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Pulsed electric field before Kobe and Izu earthquakes from Seismically-induced Anomalous Animal Behavior (SAAB)

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Sea lions, hippopotamus and crocodiles in the Kobe-Oji Zoo were reported to have shown seismic anomalous animal behavior (SAAB) before the Kobe Earthquake. Crocodiles at the Izu-Atagawa Banana-Alligator Garden were observed to have cried before volcanic eruptions and earthquakes in the Izu area. Critical electric field intensity which causes a field-avoidance behavior has been estimated for these animals and some reptiles. Behavioral responses to seismic electric pulse stimuli due to the emerged pulsed charges or electromagnetic waves were tentatively attributed to the cause of SAAB. Seismic field intensities prior to the Kobe Earthquake were estimated from the electric field effects and citizen's statements on SAAB are shown in a geographic map with the number of statements. The anecdotal reports of significant animal disturbances at the epicenter were entirely consistent with the electric field effects. An attempt was made to observe natural electric pulses prior to earthquakes with a digital storage oscilloscope conforming to geophysical theory, also at the time of lightning and by electric discharges. Some electric pulses were detected simultaneously occurring in a laboratory with startled movements of eels as well as with fighting and grooming of hamsters known as anomalous behavior caused by electric field effects.

Introduction

It has long been discussed that animals become excited and fall into panic before earthquakes as if they are sensitive to their onset (Masuya, 1955; Rikitake 1978; Tritusch, 1978). Anomalous behavior was observed for animals at the Kobe-Oji Zoo in a day heading up to the Kobe Earthquake on January 17, 1995. Sea lions cried and would not eat, while hippopotami sank into their pool and would not reface, crocodiles became violent and left scratches to the glass wall of their enclosure. It was also reported that fish and silkworms aligned themselves in a common direction prior to the Kobe Earthquake and some fish died in panic by jumping out of water. Earthworms came out of the earth and swarmed. It was not surprising therefore to find Wadatsumi (1995) collecting from citizens through

faxes and internets and reporting 1519 statements in which most animals were claimed to show seismically-induced anomalous animal behavior (SAAB) before the Kobe Earthquake. The behavior is not confined to the Kobe Earthquake; crocodiles at the Izu-Atagawa Tropical & Alligator Garden were photographed for crying and behaving violently before volcanic eruptions and earthquakes in the Izu area.

Scientists are skeptical and regard SAAB as just a superstition or as retrospectively asserted stories after an earthquake under the psychologically abnormal condition caused by a natural disaster. However, they may have detected some kind of intense signals such as sounds, odor, electric or magnetic stimuli before earthquakes (Bushirk et al., 1981). The Japanese folk story that catfish cause earthquakes was once studied from the viewpoint of seismic electric fields (Abe, 1932). More recent investigations suggest that there could be some biological basis to these claims.

Seismic activity in fault movement could be modeled as an electromagnetic phenomenon (Ikeya and Takaki, 1996) and produces seismic transient free charges by means of a piezoelectric effect of such intensity to cause lightning discharges sometimes observed in connection with earthquakes. Ikeya et al (1996) showed that SAAB might be related with the charge effects in precursory earthquake swarms. Laboratory experiments with electric fields reproduced the alignment behavior and mysterious shape of candle flame (Ikeya and Matsumoto, 1997) reported anecdotally.

This paper describes the estimated seismic electric field intensity and its direction before the Kobe Earthquake from the statements, assuming that they are correct, and from experimental data on the response of sea lions, penguins and snakes to electric fields in the Kobe-Oji Zoo. Crocodiles at the Izu-Atagawa Tropical & Alligator Garden were also studied. Pulsed electric field measurements in water were attempted with a digital storage oscilloscope.

Experimental

Location and animals

The Kobe Oji Zoo

The Kobe Oji Zoo is located about 25 km away from the north edge of the Nojima Fault that moved in the Kobe Earthquake. California sea lions, hippopotami, penguins, flamingos and green snakes were used for the study of electric field effects.

