Electrostatics from Nano-scale to Space

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***Abstract*—Electrostatics is important in various system with different scale. In nano-scale, composition and function of the molecular system are affected by electrostatic force, therefore, electrostatics can be used for manipulation and analysis of molecules. For instance, DNA molecules can be manipulated for analysis using electrostatic force and optical tweezers. Combination of E-field and Laser provides more flexible tools for manipulation and for micro-pumping. At the meantime, in our earth, known as the global circuit, atmospheric ionic current (AIC) is flowing into the ground from ionosphere. This current could be affected by the sudden change of surface potential of earth prior to an intense earthquake. In medium scale, electrostatics is also important. Electric field generated by walking of human or animals is of interest. For instance, human is generating rather high voltage while walking, and the voltage waveform has specific spectrum profile. In this talk, several interesting phenomena of electrostatics from nano to large scale are introduced.**

Keywords-component; electrostatics, DNA molecules, Charging of human body, Atmospheric current, earthquake

I. INTRODUCTION

Electrostatics force is essentially important in Nano-scale to determine the composition and function of the molecular system because of large q/m ratio. For instance, folding of proteins and DNA molecules, are greatly affected by the electric field between molecules. Electrostatics, therefore, provides useful means to manipulate molecules. There are important works in this field, such as stretching of DNA molecules using AC electric field by Washizu[1]. In nature, regardless of scale, electrostatics plays important roles. Known as the global circuit, in our earth, atmospheric ionic current (AIC) is flowing into the ground from ionosphere[2]. This current could be affected by the electrostatic charge generated by rapid pressure change in crust just before an intense earthquake[3]. This is because the surface potential changes rapidly due to the generated charge, and the change of the surface potential should affect the ionosphere that is regarded as the counter electrode of the earth capacitor. Sudden increase of total number of electrons in ionosphere, and abnormal transmission of electromagnetic wave prior to intense earthquakes has been reported[4,5] Inside the earth, existence of perovskytes was discovered in the D’’-layer which is a transition area between the liquid core and the mantle of the Earth. This high permittivity layer could cause charge generation and circulating current[6]. This could cause geomagnetism. This mechanism is different from the generally known MHD theory which still need to be proved. Those are a few examples of importance of electrostatics in nature to be studied further. In medium scale, electrostatics is also important. Electric field generated by walking of human or animals is of interest. For instance, human is generating rather high voltage while walking, and the voltage waveform has specific spectrum profile. Therefore, we are surrounded by low frequency electromagnetic waves, or induction voltages. In this talk, several interesting phenomena of electrostatics in nature from nano-scale to large scale are discussed.

II. OPTO-ELECTROSATATIC MICROMANIPULATION OF DNA MOLECULES

In the post-genome stage, more rapid DNA analysis is needed to apply the available information for treatment of individuals. Analytical methods based on single DNA molecules may replace the conventional DNA analysis procedure. This method also provides a more precise tool for studying interactions between DNA and proteins. For DNA analysis, all the DNA molecules from single cell are extracted and matched with the known sequences as shown in Fig.1. In this method, following steps are required: preparation of DNA extracted from single cell, manipulation of genomic DNA, fixation in stretched form, mapping, cutting, recovery of the fragment, and PCR amplification[6]. The globular transformation can avoid breakdown of long genome DNA and permits manipulation of large DNA molecules as shown in Fig.2. This is a phase shift of DNA between coiled and globule state, and this is due to charge elimination by conter positive ions[7]. Because the globular transition is reversible, the DNA can be pulled out sequentially from the globule of DNA and fixed on a substrate in an arbitrary pattern. Electrostatic force, especially, dielectrophoresis is an important tool for manipulation of DNA molecules. Optical tweezers, or laser trapping is also an important tool for manipulation as depictred in Fig.3. Charge of the globule DNA is very small due to cancellation of original negative cyarge by counter positive ions, and dc electric field does not cause driving force. However, an ac electric field in non-uniform field produces dielectrophoresis. This force is suitable to drive globule molecules.

