Japan TRIZ Society 20th TRIZ Symposium 2024
Aug. 29-30, 2024, Waseda University, Tokyo

Earthquake Prediction Research Based on the TRIZ Philosophy

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1. Introduction: EQ Prediction Research Background

Japan has often suffered from disasters caused by earthquakes (EQs).

The Seismological Society of Japan (SSJ) was founded in 1880, and contributed to develop the seismic observation network extensively and highly, and to reveal the historical course, distribution, and mechanisms of EQs of both trench and inland types.

It has also conducted research on foreseeing EQs and has issued (region-specific) long/medium-term forecasts of medium- to large-scale EQs on a probabilistic basis.

However, the Hanshin-Awaji EQ (1995) and the Great East Japan EQ (2011) were totally "unexpected" and never be predicted at all.

After the two EQs, SSJ and the government stated:
"Short-term/imminent prediction of EQs is impossible with current technology.
Therefore we will not focus on short-term EQ prediction research, but
on the observation and analysis of EQs to deepen our basic understanding of EQs."

Introduction (continued)

Most of the public, however, want to have the Short-term EQ Prediction possible to reduce human, material, and social disaster caused by EQs.

The Earthquake Prediction Society of Japan (EPSJ) was established in 2014.
I joined it in Feb. 2015. It is a small academic society with about 70 members.

It has been working to find EQ precursor phenomena, especially electromagnetic ones.

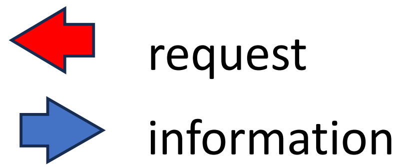
Until recently, however, I feel we are in the dark with many different approaches but no effective methods in sight.

In Dec. 2022, Minoru Tsutsui reported the work of observing variations in the DC electric field deep under the ground.

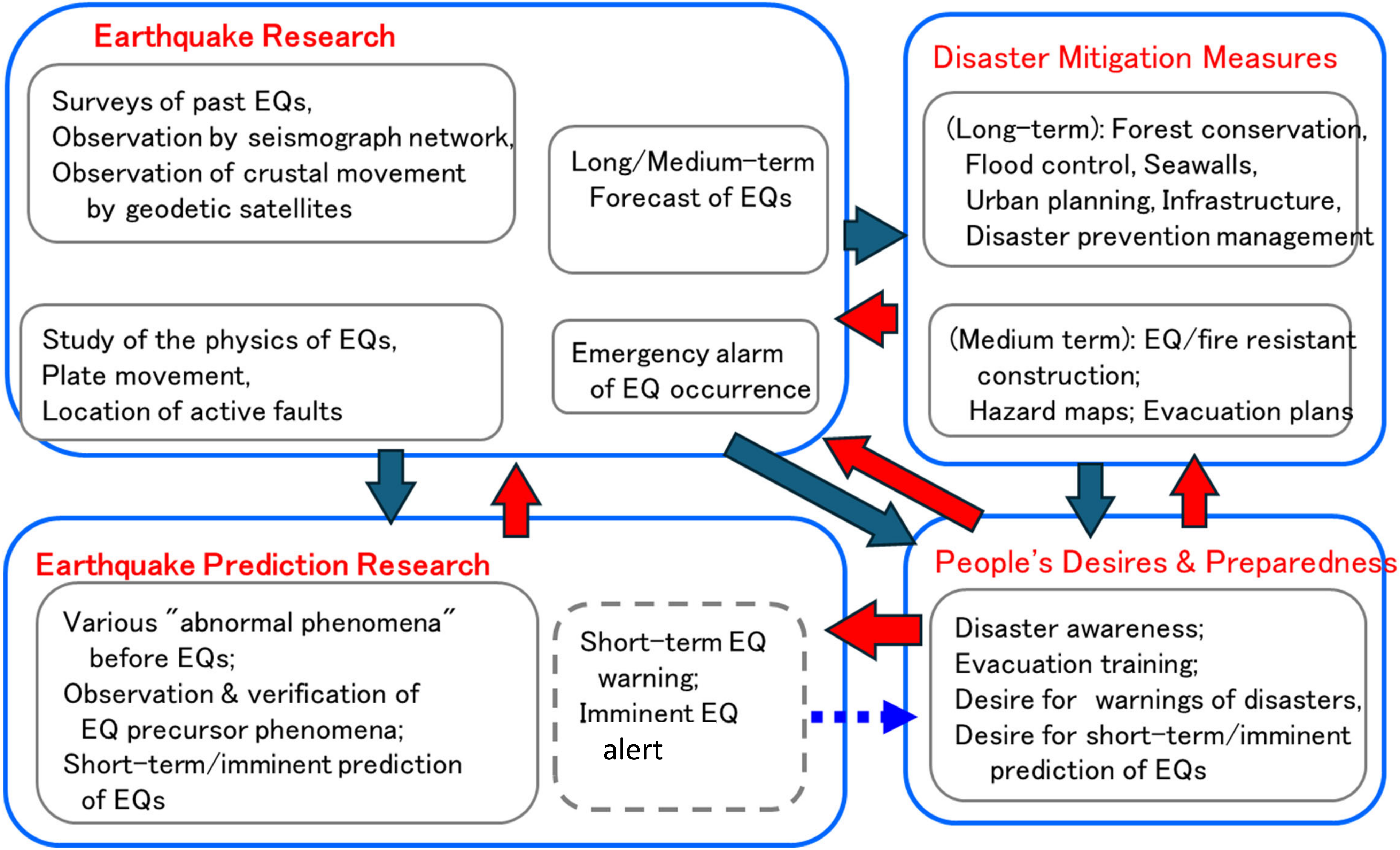
I was amazed with its clarity and was convinced of its significance and validity.