Atagawa Tropical Banana and Alligator Garden

Crocodiles in this zoo cried and behaved violently before volcanic eruptions at Izu-Ohshima in 1971 and before earthquakes. Alligators

alleged responded to approaching thunder storms, while crocodiles neglected them.

Apparatus

Iron-mesh barbecue nets covered with an aluminum cooking foil were used as electrodes of 0.5 m x 0.7 m and dipped into a pool at separations *d*, from 1 to 5 m. The electrode resistance is less than 1 ohm. The DC voltage was generated using either a home-made battery pack having a series-connected twelve 1.5 V batteries connected in series or a series of ten 9 V batteries. Electric fields were applied by switching the batteries on and off. The electric pulses were applied using a commercial 'Elepulse (Omuron HV-FO4)' for the electronic massage apparatus.

Determination of critical electric field

Responses of animals to the fields were recorded using a commercial video recorder. Electric field intensity estimated by dividing the applied voltage by the distance is not accurate in a big pool where the electrode separation of 5 m is much larger than the length of the electrode, 0.5 m, so the static field intensities at several sites were calculated using an electric field simulator for the electrode separation of 5 m and the applied voltage of 100 V as shown in Figure. 1.

Observation of pulsed electric field in an aquarium

Parallel plate electrodes with a separation of 20 cm were placed in an aquarium. Electric noises were observed with a digital storage oscilloscope (DSO:A&D Co., AD-5146) with a triggering level of 10

noises less than this level was not recorded. The sampling frequency is 40 million samplings per second with storage memories of 2048 bytes. The data was transfered to a computer hard disc in 12 s which is a dead time during which no observational data is measured with DSO.

Electric field effects on animals

Animals at the Kobe-Oji Zoo

California sea lions

Electric field intensities which caused abnormal behavior at the Kobe Oji Zoo were evaluated from an experiment on the effects of electric fields on sea lions and hippopotami. Sea lions seemed to be noticed the electric field and returned as shown in Figure 2 from the position of the electric field intensity of 0.5 V/m as estimated from the calculated results in Figure 1. They cried and did not approach the high field area close to the electrodes. They did not eat for a few hours. This result indicates that the minimum seismic electric field is 0.5 V/m for sea lions.

Hippopotamus

This animal sank and did not appear before the Kobe Earthquake. The electrode separation of 20 m required by the size of the hippopotamus made it difficult to accurately estimate the electric field in the experiment. Approximate field strength when the hippopotamus approached the electrode and sank was around 6.5 V/m. No

Figure 1 Calculated electrostatic field intensity at each mesh site for an electrode separation of 5 m and a voltage of 100 V in a pool. One can estimate the electric field intensity which animals detect from the behavior at the particular site. Applied field in the experiment was from 1.5 to 90 V. Sea lions approaching to the electrode returned at the indicated site from which the field intensity of 0.5 V/m was estimated.

Figure 2 Response of a sea lion in the pool of the Kobe-Oji Zoo to an electric pulse of about 0.5 V/m.

(a) swimming normally,
(b) noticed a weak electric field pulse having a peak intensity of about 0.5 V/m,
(c) returned quickly and
(d) avoiding field.

Figure 3 Green snakes (a) before and (b) after electric shock applying DC voltage from a pack of battery to a floor. Snakes avoided field by swarming to the edge and stand up. (c) Same experiment using a health-care electronic massager "Elepulse" which generates a pulse with the width of 1 microsecond every one second, and (d) increased number of pulses made snakes winded.

Figure 4 A crocodile opening the eye in (a) closed upon every application of electric pulse of of about 5 V/m as shown in (b). Crocodiles respond to a field of 0.5 V/m and the sensitive two out of eight responded at 0.02 V/m.

Table 1 Electric field effects on animals at the Kobe-Oji Zoo (KOZ), the Izu-Atagawa Tropical & Alligator Garden (IATAG) together with some results on fish and reptiles in a laboratory.

