Nonstationary electrical activity in the tectonosphere–atmosphere interface retrieving by multielectrode sensors: case study of three major earthquakes in Central Italy with M>6

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METHODOLOGY ARTICLE

Nonstationary electrical activity in the tectonosphere-atmosphere interface retrieving by multielectrode sensors: case study of three major earthquakes in Central Italy with M>6

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Abstract We present data analysis of multi-electrode measurements performed in the tectonosphere-atmosphere interface at Pizzoli and Chieti observatories located at distances 30–50 km and 90–110 km from earthquakes epicenters in Central Italy accordingly. Time intervals include 30 days of observations before earthquakes occurred on 24 August (M6.2), on 26 October (M6.1) and on 30 October, 2016 (M6.6). The recorded signals are two component time series with time step 1 s representing alternative and direct electromotive force components. Alternative electromotive force component in frequency band of 0.01 Hz to 4000 Hz is being recorded. Basic study has been carried out since 1989 at Kamchatka peninsula and since 2012 across Eurasia. The observation of nonstationary electric processes illustrates the nucleation of seismogenetic activity. We propose the hypothesis that nonstationary (sudden, abrupt in amplitude) electrical signals illustrate the proton permeability of rocks laying underneath the measuring sensor including a unique phenomenon of anomalous spontaneous deformation due to combination of proton environment and polymorphic transformation in condensed media. One of the interesting results is distinguishing the main zone of major earthquake nucleation which is corresponding as the earthquakes epicenters in Central Italy with M > 6. We suggest that by covering the northern, central and southern parts of Italy with a network of multi-electrode observatories near fault lines, towns and villages could pinpoint the possible coordinates of earthquake epicenter in a 30 day time window. The Chieti and Pizzoli observatories can form the basis of an extended network.

Keywords Nonstationary electric process · Proton permeability · Earthquake · Amatrice · Central Italy

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Abbreviations

AC	alternative component of ground electromotive force
C	central pit
Cosmetecor	Cosmic-meteo-tectonic correlations, also abbreviated to Distant School Cosmic-Meteo-Tectonics, based in Petropavlovsk-Kamchatskiy, Russia
DC	direct component of ground electromotive force
Emf	electromotive force
GND	local earthing system
iAReSP	International Association for Research Seismic Precursors, L'Aquila, Italy
INGV	Istituto nazionale di geofisica e vulcanologia, Italy
KPC	Kamchatka Prognostic Center at Petropavlovsk-Kamchatskiy Civil Defence and Emergency Regional Headquarter in 1991–1994 ya
M	magnitude of the earthquake

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MChS	Ministry of the Russian Federation for Affairs for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters, or internationally as EMERCOM
MTK	Matsukawa location of mountain Iwate telluric network, Japan
NE	north-east pit
RAS	Russian Academy of Sciences
SW	south-west pit
USB DAQ	data acquisition module connected to computer via universal serial bus
USGS	The United States Geological Survey
YRK	Yoriki location of mountain Iwate telluric network, Japan
VINITI	Institute for Scientific and Technical Information of Russian Academy of Sciences
VLF	very low frequency, designation for radio frequencies in the range of 3 kHz to 30 kHz

Introduction

In the fall of 2010, Department of Earth Science, Università "G. d'Annunzio" installed the first multielectrode observatory to monitor abrupt changes (nonstationary) in amplitude of alternative and direct ground electromotive force (acr. EMF) components before, during and after earthquakes. Before 2013 ground EMF values have been recorded nonregulary. In 2013 year the automatic data acquisition system was installed for continuous recording and archiving of ground electric signals at the Università "G. d'Annunzio and Web and Archive Servers of Distant School "Cosmic-Meteo-Tectonics" (acr. Cosmetecor) Network (http://cosmetecor.org). This ground EMF values time series provide the first on the go opportunity to investigate nonstationary (sudden, abrupt in amplitude) electrical process in time and frequency domains occurred in subsurface soils on the territory of Abruzzo region in central Italy in 30 days time windows. The paper presents technical parameters of observatory and specific nonstationary electric pre-earthquake signals obtained before Amatrice earthquake with M6.2 (24.08.2016) as well as before M6.1 (26.10.2016) and M6.6 (30.10.2016). Investigation is an approach to determine the location of earthquake with M6+ nucleation epicenter by placing dense multielectrode sensors network for analysing ground EMF values time series. First results were presented at the special session on 2016 Amatrice earthquake during 35rd General Assembly of the European Seismological Commission (7 September, 2016) with Dr. Alberto Michelini of INGV who was organizing the session.

The case study of earthquakes sequence in Central Italy with magnitude M > 6 as part of the many years of ground EMF values multi-electrode monitoring in Eurasia demonstrate the contradiction of theoretical hypothesis explaining the phenomenon with seismic mechanoactivation of rocks, for example, made in [Doda et al. 2010, Doda et al. 2011]. Accordingly to the Reid model, during the stress build-up, a rock deep below, experiences increasing levels of stress, that continuously vary with time [Reid 1910]. Then it releases in a sudden earthquake. The many years observation of nonstationary electrical signals has not shown response to the stress build-up. Nonstationary electrical signals are registered in step sequence manner before major earthquakes with magnitude M7+: one day and/or two days and/or several days, and/or tens days before earthquake in a 30 day time window [Bobrovskiy 2011b, Bobrovskiy and Kuznetsov 2016]. But no nonstationary electrical signals were registered in the time of earthquake releasing. The case study of earthquakes sequence in Central Italy provides a strong argument for ongoing practice of multielectrode sensor installment instead of using spatial dipoles. Finally obtained results is in accordance of what is called proton (positive charges) migration hypothesis [Vernadskiy, 1912, 1933, Larin 1970, 1993] that provides a further steps to probing Earth's interior from the study of ground EMF values, a conclusion that should be of wide interest to the Earth science community and system for Earth- and space-based monitoring of earthquake precursors.

Multielectrode observatory in tectonosphere-atmosphere interface in Abruzzo region

The Chieti University was the first location and the first European outpost of the novel multielectrode measurements in Eurasia. The installation has been realized by international group of scientist in the course of 14 days lectures and seminars on state-of-the-art of earthquake phenomena in Scuola Sisma of Chieti University. Course was directed by Full Professor Francesco Stoppa. The school is actually a research project applied to the Abruzzo area in an effort to involve young scientists, researchers and citizens in the learning of a potentially useful method to detect earthquake precursors before a strong local earthquake. It is based on a collaboration established between the researchers of the Department of Earth Science and Distant School Cosmo-Meteo-Tectonics (Vadim Bobrovskiy) from Petropavlovsk-Kamchatsky (Russia) (see Fig. 1).

Evaluation of the geological data for the selection of location of measurement system was a training task involving students. The multi-electrode electric ground observatory was installed at the Università "G. d'Annunzio" Chieti campus (geographical coordinates are 42°22″N 14°8″E), town in the Abruzzo region. Observatory sensors are buried in water-saturated soils at the distance of ~1.5 km away from the river bank and ~13 km north-east of the Adriatic Sea coast. The site is equipped with 3 shallow pits, each is ~2 m depth. Each pit contains four metal plates closely-spaced and horizontally arranged to be in intimate contact with the soil (see Fig. 2 and Fig. 3).

Fig. 1 From left to right: Adelaide Romano, Vadim Bobrovskiy,Carmellina Derose, Fancesco Stoppa, Antonio Moretti (Cosmetecor archive)

During the first year, data collection was performed occasionally by Giovani Iezzi in the laboratory of the Department of Earth Science till the end of 2012 when zero-floor room with equipment was affected by rain floods. After repairing and adding VLF instrumentation by PhD researcher Cristiano Fidani, the site was equipped with certified USB DAQ module E14-140 M by L-Card LLC (http://www.lcard.ru) and special software developed by the Cosmetecor collaborators. The recorded data is sent to Cosmetecor web-server via University Wifi network, and necessary time synchronization is provided by ntp software.

The second multielectrode observatory is located at Pizzoli (42°25″50.5″N 13°19″22.8″E), ~68 km north-west of Chieti and ~20 km South of town Amatrice, which was almost destroyed by Norcia earthquake on 24 August 2016 with magnitude M6.2. Organization of the Pizzoli multielectrode observatory is a result of international cooperation between scientific non-profit organizations International Association for

Fig. 2 Pit with single steel electrode in it: 1 – steel electrode, 2 – end of the coaxial cable, connected to the electrode

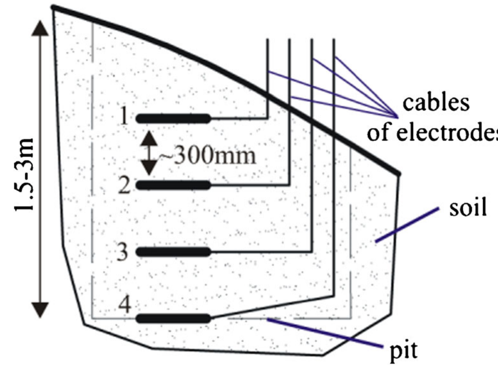


Fig. 3 General pit structure: 1,2,3,4 – electrodes

Research Seismic Precursors (iAReSP) and Cosmetecor and local authority, which is an overall efforts carried out by talented international research coordinator Yulianna Losyeva and director iAReSP Leonardo Nicoli (see Fig. 4).