==> I made up my mind to support and develop Tsutsui's method further, and am proposing within EPSJ to start a collaborative research project to develop Tsutsui's method further into a practical system for Short-term EQ Prediction.

2. Position of EQP Research



2A. EQ Research, EQP Research, and Disaster Mitigation Measures



2B. Study of EQs (conventional seismology)

Investigation of past earthquakes

Faults, Sediments, Paleoseismology

Observation by seismograph network

With a network of high-sensitivity seismographs;
With a network of strong-motion seismographs;
Analysis of seismic waves → Real-time analysis
→ Analysis (epicenter area, magnitude, seismic process,

Observation of crustal movement by geodetic satellites

Longitudinal measurement of relative movement
at multiple locations; Accumulation of stress

Study of the physics of earthquakes

Plate boundaries, Tectonic structure,
Plate movement;
Location and historical events of active faults;
Assessment of stress accumulation
Study of EQ processes (hypothetical)

Limitations of mechanistic observation

Emergency alarm of EQ occurrence

Epicenter, magnitude,
Seismic intensity forecast,
Tsunami Warning

Effective for emergency evacuation
(Sometimes too late to evacuate.)

Long/medium-term forecast of EQs

Probabilistic forecasting:
Damage simulation (Hazard Map)

Short-term/imminent prediction
is "impossible".
(Seismological Society of Japan (SSJ)
and the Government evade
EQ prediction research)

2C. Current State of EQP Research: A Clear Light in the Dark !!

Fundamental Difficulties

Seismic energy accumulation : for several thousand years to several decades

>==< EQ = Instantaneous destruction: for seconds to minutes

Physical situations at epicenter are not clear (diverse, complex, unknown, ...).

Processes of destruction (EQ) is not well known.

Phenomena associated with the destruction are not well known

(different precursor phenomena; mechanical, electromagnetic, thermal, ...) .

Search for Precursor Phenomena

Unusual animal behavior, clouds, etc.   ==> Lack of objective measurements

Observations of electromagnetic waves, etc. ==> Noise is high and unclear,

Ground-based observation of ionospheric anomalies ==> Indirect information, noisy

New results

M. Tsutsui (2022.12) Continuous measurement of vertical electric field underground:

Clear (S/N ≥ 30) signals with fine structure from 1.5hr before to 9hr after EQ.

M. Kamiyama (2023.12) Change in crustal strain (3 yr to 3 mo before EQ): satellite.

K. Heki (2023.12) Local increase in TEC of ionosphere (10–100 min before EQ).

Vision

'Imminent EQ Prediction Alert System" can be realized in 20 years (?).

3. Tsutsui's method (2022.12) : 3A. Observation Instrument

Continuous observation of underground electric field at a remote station with high S/N ratio.

A secondary effect of EQ is observed directly through the geosphere avoiding disturbance by noise.