Animal	F(V/m)	Responses
The Kobe-Oji Zoo (KOZ)		
California Sea Lion	0.5	Quick avoidance from field
Otariidae <i>Zalophus californianus</i>		no longer approaches electrodes
Hippopotamus (KOZ)	6.5	No clear reaction, merely submerge
Flamingo	4	Puffing up? no clear reaction
Goose	15	Puffing up? slight compulsion?
Penguin	15	Reduced appetite, avoiding?
Pelican	14	No clear reaction
Snake (Green snake)	66	Startled movement
	90	Reacted to pulse with shock
	114	Muscle cramped
cf. Rat (<i>Ratus norvegicus</i>) ^{a)}	2	Grooming
	72	Cramps in legs
Sparrow (Amandava) ^{a)}	100	Puffing up? grooming
Izu-Atagawa Tropical & Alligator Garden (IATAG)		
(a) Young crocodiles (L = 1 m, d = 1.5 m)		
Spectacled caiman	1	One sensitive specimen bit electrodes
<i>Caiman crocodilus</i> (LINNE)	2	Two bit electrodes
R _{leg-leg} > 40MΩ	5	All moved
R _{belly-mouth} = 2 MΩ	8	Legs cramped, all responded
Paraguay caiman	3.7	No clear response
<i>Caiman crocodilus yacare</i> (DAUOIN)	5	Eye closed by switching on,
R _{leg-leg} > 40 MΩ	6.2	Jaw compulsions
R _{belly-mouth} > 40 MΩ		
(b) Baby crocodiles (30-40 cm) d = 22 cm		
(Field perpendicular to the body)		
Nilotic crocodile	0.5	Eye movement (only 1 specimen of 3)
<i>Crocodylus niloticus</i> LAURENTI	6-7	Eye & front leg movement
	20	Compulsion of front & rear legs
	35	Compulsion of head
	50	Compulsion of jaw & eyes
Mugger, Marsh crocodile	6-7	Movement of eyes & rear legs
<i>Crocodylus palustris</i> LESSON	13	Movement of front & rear legs
	20-27	Compulsion of all four legs
	40	Eyes closed, cramp, run away
Turtle from Thailand	2	Startled movement, retracted head
<i>Hieremis annandali</i> Boulenger	4	Opened and closed eyes
	12	Washed face
Snake (<i>Bore Confrictor</i>)	15	Responses in tail and tongue
		Adoption of S-configuration in neck
cf. Goldfish ^{a)}	15	Startled reaction to initial pulse
	23	Oriented body perpendicular to field

a) Responses depend on individuals and species (Ikeya et al. 1996b)

b) Almost the same as Japanese minnows and other fish (Ikeya et al. 1996a)

Figure 5 (a) Estimated directions and intensities of preseismic electric fields at several places from the reported seismically-induced anomalous animal behavior (SAAB) before the Kobe Earthquake. (b) Numbers of reported SAAB per 10 km² before the Kobe Earthquake are indicated in the map together with the fault (line) and epicenter (double circles). The field direction was estimated from the direction of floating fish. Electric field pulses or wave packets of electromagnetic waves may be responsible.

clear reaction was seen except sinking to the bottom of the pond and leaving the site. It is not possible to tell whether this result constitutes field-avoidance behavior.

Birds

Flamingos and geese were subjected to fields from 4 to 15 V/m. No clear reaction was seen except the puffing as observed for red sparrows in the previous work (Ikeya et al.1996). A goose seemed to notice the field application by on and off and showed slight convulsion at the field of 15 V/m. Penguins avoided the pool with electrodes where pulsed electric voltage was applied and gathered in another adjoining pool though food fish was in the former pool.