Yulianna Losyeva efforts include "what to do" workshop related to earthquake research, earthquake prevention and mitigation through public-private collaboration. Meeting took place in Senate della Republica in Rome, on 24 November 2015 two days before Pizzoli installation. Representatives of both (iAReSP and Cosmetecor) non-profit scientific organisations, researchers, professors and senators spoke about acceptable approach to prevent seismic calamity. Chieti and Pizzoli multielectrode observatories located close to the main fault line of Central Italy are the first stations which shows up the advances of measuring technique and gives hope to pinpoint the possible coordinates of earthquake epicenter and could map a possible earthquake nucleation zone with M6+ in a 30 days time window.

Fig. 4 International research coordinator Yulianna Losyeva and Leonardo Nicoli from iAReSP on 26 November 2015 in Pizolli (Cosmetecor archive)

Methodology

Prehistory of utilizing terrestrial electricity in the problem of earthquake prediction

Throughout recorded history, reliable observations of terrestrial electricity have been obtained on faults in seismic active regions of Japan, Greece, China, Russia, California and several other locations. Classical approach (classical telluric measurements) is a measurement of potential differences between the two pairs of non-polarizable electrodes which were distributed at a distance of hundreds meters to several kilometers in magnetic meridian and parallel direction. Such "crosses" are being used up to now to recognize the nonstationary processes occurring before earthquakes in seismic-hazardous areas of Greece and Japan. The most important problem with classic telluric measurements is the integral character of signals (many potential sources of hardly accountable influences) on the dipoles while approaching to the earthquake and uncertainty of location of next strong earthquake's epicenter. Figure 5 shows data from two sites: Yoriki (YRK) and Matsukawa (MTK) of Mt. Iwate network ~14 days before the earthquake with M6.1 occurred on 03 September 1998 [Uyeda et al. 2000].

The intensity of the transient signals on the long dipole (L = 3.06 km) of YRK was much smaller than that on the short dipoles. In fact, one of the short dipole (L = 20 m) at YRK did not show any change at all. Moreover, no changes occurred at MTK, which is ~3 km from YRK.

Such examples state the following questions:

- What was the cause of difference in signals at stations located ~10 and 13 km from epicenter M6.1 earthquake?
- Is the distance between earthquake epicenter and monitoring station an important characteristic for monitoring of earthquake nucleation activity or the location of monitoring station is of greater importance?

Generally, telluric electric potential differences anomalies demonstrate mosaic behavior registered at the regional measuring lines. This causes a false alarms evolving in civil protection decisions. In fact, spatial dipole measuring instrumentation has no essential improvements since Schlumberger times. Spatial dipoles record integral signal from sources, mainly having magnetosphere-ionosphere origin. Since electrotelluric anomalies have being almost discussed 100 years, geophysicists agree that extraction anomalies of intra-Earth origin from spatial dipoles is a very complex task. The question "What is happening with telluric electricity at other distant locations laying outside the regional network of monitor stations?" was never systematically investigated.

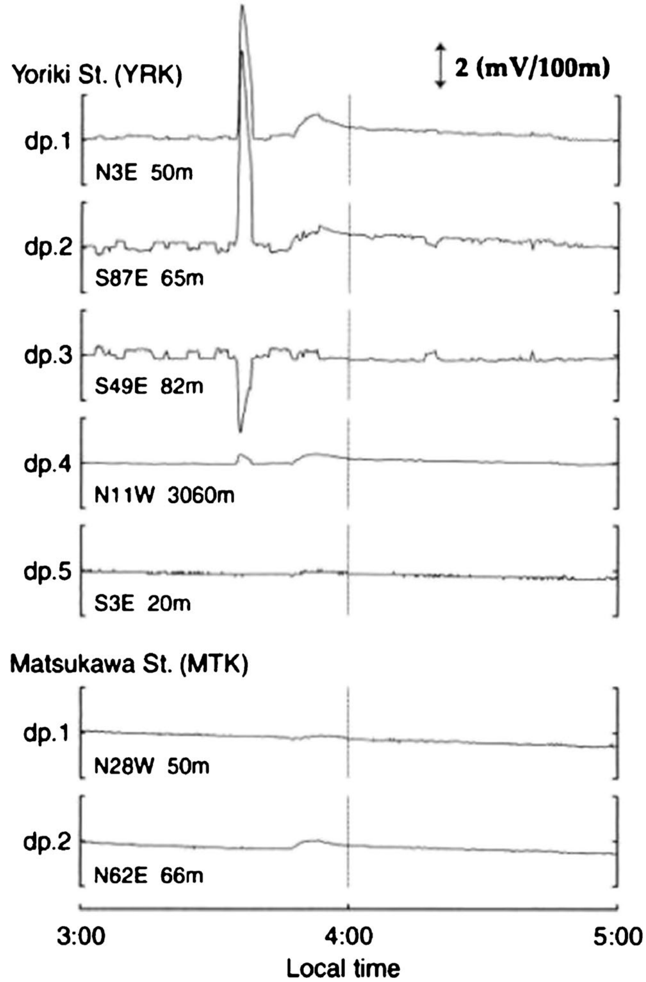


Fig. 5 Preseismic transients on 20 Aug 1998 recorded at YRK and MTK stations before earthquake M6.1 occurred 03 September 1998 [Uyeda et al. 2000]

Background of multi-electrode observatories development in Eurasia

Multi-electrode ground measurement technique was introduced by Docent D. Kuznetsov at the end of 1980-s years in Kamchatka. He developed and tested the system of the vertical sequence of electrodes closely-spaced and horizontally arranged. At the development stage, it was expected to obtain signals with less potential (magneto-ionosphere origin) effects than classical spatial dipoles and as a consequence to register nonstationary electric process with much richer signal structure and its information content in the tectonosphere-atmosphere interface. Multielectrode system has become the basis of international monitoring network containing the observatories across Eurasia for synchronous recording of ground EMF values.

The first pit with vertical sequences of electrodes was installed at the backyard of Kamchatka State University in spring 1989 yr., when Candidate in Physical and

Table 1 Short-term and operative predictions developed by the Kamchatka Prognostic Center

Date of prediction	Prediction statement	Actual event
07 October 1991 Short-term	…in a square 4*4 of geographical degree with center in Petropavlovsk-Kamchatskiy (main site of Kamchatka Prognostic Center) it was observed increasing of a probability up to 0.6 ± 0.2 of an earthquake with magnitude M ≥ 7.75 over interval from November, 1991 till February, 1992	Strong earthquake with magnitude Mpsp = 6.8, Mplp = 7.1, Ms. = 7.1 occurred on 02 March, 1992 12:29:59.3UT; epicentre distance *R* = 60 km;
04 March 1992 Operative term	Probability of the earthquake with magnitude M7 within a radius of 100 km from Petropavlovsk-Kamchatsky on 06:50 ± 01 (Kamchatka local time) 06 March 1992 is 0.7 ± 0.2	Strong earthquake with magnitude Mpsp = 6.7, Mplp = 6.8; occurred on 06 March, 1992 02:39 Kamchatka local time (05 March 1992 14:39:10UT), epicentre distance *R* = 80 km

Mathematical Sciences, member of International astronomical union Dmitriy Kuznetsov had arrived on Kamchatka. Docent Kuznetsov and students of the physics department organized Kamchatka Prognostic Center. The scientific progress of Kamchatka Prognostic Center was developed during "seismic panics" of winters of 1989/1990 yr. and 1990/1991 yr., when the prediction of catastrophic seismic calamity threatened local Kamchatka authorities and public. Docent Kuznetsov provided daily reports with data analysis of changes of ground EMF values to the rector of Kamchatka State Institute and Deputy of Regional Council, who sent it to the Chief of Emergency Committee of Kamchatka region. In his report he explained scientific observation of data and showed that he did not expect any seismic hazard during specified timeframe.

During the summer of 1991 yr. in Kamchatka, Emergency Committee of Kamchatka region organized all-Soviet Union workshop focused on the topic of "Problems for earthquake prediction" under Kuznetsov supervising. Afterwards, routine multielectrode measurements were started and carried out from December 1991 to November 1994 yr. The main site and office of Kamchatka Prognostic Center was situated in the Petropavlovsk-Kamchatsky Civil Defence and Emergency Regional Headquarter.

The most significant achievement of Kamchatka Prognostic Center was the development of short-term and operative (two days in advance) earthquake predictions of strong earthquakes in 1991 and 1992 years. Predictions were officially submitted to the regional authorities and the Ministry of the Russian Federation for Affairs for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters (MChS). Table 1 summarizes prediction statements and its realizations. The expert council of Russian Academy of Sciences (RAS), headed by the RAS corresponding member G. Sobolev, had examined on 23 April 1993 the results of the research carried out by Kamchatka Prognostic Center. The report of experts contained the recommendation to implement the network of such observatories and continue research.

In spring of 1994 Docent Kuznetsov summed operative pre-earthquake and pre-volcanic signals observed at Central station (main site of Kamchatka Prognostic Center) in 1993 year. He sent as a chief of Kamchatka Prognostic Center under Kamchatka Emergency Committee the results of analysis (see Fig. 6) to M.A. Shakhramanjan, the Chief-Deputy of Department for scientific and technical programs of MChS.

In year 1995 multielectrode measurements were terminated and Docent Kuznetsov moved to Kamchatka Technical University, where he and his team of graduated student were working throughout the several years to examine the nonstationary electric ground EMF values at many locations in Kamchatka before earthquakes with magnitude M6 + .

In 1997, V. Bobrovskiy, being at that time a second year student of electrical engineering, joint for the first time Kuznetsov's laboratory. This work evolved through the years to the Cosmetecor Distant School: in 2001 year, the experience including technical, electric engineering and computational education of a research group, has strengthened well to establish the Cosmic-Meteo-Tectonics Distant School (Cosmetecor) and obtain the whole records and archives of Kamchatka Prognostic Center. Till today, the Cosmetecor is growing and always open to collaboration, specially to the young talent students who represent the future of the science.