Vertical electric field under the ground

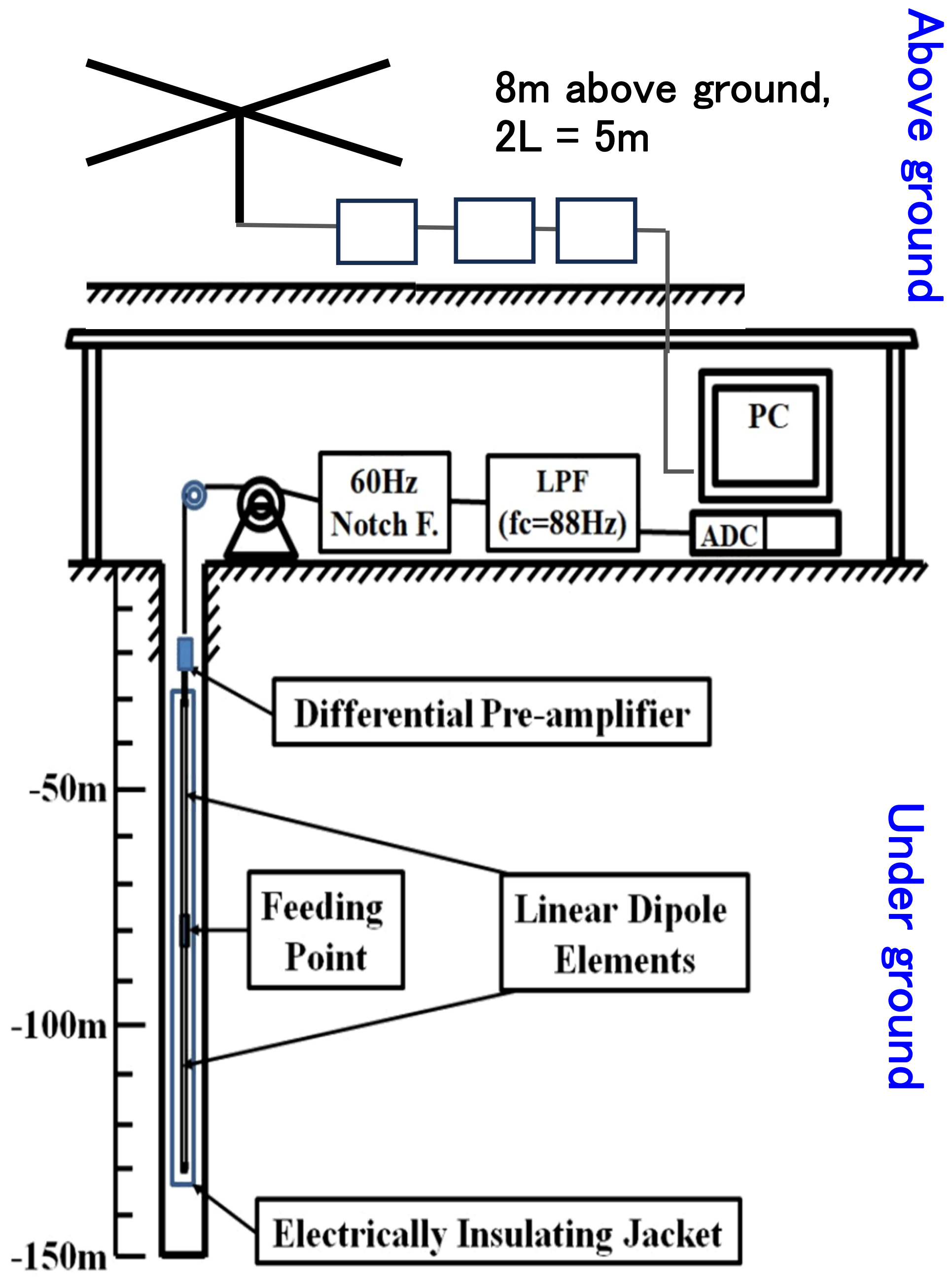
At a small island near the southern tip of Kii Peninsula, Linear dipole type DC electric field sensor (100m) is set in a borehole (20 cm Φ), 150 m deep underground, Differential preamplifier is installed 20 m underground. Signals are observed every second and stored in a PC after passing through 60Hz Notch filter, Low pass filter, and AD converter.

=> Noise is steady at 0.5 μV/m

Horizontal electric field above the ground

EW and NS antenna are set 8m above the ground at the same site.

Continuous observation is recorded in parallel..



M. Tsutsui (2022)

3B. Observed result (1)

The instrument ran for 2.5 months (Apr. – Jul. 2021).

