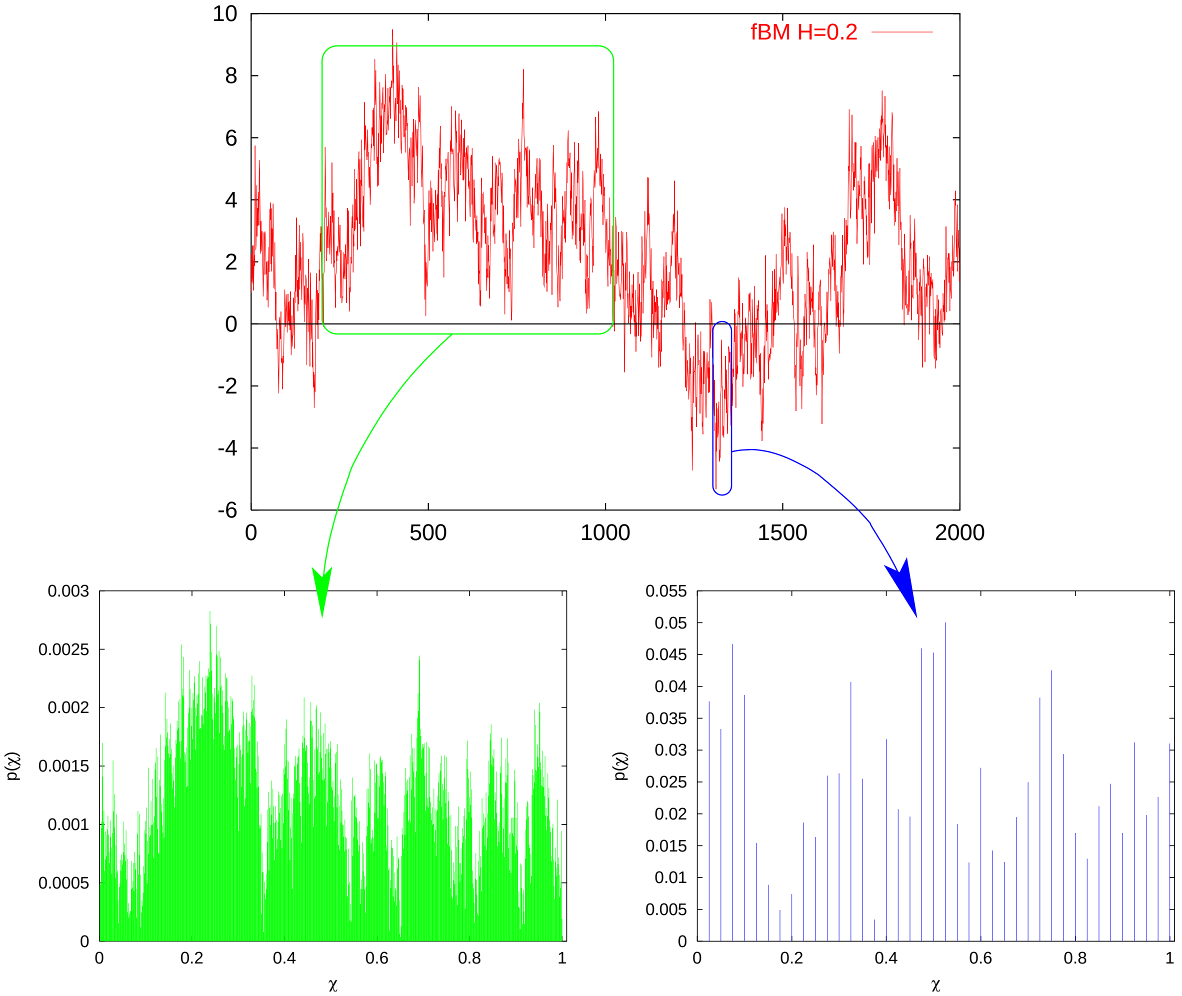

FIG. 5: An example showing how the one sided segments of a fractional Brownian motion (upper panel) are defined and then read in natural time (lower panel)