Cosmetecor organized permanent voluntary service for operative (from hours to 30 days) identification of earthquake precursors of electrical origin in the subsurface soils (in the tectonosphere-atmosphere interface). Data analysis involved also astrophysical and cosmophysical nonstationary processes as well.

The first, scientific achievement of Cosmetecor is associated with bad-known seismic panic at Kamchatka in autumn of 2005 year. Peter Shebalin (from Institute of earthquake prediction theory and mathematical geophysics, founded by academician Keilis-Borok in Moscow, Russia) had made the prediction of earthquake with M > 7.1 with probability of 50% on the South of Kamchatka for autumn of 2005 yr. Time series analysis of ground EMF values obtained at measurement site in Petropavlovsk-Kamchatsky did not reveal any evidence for strong earthquake on Kamchatka in autumn 2005 yr. On the contrary, time series analysis of ground EMF values revealed

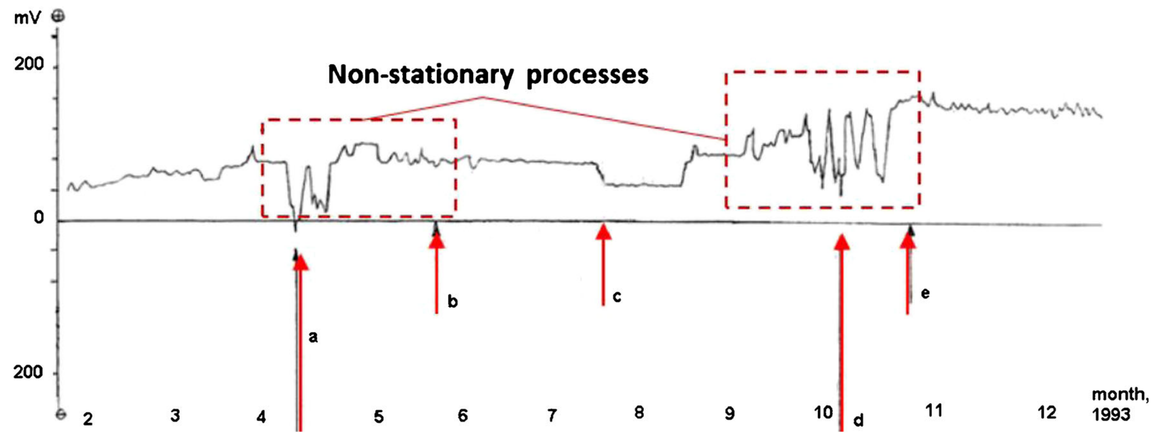


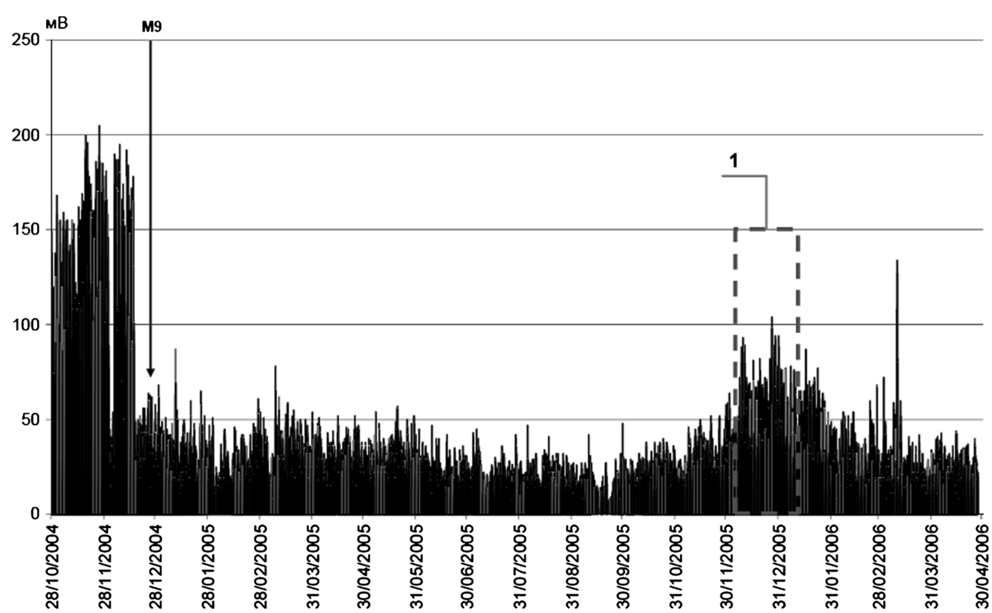
Fig. 6 Archive data of pre-earthquake and pre-volcanic EMF signals at Central Station of Kamchatka Prognostic Center, Petropavlovsk-Kamchatsky, 1993 year. (**a**) eruption of Shiveluch volcano (height of ash cloud of 16–18 km on 22.04.1993 (**b**) M7.5 06.06.1993 (I = 6 balls in Petropavlovsk-Kamchatskiy of 12 intensity MSK-64 scale) of east coast of Kamchatka (**c**) eruption of Kluchevskoi volcano (**d**) eruption of Bezymyannij volcano (long ashes tail of Komandorskij island e) M7 13.11.1993 (I = 5 balls in Petropavlovsk-Kamchatskiy of 12 intensity MSK-64 scale) of east coast of Kamchatka

the possibility of the strong earthquake with M ≥ 7 risen up to 75% during spring of 2006 yr. (see Fig. 7).

This regional prediction of strong earthquake with M ≥ 7 was developed and presented at the conference "Decrease of seismic risks in Kamchatka-Kuril zone". Ministry of the Russian Federation for Civil Defense (MChS), Institute of Earthquake Prediction Theory and Mathematical Geophysics (http://mitp.ru/), Russian expert council for earthquake prediction (Moscow) organized the conference on the 7 December, 2005 in Petropavlovsk-Kamchatsky. Bobrovskiy presented on the conference short-term regional Kamchatka peninsula prediction of strong earthquake with M ≥ 7 that should occurred in the following months from January to May of 2006 with maximum probability on 05th May 2006 ± 14 days. Then Bobrovskiy published prediction and its enlarged illustrative materials in All-Russian institute for Scientific and Technical Information Russian Academy of Science [Bobrovskiy 2005]. Earthquake with magnitude M7.6 occurred on 20 April, 2006 23:25:05 UT in the north of Kamchatka peninsula territory (Koryak Highlands). Figure 8 represents operative pre-earthquake signals.

The last strong earthquake with M7.2 at a distance ~100 km from Petropavlovsk-Kamchatsky occurred on January 30, 2016. Cosmetecor group developed the short-term regional Kamchatka peninsula prediction of strong earthquake with M ≥ 7 that should occurred in the following months from January to May of 2016. The short-term prediction was sent on December 25, 2015 and was registered in Russian expert council for earthquake prediction (sent by e-

Fig. 7 Archive data of pre-earthquake signals at station #1 (expert school polygon), channel North-East, alternative EMF, Petropavlovsk-Kamchatsky, 2004–2006 year. M9 – tsunamigenic earthquake in Indonesia 26.12.2004; 1) – short-term anomaly



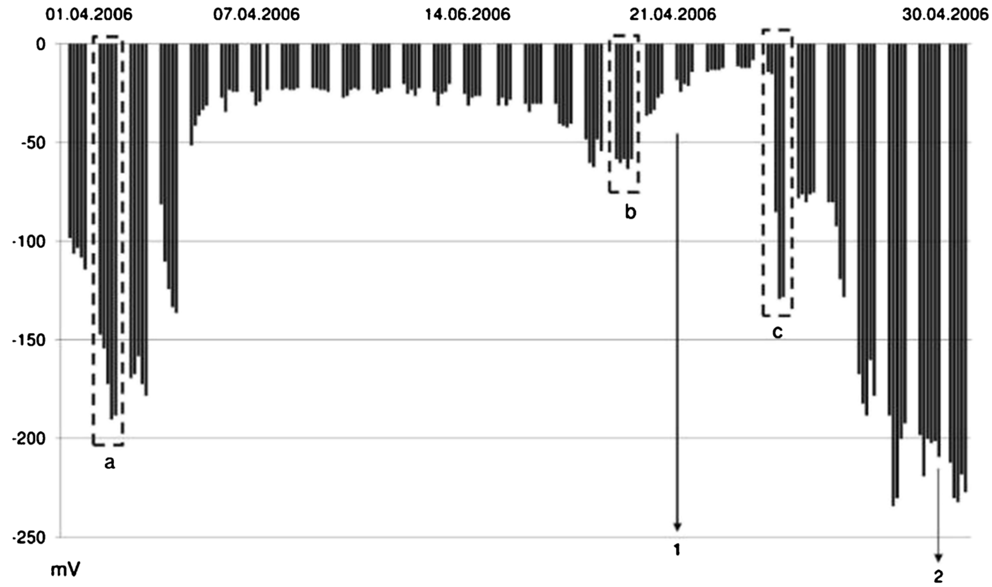


Fig. 8 Archive data of pre-earthquake signals at station #1 (expert school polygon), channel South-West the deepest pair of electrodes with number 5 and 6, direct EMF, Petropavlovsk-Kamchatsky, 01.04.-30.04.2006: 1) – EQ. 20.04.2006 with M7.6; 2 – aftershock 30.04.2006 with M6.4; a) signal ~19 days prior to EQ-M7.6; b) signal ~2 days prior to EQ-M7.6; c) signal ~5 days prior to aftershock EQ-M6.4

mail to academic secretary A. Ruzaykin on December 25, 2015, reception was confirmed by addressee). Figures 9 and 10 represent the development of pre-earthquake nonstationary electric processes.