DNA molecules in coiled state is usually not possible to trap by laser. If latex beads are suspended in solution, the laser trapping holds the beads, accumulating around the molecules, to grab the molecule. This is a convenient tool for manipulation of any visible molecules[8].

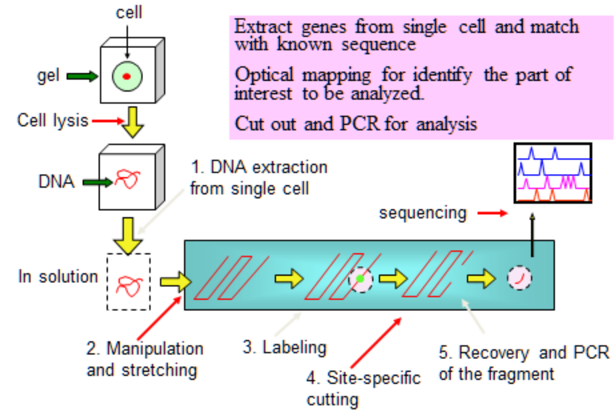


Fig.1. Analysis of DNA extracted from single cell

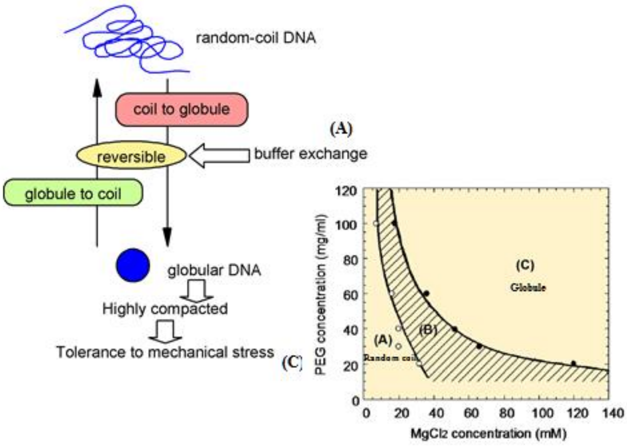


Fig. 2 Coil-globule phase transition of DNA molecules

Stretched and fixed DNA molecule can be characterized by attaching a fluorescent-labeled restriction enzyme or by other probes. Activity of the restriction enzyme can be eliminated by removing Mg ions in the solution. In this condition, fluorescence-labeled restriction enzymes are attached and an optical restriction map can be made, but they do not cut the DNA. After mapping, Mg ions can be released locally to cut out the necessary part of DNA molecules for analysis. The part can be recovered by a glass capillary using electrophoresis. The PCR method based on a water-in-oil emulsion, single DNA fragment can be amplified. These single-molecule techniques provide a new analytical method.

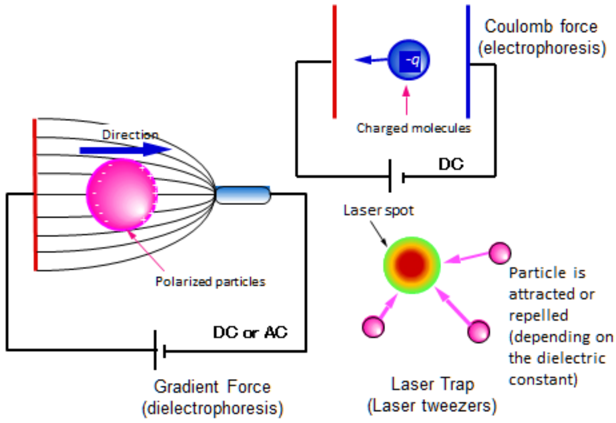


Fig.3 Electrostatic force and Laserl tweezers

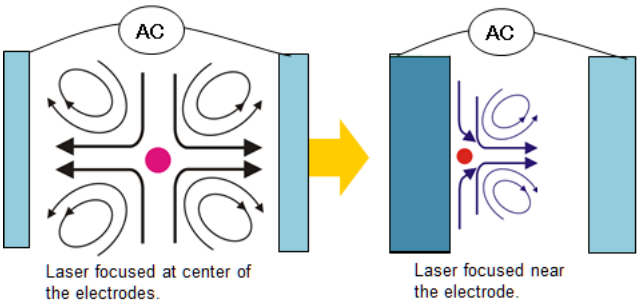


Fig.4 Micro-vortex mixer and micro-pump by ac electric field and focused laser

The combination of an ac electric field and laser is also useful to drive liquid in micro fluidic system. Fig.4 depicts the micro-vortex generation and the micro-pump to drive liquid in one direction. These tools are useful, because of no moving parts[9,10].