Form 1: Observed on May 1, 2021. Drastic (±) fluctuations before and after an EQ

Underground vertical electric field:

Noise is steady

08:50 – for 46 mins,
Drastic (±) fluctuations

10:27 Spike signal
(An EQ at the same time,
off the coast of Miyagi M6.8)

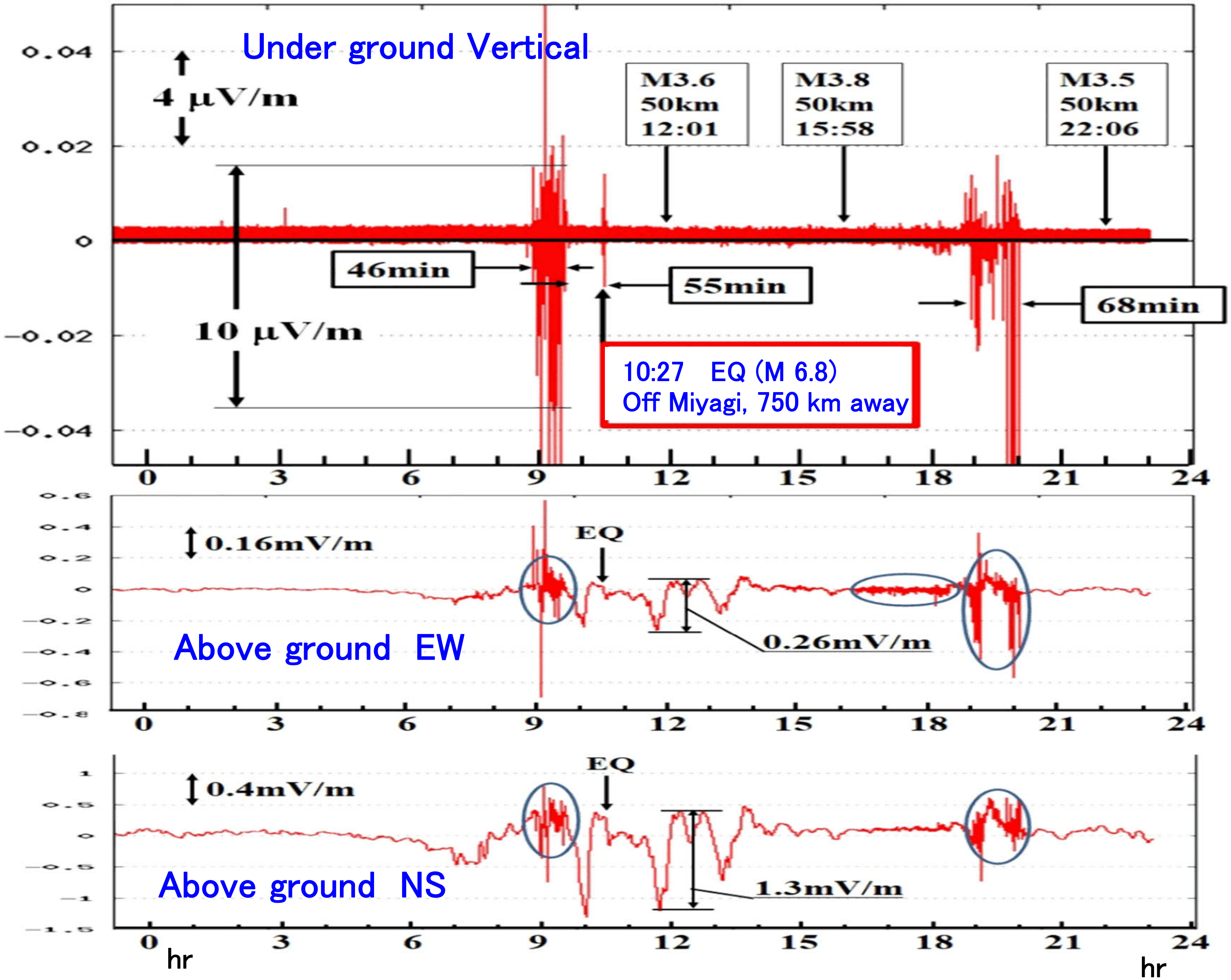
19:00 – for 68 mins,
Drastic (±) fluctuations

Aboveground horizontal electric field:

08:50 – and 19:00 –
(Drastic) (±) fluctuations
(same as the underground)

10:27 Weak signal fluctuation

Daytime: Slow diurnal variation of ionospheric electric field (noise)



M. Tsutsui (2022)

3C. Observed result (2)

Form 2: Observed on May 6, 2021 Electric field rises and holds for several hours

Underground vertical electric field:

05:25 – Electric field rises to 2 μV/m and holds for about 5 hrs.