In 2012 year, Cosmetecor under Bobrovskiy supervising organized international research collaboration. Multielectrode observatory network covers the locations across Eurasia: Kamchatka peninsula, South of Siberia (Gorno-Altaisk town), Central Russian Upland (Tula city), Black Sea (Crimea peninsula), Italy (see Fig. 11). Twelve stations, each consisting of 12 buried electrodes at depth of 1 to 3 m, recorded ground EMF values once per second. Recent results of research activity can be found in the paper [Lyubushin et al. 2016]. The scientific reports with total number of 24,000 pages sum continuous multielectrode measurements since 2001. They were published in Institute for Scientific and Technical Information of Russian Academy of Sciences (VINITI RAS, http://viniti.ru).

In 2016 Cosmetecor with help of international research coordinator Yulianna Losyeva has established cooperation with partners from South African National Space Agency (SANSA), SASTRA University (India) and GeoCosmo Science SPC (California, USA) to expand Cosmetecor-net in other continents.

Global seismic conception by Gutenberg and Båth

Conception of seismic globalism forms the basis of a global distributed multi-electrode observatories and has associations with eminent seismologists Beno Gutenberg and Marcus Båth.

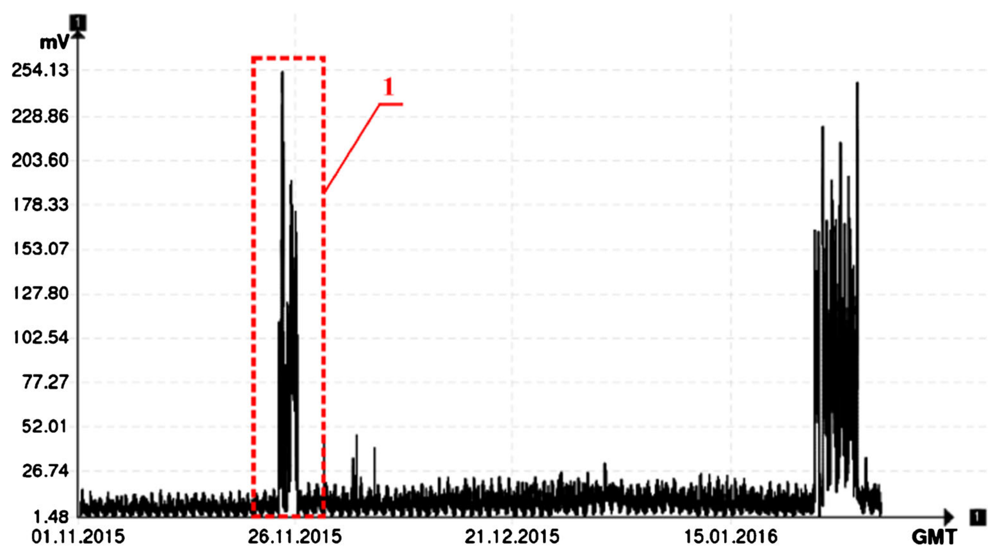


Fig. 9 Archive data of pre-earthquake signals at station #1 (expert school polygon), channel South-West, subsurface electrodes with number 1 and 2, alternative EMF, Petropavlovsk-Kamchatsky, 2015–2016 year. 1) – short-term anomaly

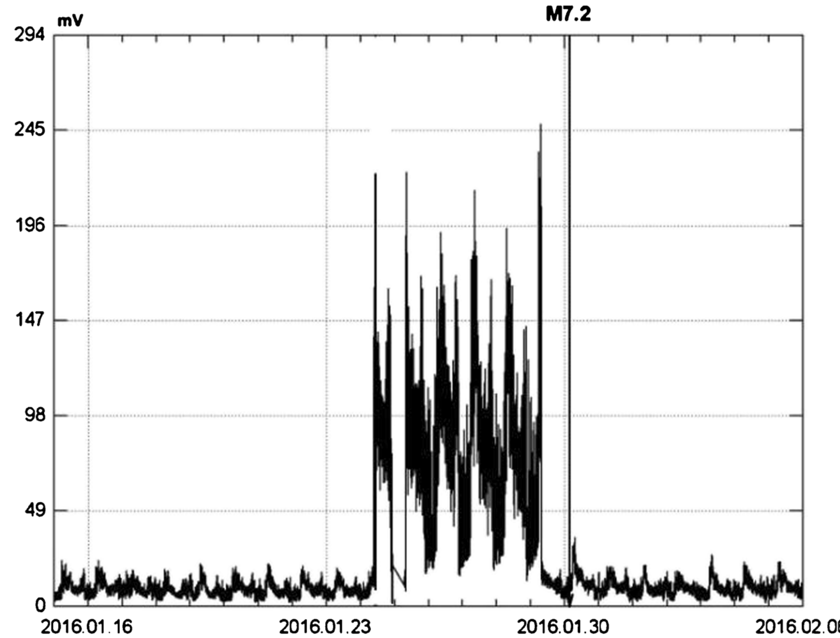


Fig. 10 Archive data of pre-earthquake signals at station #1 (expert school polygon), channel South-West, subsurface electrodes with number 1 and 2 alternative EMF, Petropavlovsk-Kamchatsky, 15.01.-05.02.2016 year. M7.2 – EQ in Kamchatka 30.01.2016

In the early works, Gutenberg determined the radius of the Earth's core, a value still used in many modern textbooks. Gutenberg wrote his monograph "Grundlagen der Erdbebenkunde" (Basic principles of seismology) [Gutenberg 1927], at that time he was an associate professor at the University of Frankfurt-am-Main. Among the books published or edited by Gutenberg this one popularizes the most intriguing tasks and concerns in seismology and geophysics of the twentieth century.

In eleventh paragraph of his book [Gutenberg 1927] called "§11 Parallelismus Erdbebenhäufigkeit und zwischen meteorologischen Elementen sowie kosmischen Erscheinungen" Gutenberg reviewed much discussed correlations between earthquakes frequency, meteorological elements and cosmic phenomena. The term "cosmic phenomena" is related to Sun spots, whose magnetic fields were considered as the surface occurrence of currents, flowing in the deep layers of the Sun. The term "meteorological elements" is related to structures, that appeared by condensation of electric dipoles (molecules of water), as it was assumed, on the charged particles of dust in the Earth atmosphere.

Set of data observation from Europe and Japan have been given for consideration of meteo-tectonic correlations. It was found very high correlation between both phenomena constituting the possibility that these phenomena are taking place in parallel. An assumption is made by Gutenberg is that distinct critical changes in meteo-elements (barometric pressure, cyclones) and their geographical distribution could assume a fundamental role in occurrence of the earthquakes. Gutenberg asked: how can be achieved that such global meteo-tectonics effect covers broad areas and cumulates in such very small volumes of earthquakes foci? It is a reasonable question of seismologist, who estimates the parameters of earthquake source obtained from records in a specific location on the earth surface while extension of meteo-elements and their effects dominate broad area above the earth surface including earthquake focus underneath as a small part of it.

The second scientific question posed by Gutenberg is a relationship between sunspots and frequency of earthquakes. After the research, his conclusion was that there is a flaring parallelism between earthquakes frequency and sun affecting space weather of which perturbation covers whole globe. As in case of meteo-

Fig. 11 Multielectrode SE observatories: 1–5 stations in Petropavlovsk-Kamchatskiy and Elisovo; 2 – Esso; 3 – Gorno-Altaisk; 4 – Crimea; 5–2 stations in Italy; 6,7 – Russian Upland (Tula, Efremov)

parallelism the same question arise on a parallelism between sunspots, magnetic perturbations and earthquakes frequency: how can be achieved that such global cosmic effect covering whole globe cumulates at once in the earthquake focus?

B. Gutenberg was a single one among other scientists who claimed that seismic process has a global nature, but without proposition of a mechanism. There was not any investigation of seismic globalism until then 1960s. A number of disastrous earthquakes of 1960s gave a chance to make the prospects by supplementing planned international projects with studying of global seismic effect.

In 1966 Sweden seismologist M. Båth [Båth 1966] outlined that seismic activity was being decreased in the rest of the globe during intensive aftershock sequences of Alaska earthquake (28 Mar. 1964) and Aleutian earthquake (4 Feb. 1965). Figure 12 illustrates his findings. Båth called it global seismic effect. This global seismic effect shows global inter-connections between earthquakes epicenters, which are located at a distances of thousands kilometers apart. He was so certain about his theory that he proposed several international and regional projects for further investigate his findings.

Proton tectogenesis hypothesis and proton permeability of rocks

Thin layer of subsurface soil is used to measure nonstationary electrical process parameters in tectonosphere and atmosphere interface. In scientific publications tectonosphere is defined as combination of tectonic processes in earth crust and upper mantle [Beloussov 1990].

The scientific method of measurements has deep roots in the theory developed by prominent Russian scientists [Vernadskiy 1912, 1933; Larin 1970, 1993; Kuznetsov 1991]. They have been elaborating theory since the beginning of XX century in Soviet Union. The theory is saying that tectonic processes occur while protons migrate upward from outer Earth hydride core into the outer space near Earth through lower mantle, asthenosphere, tectonosphere, atmosphere, ionosphere and magnetosphere. By the years it has been implemented and enhance with research in laboratories and natural-scaled experiments, were being carried out since 1970s.