III. VOLTAGE CHANGE OF HUMAN BODY DURING WALKING

It is well known that human body is electrostatically charged during walking. There are several standard methods to measure the voltage of human body while walking[11,12]. In these methods, human body is connected by wire to a plate electrode, and a surface voltage meter measures the voltage of the plate electrode. In this study, wireless method has been used to monitor the human voltage while walking. A metal electrode is used, being set on ceiling or wall. When charged body approaches to the electrode, induction charge appears. Using an electrometer having high input impedance, the voltage due to the induction can be measured. The human voltage fluctuates according to the movement of walking. The body voltage is sensitive to the movement of feet, especially the spacing between a foot and ground, since the body voltage V = Q / C (Q: charge of the body, C: capacitance between the body and the ground. Body voltages sometimes exceed 10 kV, and these high voltages should enhance suspended particles in air, including bacteria and viruses. To reduce the chance of infection, it may also be important to keep the human voltage below a certain level.

A metal mesh of 90 cm x 120 cm was set on ceiling of a room. An electrometer (Keithley) was used in the voltage mode to measure the induced voltage of the metal mesh as shown in Fig.5[13]. At the output of the electrometer, a low pass filter of 0.1 sec time-constant was inserted to cut electro-magnetic noise from commercial power line. The floor of the room was covered by vinyl cloth for floor finishing. Surface resistivity was about 2.2 G-ohm. (Denoted as A) For comparison, grounded aluminum foil was used to cover the floor. (Denoted as B) 8 different foot-wear was used including sneakers, sandals, slippers, and Japanese traditional footwear made of wood (Geta), and bare foot was also measured. Under the mesh electrode, a human stood up and 10 or 20 V dc voltage was applied to the human body periodically. The induction voltage appeared due to this dc voltage application. This ratio is determined by the capacitances between the electrode and ground, and the human body and the electrode. In this experimental condition, the human voltage was about 250 times of the measured induced voltage at the mesh electrode.

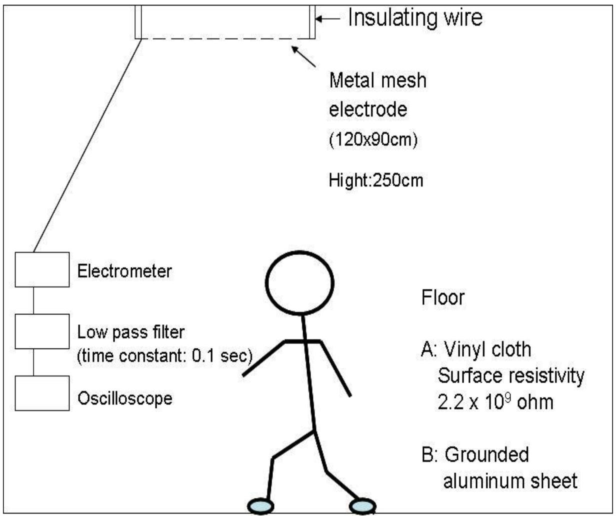


Fig.5 Measurement of induction voltage from charged human body during walking

Fig.6 shows an example of the induction voltage due to charged human voltage during walking. The floor A, and the rubber slippers (sole is made of rubber) were used.