10:30 – Stays near 0 for 3 hrs.

13:30 – Rises suddenly to +2 μ V/m

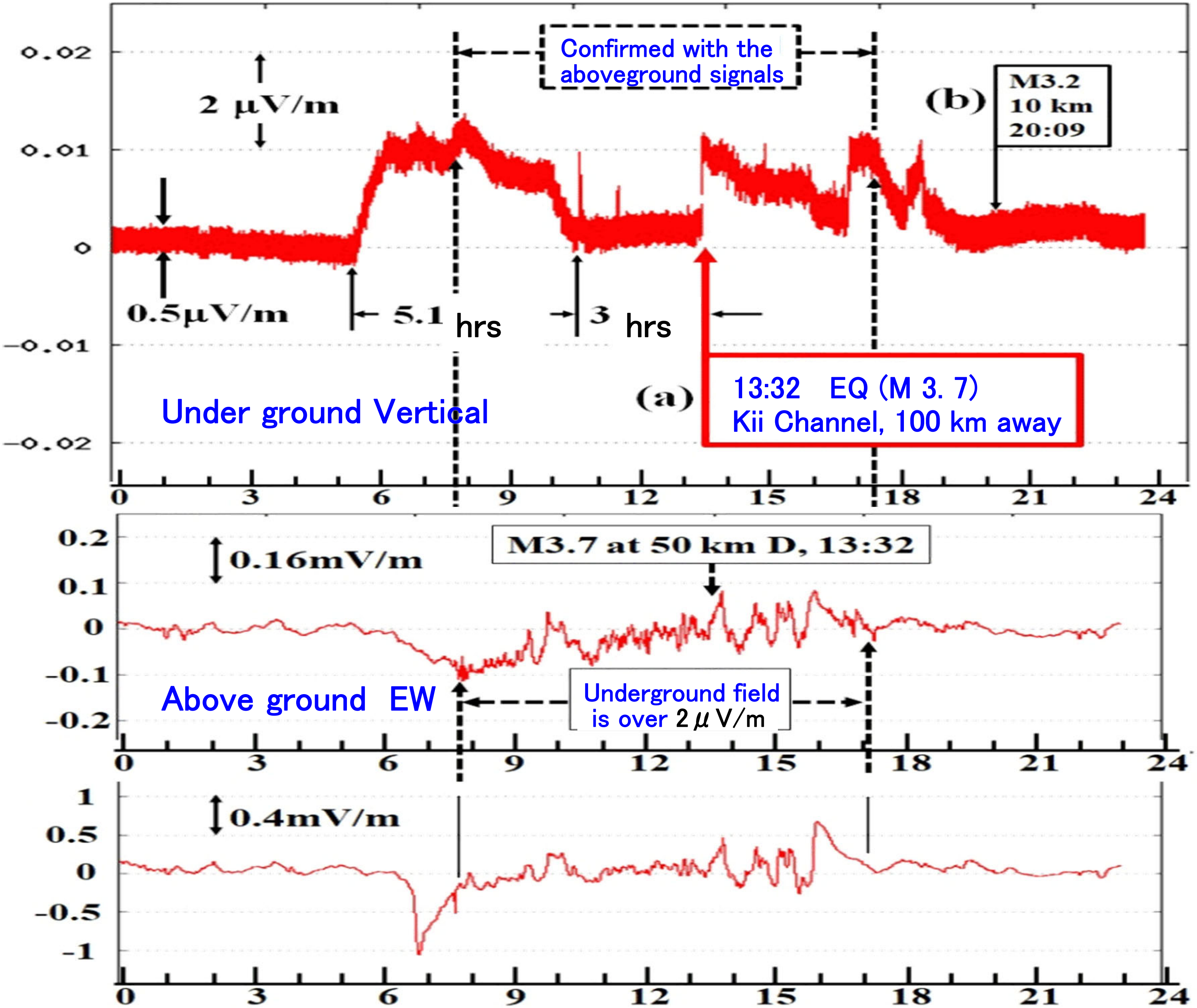
(13:32 an EQ (M3.7) at Kii Channel (100 km away))

Then slowly returned to 0 in about 6 hrs.