The presence of significant amounts of hydrogen nucleus in the Earth"s core is an essential precondition of the theory that fits well with the most sophisticated density measurements of the planet and most advanced studies on the dynamics of Earth core and its interaction with the mantle. The presence of ultra deep chemical plume (ultra-alkaline magmatism) mobilized by H+ is thoroughly investigated by research groups led in Italy [Stoppa and Lavecchia 1992; Stoppa 2010] and in Canada [Bell and Tilton 2002; Bell et al. 2005].

The model of the Earth"s hydride core has been discussed by many authors to justify some otherwise mysterious peculiarities [Hemley and Mao 1990; Badding et al. 1991; Loubeyre et al. 1996]. The topic involves the behavior of metallic solids in the presence of liquid hydrogen in the ultra pressure conditions. With the launching of Earth observation satellites, Vernadsky's hypothesis was confirmed [Cannata and Gombosi 1989], leaving a little doubt that origin of proton upwelling phenomenon, i.e. lifting of hydrogen ions from ionosphere into near Earth space, has deep roots in Earth interior.

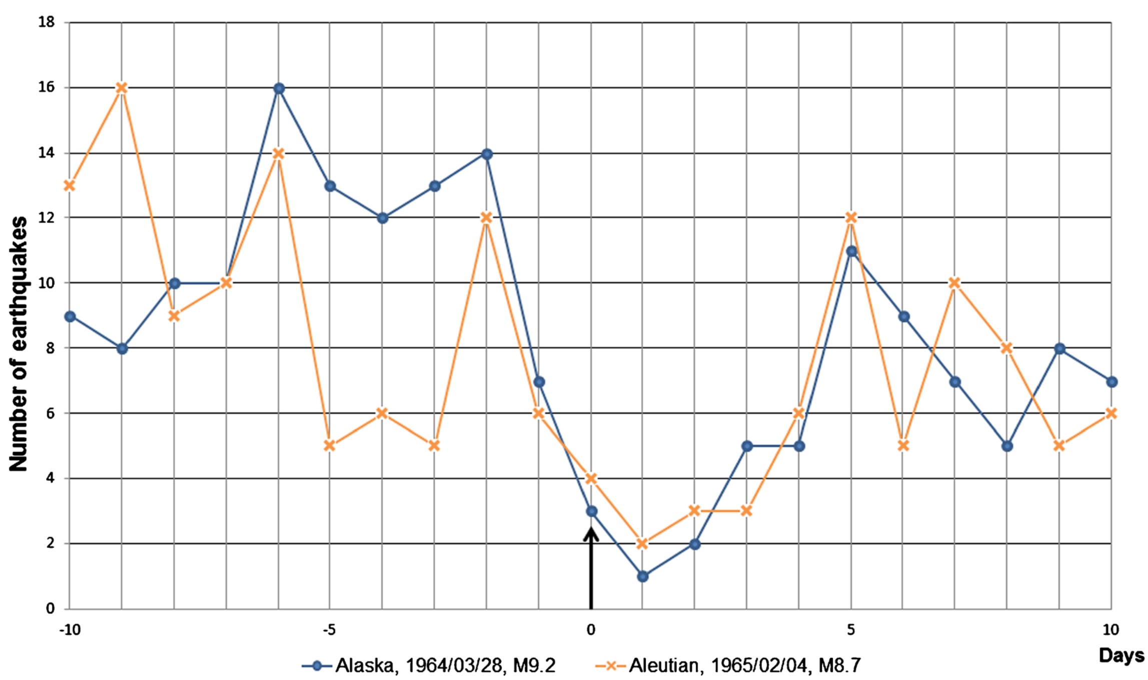
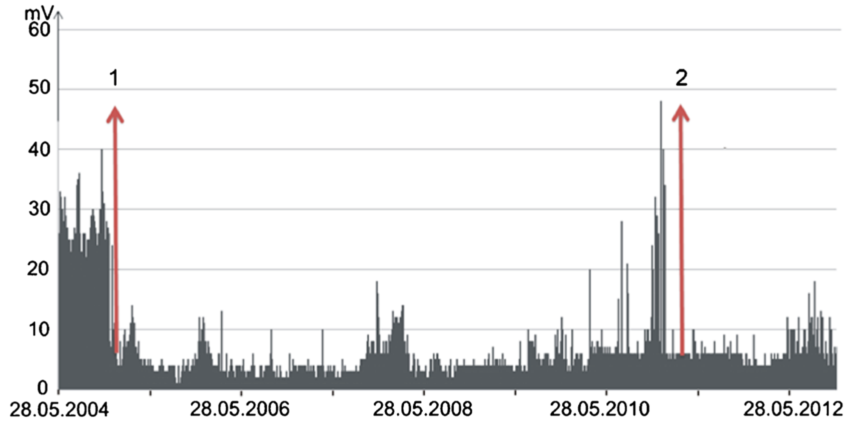


Fig. 12 Illustration of seismo-global process from M. Båth [1966]

Fig. 13 Long-term observation of nonstationary geoelectric changes 2004–2012 yrs. channel SW56 at S1-DESP in Kamchatka, 1 – tsunamigenic earthquake M9.1 26.12.2004 in Indonesia; 2 - tsunamigenic earthquake M9 11.03.2011 in Japan



Migration of hydrogen in proton form (H^+) was proposed by Larin on the basis of earlier observations made by Vernadsky. Larin showed that the migration of hydrogen in the atomic form is impossible from the Earth core, but migration of H^+ ions from the Earth's core upward to the Earth's surface and near Earth space can be linked with increased tectonic activity [*Larin* 1970, 1993]. The presence of H+ in the core has strong implications on many phenomena that propagate to the surface of the planet as the carbonate magmatism, the formation of diamonds and hydrocarbons with implications on seismic and volcanic risk [Stoppa 2010]. Kuznetsov studied Larin's model in natural-scaled experiments. He proposed that proton migration is impulse process [Kuznetsov 1991]. Many years study of ground EMF values has proved this hypothesis. Proton migration phenomenon demonstrates its intermittent behavior prior to the strong earthquakes with magnitude M7+, i.e. it is nonstationary process [Bobrovskiy and Kuznetsov 2011a, 2011b, Bobrovskiy and Kuznetsov 2016].

Kuznetsov's measurement technique provides an instrument probing Earth's interior from the study of ground EMF values. Recorded nonstationary electrical signals significantly illustrates how ground density of tiny protons pathways in the tectonosphere and proton permeability of the rocks are a regulating mechanism of structural and phase transformations in geological structures. It appeared that atoms of metals incorporate protons into their crystalline lattice which in turn causes polymorphic transformation in condensed media including a unique phenomenon of anomalous spontaneous deformation [Shapovalov 2009] due to combination of cycles of protons accumulations. Experimentally, this can be detected by the sudden changes of EMF amplitudes registered by the network of multi-electrode sensors. While intensification of nonstationary electric processes in the ground-air interface occurs around nucleation of seismogenetic activity zone, we wouldn't observe intensive nonstationary electric processes due to the lower proton permeability of rocks in the inner idealized cylinder-like zone. Finally, seismic waves illustrate structure transformation.

One of the major difficulties faces in determining such effects has been the lack of long-term records of ground EMF values on a dense local, regional and global network. On-going research and investigation in Kamchatka and in Eurasia have shown that nonstationary electric processes in the ground-air interface could be observed at multielectrode stations (see Fig. 13) at spatially distributed locations with great distances from each other [Bobrovskiy and Kuznetsov 2011a; 2011b; Bobrovskiy and Kuznetsov 2016]. This provides a strong argument to investigate fast global connections (M.Båth) between earthquake's epicenters in the context of nonstationary electrical processes distribution around the globe. Some examples of signals registered before strong earthquakes in the world are shown in [Bobrovskiy and Shopin 2015].

Cosmetecor network of multielectrode observatories reveals uniqueness of recorded ground EMF values across Eurasia. Recent complexation analysis [Lyubushin et al. 2016] of Cosmetecor data time series found that behavior of multi-electrode data time series was constantly synchronous (collective) between combinations of signals from stations in Kamchatka, in Altai, and Italy before, during and after mantle earthquake with M8.3 in Okhotsk Sea (24 May 2013). Also it was found synchronization (coherence) of Cosmetecor-net data along with low frequency microseismic background noise (F-net broadband seismic network, Japan) in the time-frame of preparation of strongest deep-focus Okhotsk Sea earthquake of 24 May 2013.

The two multielectrode observatories in Central Italy formed a platform with the ability to register nonstationary electric parameters at relevant scales on a regional basis and help to study the relationship between earthquake nucleation zone and ground EMF values changes.

Chieti and Pizzoli multielectrode observatory

The seismic hazard in the province of Chieti, Pescara and in the high Valle Peligna Conca is very high. The high-populated cities are in this area such as Chieti and Sulmona, dams, industrial plants etc. For earthquake precursors research, measuring stations (multi-electrode stations) are suggested to be placed according to main seismic genetic structures including dense network of station at villages, villas, schools.

At Chieti and Pizzoli observatories, typical measurement scheme [Bobrovskiy and Shopin 2015] is used. Chieti station as well as Pizzoli station are equipped with three shallow pits: south-west (SW), central (C) and north-east (NE) spaced 2 m apart and 45 degrees to geomagnetic meridian. Each pit has a depth of 2 m. Four metal electrodes having typical sizes of 500x500x3 mm are horizontally arranged in the pit in the intimate contact with soil of thickness of ~400 mm. Figure 3 shows pit construction with a bit different dimensions of elements.