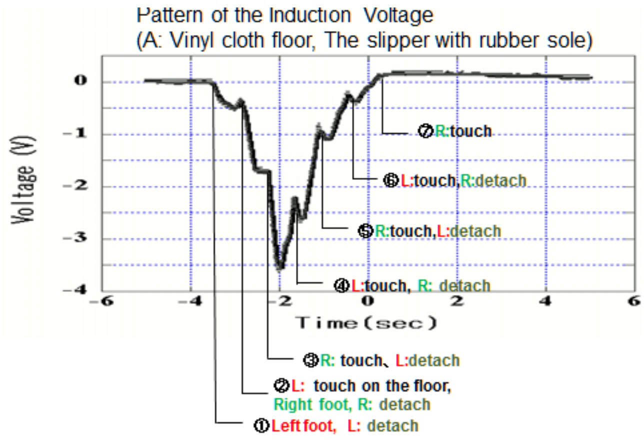


Fig.6 An example of the measured induction voltage from a charged walking human body

Fourier transform was made on the measured waveform of the induction voltages. A low-pass filter with its time constant of 0.025 sec was used at the output of the electrometer. Induction voltage of 4 person (A, B, C, D) was measured. Induction voltage of one person, D, with different walking manner was also measured. Fig.7 shows the normalized spectrum of the induced voltage of A – D using the frequency of steps of walking (about 2 Hz). Each point is an average of 8 measurements. Vertical axis is the frequency component (Arbitrary Unit), and the horizontal axis is the normalized frequency (Hz). Higher frequency components could add original characteristic pattern to the induction voltage.

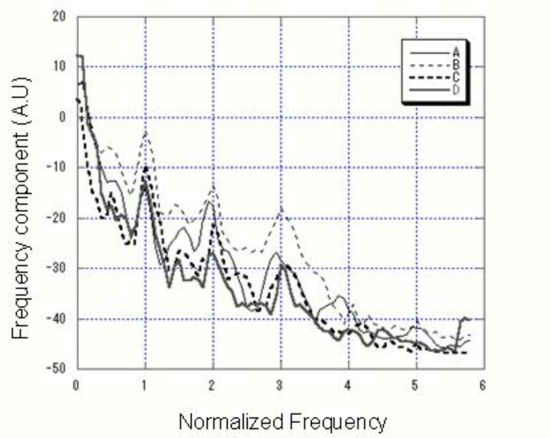


Fig. 7 Normalized spectrum of the induction voltage from charged human body while walking

Co-relation of the obtained normalized spectrum has been calculated for different person. Table 1 shows the co-relation between the averaged value of A and the spectrum of single measurement of A - D. The results showed that the co-relation was high between the same person, A.

Table 2 shows the co-relation between the averaged value of D, and single measurement of different walking manner of D (D-1, D-2, D-3) and A, B, C. The co-relation was the highest with the same person, even the person intentionally changed the manner of walking.

Table 1 Co-relation of the body voltage spectrum between A, and A-D while walking

	1st	2nd	3rd	4th	5th	6th	7th	8th
A	0.961	0.958	0.964	0.953	0.962	0.969	0.955	0.969
B	0.944	0.938	0.953	0.917	0.927	0.932	0.919	0.921
C	0.936	0.940	0.942	0.909	0.910	0.914	0.915	0.919
D	0.932	0.944	0.937	0.912	0.917	0.910	0.915	0.912

Table 2 Co-relation of the body voltage spectrum between D and different person A-C, different walking manner of the same person D-1, D-2, D-3

	1st	2nd	3rd	4th	5th	6th	7th	8th
A	0.931	0.895	0.937	0.948	0.916	0.916	0.973	0.918
B	0.922	0.889	0.929	0.913	0.895	0.899	0.946	0.877
C	0.942	0.917	0.950	0.928	0.922	0.914	0.960	0.902
D－1	0.964	0.956	0.983	0.982	0.972	0.980	0.975	0.970
D－2	0.951	0.941	0.962	0.953	0.941	0.943	0.969	0.925
D－3	0.941	0.947	0.960	0.961	0.954	0.950	0.952	0.940