Aboveground horizontal electric field

7:40 – 17:00 Signal fluctuates in a way similar to the underground signal.

During the whole day, various noise overlaps to disturb the signals.



M. Tsutsui (2022)

4. Procedures for EQ Prediction Research (1) Preparatory Stage

4A. Overview of the Preparatory Stage

(a) From the mechanistic/geodetic perspectives in the traditional seismology,
the timing of destructive events, i.e., EQs, is difficult to predict.
We need to observe some precursor phenomena.

(b) We should think of various precursor phenomena candidates,
and select them through experiments and observations.

(c) Various electromagnetic phenomena generated by the piezoelectric effect
in the crustor are important keys.
TRIZ recommends the evolution from mechanical to electromagnetics methods.

(d) We should investigate their propagation and accompanying effects.

(e) The place of detecting the signals (underground, on the surface, in the air,
with satellites, etc.) need to be carefully chosen,
because there are different types of phenomena and noise.

4B. Requirements of Precursors for Short-term EQ Prediction

(0) Fundamental Requirements: X is related with and caused by EQs,
occurs short time before for various types of EQs, ...
==> Can examine only after extensive observation and analysis.

(1) Basic Req.: Observable/measurable clearly with high S/N ratio.
==> Need to develop measurement method/instrument (at one site)

(2) Confirmation Req.: Observable at multiple sites similarly, for many EQs,
confirming occurrence of EQs just as predicted.
==> Data accumulation at multiple sites to confirm correlation with EQs

(3) Practical Req.: Automatic/stable/continuous measurement, and
methods for predicting EQs (where, when, magnitude)
==> Reliable technical system and thorough analysis of experimental data

(4) Advanced Req.: System integration and proving causality with EQs.
==> Need advanced research in seismology, esp. the EQ process.

(5) Social Req.: Reliable operation of short-term EQ prediction/alert system.
==> Need recognition/approval by academia, society, government, etc.

4C. Candidates of EQ precursor phenomena and their observation methods

EQs = Rupture phenomenon caused by moving pressure between plates/faults

Energy accumulation: from thousands to tens years
Destruction: from minutes to seconds

Primarily: Mechanical Phenomena

Secondary effects

Electrical phenomena

(Piezoelectric effect)

Magnetic, Electromagnetic phenomena

Other various phenomena

Effect is small, but epicenter area is large

Observation of Dynamical Phenomena

- Horizontal/vertical Movement
- Pressure / Strain
- Fore-shocks
- Geodetic satellites
- Pressure /strain gauges
- Seismo-meters

Timing of destruction is difficult to predict

Increasing precision

Observation of Electromagnetic Phenomena

Versatile and sensitive methods of measurement of various/long-distance propagation phenomena

- Underground Electric field
- On the ground Electric field
- On the groun electro-magnetic wav
- Ionosphere Electrical prop from the grour
- Ionosphere. Electrical properties from satellites
- Vertical electro continuous observation
- EW/NS antennas on the ground, Continuous observation, various frequencies
- Measurement of reflection of EM waves
- Global observation with Satellites

Direct observation, Large S/N ratio

Local predictive information

Easy to observe with high sensitivity, but a lot of noise.

Promising for large EQs

Worldwide predictive Information

5. Procedures for EQ Prediction Research
(2) Development Stage (Experiment, Measurement, Analysis)

5A. Overview of the Development Stage

(f) (Ⅰ) At a single site, carry out the observation experiments for a few years, and examine the correlation with EQs.

(g) (Ⅱ) At multiple sites, carry out the observation experiments in parallel to confirm the correlation with EQs.

(h) (Ⅲ) At many sites in a network, carryout the observation experiments, and clarify which types of EQs show the phenomena and create a method to predict the location, time, and magnitude of the shortly coming EQ.

At this stage, develop a technical system of a method for short-term EQ prediction.

(h) (Ⅳ) Integrate several other methods that use different phenomena, and establish a comprehensive technical system of Short-term EQ Prediction.

5B. Development: （I） Single Site Stage: Research Agenda

(I – 1) Select "(candidate) precursor phenomenon" to observe.

(I – 2) Research for the methods of observing/measuring the phenomenon.

(I – 3) Develop and set up the observation site, facilities, instruments, and software.

(I – 4) Start test observations, increase signal sensitivity, and remove/isolate noise.

(I – 5) Develop the measurement system to acquire, record, transfer, store, and illustrate the observed data.