Each electrode is connected to a coaxial cable. Measured values are the EMF between pairs of electrodes in a single pit (electrode-electrode scheme), between the second electrode in the NE pit and electrodes in two C- and SW pits (subhorizontal scheme) and between each electrode and the common electrical ground. Mains neutral wire or local earthing system or steel water pipeline, having electrical contacts with the ground, are used as the local electrical ground. Electrodes in pits are marked by increasing sequential numbers from uppermost to lowermost. Zero electrode is GND. Measured EMF values are denoted using pit name and electrode numbers, i.e. channel NE2SW3 means EMF values between electrodes NE2 and SW3, NE04 means EMF values between GND and NE4 electrode, NE12 means EMF values between electrodes NE1 and NE2.

Set of measuring parameters contains at Chieti and Pizzoli observatories contains 16 measurement channels:

- five EMF values in electrode-electrode scheme (NE12, NE23, NE34, C12, SW12)
- five EMF values in subhorizontal scheme (NE2C1, NE2C4, NE2SW1, NE2SW2, NE2SW3);
- six EMF values between electrodes and GND (NE01, NE02, NE03, NE04, C01, SW01).

Currently, for each channel, AC and DC component of subterranean electromotive forces are measured. Measurements are performed in the ultra-low frequency band (4...4000 Hz), including quasi-DC component and covering the frequency range of waveguide ground-ionosphere. AC component is calculated as half-period average voltage. Measurement time series are stored with ~1 s time step.

AD conversion is performed using a sample rate of 12.5 kHz and 14 kHz (for each channel). Antialiasing filter is 8-th order Chebyshev filter with cut-off frequency of 4 kHz. Signal processing is done by software. Currently DC- and AC-components are computed for each channel. Signal processing scheme is shown in Fig. 14.

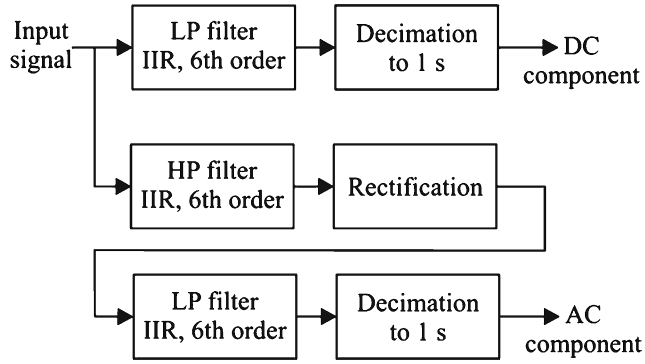


Fig. 14 Signal processing scheme

The DC component is calculated by low-pass filtering of the input signal with IIR 6-th order filter with cut-off frequency of 10.0 mHz and followed by decimation to 1 s sampling interval. The AC component calculation is performed by high-pass filtering of the input signal with IIR (infinite impulse response) 6-th order filter with cut-off frequency of 4 Hz, followed by rectification (getting the absolute value of signal), low-pass filtering and decimation to 1 s sampling rate. Low-pass filtering in AC component stage is performed by the same filter as used in the DC component stage. Digital lowpass and highpass filters are designed as cascaded biquadratic Bessel filters. Calculated values of AC and DC components are written to hard drive on a daily basis.

Developed processing scheme is analogous to the measurements of AC and DC voltages by regular multimeter. It was used to provide comparability of new data with the old one, because prior to 2012 year measurements were human-made using a multimeter and significant data archive was acquired this way.

Because of the constraint on the input channel count of the measuring equipment, channel count for Chieti and Pizzoli stations is decreased to only 16 measuring channels. Full set of EMF alternative and direct components is 32.

Pre-earthquake signals for the Central Italy earthquake sequence of 2016 year

Here we show ground EMF data time series at Chieti and Pizzoli locations noted as station No.6 (acr. S6) and station No.9 (acr. S9). Table 2 summarizes recent seismic activity with magnitude M > 6 occurred in Central Italy in August–October 2016. We are seeking for the nonstationary (intermittent, sudden changes in amplitude) signals in the data registered by Chieti and Pizzoli observatories. Such signal examples obtained at the Kamchatka observatories are shown in [Bobrovskiy and Shopin 2015].

The datasets generated and analysed during the current study are available in the Figshare repository, [doi: 10.6084/m9.figshare.4256612] and [doi: 10.6084/m9.

Table 2 Earthquake M6+ epicenters in Central Italy and distance from epicenters to sensor location, source the United States Geological Survey (USGS), http://earthquake.usgs.gov/

Date, Time, UT	Coordinates, degrees	Depth, km	Magnitude	Chieti sensor, distance to epicenter, km	Pizzoli sensor, distance to epicenter, km
2016/08/24 01:36:32	42.723°N 13.188°E	4	6.2	88	34
2016/10/26 19:18:08	42.934°N 13.043°E	10	6.1	110	59
2016/10/30 06:40:19	42.855°N 13.088°E	10	6.6	102	50

figshare.4256603] and included in its supplementary information file.

Amatrice earthquake case of 24 August 2016, M6.2

Accordingly to USGS analysis, an earthquake, measuring with magnitude M6.2 hit Central Italy on 24 August 2016 at 01:36 UT. Its epicentre was close to Accumoli, approximately 75 km southeast of Perugia and 45 km (28 mi) north of L'Aquila, in an area near the borders of the Umbria, Lazio, Abruzzo and Marche regions. As of December 2016, 299 people have died across the region, and at least 230 of 299 were killed in the Amatrice town.

Analysis of the 30 days plots (from 26 Jul to 28 Aug 2016) of Chieti measuring observatory shows two types of nonstationary signals of ground EMF values.

1) impulse sequence lasted ~7 days long during 31 July-06 August 2016. It was 19 days before M6.2 (24 Aug 2016).
2) impulse-like, intermittent signal recorded on 20 August 2016. It was ~3 days before M6.2 (24 Aug 2016).

Examples are shown in Fig. 15 (full list of plots is provided in Appendix 1). There are 14 dipoles out of 16 that demonstrate nonstationary electric processes during the period from 31 July to 06 Aug 2016.

There are only 4 channels out of 16 (both alternating and direct current) that shows up nonstationary electric impulse-like process on 20 Aug 2016 presented on Figs. 16 and 17.

Pizzoli station is just of ~20 km from devastated Amatrice town and of ~30 km from earthquake epicenter M6.2 (24 Aug 2016). Analysis of 30 days of pre-earthquake signals (from 26 Jul to 28 Aug 2016) of Pizzoli observatory doesn't show any nonstationary process. Figure 18 shows typical signal example at Pizzoli observatory (full list of plots is provided in Appendix 1). There was out of electricity on 24 of August, that was shown as short down peak in EMF, alternating component of some channels).

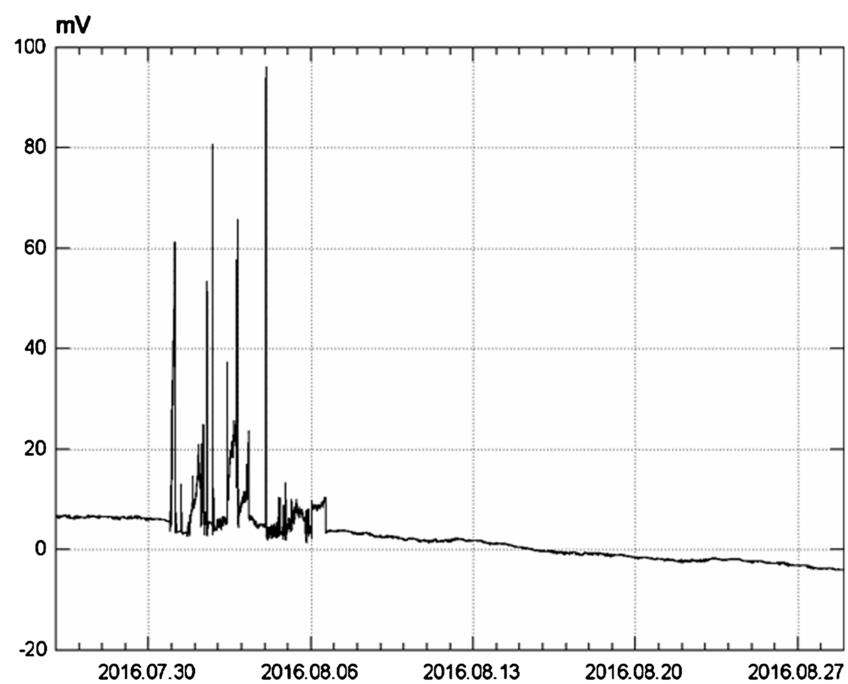


Fig. 15 30 days plot of EMF, direct component, channel NO1 at Chieti obseratory

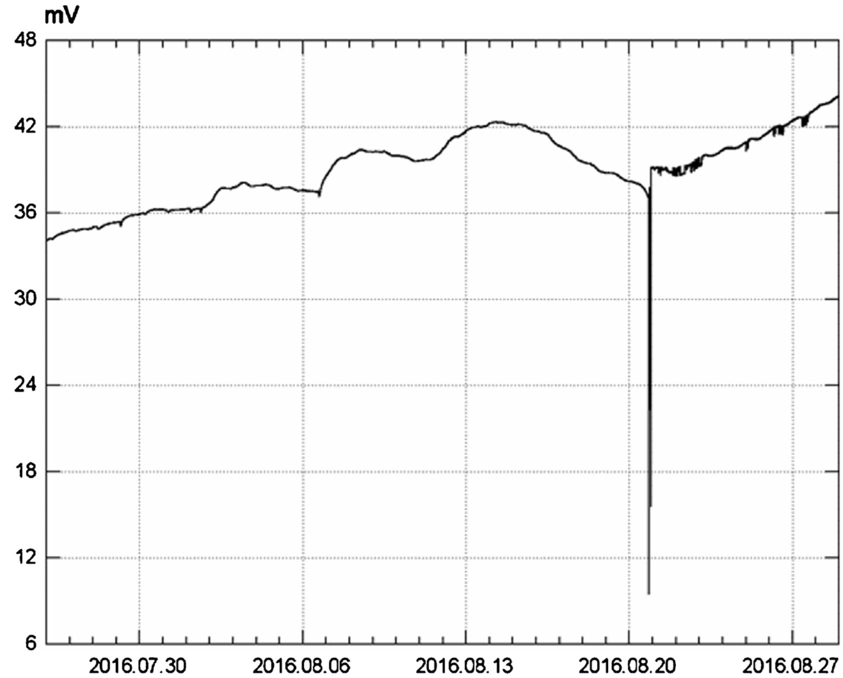


Fig. 16 30 days plot of EMF, direct component, channel SW12 at Chieti observatory

Visso earthquake of 26 Oct 2016, M6.1 and Norcia earthquake of 30 Oct 2016, M6.6

Accordingly to USGS, two major earthquakes struck Central Italy between the Marche and Umbria regions in October 2016. The quake with M6.6 on October 30 was the largest in Italy in 36 years since 1980.