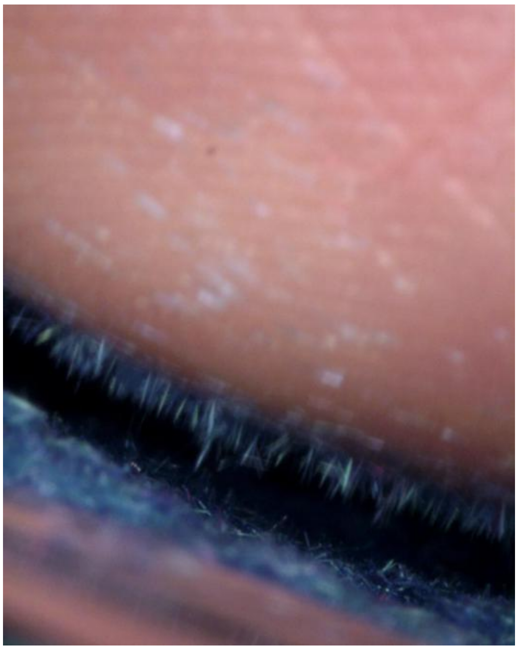


Fig. 8 Attracted fibers to the tip of finger of charged human body

When human body is charged and voltage becomes high, suspended particles in air may more easily be attached on human body. Certain rate of suspended particles have charges, therefore, they should be driven by the electrostatic force due to the voltage of human body.

In order to demonstrate the enhancement of deposition of dust to charged human body, an experiment was carried out. The fibers of ca. 30 μ m diameter and 200 μ m length was put on a ground aluminum sheet, and a finger was approached to the fibers. The rubber slippers were put and walking motion was made. When the distance is about 2 to 1 mm, the fibers were lift and jumped to attach to the approaching finger, and attached vertically to the finger along the electric field, as shown in Fig.8.

The continuous measurement of the induction voltage shows that the voltage changes with the movement of foot. When one foot is apart from the floor, the highest voltage appears. Pattern of the time change of the voltage, or frequency components of the voltage pattern could be different for each individual, and could be used to obtain more information from the voltage pattern.

Value of the induction voltage is affected by footwear. Sometimes, the voltage of human body exceeds 1000 V. This high voltage could enhance attachment of suspended particles, as well as particles attaching on wall or other objects due to induction charging. Those particles are pulled to hands and body. This point should be addressed, especially for hospitals and public spaces where chance of infection is high.

Human body is regarded as an antenna, then, we are emitting low frequency electromagnetic wave, or voltage wave. This is not well perceived, however, some other animals or micro-organisms might have an ability to detect those low frequency electromagnetic wave. We need further study on electrostatics in nature.

IV. ATMOSPHERIC IONIC CURRENT AND ITS CHANGE PRIOR TO AN INTENSE EARTHQUAKE

Earth is consisted of conductive crust, insulating atmospheric air in the order of 100 km, and conductive ionosphere as depicted in Fig.9. This system is a large capacitor. Known as Global circuit, ionosphere is charged to +300 kV in average, and positive ionic current (Atmospheric Ionic Current) is flowing into soil with 2 x 10-12 A/m2 in average[2].

Intense internal pressure in crust may cause micro fractures before major earthquake. Known as an important fundamental mechanism of electrostatics, the fracture could possibly cause charge separation. With the micro-fractures, piezo-electricity or transmission of holes having positive charge also cause rapid change of surface potential of land[14,15]. Movement of underground water could also cause charge separation, similar to battery. Due to micro-fractures of soil, release of radon gas from soil is also known, taking place well in advance from major collapse of crust. The release of the radioactive gases would reduce the impedance near the surface, and could cause an increase in AIC[16].

Sudden change of surface voltage of land due to micro-fractures should cause an accumulation of counter charge in the ionosphere on opposite side, since earth is a capacitor with relatively thin insulating atmosphere. The change of electron density in the ionosphere should cause the change of AIC, and electric field in air. We have tried to measure the AIC in open air. It was, however, very difficult because of large electronic noise interference. In this study, the potential, Vm, of an electrode set on a roof was measured using an electrometer in voltage measuring mode. Vm is the multiple of AIC flowing into the electrode and the input impedance of the electrometer and the electrode insulating system.

There are reports on lowering the bottom of ionosphere prior to major earthquakes. This has been measured using reflection of low frequency electromagnetic waves [4]. Using GPS (Global Positioning System), change of electron density in ionosphere was measured, and abnormal increase in the density was confirmed prior to the major earthquake[5].