Green snakes

Snakes migrated into the Kobe-Oji Zoo to eat birds' eggs since the surrounding land area was devastated by the destruction. Several captured green snakes were placed on a wet towel spread in a box. Both DC and pulsed electric field from 1 Hz were applied to the snakes. The snakes' muscle flexed as the field strength was increased to 100 V/m. Details of the responses to electric field are tabulated in Table 1. Photograph is given in Figure 3.

Atagawa Banana-Alligator Garden

Electric field effects on different species of crocodiles and alligators (Order Crocodylia) have been investigated for adult crocodiles with length greater than 2 m, for young ones with the length of 1 m and for baby crocodiles of about 30 cm.

Alligators (Family Alligatoridae)

Spectacled caiman (*Caiman crocodilus* (LINNE)): They seem to be sensitive to climate changes but have not shown clear SAAB prior to an earthquake. Young ones showed a startled movement to a DC electric field of 4 V/m and bit the electrode at 5 V/m.

Crocodile (Family Crocodylidae)

Paraguay caiman (*Caiman crocodilus yacare* (DAU-OIN)): The eye response (closing and opening when the DC field was switched on and off as shown in Figure 4 (a) and (b)) was observed at 5 V/m. The movement of the mouth (compulsion) started at 6 V/m. They became excited and violently bit the electrodes at 9 V/m and suffered body compulsion for fields of 20 V/m. The response to the pulsed electric fields started as low as 0.02 V/m for one or two sensitive ones among a dozen crocodiles and 0.2 V/m for all.

When continuous air gap discharges of the high voltage sphere of a Van de Graaf electrostatic generator to the ground were made about 1 m away from these crocodiles, they closed their eyes. Neither intense light nor sound is produced by the discharge. This indicates that they are feeling the electric field of generated electromagnetic waves. Produced field intensity is described later.

The body resistance measured at the back was more than 40 MW for most baby alligators and crocodiles, while the belly skin of some crocodile has exceptionally small resistance of 0.5 - 1 MW. Resistivity would be a main cause of individual sensitivity difference to the electric field and presumably to seismic electric field.

Tortoise (*Hieremis annandali* Boulenger)

The tortoises opened and closed their eyes similarly to crocodiles when the field of about 2 V/m was applied. They then retracted their head. Behavior similar to that of a cat washing its face before a bad weather (as related with the Japanese folk story) was observed for a field intensity of 12 V/m. Eyes are organs with a direct electrical contact between the water and the body fluid for reptiles living in fresh water and so eye response to electric current may be anticipated.

The behavioral responses of snakes in the Banana-Alligator Garden and of other animals are tabulated in Table 1 together with the field intensity for some reptiles. Using these experimental field intensity, it is possible to use the retrospective SAAB reports to create the geographical distribution of the electric field as shown in the map. The field intensities are very high as compared with those of seismic electric signals 10⁻⁵ V/m, but may be reasonable because they are not static fields but very brief pulsed fields.

Estimated seismic electric signal intensity

An electromagnetic model of a fault

Our proposed electromagnetic model of fault behavior is based on the appearance of charge densities, + q and - q at the fault zone caused by the change of the seismic stress, σ for the fault displace-

Figure 6 An aquarium with parallel plate electrodes besides an aquarium with eels, minnows and goldfish. The electric field in water was measured with a digital storage oscilloscope with a triggering level of 10 mV/m and stored into a computer with the time and the shape of the pulse.

ment time or for the rock fracture time, τ (Ikeya and Takaki, 1996; Ikeya *et al.*, 1996). The charges decay with a time constant $\epsilon\rho$, dependent upon dielectric constant, ϵ and resistivity, ρ of the earth. The mathematical model of a fault gives a time-dependent stress $\sigma(\tau)$ leading to a pulsed charge density of $q(t)$ with risetime $\epsilon\rho$ and decay time τ . The electric field intensity, $F(t) = q(t)/\epsilon$ at a fault zone was calculated using $\epsilon\rho = 70 \mu\text{s}$ for $\epsilon^* = \epsilon/\epsilon_0 = 8$ and $\rho = 10^6 \Omega\cdot\text{m}$ for granite at a fault zone. Theoretical calculation of seismic field intensities in the form of electric pulses indicates peak intensities between 10 - 100 V/m.

