



## Natural Time Analysis and the physical verification for the existence of Seismic Electric Signals

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Recent results [1,2] have been published on the basis of the analysis of seismicity of Japan in a new time domain -termed natural time [3] -which reveals some dynamic features hidden in the time series of complex systems [4]. These recent results are as follows:

First, Varotsos et al. [1] identified that the fluctuations of the order parameter of seismicity defined in natural time [5] exhibited a clearly detectable minimum approximately at the time of the initiation of the pronounced Seismic Electric Signals (SES) activity observed by Uyeda et al.[6,7] almost two months before the onset of the volcanic-seismic swarm activity in 2000 in the Izu Island region, Japan. These two phenomena were found to be also linked in space, which is discussed in the frame of earthquake networks. SES are low frequency ( $\leq 1$ Hz) changes of the electric field of the Earth that have been found in Greece [8-11] and Japan [6,12,13] to precede earthquakes with lead times ranging from several hours to a few months. They are emitted [14] from the focal area when the stress reaches a *critical* value before the earthquake occurrence.

Second, Sarlis et al. [2] proceeded to the analysis of the Japan seismic catalog in natural time from 1 January 1984 to 11 March 2011 (the day of the occurrence of the  $M_w$ 9.0 Tohoku earthquake) and showed that the fluctuations of the order parameter of seismicity exhibits distinct minima a few months before all the shallow earthquakes of magnitude 7.6 or larger during this 27 year period in Japanese area. Among these minima, the deepest one was observed before the  $M_w$ 9.0 Tohoku earthquake on  $\sim 5$  January 2011. This fact, in view of the aforementioned findings of Varotsos et al. [1], reflects that a strong SES activity should have been initiated on the same date, i.e., on  $\sim 5$  January 2011. This SES activity should be accompanied [15] by magnetic field variations mainly on the  $Z$  component [16], which has been recently verified by Xu et al. [17] who reported that anomalous variations of the geomagnetic field have been observed mainly in the vertical component for about 10 days (4 to 14 January 2011), i.e., approximately 2 months before the  $M_w$ 9.0 Tohoku earthquake.

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