(I – 6) Visualize all the measured data, find significant signals, and examine their possible correlation with EQs.

(I – 7) Classify the cases of correlated, uncorrelated, and unobserved with EQs.

(I – 8) Report about the experiment methods, observed data, correlation with EQs, results, and discussions at academic conferences.

(I – 9) Review the study and decide further directions, such as improvement, strategic change, and progress to the next stage with multiple sites.

5C. Minoru Tsutsui's Work (2022): Single Site Stage (I) of Development

(I– 1) Selected "DC electric field from (remote) epicenter" as the phenomenon.

(I– 2) Measured "Vertical DC electric field" deep under the ground continuously.

(I– 3) Developed & Installed a sensor (100m long) in a borehole (150m deep) at a remote site on an island near the southern tip of the Kii Peninsula.

(I– 4) Achieved very high S/N ratio with a large sensor, low noise underground site, and various filters. [Still weak in detecting the incoming signal direction,]

(I– 5) Achieved continuous measurement every second, digital recording in a PC. [No automatic data transfer to the lab.] Visualizing software is ready.

(I– 6) Observed remarkable EQ signals (2 forms, with high S/N, clear fine structure, evident correlation with EQs).

(I– 7) Reported 2 correlation cases in detail [No other cases of correlation/ non-correlation/non-observation are mentioned. Not yet published lately]

(I– 8) Reported already about experimental method, observational data, proof of correlation with EQs, etc. Very remarkable results.

(I– 9) **Summary: Splendid results as an observation method. : [Occasional troubles in the equipment. Working alone as a retired professor.]**
Highly recommendable to proceed to the Multiple site stage (II).
[Necessary to establish a collaborative research project.]

5D. Development: （Ⅱ） Multiple Site Stage: Research Agenda

(Ⅱ-1) Build multiple (5-6) observation sites and operate them in parallel.

Similar signals at the same time ==> Significant signals → location and magnitude of EQ.
Signals at some sites but none at others ==> Local EQ? Anisotropy? Attenuation region?
Signal at one site only ==> Artificial/natural noise? Inadequate equipment?

(Ⅱ-2) Analyze/accumulate the data and verify correlation with EQs.

There is an EQ corresponding to a significant signal ==> Correlation case
There is no EQ corresponding to a significant signal ==> Non-correlation case
No signal is observed for EQs of significant magnitude ==> Non-observation case

(Ⅱ-3) Create a method for estimating the time, place, and magnitude of the expected EQs.

Pattern of signals ==> Estimate the time of EQ (e.g., hours later) and type of the EQ.
Directions of incoming signal, Differences of detection time and strengths at multiple sites
==> Estimate location,
Signal strengths ==> Estimate magnitude and damage.

(Ⅱ-4) Apply and test the above estimation methods to (past and present) EQ data.

Consider when and how to make a prediction call after signal detection starts?
Improve the estimation method further, more reliable and useful.

5E. Tsutsui's Method: Challenge for the Multiple Site **Stage（Ⅱ）**

Challenges to build the 2nd, 3rd ,.. sites of Tsutsui's method and work together.

First, obtain research groups who decide to work together to develop this method.

Select an observation site with low noise and convenient for maintenance.

Build a deep borehole and install the sensors and equipment.

Obtain a research fund for building the sites and operating the research groups.

Build a software system to collect and analyze the observation data in collaboration.

Initiate a joint research for transferring know-hows and developing further.

Start a research project for establishing the financial, personnel, and management bases.

Challenge to achieve the research tasks (5D) smoothly, in collaboration.

（Ⅱ−1） Build multiple (5−6) observation sites and operate them in parallel.

（Ⅱ−2） Analyze/accumulate the data and verify correlation with EQs.

（Ⅱ−3） Create a method for estimating the time, place, and magnitude of the expected EQs.

（Ⅱ−4） Apply and test the above estimation methods to (past and present) EQ data.

5F. Development （Ⅲ）Stage of establishing an EQ prediction method
(Case of Tsutsui's method with many sites in a nationwide network)

Challenges to deploy and test Tsutsui's method with many sites in a nationwide scale.

Get recognition by the academic community (SSJ) and get official research funding.

Deploy the observation sites in a nationwide scale, about 40 sites 150 – 200 km apart.