It was suggested that the above behavioral responses of animals to electrical stimuli may be attributed to SAAB observed in experiments on fish with electrosensory organs and on birds and rats without them (Ikeya *et al.*, 1996a, 1996b).

The seismic stress release due to fractures in rocks prior to the major shock, presumably resulting in pulsed currents because of the release of the piezo-compensated free charges, cannot be detected with the seismograph at 100 Hz. A high current density for local fractures along the fault prior to the main shock and focusing of the current for geographical reasons would explain SAAB as electrophysiological response to the electric field of electromagnetic waves.

Electric field intensity estimated from SAAB

Japanese minnows have been observed to move quickly under electric fields as small as 10 V/m (0.2 A/m^2), and to align themselves perpendicular to the field direction (Ikeya *et al.*, 1996). Sensitive minnows were paralyzed at 50 V/m, but recovered soon responding to a single pulse with the width of 0.1 ms. The phenomena of fish alignment or paralyzed fish before the Kobe Earthquake, which was stated retrospectively by witnesses (Wadatsumi, 1995) might indi-

cate the electric field intensities of more than 10 V/m in nature before the Kobe Earthquake.

The responses of alligators are similar to those of minnows but those of crocodiles and sea lions are at least one or two orders of magnitude more sensitive than other animals owing to the presence of electrosensory organs with sensitivities of 0.1 - 200 mV/m. The estimated field intensities and their directions are indicated on the map together with the percentage of animal anomalies before the Kobe Earthquake in Figure 5 (a) as recalled by witnesses. We simply assume that the fish alignment is a seismic electric field effect here.

Aquatic animals have a highly sensitive electrosensory system which is used to acquire information for orientation and to communicate with others (Bastian, 1994; Bullock, 1983). Animals without such organs are thousands of times less sensitive to electric fields. Fields of 10 V/m are too intense for seismologists or geophysicists to accept from their experience of 10^{-5} V/m as a typical seismic electric field (SES), which lead to rejection of this work. However, only ultra low frequency (ULF) electromagnetic waves out of a wave-packet may have been measured at long distances from the epicenter in their case. The pulsed field intensity close to the epicenter must have been around 10 V/m in order to cause SAAB to ordinary animals without electrosensory organs. Electric stimuli to eyes and skins will lead to field-avoidance behavior.

Chinese seismologists observed high pulsed electric fields before the Tangshan Earthquake, but unfortunately discarded the data considering them as errors in the electrometer. What animals detected may be the pulsed flow of charges at the stress-released area around the fault zone; the peak intensity is high though the duration is less than 1 ms according to our theory. Animals would be responding to an abrupt change in the local electric field of the electromagnetic waves caused by the seismic charges.

Figure 7 The output of digital storage oscilloscope of electric pulse voltage detected in a laboratory (a) at the time of nearby atmospheric lightning, and (b) one of the five pulses happen to be observed one hour before an earthquake of the magnitude 3.9. Correlation with the earthquake is not clear. (c) Electric noises induced by switching of a phosphorescent lamp in a laboratory.

Measurement of electric field by lightning, Van de Graaff discharges and unknown

Electric pulses would propagate as wave packets, i. e., a number of electromagnetic waves having different frequencies (Ikeya *et al.*, 1997). The seismic pulse signals from a fault may be detected with a modern electronic technique, such as using a digital storage oscilloscope (DSO) with a triggering level for recording. A parallel plate electrodes were placed in an aquarium and the voltage was measured with the DSO as is schematically shown in Figure 6. A derivative form of pulsed electric field is to be measured with this apparatus. Figure 7(a) shows electric pulses observed at the nearby atmospheric lightning by setting the triggering level of 10 mV. Electric noise pulses were observed as shown in (b) by air-gap discharges from the high voltage sphere of a Van de Graaff electrostatic generator by setting a grounded wire close to the sphere. The pulse widths are of the order of 0.1 ms. We observed different pulses with a width of 1 μ s in the laboratory as shown in (c). It is interesting to note that eels in this laboratory aquarium showed startled movements and hamsters washed face and screamed by fighting with each others. No change in the behavior was noticed for minnow and goldfish.