A magnitude 6.1 earthquake struck 3 km west of Visso on 26 October at 19:18 UT. The earthquake, which occurred two months after a magnitude 6.2 earthquake in August, struck about 30 km to the northwest of the August earthquake"s epicenter. According to official data, a man died because he had suffered a heart attack as a result of the quake.

A magnitude 6.6 earthquake struck 6 km north of Norcia at 06:40 UT on 30 October. The village of Arquata del Tronto was destroyed as well as the Basilica of Saint Benedict in Norcia. Two women died of sudden heart attacks during the quake.

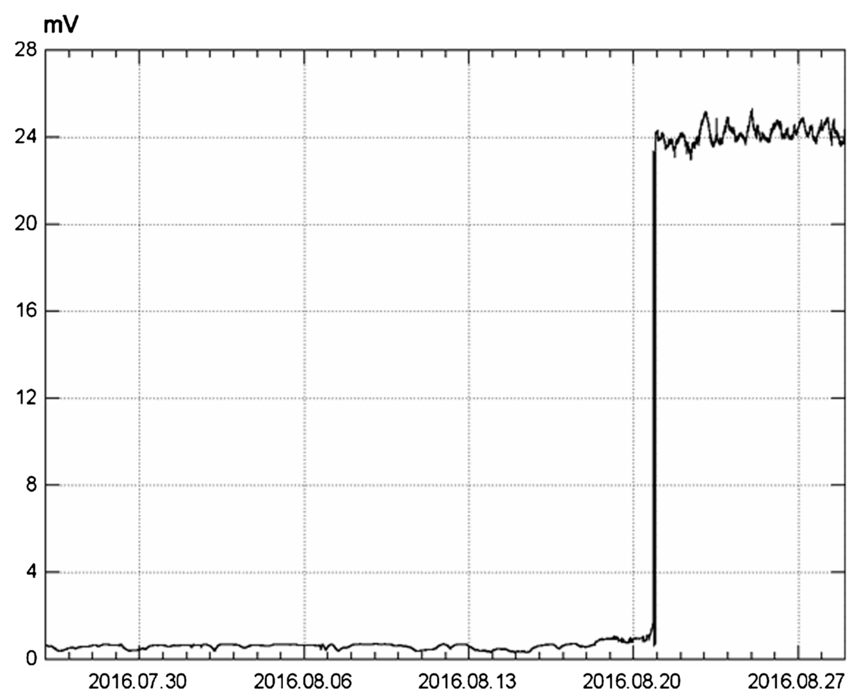


Fig. 17 30 days plot of EMF, alternating component, channel SW12 at Chieti observatory

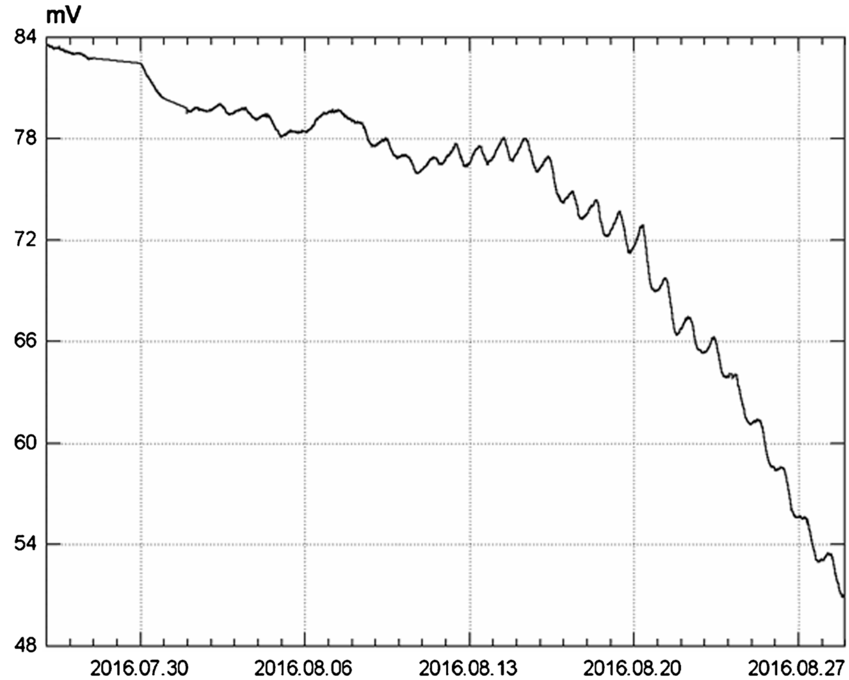


Fig. 18 30 days plot of EMF, direct compenent, channel NE34 at Pizzoli obseratory

Analysis of the 30 days plots (from 01 Oct to 30 Oct 2016) of Chieti measuring observatory shows nonstationary signals of ground EMF values.

1) impulse-like, intermittent signals recorded 14 days, 11 days, 7 days and 2 days before M6.1 (26 Oct 2016).
2) impulse-like, intermittent signal recorded twice during 29 Oct 2016. It was one day before M6.6 (30 Oct 2016).

Examples are shown in Figs. 19, 20 and 21 (full list of plots is provided in Appendix 1). There are 12 dipoles out of 16 that demonstrate nonstationary electric processes during 01–30 Oct 2016.

Analysis of 30 days of pre-earthquake signals (from 01 Oct to 30 Oct 2016) of Pizzoli observatory doesn't show any non-stationary process. We can noticed only slow transient signal. Figure 22 shows typical signal example at Pizzoli observatory (full list of plots is provided in Appendix 1).

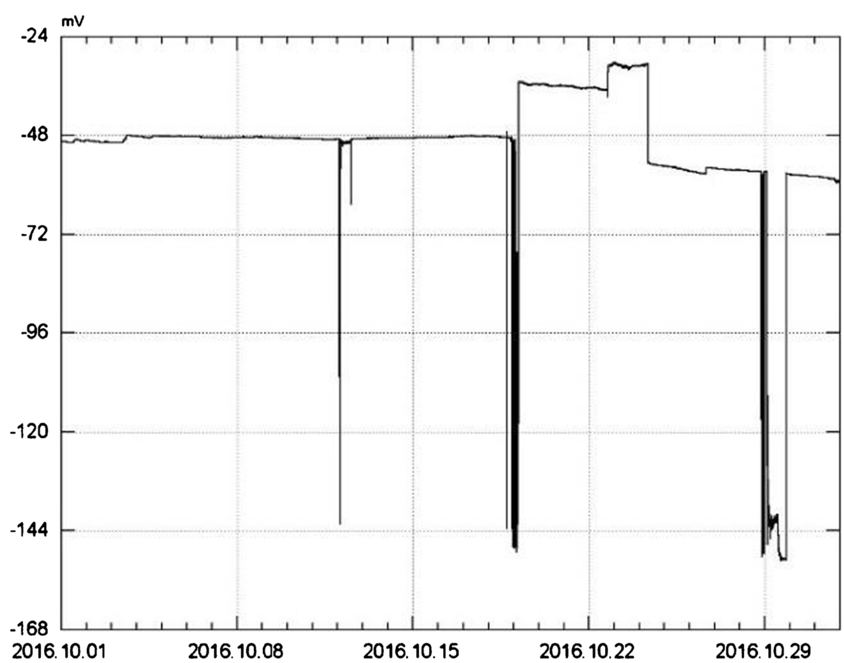


Fig. 19 30 days plot of EMF, direct compenent in channel NE34 at Chieti obseratory