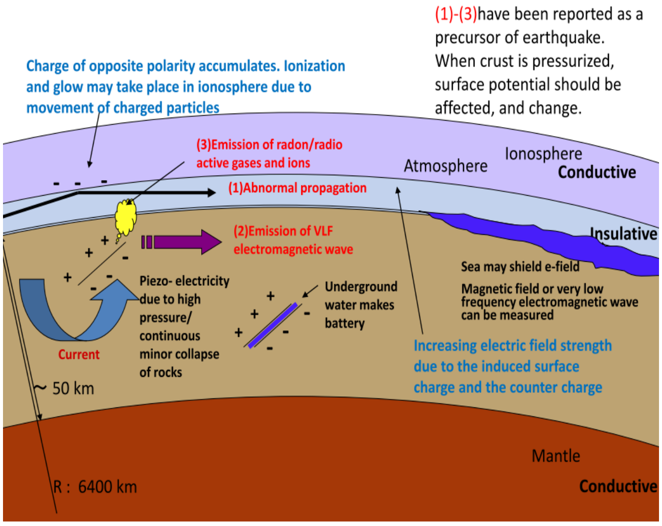
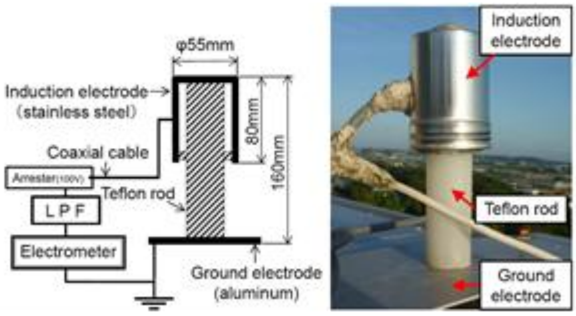
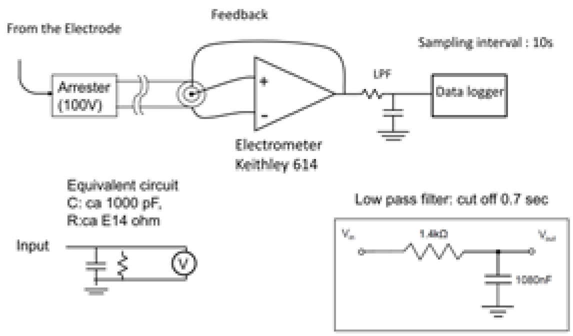


Fig.9 Reported electrostatic phenomena associated with earthquake

Fig. 10 shows the measurement system of AIC. The electrode is a 55 mm diameter cylinder covering the insulating support to avoid wetting during rain. The electrode system was fixed on a roof of 6 stories building. The electrode is connected to an Electrometer (Keithley 614) using coaxial cable of about 10 m length with about 1000 pF capacitance. An arrester has been inserted to protect overvoltage. At the output of the electrometer, a low pass filter (10 ms time constant) was inserted to cut the noise from commercial power lines. The measured voltage, Vm, should be the multiple of AIC and the input impedance. This system can also measure the induction voltage due to rapid change of electric field in air.



(a) Electrode setting



(b) Measuring circuit

Figure 10 Measuring system of AIC and rapid change of electric field in air

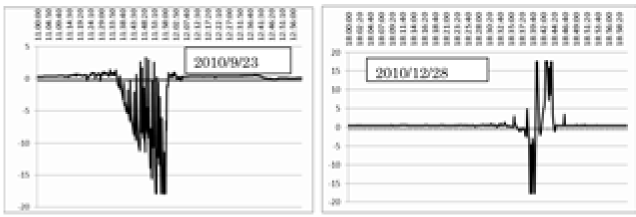


Fig.11 Oscillation of *Vm* caused by rain

Rain drops usually have charge, and give a sharp change of Vm, as shown in Figure 5. The perturbation due to rainfall can usually be noticed because of large oscillation of the measured value.

Daily time evolution of Vm normally shows a regular change as shown in Fig. 12. During night, Vm is small value. With sunrise, Vm gradually increases with time, reaching a peak around noon. Then Vm decreases gradually towards evening, and becomes small value after sunset. This is the effect of sun that ionizes and produces layer D of ionosphere during daytime.