An earthquake of magnitude, $M = 3.9$ occurred 3.2 days later. Unfortunately, it is not possible to link these electric pulses and animal behavior to the earthquake since the campus is surrounded by the source of electric noises, monorails, heavy traffic roads, nuclear accelerator, etc. However, Rikitake's empirical formula of the relation between the precursor time, T and the magnitude M , i. e., $\log_{10} T = 0.37 M - 0.89$ for the SAAB gives 3.5 days and the area R of the SAAB appearance is obtained from $M = 2.67 \log R_{\max} - 0.91$ as $R_{\max} = 70$ km. The epicenter 35 km away from the observation campus is well within this distance. Unless we determine the source of the electric pulses, it is not possible to ascribe the observed pulses to an earthquake precursor.

Atmospheric lightning and artificial discharges using a Van de Graaff electrostatic generator also caused electric pulses in water and sudden movement of eels and grooming of hamsters. Minnows and goldfish seemed less sensitive at that time. They respond to the electric field of more than 10 V/m (Ikeya *et al.*, 1996a), while eels responded to the field of less than 1 V/m.

Discussion

It would be possible to improve some of the experiments by use of several recording equipment with cooperation of zoos. Animals are kept under specialist care at thousands of zoos all over the world.

Animal's behavior in relatively controlled conditions may be watched daily by professional keepers with scientific backgrounds. Video recorders adopted to cyclic tape continuously or triggered by environmental electric pulses could record behavior. Statistical comparison of behavior should give an objective measure of the effects of such pulses whether they are from lightning, earthquake or other origins. Therefore, anomalous behaviors may be noticed without difficulties if SAAB are well categorized and scientifically understood as behavioral responses to electric pulse stimuli or to electric field of electromagnetic waves. It would be best to set up such equipment in countries prone to earthquake, and preferentially monitor sensitive species such as sea lion, crocodile and eels.

Anomalous behavior of eels, birds and rats was also observed in preliminary fracture experiments of granitic rocks using 200 and 500 ton compression machines simultaneously with the detection of electromagnetic waves as described separately elsewhere. Both phenomena preceded above 10^7 Pa well before the fractures at 10^8 Pa and the detection of acoustic emissions by piezoelectric sensor attached to the rock. Although detailed work will be published elsewhere, the observation indicates that SAAB and electromagnetic wave generation are common phenomena before the main shock. The determination of the precursor time is the main difficulty in earthquake prediction using SES.

It would be particularly interesting to determine whether an early stage earthquake warning well before the arrival of seismic P- and S-waves might be made by electronic detection of seismic pulses rather than from the observation of SAAB; the exact triangulation of time and place of pulse origins would be difficult to determine without recording observational data at several places using global positioning system (GPS) clocks. Considering the speed of light, P-waves and S-waves, the S-waves which cause disaster come after P-waves arrive in a time with the same interval between the observation of coseismic electromagnetic waves and the P-waves.

Conclusion

This paper asserts that SAAB is not a superscientific phenomenon, but behavioral response to electrical stimuli and that a pulsed seismic field intensity of about 10 V/m before the Kobe Earthquake must have caused panic to ordinary animals at the Kobe-Oji Zoo. The responses of sea lions at 0.5 V/m and crocodiles down to 0.02 mV/m similar to the field which surprised eels was confirmed in the experiment of electric field effects. Animals showed the same behavior as electric field effects in experiments of rock fractures using a 500 ton

press machine. Most of reported SAAB in the Kobe Earthquake is similar to reported behavior before atmospheric lightning.

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