Establish about 10 research bases (e.g., Sapporo, Sendai, Tsukuba, Chiba, Tokyo, Nagoya, Kyoto, Hiroshima, Fukuoka, Okinawa)

Each research base, with researchers and engineers, works to build/operate their sites, analyze the observation data, and do research for advancing the method.

Collect all the observation data to the project center in real time, and visualize, analyze, monitor, and call for emergency. To feed back all the results to research bases.

Challenges to clarify, verify, and establish the following points.

(Ⅲ -1) Verify the correlation with EQs, cases of correlation/uncorrelation/unobserved.

(Ⅲ -2) Clarify the characteristic patterns and effectiveness for different types of EQs.

(Ⅲ -3) Establish the methods for predicting the EQs (where, when, and magnitude).

(Ⅲ -4) Verify the features, validity, versatility, and reliability of this prediction method, and recognize the limitations of this method.

5G. Development （Ⅳ）Stage of Integration into Short−term EQ Prediction System

Item ╲ Method	Kamiyama's Method	Tsutsui's Method	Heki's method
Phenomenon to detect	Distortion of the crust in the local area	Underground DC vertical electric field	Variation of Total electron content (TEC) in ionosphere
Detection method	Triangular mesh analysis of geodetic satellite GEONET data	DC dipole sensor set 150m underground	Analyze communications between GNSS satellites and ground stations
Types of EQ	All types (weak for trench type)	EQs with EM phenomena (almost all types) (Trench type OK)	EQs with EM phenomena (almost all types) (weak for trench type)
Range of EQ detection	Nationwide. Mesh range of land stations. Weak for trench type.	Nationwide. Near and distant from each site. High S/N. Large and medium EQs.	Worldwide. Anywhere in the vicinity of ground stations. Slightly weak for trench type. Suitable for large EQs ($M \geq 7$).
Time range of detecting the event	3 yrs - 3 mos before EQ (and continue later). (No signal just before the event)	A few hours before till several hours after the EQ, with fine structure. A spike signal at the moment of EQ.	100-10 mins before EQ and till about 1 hr after EQ. No fine structure, no signal at the moment of EQ.
Time resolution	Once daily. (Can be done some more frequently)	Every second, continuously. Drastic variation fine structure.	About 1 minute. No fine structure.
Detection sensitivity, S/N	Significant, clear.	High S/N (>30). Clear for EQ (M6.8) 750 km away, EQ (M3.8) 100 km away.	TEC signal increase 3-30%, while noise about 0.5%. Need a special algorithm..

6. Procedures for EQP Research (3) Public Recognition & Usage Stage

(i) Get recognized by academia and society, and implement this system nation wide.

Install the system stepwise from the parts necessary, appropriate, and effective.

Coordinate with researches on EQ analysis, long/medium-term EQ forecasting, seismic processes, etc.

In case of predicting a medium-scale EQ, provide the information in advance only to relevant organizations, and make it public only afterward.

In case of predicting a large-scale damaging EQ, make an Emergency EQ Prediction Alert public, 1-2 hours in advance.

Through field operation for several years, improve the system and prepare for the next stage.

(j) Establish an official system for EQ prediction and warning.

Through academic and public discussions, establish an official system of EQ prediction and alert operated by Japan Meteorological Agency (?).

Operate 'EQ Prediction Warning' (a few to 1 day in advance) and Emergency EQ Prediction Alert (a few to half hrs. in advance).

(k) Explore international research cooperation and global implementation of the system.

Concluding Remarks: Summary and Future

EQ prediction research has been in the dark stage until now.
The SSJ and the government think EQ prediction impossible and avoid its research.

Recently, a groundbreaking research was presented by Minoru Tsutsui within EPSJ.

He observes the vertical DC electric field deep under the ground.
At a site near the southern tip of Kii Peninsula, he observed the signal of the M6.8 EQ off Miyagi, from 1.5 hrs before to 9 hrs after the EQ, with S/N above 30 and fine structure.

Currently, however, he works alone at a single site as a retired professor.

If we, researchers, understand the significance of this method and collaborate together, we can operate 5–6 observation sites in parallel, demonstrate the correlation with EQs, and predict where, when, and magnitude of EQs in 1–2 hours in advance.

Through the years of observation and verification, we will gradually improve our methods and get recognized by academia and society, and in 20 years we will officially operate the "Short-term EQ Prediction Warning" and the "Emergency EQ Prediction Alert".

The present research is based on the TRIZ philosophy and the experimental science approach.

I wish you and many others to understand and cooperate for realizing the EQ prediction.