Change of the measured potential follows the above time course in most cases. Fig.13 shows the voltage measured between January and March 2011. In this figure, square shows time 0:00 am. In January, Vm showed rather regular pattern of the daily change compare to Feb. and March. During February 10th and 22nd, Vm showed abnormal change. Again from Feb. 26th, Vm was abnormal. During Feb. 27th and March 1st, Vm stayed almost zero during daytime. Then Vm increased and overscaled during March 2nd and 6th. On March 7th, Vm became zero at 0:00, then again Vm increased abnormally during March 8th and 11th.

On March 9th at 11:45 there was a large earthquake (M7.3, 38o19.7'N 143o16.7'E, 8 km depth), on March 10th (M6.8, 06:23 59.7, 38o10.3'N 143o2.6'E, 9 km depth) in north part of Japan, and on March 11th at 14:46 there was a most intense earthquake in the same area (M9.0 14:46 18.1, 38o6.2'N 142o51.6'E, 24 km depth), and several more in the order of M7 (M7.7, 15:15 34.4, 36o6.5'N 141o15.9'E, 43 km depth, etc.) [7]

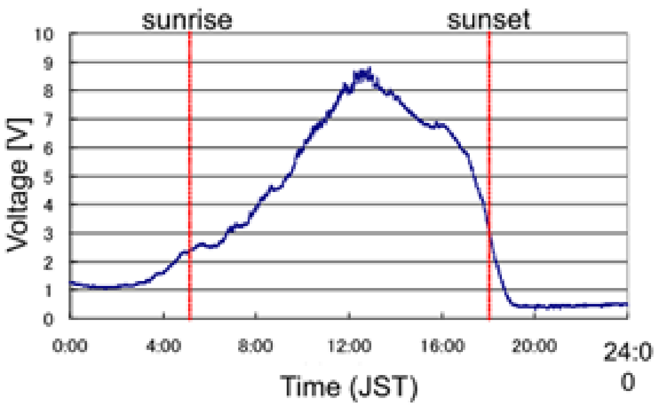


Fig.12 Typical daily change of Vm

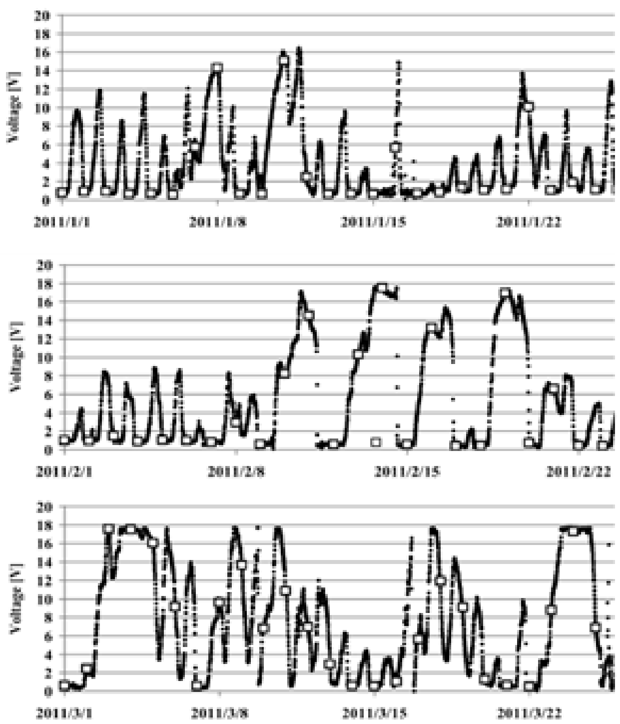


Fig.13 Vm between Jan. 1st and March 31st, 2011

Even several weeks before the major earthquake, an abnormal increase in AIC was observed through the measurement of Vm. This could be due to release of radon, which reduces the resistance between the ionosphere and the land.