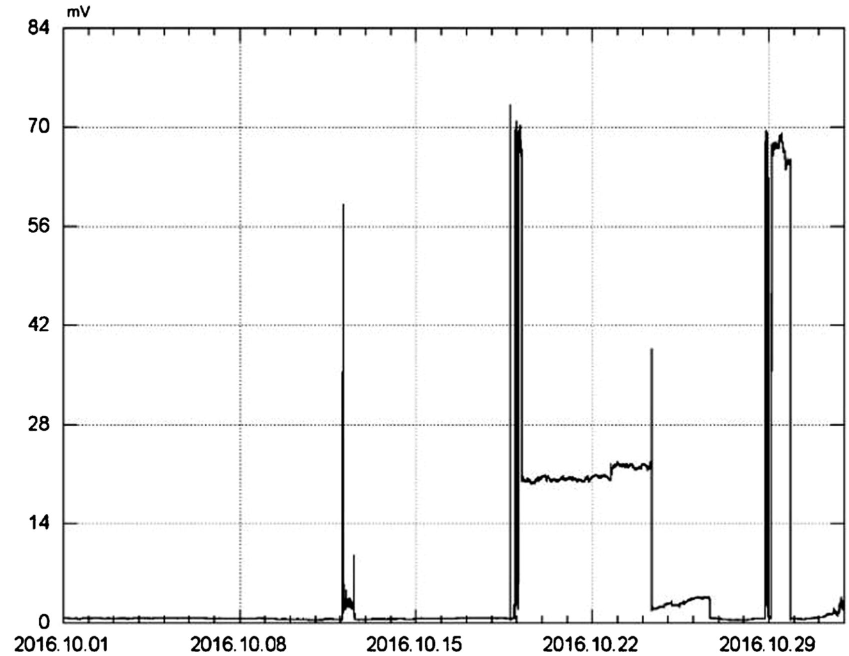


Fig. 20 30 days plot of EMF, alternative compenent in channel NE34 at Chieti observatory

Two observatories showed opposite and different variations of ground EMF values at distances 30–50 km and 90–110 km from earthquakes epicenters in Central Italy. Time intervals for analysis include 30 days of observations before earthquakes occurred on 24 August (M6.2), on 26 October (M6.1) and on 30 October, 2016 (M6.6). Investigation of EMF values times series revealed that nonstationary ground electric processes occurred before earthquakes with magnitude M > 6 in Central Italy at Chieti observatory. In contrary, recorded EMF values did not show sudden changes in amplitude at Pizzoli observatory. This provides support to the hypothesis that nonstationary electrical process shows the state of geological structures laying underneath the measuring multi-electrode sensor. According to the proton tectogenesis hypothesis, tectonosphere constitutes of subvertical proton tectonogens extended from outer Earth core to the surface. In turn, the proton tectonogen constitutes of a number of protons plumes limited in its subhorizontal arrangement by geological properties of rocks. Each proton plume is thought to have the different surface density of proton pathways in the ground-air interface. Nonstationary electrical signals significantly illustrate the intensification of proton migration processes before earthquake nucleation and how the difference in

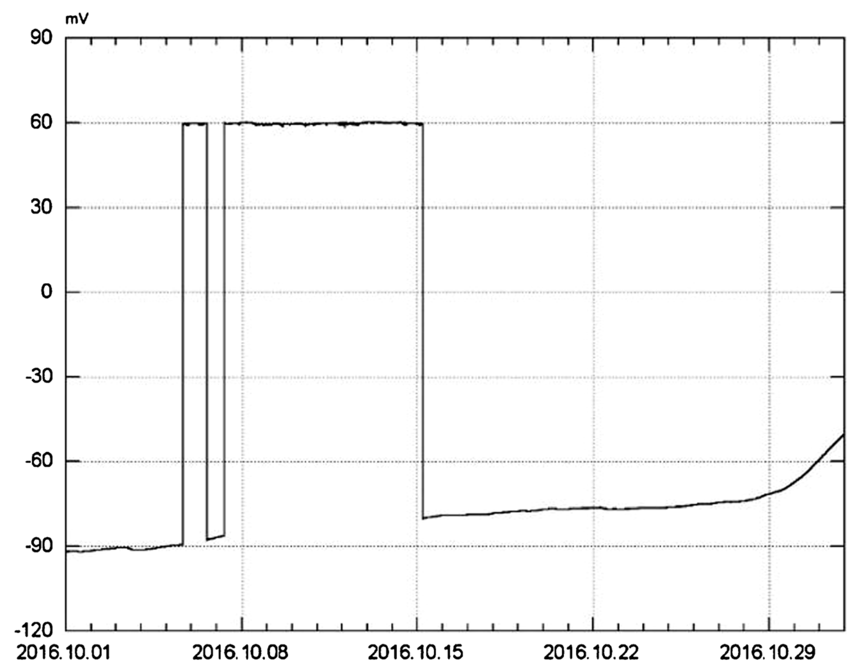


Fig. 21 30 days plot of EMF, direct compenent in channel SW12 at Chieti observatory

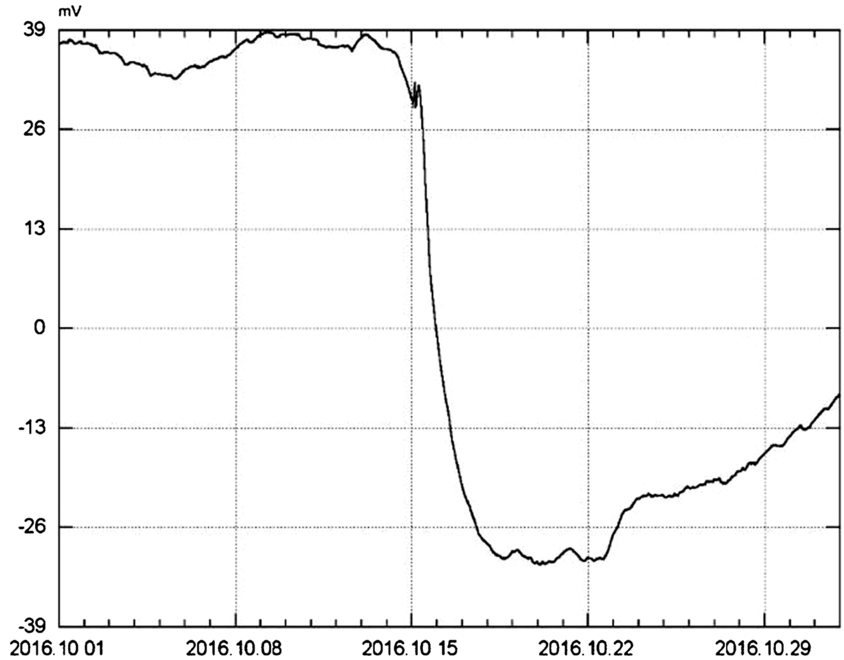


Fig. 22 30 days plot of EMF, direct compenent, channel C2NE1 at Pizzoli observatory

proton permeability of rocks plays an important part to distinguish the main zone of major earthquake nucleation. In simple manner, recorded EMF values can express how protons would migrate through a deepen geological structures, volumes, discontinuities and displacements, where protons can be mostly accumulated and what site is mostly like to be forced to produce sudden deformations. So dense monitoring network of multi-electrode observatories can possibly reconstruct and map the patterns of proton permeability of underlying geological structures. Nonstationary electrical processes at Chieti observatory were the precursors observed from 19 days to one day prior to the earthquakes releases in Central Italy with M > 6.

Therefore, the dynamic map with possible coordinates of earthquake epicenter can be constructed. This gives the opportunity to determine the coordinates of earthquake's epicenter by covering the region under study with multi-electrode observatories. Dense monitoring network of multi-electrode observatories would show the location of future sudden stress release associated with major earthquake nucleation zone.

Conclusions

Now a lot of research is being carried out in the devastated area near Norcia, Amatrice and other small towns and villages just try to understand what fault caused the calamity. INGV"s seismologists are performing geodetic, geological and geochemical surveys; installing new seismometers and accelerometers. However, the earthquake nucleation process, before seismic energy would release, is still poorly studied. What physical process does control the earthquake focus nucleation at the final stages before its energy release and seismic waves would propagate out from the focus? At other hand, the methodology which we apply is a different problem solving approach, that assist in the identification of the parameters of physical process in subsurface soil (in the tectonosphere-atmosphere interface).

Multielectrode ground electric observatories provide a basis to consider nonstationary electrical processes for determination of coordinates of earthquake's epicenter. We found that nonstationary signals of ground EMF values can possibly map the difference of proton permeability of rocks laid beneath measuring stations. Experimentally, this was detected at the closest Pizzoli observatory to Central Italy earthquake's epicenters. No any abrupt subterranean electrical changes were observed in 30 days time window before Amatrice earthquake M6.2 (24.08.2016). Very slow electric process were observed at Pizolli station before earthquake M6.1 (26.10.2016) and M6.6 (30.10.2016). So, Pizolli observatory has pinpointed the inner zone of idealized cylinder-like structure that is adjusted to the main zone of major earthquake nucleation. The geological features have presented the higher rocks stability for proton permeation.

Intensification of nonstationary electric processes significantly illustrates the nucleation of seismogenetic activity and report earthquake precursors in sequence step manner. Experimentally, nonstationary signals of EMF values were detected at Chieti observatory in 30 days time window before 24.08.2016 Amatrice earthquake M6.2, before 26.10.2016 Visso earthquake M6.1 and 30.10.2016 Norcia earthquake M6.6.

For purpose of situational awareness, multi-electrode observatories should be utilized across northern, central and southern parts of Italy. We suggest that by covering the region under study with dense network of multi-electrode observatories placed close to the fault line, towns and villages could map an earthquake nucleation zone. Such area has its expression in idealized cylinder-like form and can pinpoint the possible coordinates of earthquake epicenter with M5+ in operative 30 days time window. Experimentally, it was found that Chieti and Pizzoli observatories can form the basis of an extended network realizing in form of private-public cooperation between science, university, non-profit organizations and local authority. Also this is of much interest for system for Earth- and space-based study of earthquake precursors.

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Author contributions Author, on his will and hope with the consultation and support of public-private organizations carried out this work and drafted the manuscript.

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Data availability The datasets generated during and analysed during the current study are available in the Figshare repository, [doi: 10.6084/m9.figshare.4256612], [doi: 10.6084/m9.figshare.4256603], [10.6084/m9.figshare.4256630] and included in its supplementary information file.

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