Fig. 14 shows the Vm on the day of the major earthquake in northeast part of Japan(14:46, M9). Vm in the midnight was abnormally high. Vm decreased before sunrise at around 4 am, and then started to increase with the sun rise. At 13:00 for 7 min., Vm decreased from 9.2V to 7.5 V. Then Vm rose again, and at 13:36'30'', 9.44V, Vm decreased again to 13:43'00'', 2.68V, There are several possible causes for the sharp decrease. Usually rain gives more rapid and oscillating change. Slope of Vm during the decrease on March 11 was about 1/10 of that due to rain. In addition, we observed no rain when the earthquake took place. If birds of insects stopped on the electrode, some signal might be detected. As reported from the measurement of total electron count (TEC) using GPS system, TEC around the epicenter started to increase 40 min. prior to the major earthquake, and the change was observed above the observation point of Vm in Toyohashi[5]. The decrease of Vm on March 11 prior to the major earthquake could be due to sudden change of charge density in the ionosphere.

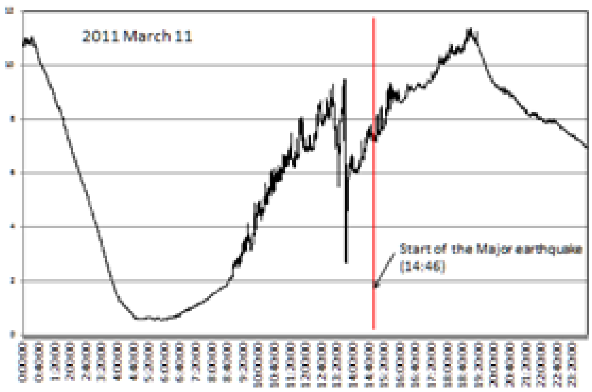


Fig.14 Vm before and after the major earthquake on March 11, 2011

As depicted in Fig.15, when surface voltage of the land near epicenter increases, counter charge (electron) is driven to the opposite side in the ionosphere to cancel the electric field. The electrons are driven towards the stratosphere, and are attaching to air molecules to become negative ions. This negative ions form an intense space charge, and will expand due to the self electric field. During expansion, the negative space charge attracts positive ions, resulting in reduction of AIC measured on the surface under the space charge.

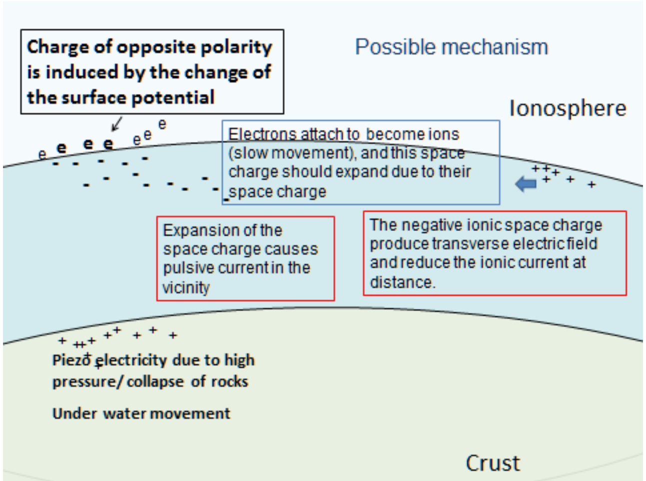


Fig.15 Possible cause of reduction of AIC prior to the major earthquake

In summary, the data of continuous measurement of Vm suggest certain correlation between intense earthquakes and Vm. Usually Vm shows regular change, increasing with sunshine and shows a peak at around noon, and then decrease. After dark, Vm becomes small value. Prior to major earthquakes, Vm showed irregular behavior. Vm increased to higher value more than 3 weeks before the major earthquake. Sometimes Vm stayed over scale, and even during night time, Vm was higher value. Then, just very close to the occurrence of major earthquakes, there is a day during which no increase in Vm during daytime. About one hour prior to the major earthquake, Vm decreased sharply.

V. CONCLUDING REMARKS

Electrostatics plays important role in nature in nano-scale to very large scale phenomena, and there are many interesting subjects that have not been studied in detail. Some of the examples listed in this manuscript is just a few of very interesting phenomena. We are very lucky to have our interest in this attractive and profound scientific area of electrostatics.

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